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Environmental Disclosure and the Cost of Capital: Evidence from the Fukushima Nuclear Disaster

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ABSTRACT We examine the relation between environmental disclosure and the cost of capital by exploiting the Fukushima nuclear disaster as a source of variation in the relevance of environmental information for investors. Using a large hand-collected sample of Japanese firms, we find that firms disclosing carbon emissions experience a lower increase in the cost of capital than non-disclosing firms. Cross-sectional analyses suggest that the association between disclosure and the cost of capital is driven by the increase in investor uncertainty about the energy supply shortage that followed the disaster rather than future regulatory costs. Moreover, we find that after the disaster, non-disclosing firms in the pre-disaster period increase their environmental disclosures to a greater extent relative to disclosing firms. Taken together, our results provide insight into the link between non-financial, unregulated disclosures and the cost of capital.

Keywords: Environmental disclosure; Cost of capital; Disclosure reaction; Carbon emissions

JEL codes: G10, G14, G30, M40, M41

1. Introduction

Environmental risks have grown significantly in the last five years (World Economic Forum, 2020). The most recent Global Risks Report (World Economic Forum, 2022) indicates climate action failure, natural disasters, and biodiversity loss as the most severe risks. For businesses, natural disasters are associated with direct economic costs (e.g. loss of property or interrupted production due to flooding), whereas climate action is mainly associated with potential regulatory costs arising from policies on carbon emission reduction. While the accounting literature has since long suggested that environmental disclosures inform stakeholders about the environmental impacts of corporate activities (Clarkson et al., 2011; Cormier et al., 2005; Cormier & Magnan, 1999; Lys et al., 2015), evidence on whether environmental disclosure can affect firm cost of capital remains mixed. Prior research has suggested that credibility issues and low litigation costs can reduce the usefulness of environmental disclosures (Blacconiere & Patten, 1994;

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Cho & Patten, 2007; Dhaliwal et al., 2011). Further, while the literature has found a negative association between environmental disclosure *initiation* and the cost of capital, these associations are conditional on the underlying environmental performance (Dhaliwal et al., 2011). Not least, the endogeneity of the relation poses significant empirical challenges that concur to explain the mixed evidence (Clarkson et al., 2013; Plumlee et al., 2015; Richardson & Welker, 2001).

We examine whether environmental disclosure affects firm cost of capital by exploiting the Fukushima nuclear accident (henceforth, ‘the disaster’) as a shock to the cost of capital for Japanese firms. On March 11, 2011, a tsunami disabled the power supply and cooling units of the Fukushima Daiichi reactors, leading to the meltdown of all nuclear cores over the following three days, and causing long-lasting economic, ecological and social consequences (Hayashi & Hughes, 2013). Because of these consequences, we argue that uncertainty about the long-term implications of the disaster made environmental disclosures more relevant for investors. Specifically, we hypothesize that firms disclosing carbon emission information in the pre-disaster period experience a lower increase in the cost of capital after the disaster, compared to firms that do not disclose such information. Moreover, we predict that the intensity of this association is related to firm exposure to operating and regulatory risk.

Fukushima is well suited for our analysis. First, in the aftermath of the disaster, the closure of all nuclear reactors across the country caused a considerable energy supply shortage and concerns about energy availability and affordability (Hayashi & Hughes, 2013; Vivoda, 2012). This shortage *increased* investor uncertainty about Japanese firms’ exposure to the energy shortage and consequently the relevance of information about a firm *operating risk* (i.e. how firms manage their energy policies). Second, the reduced production of nuclear energy caused an increase in pollution, as ‘clean’ nuclear power was replaced by fossil fuels (Srinivasan & Gopi Rethinaraj, 2013; Vivoda, 2012).¹ Because combating pollution has always been a priority for Japan (Duffield & Woodall, 2011), the disaster *increased* the threat of regulatory actions to impose pollution abatements. Consequently, it also increased investor uncertainty about a firm *regulatory risk*, namely the ability to withstand future regulatory costs (e.g. Blacconiere & Patten, 1994; Heflin & Wallace, 2017).

Environmental disclosures provide information about both firm energy policies and pollution levels (GRI, 2013; Schiemann & Sakhel, 2019). We focus on carbon emissions disclosures because such disclosures can convey information about firm energy policies, allowing investors to estimate a firm operating risk (Apergis et al., 2010; Davis & Caldeira, 2010; Sims et al., 2003), and about firm exposure to future compliance costs related to pollution abatements, allowing investors to estimate a firm regulatory risk (Blacconiere & Patten, 1994; Clarkson et al., 2015; Griffin et al., 2017; He et al., 2022; Matsumura et al., 2014). Thus, carbon emissions disclosures can inform investors about how an energy shortage and/or increased regulatory costs might impact a firm’s cash flows and ultimately its cost of capital.

Our sample comprises 4,216 firm-year observations from 392 unique firms with an environmental report over the period 2002–2013. Our empirical strategy is akin to a difference-in-differences design in which we exploit the disaster as a source of time-series variation in the relevance of carbon emission information, and the disclosure of carbon emission information in the pre-disaster period as a source of cross-sectional variation. This approach compares the

¹Nuclear energy is deemed cleaner than fossil energy because of its lower level of carbon emissions (Apergis et al., 2010; Menyah & Wolde-Rufael, 2010; Sims et al., 2003). ‘The life cycle GHG emissions per unit of electricity from nuclear power plants are at least two orders of magnitude lower than those from fossil-fueled electricity generation and are comparable to most renewables at near zero. Hence, nuclear power generation is an effective GHG mitigation option’ (Sims et al., 2003, p. 1317).

change in the cost of capital around the disaster between firms that, at the time of the disaster, disclose carbon emission information and firms that do not disclose such information.

Our setting alleviates many endogeneity concerns because the timing of the disaster is exogenous to firm characteristics and performance. However, there are at least two important endogeneity threats. First, the disclosure of environmental information in the pre-disaster period is likely associated with other firm characteristics that may correlate with the changes in the cost of capital around the disaster. We address this issue by employing firm fixed effects, thus focusing only on *within-firm* changes in the cost of capital. Further, we reduce the degree of heterogeneity between disclosing and non-disclosing firms by relying on an entropy balance matching (EBM) design (Hainmueller, 2012). Second, the disaster has likely affected firms' cost of capital not only through an information channel (i.e. by increasing investor uncertainty about firm cash flows) but also by affecting firms' future cash flows (e.g. by lowering firms' growth prospects, increasing costs, and reducing revenues). To alleviate the concern that changes in firms' cost of capital around the time of the disaster also reflect contemporaneous revisions of future cash flows, we use estimates of firms' implied cost of capital as dependent variables.²

We find that the disaster had substantial economic consequences on Japanese firms with an average increase in the cost of capital – irrespective of firms' carbon emissions disclosure – of approximately 2 percent points. More importantly, firms that disclose carbon emission information before the disaster experience a lower increase in their cost of capital of 1.2 percent points than the increase experienced by non-disclosers. Moreover, we find that the association between carbon emission disclosure and the cost of capital depends on firm capital intensity, our proxy for firm exposure to the energy shortage, suggesting that carbon disclosure is informative about firm operating risk. On the contrary, we are unable to document that the association between carbon emission disclosure and the cost of capital depends on regulatory risk.

Next, we investigate whether firms change their environmental disclosures after the disaster. If the disaster has changed the cost–benefit trade-off underlying firms' disclosure choices, then firms would adjust their disclosure policies considering the new cost–benefit tradeoff. We find that non-disclosing firms react more strongly to the disaster, and thus to the cost of capital shock, by increasing both the length of their environmental reports and the numerical and forward-looking nature of the information disclosed to a greater extent than disclosing firms.

Although our results are generally robust to alternative explanations, there are at least three caveats that should be considered when interpreting our findings. First, the absence of a control sample does not allow us to properly control for contemporaneous events that might affect the cost of capital around the disaster. Second, disclosure choices are endogenous, and we are unable to find a proper instrument for them. While our empirical strategy attempts to mitigate this concern, we caution the readers to read our evidence as identifying a causal effect of environmental disclosure on the cost of capital. Third, our results are based on a particular setting, i.e. the Fukushima Nuclear Disaster. Therefore, the generalizability of our results to other settings remains a concern.

Our paper makes several contributions to the literature. First, we advance the literature studying the link between CSR disclosures and firm cost of capital. Prior evidence shows that environmental disclosure reduces the cost of capital conditional on firms reporting good environmental performance (Clarkson et al., 2013; Dhaliwal et al., 2011; Plumlee et al., 2015), consistent

²There are three reasons for employing implied cost of capital metrics. First, as they are based on prices and analyst earnings forecasts, their use allows us to directly control for revisions in firms' future cash flows (Cao et al., 2014; Cao et al., 2017; Hail & Leuz, 2006) and thus better estimate the informational consequences of the disclosures around the disaster. Second, Gode and Mohanram (2003) and Botosan and Plumlee (2005) validate implied cost of capital estimates by showing that they are related to proxies capturing various sources of risk. Third, implied cost of capital measures are more suited for studies outside the U.S. (e.g., Erb et al., 1996; Harvey, 1995; Solnik, 1974; Stulz, 1981).

with the notion that environmental disclosure is a signal of future environmental performance (Grewal et al., 2019; Lys et al., 2015). However, this evidence does not directly speak to the informational consequences of such disclosure. We exploit firm-level heterogeneity in disclosure practices and show that environmental disclosures affect the cost of capital unconditionally on the underlying carbon performance (Dhaliwal et al., 2011; Grewal et al., 2019; Griffin et al., 2017). In this vein, we further complement single-industry studies focusing on overall economic effects (e.g. Blacconiere & Patten, 1994; Heflin & Wallace, 2017) by documenting cost-of-capital effects beyond the single-industry affected by the disaster. Using an innovative setting we shed light on an additional factor (i.e. operating risk) that moderates the association between environmental disclosure and the cost of capital, which adds to prior evidence on environmental disclosure and regulatory/political costs (Blacconiere & Patten, 1994; Grewal et al., 2019; Heflin & Wallace, 2017).

Second, our findings bring insights into the relevance of carbon emission disclosures (Chapple et al., 2013; Clarkson et al., 2015; Griffin et al., 2017; He et al., 2022; Ioannou et al., 2016; Matsumura et al., 2014). Specifically, we draw from environmental economics and energy policy research on the relation between energy consumption and pollution levels, and document that carbon emission information is relevant to the assessment of firm energy dependence and operating risk.

Third, we provide insights into the dynamics of voluntary environmental disclosure beyond the economic consequences of CSR reporting adoption (Dhaliwal et al., 2011), and in the context of an unexpected environmental disaster. We show that firms experience differential shocks to their cost of capital depending on their carbon emission disclosures in the pre-disaster period, and that firms change their disclosure practices based on the new cost–benefit trade-off. In this vein, we document that investors are concerned about environmental risks (Barth et al., 1997; Li et al., 1997) and that firms adjust their disclosures to meet investors' informational demand.

Fourth, we contribute to the broad literature on the consequences of voluntary disclosure. We focus on an unregulated setting with considerable variation in the information disclosed and show that the disclosure of unregulated, non-financial information provides benefits to firms when they are hit by economic shocks. Our focus on non-financial disclosure complements the evidence in Leuz and Schrand (2009) regarding the relation between financial disclosure and the cost of capital and the findings of Balakrishnan et al. (2014) on the effect of managerial forecasts on market liquidity.

2. Prior Literature and Hypotheses Development

Theory predicts that firms can affect their cost of capital by committing *ex ante* to voluntarily disclose financial information *ex post*, regardless of the content disclosed (Diamond & Verrecchia, 1991; Hail, 2002; Leuz & Verrecchia, 2000; Verrecchia, 2001). However, in the environmental disclosure setting, the literature has pointed out several features as to why such relation may not hold. First, environmental disclosure is mainly concerned with reporting the impacts of corporate activities borne by others and with no direct financial consequences (i.e. corporate externalities). Further, environmental 'reports often take a rather siloed approach to individual issues instead of clearly articulating connections between different areas of impact.' (Unerman et al., 2018, p. 498). Therefore, it is difficult and costly (i.e. high processing costs) for market participants to assess the implications of environmental disclosures. Second, the voluntary nature of environmental reporting and the absence of regulatory guidance or penalties for misreporting raise concerns about the usefulness of these disclosures because of credibility issues and low litigation costs (Blacconiere & Patten, 1994; Cho & Patten, 2007; Dhaliwal et al., 2011;

Mittelbach-Hörmanseder et al., 2022). Lastly, the endogeneity of the relation poses significant empirical challenges that concur to explain the mixed evidence (Clarkson et al., 2013; Dhaliwal et al., 2011; Plumlee et al., 2015; Richardson & Welker, 2001).

Extant research documents that the economic effects of environmental disclosure *initiation* on the cost of capital are conditional on the underlying environmental performance (Dhaliwal et al., 2011). Other studies provide evidence consistent with the notion of environmental disclosure as a signal for the firm's future performance (Lys et al., 2015) but face the challenge of disentangling the effects of environmental disclosure from the underlying environmental performance or activities. For example, Clarkson et al. (2013) find that voluntary environmental disclosure has more explanatory power than current environmental performance for firm market value but not for firm cost of capital. Plumlee et al. (2015) do not find a significant association between environmental disclosure quality and cost of capital, on average. However, when they classify the sample based on the type (soft/hard) and the nature (positive/neutral/negative) of the information disclosed, they find that soft/positive environmental disclosures are associated with a lower cost of capital, whereas soft/negative environmental disclosures are positively related to the cost of capital.

On the other hand, there are at least three non-mutually exclusive explanations for expecting a negative relation between environmental disclosure and the cost of capital. First, if a firm's environmental disclosures provide information about the firm's impact on the environment, then market participants will face less uncertainty in estimating the firm's future cash flows (Clarkson et al., 2013; Cormier & Magnan, 1999). For example, environmental disclosures can serve as a source of information to forecast costs arising from the potential regulatory imposition of pollution abatement schemes and the risks associated with future compliance requirements (Blacconiere & Patten, 1994; Patten & Trompeter, 2003). Second, environmental disclosures provide information about firms' environmental policies (Clarkson et al., 2011), which in turn can improve investors' information base and reduce a firm's cost of capital (Diamond & Verrecchia, 1991; Easley & O'Hara, 2004; Lambert et al., 2007; Shevlin, 2013). Third, environmental disclosures could affect the cost of capital directly through a change in the investors' non-cash-flow-based preferences if investors believe that firms' practices conflict with those preferences or if investors are willing to accept a lower expected return on investments that also fulfill other social or environmental purposes (e.g. Christensen et al., 2017; Fama & French, 2007; Friedman & Heinle, 2016; Richardson & Welker, 2001).

Based on the arguments above, we posit that the increase in uncertainty about firms' exposure to the disaster raises the relevance of environmental disclosure (Liang & Renneboog, 2017), so that firms disclosing environmental information in the pre-disaster period experience a lower increase in the cost of capital (Diamond & Verrecchia, 1991; Easley & O'Hara, 2004; Lambert et al., 2007, 2012). We thus posit the following hypothesis:

H1: Firm environmental disclosure in the pre-disaster period is negatively associated with the impact of the disaster on the firm's cost of capital.

Next, we consider whether the change in the cost of capital after the disaster is related to (i) the impact of the energy shortage on firms' future cash flows (i.e. operating risk) and /or (ii) firm exposure to future regulatory actions (i.e. regulatory risk).

Fukushima represents a shock to the supply of clean energy. The shutdown of the Fukushima reactors and subsequent closure of all other nuclear reactors in the country caused nuclear power to fall from 31.2 percent in February 2011 to 12.4 percent in August 2011 and to zero in May 2012 (Hayashi & Hughes, 2013) and consequently increased investor concerns about firms' operating risk in relation to energy policies. Hence, we expect that firms with higher operating risk are more likely to be affected by the energy shortage caused by the disaster due to their higher levels

of energy dependence. However, conditional on operating risk, disclosing firms are expected to experience a lower increase in their cost of capital if disclosure lowers investor uncertainty about their ability to manage the energy shortage. Hence, we posit the following hypothesis:

H2: The negative association between environmental disclosures in the pre-disaster period and the cost of capital is stronger for firms with higher operating risk.

In the aftermath of the disaster, the reduction in clean nuclear energy increased CO₂ emissions by 2.1 percent in 2011; at the time, it was estimated that CO₂ emissions would increase by an additional 5.5 percent in 2012. These increases created tension over the ability of Japan to reach the 2020 CO₂ reduction targets established in the Kyoto Protocol (Srinivasan & Gopi Rethinaraj, 2013; Vivoda, 2012). Given that low emission levels have always been a priority for Japan (Duffield & Woodall, 2011), Fukushima has increased the threat of regulatory actions to compel pollution abatements and consequently has increased the relevance of information about firms' ability to bear future regulatory costs (Blacconiere & Patten, 1994; He et al., 2022). Firms in highly polluting industries (e.g. mining, chemical, and metals industries) are more likely to be affected by future regulatory actions (Patten, 2002). However, among firms in highly polluting industries, firms that disclose environmental information are expected to experience a lower increase in their cost of capital if this disclosure reduces investor uncertainty about the cash flow implications of future regulatory actions. Hence, we posit the following hypothesis:

H3: The negative association between environmental disclosures in the pre-disaster period and the cost of capital is stronger for firms in highly polluting industries.

3. Research Design

3.1. Research Setting

The Japanese setting is particularly relevant and powerful from a research design perspective. In the years considered in this analysis, Japan did not have any formal or comprehensive environmental disclosure regulations and thus environmental reporting was a voluntary corporate activity—which means there was substantial variation in firms' disclosure practices.³ However, environmental reporting in Japan was aligned with international practices. Environmental disclosures are presented in stand-alone CSR reports and prepared in accordance with international reporting guidelines such as the Global Reporting Initiative.

Further, Fukushima is the largest nuclear accident since Chernobyl. Radioactive materials contaminated the air, soil and water, creating a long-lasting impact on the environment and serious consequences for human health (Steinhauser et al., 2014). Such long-term effects can increase the relevance of environmental information in general. Most importantly for our purposes, Fukushima represents a shock to the supply of clean energy and to expected pollution levels.

Lastly, despite the lack of mandatory environmental reporting, Japan has a long-standing commitment to combating global warming stemming from the Rio Summit in 1992 and thus has a tendency toward pollution abatement. In July 2008, Japan introduced the '*Action Plan for Achieving a Low-carbon Society*', and as part of the Copenhagen Accord in 2009, it pledged to

³Under the 1999 Act on Promotion of Global Warming Countermeasures, plants of certain industries that use more than 1500 kiloliters of crude oil or emit more than 3000 tons of CO₂ annually are required to report CO₂ emissions to the Pollutant Release and Transfer Register (PRTR). However, there are no requirements to provide any information at the firm level. Our main finding remains unaffected if we control for whether any firms in our sample own plants that report to the PRTR.

reduce GHG emissions to 25 percent below 1990 levels by 2020. In December 2010, just a few months before the Fukushima disaster, the Japanese government committed to a 2030 goal to reduce carbon dioxide (CO₂) from fossil fuels to 30 percent below 1990 levels and introduced the bill for the ‘Basic Act on Climate Change Countermeasures’, which contemplates the introduction of a tax on fossil fuels and a feed-in tariff for renewable energy.⁴ Overall, regulatory intervention to control pollution is not unusual in Japan (Gouldson et al., 2014). Therefore, in the aftermath of the disaster the relevance of environmental information may increase if it allows investors to estimate firms’ exposure to future regulatory costs.

3.2. Empirical Strategy

Theory suggests that the negative relation between disclosure and the cost of capital increases with disclosure precision (Diamond & Verrecchia, 1991). As carbon emission information increases the precision of the environmental disclosure because it provides quantitative and verifiable information about a firm’s environmental performance (Clarkson et al., 2015), we examine whether firms that disclose carbon emission information in their environmental reports in the pre-disaster period experience a lower shock to the cost of capital relative to firms that do not disclose their carbon emission information. We justify the choice of using carbon emission information in three ways. First, prior literature shows that carbon emissions are value relevant (Chapple et al., 2013; Clarkson et al., 2015; Griffin et al., 2017; Matsumura et al., 2014) and can be integrated by investors into valuation models (Eccles et al., 2011). Second, the inclusion of carbon emission information in an environmental report increases the precision of environmental disclosure because it provides quantitative and verifiable information about a firm’s environmental performance (Clarkson et al., 2008; Plumlee et al., 2015). Third, studies in environmental economics and energy policy document the existence of a link between energy consumption and carbon emission levels (Apergis et al., 2010; Menyah & Wolde-Rufael, 2010; Sims et al., 2003), suggesting that carbon emission disclosures convey information about both energy policies and pollution levels. For this reason, information about carbon emissions is well suited to discern whether the cost of capital effect is related to reduced uncertainty about operating risk and/or firms’ exposure to future regulatory costs (Griffin et al., 2017; Matsumura et al., 2014).

In our baseline specification, we compare the change in the cost of capital around the disaster between firms that at the time of the disaster disclose information about their carbon emissions and firms that do not. We thus propose the following general specification:

$$ICC_{i,t} = \alpha_i + \phi_t + gPOST_t \times CO_2_DISCLOSURE_{i,PRE} + b_1 C_{i,t} + b_2 POST_t \times C_{i,t} + e_{i,t} \quad (1)$$

where *ICC* stands for the implied cost of capital, α_i is a firm fixed effect, and ϕ_t is a year fixed effect.⁵ *POST_t* is a binary variable equal to one for fiscal years ending after the disaster (i.e. fiscal year 2010).⁶ In this model, we assume that firms set their environmental disclosures in

⁴Specifically, the Basic Energy Plan approved in 2010 targets a 30 percent reduction in energy-related CO₂ emissions coupled with a twofold increase in the percentage of electricity generated by clean resources (renewables and nuclear power) by 2030 (Duffield & Woodall, 2011).

⁵In alternative specifications, we replace the year fixed effects with industry-year fixed effects to control for industry-specific cost of capital time trends (using the two-digit SIC industry classification code). In addition, we replace the firm-fixed effects structure with a lagged first- and second-order polynomial of cost of capital to address the concern that changes in the cost of capital may vary with pre-treatment cost of capital levels. Finally, we replace year fixed effects with a first- and second-order polynomial of a time trend variable. We also include differential time trends (in the first- and second-order polynomial form) between disclosing and non-disclosing firms.

⁶The fiscal year end of all firms included in the sample is March 31st. Hence the first fiscal year after the disaster is 2010, ending March 31, 2011. Environmental reports are released in the following 3–6 months.

the pre-disaster period according to a cost–benefit trade-off. We thus define a dummy variable, $CO_2_DISCLOSURE_i$, which captures pre-disaster variation in environmental disclosures. Specifically, $CO_2_DISCLOSURE_i$ is a time-invariant dummy variable that is equal to one if a firm provides historical and forward-looking quantitative information about its carbon emissions at least since the fiscal year before the disaster (i.e. fiscal year 2009), zero otherwise. We predict that firms that disclose carbon emission information experience a lower increase in the cost of capital relative to firms that do not disclose carbon emission information.

The vector $X_{i,t}$ includes a set of firm characteristics that are likely to correlate with firms' cost of capital and disclosure choices. Specifically, in line with prior research (Fama & French, 1992; Hail & Leuz, 2006), we expect the cost of capital to be negatively associated with firm size and positively associated with book-to-market ratio. Therefore, we control for firm size ($SIZE$) using the log of firm total assets at the beginning of its fiscal year. The book-to-market ratio (B_M) is computed as the ratio of firm book value to its market value of equity at the beginning of its fiscal year. We also consider traditional controls for risk. Return variability (RET_VAR) is measured as the standard deviation of monthly stock returns over the previous twelve months.⁷ Firm leverage (LEV) is the ratio between beginning-of-year total liabilities and beginning-of-year market value of equity. We control for firm profitability (ROA) using return on assets, which is computed as the net income before interest and taxes over total assets. The quality of financial reporting can also correlate with a firm's environmental disclosure choices and cost of capital. Thus, we include total accruals ($ACCRUALS$), determined as the difference between net income before extraordinary items and discontinued operations and cash flow from operations, scaled by total assets at the beginning of the period. Analyst following is computed as the logarithm of the number of analysts that issue a forecast during the year ($FOLLOWING$). To address concerns that our results are mechanically driven by changes in forecast precision around the disaster, we control for forecast error, which is computed as the mean one-year-ahead consensus forecast minus actual earnings scaled by actual earnings ($ERROR$).⁸ Finally, following Cao et al. (2014) who document that firms with better reputation enjoy a lower cost of capital, and Griffin et al. (2017), who show that the underlying level of carbon emissions is associated with a market-implied equity discount, we control for carbon performance (CO_2_PERF), measured by using the emission reduction category score from Thomson Reuters ASSET4. This variable captures corporate effectiveness in reducing environmental emissions in a firm's production and operational processes on a scale from 0 (not effective) to 100 (very effective).⁹ Appendix A provides the definitions of all the variables employed in this study.

⁷We use stock return variability rather than firm beta as a control for fundamental risk, because firm-level beta outside the U.S. can be noisy given concerns about sample size and stock market liquidity (Lee et al., 2009).

⁸The evidence reported in Table 4, Panel A is robust when $ERROR$ is measured alternatively as the mean one-year-ahead consensus forecast minus actual earnings divided by stock price at the fiscal year end.

⁹The Emission Reduction Score in ASSET4 'measures a company's management commitment and effectiveness towards reducing environmental emission in the production and operational processes. It reflects a company's *capacity* to reduce air emissions (greenhouse gases, F-gases, ozone-depleting substances, NO_x and SO_x, etc.), and to partner with environmental organisations to reduce the environmental impact of the company in the local or broader community.' Therefore, it tackles the problem that firms with lower historical carbon footprint may have less scope for reducing carbon emissions (a problem that is mitigated also by the firm-fixed effect structure of our research design). However, ASSET4 does not cover approximately sixty percent of the firm-years in our sample. Building on the argument that environmental performance tends to be homogenous within an industry, we replace the missing values for these performance variables using industry-year means (based on two-digit SIC industry classification codes) to increase the power of our tests. To test the robustness of our approach, we also restrict the sample to only firms covered by ASSET4 and obtain results that are qualitatively the same. Alternatively, we estimate carbon emission levels for all firms in our sample adopting the method proposed by Griffin et al. (2017).

To reduce heterogeneity between disclosing and non-disclosing firms, we employ an EBM strategy (Hainmueller, 2012). This matching strategy allows us to minimize the degree of observable heterogeneity between disclosing and non-disclosing firms by assigning a specific weight to each firm in the sample such that the distributions of the determinants of firms' disclosure choices after the re-reweighting satisfy a set of pre-specified moment conditions. In particular, we require the means of the determinant variable distributions between disclosing and non-disclosing firms to be equal, with the additional condition of minimum differences in variance and skewness.

Operationally, we proceed as follows. We limit the sample to firms that issued an environmental report in fiscal year 2009, i.e. the year before Fukushima. Then, we take the firm-specific average of each disclosure determinant variable over the three years prior to the disaster (i.e. 2007–2009). As determinants of a firm's disclosure choices, we use the full set of controls described above. Then, we collapse the sample to the firm level, i.e. one observation per firm. Next, we regress the $CO_2_DISCLOSURE_i$ dummy on the firm-specific average of the determinant variables, with industry fixed effects using the two-digit SIC industry classification code, to obtain the firm-specific weights¹⁰ that satisfy the pre-determined moment conditions.¹¹ This disclosure determinant model allows us also to explore the differences between disclosing and non-disclosing firms. The main factors explaining heterogeneity in disclosures across firms are size, total accruals, and carbon performance.

Time invariant confounders, such as the importance of nuclear energy to a firm's energy policy or distance to the Fukushima site, are captured by firm fixed effects. However, there may be other firm characteristics that correlate with disclosure choices and cost of capital that vary around the year of the disaster and thus explain the differential cost of capital effects between disclosing and non-disclosing firms. For example, firms that experience a lower increase in return variability around the time of the disaster may be more likely than other firms to disclose information about their carbon emissions. In this case, the estimates will be biased if the changes in firm return variability correlate with changes in the cost of capital. Hence, we propose a flexible specification in which we allow the coefficients of the vector of the control variables to vary around the time of the disaster (i.e. $POST \times X_{i,t}$) to account for the extent to which these factors co-vary with changes in the cost of capital. Our inference is based on clustered standard errors at the firm level.

3.3. Implied Cost of Capital Measures

We follow the prior literature and rely on accounting-based valuation models to estimate the implied cost of capital (Claus & Thomas, 2001; Easton, 2004; Gebhardt et al., 2001; Hail & Leuz, 2006, 2009; Ohlson & Juettner-Nauroth, 2005). These approaches build on discounted dividend models that are translated into a valuation equation based on residual income using accounting identities. The underlying idea is to replace price and analyst earnings forecasts in the valuation equations and obtain the cost of capital as the internal rate of return that equates actual share price and the time series of expected residual income. To the extent that shocks to growth opportunities enter directly into the cost of capital estimation in terms of analyst forecasts and long-term growth prospects, the use of these metrics allows us to control for concurrent cash

¹⁰We obtain firm-specific weights using the *ebalance* STATA function (Hainmueller, 2012).

¹¹We also run a propensity score matching (PSM), with replacement, and requiring a caliper of 20 percent of the standard deviation of the propensity score. The PSM is executed using the same procedure and with the same set of determinants used to compute the weights in the EBM. The evidence (untabulated) suggests that our results are not driven by the choice of the matching strategy: the coefficient on our variable of interest, i.e., interaction between *POST* and *CO2_DISCLOSURE*, is still negative and significant, and with magnitudes comparable to the ones in the EBM approach. See Supplemental Information, Tables B1 and B2 and Graph B1.

flow effects. To address concerns about measurement errors related to the use of a single measure, we use the yearly average of the four models as our proxy for the cost of capital.¹²

The main concern about relying on the implied cost of capital measures is that these measures are based on analyst forecasts that are potentially affected by measurement errors due to errors in analyst forecasts (Easton & Monahan, 2005). To partially address this concern, we control for analyst forecast errors in the empirical models. Given that we look at within firm changes in implied cost of capital rather than at differences across firms at a given point in time, errors in analyst forecasts can bias our estimates only if they vary over time within firms.

3.4. Environmental Disclosure

Firm environmental reports were hand-collected from the Japanese Ministry of Economy, Trade and Industry¹³ and from corporate websites. We exploit cross-sectional variation in firm disclosure practices by splitting the sub-sample of disclosing firms into non-overlapping groups according to whether firms included historical *and* forward-looking (i.e. target) carbon emission information since fiscal year 2009. We consider the presence of both historical and forward-looking information because we wish to capture disclosure precision, firms' ex-ante environmental commitment and effort (Ioannou et al., 2016) and its verifiability ex-post by investors.¹⁴ Further, the disclosure of carbon emission information provides information about firms' ability to manage the shortage in the energy supply and related transitory arrangements, as well as exposure to future compliance and regulatory actions. Therefore, we code a dummy variable that equals one if the firm provides both historical *and* target carbon emissions in fiscal year 2009 and equals zero otherwise (i.e. *CO₂_DISCLOSURE*).¹⁵

4. Data and Descriptive Statistics

The sample comprises 4,216 firm-year observations from 392 unique firms over the 2002–2013 period. To be included in the sample, a firm must have data available to compute the implied cost of capital, disclosure¹⁶ and control variables. We do not require a firm to be continuously listed over the entire sample period but rather that it is listed at least two years before and two years after the disaster. To compute the implied cost of capital, we collect financial data from Compustat Global and price information from Datastream. Data on analyst earnings forecasts were hand-collected from the 'Tokyo KeizaiShinpo-Sha', which reports outstanding analyst consensus

¹²The details of the computation of the four metrics are reported in Appendix B.1. In additional analyses, we gauge the extent to which our main results are robust to the use of each individual implied cost of capital measure.

¹³Data were collected from <http://www.ecosearch.jp/en/>.

¹⁴We note that disclosure of historical and forward-looking information also increases the comparability of the information with firms following ESG standards (e.g., GRI). Our sample firms disclosing carbon emissions targets tend to use precise estimates, expressed as percentages. A typical example is reported in Figure B2 in the online appendix. A firm that would only release a *qualitative* estimate (e.g., emissions are likely to decrease, or will be lower than the current year) would not have been coded as a firm disclosing carbon emissions targets. Further, we did not come across range estimates. Appendix B.3 provides further supporting arguments on the variable measurement and also a series of sensitivity tests.

¹⁵In an un-tabulated analysis, we replace *CO₂_DISCLOSURE* with a dummy indicating the presence of an environmental report (and thus we augment the sample to include firms that do not issue an environmental report). The coefficient on the disclosure of environmental report is still negative but insignificant. This evidence confirms the idea that environmental reports without the disclosure of historical and forward-looking carbon emissions contain mostly boilerplate sentences with little relevance for investors.

¹⁶This implies that we limit the sample to firms that issued an environmental report in fiscal year 2009, i.e. the year before Fukushima.

Table 1. Sample characteristics.

<i>Panel A: Sample selection</i>		
Firm-years listed in the First Section of the Tokyo Stock Exchange (2002–2013)		12,958
Less firm-years missing data to compute the implied cost of capital		6,226
Less firm-years non-continuously listed between 2003 and 2013		2,070
Less firm-years non-continuously issuing environmental reports		446
Final sample		4,216
<i>Panel B: Number of times a firm appears in the sample</i>		
# years	# firms	<i>N</i>
4	1	4
6	4	24
7	13	91
8	50	400
9	31	279
10	18	180
11	50	550
12	224	2688
<i>Panel C: Distribution of firm-year observations by year</i>		
Year	<i>N</i>	%
2002	291	6.90
2003	369	8.75
2004	375	8.89
2005	384	9.11
2006	390	9.25
2007	383	9.08
2008	381	9.04
2009	383	9.08
2010	385	9.13
2011	304	7.21
2012	275	6.52
2013	296	7.04

forecasts on a monthly basis for all firms listed on the Tokyo Stock Exchange. To be included in the implied cost of capital computation, firms must have one-year- and two-year-ahead analyst forecasts and either a three-year-ahead earnings forecast or a long-term growth forecast. Data for prices and analyst earnings forecasts are measured seven months after the fiscal year end to guarantee that accounting data are publicly available and priced by the market at the time of the cost of capital computation. Finally, we delete the one percent of observations at the top of the sample distribution of the yearly average of the four cost of capital models. Table 1 summarizes the sample selection procedure and provides the breakdown of the sample by year.

Panel A of Table 2 reports descriptive statistics of the variables used in the analyses. The mean *ICC* estimate is 13 percent. Table 2, Panel B reports the distributions of the control variables before and after the EBM procedure separately for disclosing and non-disclosing firms. The panel shows that before the EBM weighting, the variable distributions of the two sub-groups are systematically different from each other. Firms that disclose carbon emissions are larger, have lower growth prospects and lower carbon emissions and are followed by more analysts. However, after the re-weighting procedure, the mean of the covariates of interest is the same for the disclosing and non-disclosing firm groups, with the second and third moments being minimized. This evidence supports the validity of our matching procedure, which allows us to minimize the degree of heterogeneity between the two groups of firms.

Table 2. Descriptive statistics.

<i>Panel A: Descriptive statistics – Overall sample</i>								
Variable	N	Mean	p5	p25	p50	p75	P95	SD
ICC	4,216	0.131	0.055	0.086	0.112	0.154	0.272	0.071
SIZE	4,216	8.013	5.686	6.953	7.881	9.072	10.687	1.493
B_M	4,216	0.962	0.349	0.611	0.874	1.194	1.899	0.503
ROA	4,216	0.024	−0.032	0.010	0.024	0.041	0.076	0.036
LEV	4,216	0.539	0.213	0.399	0.551	0.689	0.828	0.189
RET_VAR	4,216	0.094	0.040	0.061	0.082	0.110	0.181	0.057
FOLLOWING	4,216	1.816	0.693	1.099	1.946	2.565	2.996	0.802
ACCRUALS	4,216	−0.044	−0.121	−0.069	−0.041	0.018	0.028	0.045
ERROR	4,216	0.348	−1.105	0.034	0.126	0.336	1.980	1.463
CO2_PERF	4,216	82.783	38.730	84.750	90.940	92.695	94.060	18.074

<i>Panel B: Covariate balancing</i>								
Before entropy balance weighting								
Covariate	CO ₂ _DISCLOSURE = 1				CO ₂ _DISCLOSURE = 0			
	N	mean	variance	skewness	N	mean	variance	skewness
SIZE	644	8.657	1.463	0.011	3,572	7.893	2.280	0.351
B_M	644	0.861	0.176	1.553	3,572	0.981	0.265	1.438
ROA	644	0.023	0.001	−0.938	3,572	0.024	0.001	−1.482
LEV	644	0.578	0.033	−0.339	3,572	0.532	0.036	−0.176
RET_VAR	644	0.094	0.003	3.924	3,572	0.094	0.003	3.583
FOLLOWING	644	2.097	0.552	−0.665	3,572	1.764	0.643	0.015
ACCRUALS	644	−0.046	0.002	0.003	3,572	−0.043	0.002	−0.209
ERROR	644	0.365	2.394	4.119	3,572	0.345	2.092	4.820
CO2_PERF	644	86.122	139.399	−2.584	3,572	82.159	359.242	−2.006

After entropy balance weighting								
Covariate	CO ₂ _DISCLOSURE = 1				CO ₂ _DISCLOSURE = 0			
	N	mean	variance	skewness	N	mean	variance	skewness
SIZE	644	8.657	1.463	0.011	3,572	8.657	2.348	−0.147
B_M	644	0.861	0.176	1.553	3,572	0.861	0.178	1.396
ROA	644	0.023	0.001	−0.938	3,572	0.023	0.001	−1.284
LEV	644	0.578	0.033	−0.339	3,572	0.578	0.033	−0.427
RET_VAR	644	0.094	0.003	3.924	3,572	0.094	0.004	4.180
FOLLOWING	644	2.097	0.552	−0.665	3,572	2.097	0.561	−0.774
ACCRUALS	644	−0.046	0.002	0.003	3,572	−0.046	0.002	−0.415
ERROR	644	0.365	2.394	4.119	3,572	0.365	1.868	5.035
CO2_PERF	644	86.122	139.399	−2.584	3,572	86.122	180.324	−2.943

Table 2, Panel A reports descriptive statistics of the variables used in the empirical analyses. Table 2, Panel B presents descriptive statistics of the variables used in entropy balance matching. We split the sample based on whether firms disclose or do not disclose carbon emission information in fiscal year 2009, before and after the entropy balance matching. All variables are defined in Appendix A.

5. Results

We start our empirical analysis by estimating the change in firm cost of capital and the market reaction to the disaster unconditional on firms' carbon emission disclosures. This analysis provides evidence about the magnitude of the economic consequences associated with the disaster irrespective of firm disclosure choices.¹⁷ Table 3 reports that on average, the disaster is associated

¹⁷Because there is no control group in this specification, we replace year fixed effects with a time trend variable.

Table 3. Average effect on cost of capital.

	ICC	
	(1)	(2)
<i>POST</i>	0.028*** [0.005]	0.021*** [0.007]
<i>SIZE</i>	−0.010*** [0.002]	−0.003 [0.008]
<i>B_M</i>	0.022*** [0.005]	0.029*** [0.006]
<i>ROA</i>	−0.298*** [0.071]	−0.307*** [0.069]
<i>LEV</i>	0.085*** [0.011]	0.100*** [0.030]
<i>RET_VAR</i>	0.198*** [0.035]	0.070*** [0.025]
<i>FOLLOWING</i>	0.012*** [0.003]	0.011** [0.005]
<i>ACCRUALS</i>	−0.001** [0.000]	0.001 [0.000]
<i>ERROR</i>	0.001 [0.001]	0.001 [0.001]
<i>CO2_PERF</i>	−0.010** [0.005]	−0.008* [0.005]
FIRM FE	Yes	Yes
POST × CONTROLS	No	Yes
TIME TREND	Yes	Yes
Observations	4,216	4,216
R-squared	0.423	0.428

Table 3 reports the results from regressing the yearly average of the four cost of capital metrics on an indicator variable marking the years after the Fukushima nuclear disaster (*POST*) and a set of control variables. The table reports OLS coefficient estimates and (in parentheses) robust standard errors that are clustered at the firm level. All the variables are defined in Appendix A. ***, ** and * denote significance at the 1, 5 and 10 percent levels (two-tailed), respectively.

with an approximate 2 percent (200-basis) points increase in firms' cost of capital. Untabulated evidence also suggests that our sample firms experience negative returns at the disaster date (i.e. $AR[0]$)¹⁸ of approximately -0.012 implying a 1.2 percent average decrease in firms' market capitalization (calculated against the market returns of the Japan NIKKEI 225). The average 2- and 3-trading day cumulative returns (i.e. $CAR[0,1]$ and $CAR[0,2]$, untabulated) around the disaster date are also negative, significant, and higher in magnitude than the returns at the disaster date, suggesting that returns do not reverse right after the disaster. Taken together, these results support the argument that the disaster is associated with economic and cost of capital consequences for the firms in our sample.

Next, we provide descriptive evidence of whether the disaster triggers a shift in the relevance of environmental information, by investigating whether the disaster is associated with a change in the weight placed by investors on environmental information when discounting firm cash flows. That is, we measure the extent to which the disaster is associated with an increase in the sensitivity of the cost of capital to firm carbon performance.¹⁹ Such evidence would be consistent

¹⁸Operationally, we compute abnormal returns based on the market model for each firm in the sample for the 253 trading days ending 127 trading days before the day of the disaster [trading day 0].

¹⁹An increase in the sensitivity of the cost of capital to firm carbon performance could also be driven by a change in investors' preferences. However, as noted by Richardson and Welker (2001), disentangling the two explanations is a very difficult task, given that investors' preference cannot be observed.

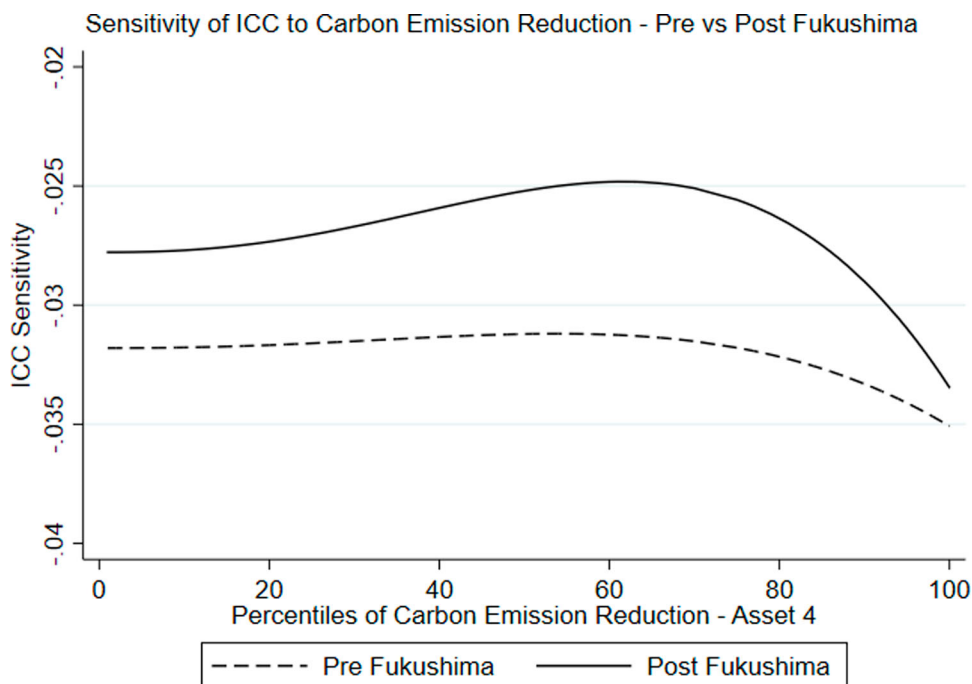


Figure 1. Sensitivity of cost of capital to carbon performance. Figure 1 plots the sensitivity of the cost of capital, measured as the yearly average of the four cost of capital metrics, to carbon performance, measured as the carbon emission reduction score from Asset4, separately for the pre- (dash line) and post-disaster (continuous line) periods. All variables are defined in Appendix A.

with the idea that firm environmental information is more relevant in discounting future cash flows after the disaster. We thus regress firm cost of capital on the Thomson Reuters ASSET4 emission reduction score (CO_2_PERF , our measure of carbon performance) and the sets of control variables separately for the pre- and post-disaster periods. Figure 1 plots the coefficients of the emission reduction score conditional on the percentiles of the score distribution separately for the two periods. This figure shows a sharp increase in the sensitivity of the cost of capital to carbon performance after the disaster, given that for any percentile of the emission reduction score, the cost of capital sensitivity is higher in the post-disaster period than in the pre-disaster period. Although this evidence is only suggestive, it is consistent with the idea that the disaster increases the relevance of carbon information.

Our first hypothesis is that firms that disclose information about carbon emissions experience a less severe increase in their cost of capital relative to non-disclosing firms. Table 4, Panel A reports our main results. The coefficient of $POST \times CO_2_DISCLOSURE$ is negative and significant across the various model specifications. The economic magnitude of the coefficient is stable, ranging from 120 basis points (estimated coefficient: -0.012) in the base model to 170 basis points (estimated coefficient: -0.017) in the EBM model where the controls are interacted with $POST$. Given the evidence reported for the overall sample in Table 3, disclosing firms still experience an increase in the cost of capital between 30–80 basis points relative to the pre-disaster period. Such increase is slightly above the conventional level of significance in the most conservative specifications (untabulated, p -value: 0.230 in the matching specification). While we do not have a direct benchmark in the environmental disclosure literature to validate the plausibility of these magnitudes, our estimates are in the same order of magnitude of other studies examining the cost of capital effects of the disclosure of internal control weakness or restatements, which

Table 4. Economic consequences of environmental disclosure around the disaster.

Panel A: Environmental disclosure and the cost of capital

	ICC			
	BASE	EBM	FLEXIBLE	EBM & FLEXIBLE
	(1)	(2)	(3)	(4)
<i>POST</i> × <i>CO₂_DISCLOSURE</i>	− 0.012** [0.006]	− 0.015** [0.008]	− 0.014* [0.008]	− 0.017** [0.008]
<i>SIZE</i>	− 0.003 [0.008]		− 0.008*** [0.002]	
<i>B_M</i>	0.029*** [0.006]		0.021*** [0.006]	
<i>ROA</i>	− 0.308*** [0.069]		− 0.234*** [0.060]	
<i>LEV</i>	0.100*** [0.030]		0.083*** [0.012]	
<i>RET_VAR</i>	0.069*** [0.024]		0.192*** [0.039]	
<i>FOLLOWING</i>	0.011** [0.005]		0.008** [0.004]	
<i>ACCRUALS</i>	0.001 [0.000]		− 0.001 [0.000]	
<i>ERROR</i>	0.001 [0.001]		0.001 [0.001]	
<i>CO₂_PERF</i>	− 0.013** [0.005]		0.007 [0.004]	
YEAR FE	Yes	Yes	Yes	Yes
FIRM FE	Yes	Yes	Yes	Yes
POST × CONTROLS	No	No	Yes	Yes
EBM	No	Yes	No	Yes
Observations	4,216	4,216	4,216	4,216
R-squared	0.421	0.374	0.462	0.403

Table 4, Panel A reports the results from regressing the yearly average of the four cost of capital metrics on the interaction between an indicator variable marking firms that disclose carbon emission information in fiscal year 2009 (*CO₂_DISCLOSURE*) and *POST*, as well as controls and fixed effects. Column (1) reports OLS coefficient estimates using the base model as specified in Eq. (1) (BASE). Column (2) reports OLS coefficient estimates using the EBM strategy (EBM). Column (3) reports OLS coefficient estimates using the flexible specification, in which we include in the regression the interactions between the controls and *POST* (FLEXIBLE). Column (4) reports OLS coefficient estimates with the EBM strategy in which we include in the regression the interactions between the controls and *POST* (EBM & FLEXIBLE). Robust standard errors clustered at the firm level are reported in parentheses. All variables are defined in Appendix A. ***, ** and * denote significance at the 1, 5 and 10 percent levels (two-tailed), respectively.

estimate cost of capital changes of around 100–150 basis points (Ashbaugh-Skaife et al., 2009; Hribar & Jenkins, 2004).²⁰

To link firms' carbon emissions disclosure with the short-run consequences of the disaster, and thus reassure that the cost of capital effects related to disclosure are ascribable to the disaster, we report market reaction results in Table 4, Panel B. Disclosing firms experience a less negative

²⁰Note, however, that our cost of capital measure is the average of four metrics, based on both long-term and short-term components and forecasting horizons. If we gauge our magnitudes based on the PEG ratio and the Claus and Thomas measure (see also Table B7), which are the most short-term cost of capital measures among the four used in the paper, then our magnitudes are lower, ranging from 90 to 120 basis points.

Table 4. Continued.

	CAR[0,1]	
	BASE (1)	EBM (2)
<i>CO₂_DISCLOSURE</i>	0.029** [0.011]	0.025*** [0.009]
<i>SIZE</i>	0.016*** [0.005]	
<i>B_M</i>	-0.020 [0.017]	
<i>ROA</i>	-0.321 [0.344]	
<i>LEV</i>	-0.029 [0.033]	
<i>RET_VAR</i>	0.175 [0.248]	
<i>FOLLOWING</i>	-0.007 [0.010]	
<i>ACCRUALS</i>	0.003** [0.001]	
<i>ERROR</i>	-0.000 [0.003]	
<i>CO₂_PERF</i>	-0.003 [0.003]	
INDUSTRY FE	Yes	Yes
EBM	No	Yes
Observations	392	392
R-squared	0.414	0.391

Table 4, Panel B reports the results of regressing the 2-trading day cumulative abnormal returns on an indicator variable marking firms that disclose carbon emission information in fiscal year 2009 (*CO₂_DISCLOSURE*), as well as control variables and fixed effects. The two specifications BASE and EBM are as in the note to Panel A. Robust standard errors clustered at the firm level are reported in parenthesis. All the variables are defined in Appendix A. ***, ** and * denote significance at the 1, 5 and 10 percent levels (two-tailed), respectively.

market reaction relative to firms that do not disclose such information.²¹ Overall, evidence from Table 4 supports the hypothesis that disclosing firms suffer a less intense cost of capital increase after the disaster relative to non-disclosing firms.²²

We next explore the underlying mechanisms that drive the pattern in the cost of capital changes. We test H2 by considering the firm capital intensity in the year before the disaster (*CAPITAL_INT*) as our proxy for energy dependence, measured as the standardized ratio between property, plant and equipment and total assets at the beginning of the year. Then, we augment equation (1) with interaction terms among *CAPITAL_INT*, *POST*, and *POST* × *CO₂_DISCLOSURE*. Table 5, Panel A reports the estimation results. We find that conditional on capital intensity, disclosing firms experience a lower increase in cost of capital relative to non-disclosing firms, as evidenced by the negative and significant coefficient of

²¹The average market reaction for the disclosing firms is neither economically nor statistically different from zero (*CAR[0,1]* equals 0.01, *p*-value = 0.545, untabulated).

²²In Table B8 and B9 in the online appendix, we restrict the estimation sample to a balance panel of one (three) year(s) before and after the disaster. The results look very similar to those reported in the main analyses. Such additional analysis addresses the concerns that our findings may be driven by sample composition effects or a long run time trend in the cost of capital specific to disclosing and non-disclosing firms. Further, we find no evidence that other disclosures, such as managerial earnings forecasts, change significantly around the disaster.

Table 5. Environmental disclosure and the cost of capital around the disaster conditional on energy dependence and exposure to regulatory risk.

Panel A: Environmental disclosure and the cost of capital conditional on exposure to the energy supply shock

	BASE	EBM	FLEXIBLE	EBM & FLEXIBLE
	(1)	(2)	(3)	(4)
<i>POST</i> × <i>CO₂_DISCLOSURE</i>	−0.017** [0.007]	−0.016** [0.007]	−0.015* [0.008]	−0.016** [0.007]
<i>POST</i> × <i>CO₂_DISCLOSURE</i> × <i>CAP_INTENSITY</i>	−0.014** [0.006]	−0.012** [0.005]	−0.020*** [0.006]	−0.012** [0.005]
<i>POST</i> × <i>CAP_INTENSITY</i>	0.005* [0.003]	0.004 [0.003]	0.007** [0.003]	0.001 [0.003]
<i>SIZE</i>	−0.007*** [0.002]		−0.009*** [0.002]	
<i>B_M</i>	0.017*** [0.006]		0.021*** [0.006]	
<i>ROA</i>	−0.338*** [0.074]		−0.236*** [0.059]	
<i>LEV</i>	0.068*** [0.012]		0.083*** [0.012]	
<i>RET_VAR</i>	0.129*** [0.029]		0.192*** [0.040]	
<i>FOLLOWING</i>	0.010*** [0.004]		0.008** [0.004]	
<i>ACCRUALS</i>	−0.001*** [0.000]		−0.001 [0.000]	
<i>ERROR</i>	0.000 [0.001]		0.001 [0.001]	
<i>CO₂_PERF</i>	−0.011** [0.005]		−0.001 [0.005]	
YEAR FE	Yes	Yes	Yes	Yes
FIRM FE	Yes	Yes	Yes	Yes
<i>POST</i> × CONTROLS	No	No	Yes	Yes
EBM	No	Yes	No	Yes
Observations	4,216	4,216	4,216	4,216
R-squared	0.430	0.421	0.464	0.427

Table 5, Panel A reports the results from regressing the yearly average of the four cost of capital metrics on interaction terms among an indicator variable marking firms that disclose carbon emission information in fiscal year 2009 (*CO₂_DISCLOSURE*), *POST*, and the standardized ratio of the gross property, plant, and equipment to total assets (*CAP_INTENSITY*). The definitions of the models in Columns (1) to (4) are reported in the note to Table 4 Panel A. Robust standard errors clustered at the firm level are reported in parenthesis. All other variables are defined in Appendix A. ***, ** and * denote significance at the 1, 5 and 10 percent levels (two-tailed), respectively.

the interaction term, *POST* × *CO₂_DISCLOSURE* × *CAPITAL_INT*. This evidence is consistent with the argument that the disclosure of carbon emissions reduces investor uncertainty about firm energy usage.

We test H3 (exposure to future regulatory actions) by considering whether there is a differential disclosure impact between firms in carbon sensitive industries (i.e. CSI) and other industries. We use alternative definitions to identify CSI firms. First, we consider in which industries carbon performance is considered material (i.e. bearing financial implications) following the SASB materiality guide (SASB, 2017). Second, we also adopt an alternative classification

Table 5. Continued.

	ICC			
	BASE	EBM	FLEXIBLE	EBM & FLEXIBLE
	(1)	(2)	(3)	(4)
<i>POST</i> × <i>CO₂_DISCLOSURE</i>	− 0.019*	− 0.023**	− 0.023**	− 0.025**
	[0.010]	[0.010]	[0.011]	[0.010]
<i>POST</i> × <i>CO₂_DISCLOSURE</i> × <i>CSI</i>	0.015	0.016	0.017	0.017
	[0.012]	[0.013]	[0.013]	[0.013]
<i>POST</i> × <i>CSI</i>	0.001	− 0.001	0.001	0.001
	[0.005]	[0.006]	[0.006]	[0.006]
<i>SIZE</i>	− 0.003		0.002	
	[0.008]		[0.009]	
<i>B_M</i>	0.029***		0.028***	
	[0.006]		[0.008]	
<i>ROA</i>	− 0.308***		− 0.238***	
	[0.069]		[0.067]	
<i>LEV</i>	0.101***		0.077***	
	[0.030]		[0.029]	
<i>RET_VAR</i>	0.069***		0.089***	
	[0.024]		[0.031]	
<i>FOLLOWING</i>	0.011**		0.009	
	[0.005]		[0.005]	
<i>ACCRUALS</i>	0.001		0.001	
	[0.000]		[0.000]	
<i>ERROR</i>	0.001		0.001	
	[0.001]		[0.001]	
<i>CO₂_PERF</i>	− 0.014***		− 0.003	
	[0.005]		[0.005]	
YEAR FE	Yes	Yes	Yes	Yes
FIRM FE	Yes	Yes	Yes	Yes
POST × CONTROLS	No	No	Yes	Yes
EBM	No	Yes	No	Yes
Observations	4,216	4,216	4,216	4,216
R-squared	0.502	0.420	0.427	0.512

Table 5, Panel B reports the results from regressing the yearly average of the four cost of capital metrics on interaction terms among an indicator variable marking firms that disclose carbon emission information in fiscal year 2009 (*CO₂_DISCLOSURE*), *POST*, and a binary variable that equals one for firms in industries in which carbon pollution is a material issue (*CSI*). The definitions of the models in Columns (1) to (4) are reported in the note to Table 4 Panel A. Robust standard errors clustered at the firm level are reported in parenthesis. All other variables are defined in Appendix A. ***, ** and * denote significance at the 1, 5 and 10 percent levels (two-tailed), respectively.

of environmentally sensitive industries following Cho and Patten (2007).²³ Since this classification does not change our evidence, we only report results for the first classification. We define the variable for CSIs (*CSI*) as those industries where carbon pollution is a material issue (SASB, 2017). Then, we augment equation (1) with interaction terms between *CSI*, *POST*, and *POST* × *CO₂_DISCLOSURE*. Table 5, Panel B reports the estimation results. We do not find evidence that firm exposure to future regulatory costs, as proxied by *CSI*, affects the relation between environmental disclosure and the cost of capital. Further, our results are robust if we exclude firms in the oil and gas industry, that although prone to potential future regulation on

²³About 70 percent of the disclosing firms are classified as CSI following the SASB framework, whereas about 34 percent of the disclosure observations are classified as environmentally sensitive following Cho and Patten (2007).

pollution abatement, may have experienced an increase in profitability due to the shutdown of nuclear plants. Similarly, electricity firms may have experienced both positive and negative effects from the shutdown of nuclear power plants depending on their pre-Fukushima mix of power sources. If we exclude these firms, our evidence remains unchanged.

5.1. Additional Analyses Ruling Out Alternative Explanations

Previous analyses point to the existence of a negative association between environmental disclosure and the cost of capital. However, our specifications may still pick up spurious associations between unobservable firm characteristics that correlate with firm disclosure choices. Therefore, we conduct additional analyses to rule out plausible alternative explanations. For the sake of brevity, not all tests are reported in the paper but available as supplemental information, in Appendix B.²⁴

5.2. Carbon Performance

First, environmental disclosure is bundled with several firm characteristics that may explain the differential firms' reactions to the disaster. For example, the differential cost of capital changes may be attributable not to the disclosure of carbon emissions but rather to differences in the content of the disclosure, i.e. firm carbon performance.²⁵ We thus augment equation (1) with interaction terms between $CO2_PERF$, $POST$ and $POST \times CO2_DISCLOSURE$. Table 6 reports the estimation results. We find that firms that disclose carbon emission information experience a lower increase in their cost of capital after the disaster regardless of their underlying performance. The coefficient of $POST \times CO2_DISCLOSURE$ is significant for all specifications except the flexible one (i.e. model 3). In un-tabulated results, we run a similar test using the CO_2 emissions estimation model elaborated by Griffin et al. (2017), obtain evidence consistent with main evidence.²⁶

5.3. Effect of the Disaster on Firms' Future Cash Flows

The disaster likely affected firm cost of capital not only through an informational channel (i.e. by increasing investor uncertainty about firms' future cash flows) but also by directly affecting firms' future cash flows (e.g. by lowering firms' growth prospects, increasing costs, and reducing revenues). We thus examine whether the differential cost of capital reactions to the disaster are driven by firms' distance from Fukushima, which we assume to be a proxy for the magnitude of the economic implications of the disaster. If our main evidence were the result of revisions of firms' future cash flows associated with the disaster, then we would expect the effect of environmental disclosure on the cost of capital to be concentrated among firms that are headquartered close to the nuclear site. Operationally, we split the sample into three groups according to firm distance from the Fukushima nuclear site (i.e. less than 250 km radius, between 250 and 600 km radius, and more than 600 km radius) and then estimate equation (1) separately for each group. Table 7 reports the results. In the flexible specification, the coefficient of interest is greater for firms in the group closest to Fukushima than for firms located further away.

²⁴In table B2 we explore the determinants of a firm's decision to disclose carbon emission information. The results suggest the main determinants of carbon emission data disclosure are firm size ($SIZE$), profitability (ROA), total accruals ($ACCRUALS$), forecast error ($ERROR$), and carbon performance ($CO2_PERF$).

²⁵We note that the coefficient for $CO2_PERF$ in Table 4, Panel A, column (1) is significant and negative, suggesting that firms with better carbon performance are associated with a lower increase in the cost of capital.

²⁶The correlation coefficient between CO_2 emissions derived from the Griffin et al. (2017) and the ASSET4 carbon performance proxy determined after industry level replacement is significant and around 76 percent.

Table 6. Environmental disclosure and the cost of capital around the disaster conditional on carbon performance.

	ICC			
	BASE	EBM	FLEXIBLE	EBM & FLEXIBLE
	(1)	(2)	(3)	(4)
<i>POST</i> × <i>CO₂_DISCLOSURE</i>	-0.016** [0.008]	-0.015** [0.007]	-0.012 [0.009]	-0.015* [0.008]
<i>POST</i> × <i>CO₂_DISCLOSURE</i> × <i>CO₂_PERF</i>	-0.002 [0.008]	-0.002 [0.008]	-0.004 [0.0014]	-0.004 [0.009]
<i>POST</i> × <i>CO₂_PERF</i>	0.001 [0.002]	-0.001 [0.002]	0.002 [0.002]	-0.000 [0.002]
<i>CO₂_PERF</i>	0.000 [0.003]	0.000 [0.002]	-0.001 [0.002]	-0.002 [0.002]
<i>SIZE</i>	-0.003 [0.008]		-0.009*** [0.002]	
<i>B_M</i>	0.029*** [0.006]		0.021*** [0.006]	
<i>ROA</i>	-0.308*** [0.069]		-0.234*** [0.060]	
<i>LEV</i>	0.100*** [0.030]		0.083*** [0.012]	
<i>RET_VAR</i>	0.069*** [0.025]		0.191*** [0.040]	
<i>FOLLOWING</i>	0.011** [0.005]		0.008* [0.004]	
<i>ACCRUALS</i>	0.001 [0.000]		-0.001 [0.000]	
<i>ERROR</i>	0.001 [0.001]		0.001 [0.001]	
YEAR FE	Yes	Yes	Yes	Yes
FIRM FE	Yes	Yes	Yes	Yes
POST × CONTROLS	No	No	Yes	Yes
EBM	No	Yes	No	Yes
Observations	4,216	4,216	4,216	4,216
R-squared	0.421	0.420	0.462	0.425

Table 6 reports the results from regressing the yearly average of the four cost of capital metrics on interaction terms among an indicator variable marking firms that disclose carbon emission information in fiscal year 2009 (*CO₂_DISCLOSURE*), *POST*, and the carbon performance score from ASSET4 (*CO₂_PERF*). The definitions of the models in Columns (1) to (4) are reported in the note to Table 4 Panel A. Robust standard errors clustered at the firm level are reported in parenthesis. All other variables are defined in Appendix A. ***, ** and * denote significance at the 1, 5 and 10 percent levels (two-tailed), respectively.

However, the magnitudes of the coefficients in the EBM models with a flexible specification are comparable, even though the effect for firms located in the group furthest from Fukushima is less precisely estimated. Overall, the results suggest that while the distance from Fukushima concurs in determining the economic consequences of the disaster, the disclosure of carbon emissions information has additional explanatory power in explaining the heterogeneous cost of capital implications of the disaster.

5.4. Other Alternative Explanations

First, we account for potential confounders related to heterogeneity in firm future performance and operating volatility between disclosing and non-disclosing firms. We do not find evidence that our findings are driven by changes in firms' revisions to future cash flows or by volatility

Table 7. Environmental disclosure and the cost of capital around the disaster conditional on distance from the Fukushima nuclear site.

	ICC					
	Distance < 250 km radius		250 < Distance < 600 km radius		Distance > 600 km radius	
	FLEXIBLE (1)	EBM & FLEXIBLE (2)	FLEXIBLE (3)	EBM & FLEXIBLE (4)	FLEXIBLE (5)	EBM & FLEXIBLE (6)
<i>POST</i> × <i>CO</i> ₂ <i>DISCLOSURE</i>	−0.025**	−0.018*	−0.017**	−0.016*	−0.018*	−0.020
	[0.010]	[0.011]	[0.008]	[0.010]	[0.010]	[0.012]
CONTROLS	Yes	Yes	Yes	Yes	Yes	Yes
<i>POST</i> × CONTROLS	Yes	Yes	Yes	Yes	Yes	Yes
EBM	No	Yes	No	Yes	No	Yes
YEAR FE	Yes	Yes	Yes	Yes	Yes	Yes
FIRM FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,410	1,410	1,175	1,175	1,631	1,631
R-squared	0.415	0.460	0.448	0.495	0.423	0.462

Table 7 reports the results from regressing the yearly average of the four cost of capital metrics on interaction terms among an indicator variable marking firms that disclose carbon emission information in fiscal year 2009 (*CO*₂ *DISCLOSURE*), and *POST*, conditional on the distance between a firm’s headquarters and the Fukushima nuclear site. Control variables are included but not reported for the sake of brevity. The definitions of the models in Columns (1) to (6) are reported in the note to Table 4 Panel A. Robust standard errors clustered at the firm level are reported in parenthesis. ***, ** and * denote significance at the 1, 5 and 10 percent levels (two-tailed), respectively.

of cash flows across firms. Rather, the main effects (*POST* × *CO*₂ *DISCLOSURE*) remain negative and significant (Table B10). Second, we consider whether firms that disclose their carbon emissions may be quicker to react to the cost of capital shock by, for instance, issuing environmental press releases. As a result, the documented cost of capital pattern may be attributable to firms’ initial reaction to the disaster rather than to firm disclosure in the pre-disaster period. We do not find evidence that our findings are driven by firm initial disclosure reactions (Table B10). We also rule out the possibility that our results are driven by specificities of the institutional setting. Our evidence is unaltered when we control for firms’ voluntary participation in the Japanese emission-trading scheme or for those firms which have plants reporting to the PRTR (Table B11; see also footnote 3).

6. Disclosure Reaction

In the previous sections we have shown that the disaster is associated with firm cost of capital, and that the magnitude of such an association depends on a firm’s environmental disclosures in the pre-disaster period. We now investigate how firms adjust their disclosure policies in response to the new cost–benefit trade-off. Extant research shows that a change in the disclosure equilibrium affects the supply of firm disclosures. Leuz and Schrand (2009) use the Enron scandal as a source of variation in the credibility of financial reporting and find that firms react to the scandal by increasing the amount of disclosure in their mandatory reports. Balakrishnan et al. (2014) use brokerage house closures as a source of variation in the availability of public information about firms and show that firms react to information-related shocks by increasing the supply of

Table 8. Disclosure response around the disaster.

<i>Panel A: Descriptive statistics</i>									
Variable	<i>N</i>	Mean	p5	p25	p50	p75	P95	SD	
Δ #pages	392	3.077	– 17.500	– 2.000	0.000	5.000	37.500	18.122	
Δ #words	392	211.298	– 269.700	– 268.000	0.000	576.000	4,564	2,173.194	
Δ #numerical words	392	80.213	– 247.000	– 381.500	0.000	507.000	1,878	981.819	
Δ #long-term words	392	15.232	– 116.500	– 13.000	0.000	37.500	189.000	107.776	
Δ #horizon words	392	17.881	– 149.000	– 19.000	0.000	43.000	230.500	131.696	

<i>Panel B: Multivariate analysis</i>										
	Δ #pages		Δ #words		Δ #numerical words		Δ #long-term words		Δ #horizon words	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
<i>CO₂_DISCLOSURE</i>	– 3.385***	– 4.276**	– 469.839***	– 631.663**	– 424.987***	– 561.236**	– 21.743***	– 28.383**	– 17.725**	– 24.404**
	[1.000]	[1.632]	[147.810]	[223.730]	[134.864]	[202.933]	[6.845]	[11.211]	[6.040]	[10.244]
<i>SIZE</i>	0.238		– 45.059		– 39.393		1.144		0.221	
	[0.531]		[53.327]		[47.176]		[3.379]		[2.771]	
<i>B_M</i>	1.569**		117.423**		104.997**		8.043*		6.685*	
	[0.603]		[52.632]		[46.504]		[3.696]		[3.093]	
<i>ROA</i>	15.145		– 81.513		4.222		– 73.845		– 48.246	
	[15.589]		[1,961.185]		[1,786.817]		[86.431]		[74.428]	
<i>LEV</i>	0.191		756.868		675.397		12.663		18.019	
	[3.329]		[750.296]		[690.498]		[27.679]		[21.887]	
<i>RET_VAR</i>	12.329*		807.537		693.269		102.130		63.878	
	[6.568]		[1,492.453]		[1,326.166]		[109.111]		[83.393]	
<i>FOLLOWING</i>	2.457**		116.104		102.654		7.138		6.134	
	[0.861]		[99.759]		[91.553]		[5.989]		[4.391]	
<i>ACCRUALS</i>	– 0.002		19.047		16.962		0.834		0.660	
	[0.152]		[12.825]		[11.433]		[0.509]		[0.419]	
<i>ERROR</i>	– 0.080		– 76.647		– 68.283		– 2.110		– 1.807	
	[0.366]		[74.503]		[68.355]		[1.895]		[1.613]	
<i>INDUSTRY FE</i>	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
<i>EBM</i>	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes
Observations	392	392	392	392	392	392	392	392	392	392
R-squared	0.029	0.022	0.035	0.031	0.022	0.019	0.035	0.031	0.022	0.021

Table 8, Panel A, reports descriptive statistics on the following disclosure variables: Δ #pages, Δ #words, Δ #numerical words, Δ #long-term words, Δ #horizon words. Panel B reports the results from regressions of firm-specific changes before and after the disaster in these disclosure variables on an indicator variable marking firms that disclose carbon emission information in fiscal year 2009 (*CO₂_DISCLOSURE*). The table reports OLS coefficient estimates and (in parentheses) robust standard errors that are clustered by firm. All other variables are defined in Appendix A. ***, ** and * denote significance at the 1, 5 and 10 percent levels (two-tailed), respectively.

managerial earnings forecasts. Ioannou and Serafeim (2018) investigate the effect of introducing *mandatory* CSR disclosure regulations on firm disclosure and find that disclosures of less extensive disclosing firms before the regulatory change do not catch up to those made by more extensive disclosing firms before the regulation. Rather, differences in the extent of disclosure widen because of the mandatory introduction.²⁷

Our analysis shows that firms disclosing carbon emissions experience a less severe cost of capital increase after the disaster, suggesting a less intense shock for these firms. Accordingly, if the cost of increasing disclosure is the same across firms, then we would expect the firms experiencing the most severe shocks to react more strongly and thus increase their disclosures to a greater extent. However, given that environmental information is likely to be costly to collect (Ioannou & Serafeim, 2018), especially in the short run, the way in which firms change their disclosure practices after Fukushima is an empirical question.

Ideally, one would like to examine whether firms initiate the disclosure of carbon emission information. Unfortunately, it is unlikely that firms are able to initiate this type of disclosure in a timely fashion – especially in the aftermath of the disaster – because of costs arising from the production and collection of environmental information (e.g. to disclose carbon emission data, firms must have a system in place to monitor the carbon emissions at the plant/store level).²⁸ Thus, to explore whether firms change their disclosure practices after the disaster, we measure disclosure in accordance with Muslu et al. (2015) and collect the following disclosure data from environmental reports for the years 2008–2011: *length* (number of pages and number of words), *degree of hardness* (number of numerical words), and *horizon* (number of long-term horizon words and number of references to future years).

We first take the average of the disclosure metrics in the two years before and the two years after the disaster and collapse the sample to the firm level, i.e. one observation per firm. Next, we take the difference in each disclosure metric between the post- and pre-disaster periods. Then, we regress the changes in the number of pages, number of words, number of numerical words, number of long-term words, and number of references to future years on the *CO₂_DISCLOSURE* indicator variable. We also include industry fixed effects and the full set of control variables measured in the year before the disaster. If firms that do not disclose information about their historical and future carbon emissions in the pre-disaster period react more strongly, then we expect the coefficient of *CO₂_DISCLOSURE* to be negative. Table 8, Panel A reports descriptive statistics on the distribution of these disclosure variables, while Panel B reports the estimation results. We find that firms that do not disclose carbon emission information in the pre-disaster period – and thus experience a larger increase in cost of capital – increase the length of their disclosures and the precision and forward-looking nature of the information disclosed to a greater extent relative to firms that include carbon emission information in their environmental reports in the pre-disaster period. The coefficients correspond (on average) to 19 percent increase with respect to the mean disclosures of the firms on the extensive margin and 9.3 percent increase with respect to the mean disclosures of the firms on the intensive margin.²⁹

²⁷This effect holds only for environmental and social disclosures. Firms that were laggards in governance disclosure increase their disclosure significantly, reaching levels similar to those of the leaders. The authors explain this asymmetric response as being consistent with governance information being less costly to obtain and disperse than environmental (or social) information. For example, information about environmental impact is more difficult to obtain, aggregate and release compared with information on board compensation.

²⁸In our sample there are no firms that start to provide CO₂ emissions disclosure after Fukushima.

²⁹The magnitude of the coefficients varies across the disclosure measures. For example, the coefficient of -3.385 for the number of pages (reported in column 1) corresponds to a 13.7 percent increase with respect to the average number of pages for firms on the extensive margin, and to a 7.40 percent increase with respect to the average number of pages for firms on the intensive margin. The coefficient of -631.663 for the number of words (reported in column 4) corresponds to

Finally, to explore whether the non-disclosing firms that increased their disclosure following the disaster eventually catch up the disclosing firms, we gauge the temporal patterns in the cost of capital effects. The results reported in Appendix B (Table B12) suggest that the difference in cost of capital between the disclosing and non-disclosing groups shrinks in the years following the disaster. Such evidence is consistent with the finding that the firms mostly hit by the cost of capital shock (i.e. the non-disclosing firms) have subsequently increased their disclosure to reduce the long-term effect on their cost of capital.

7. Conclusion

Using a large, hand-collected sample of environmental information disclosed by Japanese firms over the 2002–2013 period, we investigate whether heterogeneity in firms' pre-disaster environmental disclosures explains differences in cost of capital changes after the disaster. We find that firms that disclose carbon emissions experience a lower increase in the cost of capital compared with firms that do not disclose carbon emissions. Further, our evidence ascribes the effect of disclosure on the cost of capital to the relevance of carbon emission disclosures to a firm's exposure to the energy shortage rather than their relevance to future regulatory costs. Finally, we find that the firm disclosure reaction to the disaster is greater for firms that do not disclose carbon emissions before the disaster.

Overall, our results provide insights into whether unregulated, non-financial disclosures inure to the benefit of firms when they are hit with economic shocks, complementing prior research on the relation between financial disclosure and the cost of capital (Leuz & Schrand, 2009), on the effect of managerial forecasts on market liquidity (Balakrishnan et al., 2014), and on the relation between disclosures on foreign exchange risk exposure and information asymmetry (Hail et al., 2021). Although, our evidence may not be generalizable to other settings, we show that environmental disclosures mitigate the increase in the cost of capital and shed light on the underlying mechanism – energy dependence – through which environmental disclosure affects the cost of capital.

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a 25.8 percent increase with respect to the average number of words for firms on the extensive margin, and to 12 percent increase with respect to the average number of words for firms on the intensive margin.

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Supplemental Data and Research Materials

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Online Supplemental Information to ‘Environmental Disclosure and the Cost of Capital: Evidence from the Fukushima Nuclear Disaster’ by Pietro Bonetti (*IESE Business School*), Charles H. Cho (*Schulich School of Business, York University*) and Giovanna Michelon (*University of Bristol*)

Figure B1. Examples of the list of contents of firms’ environmental reports

Figure B2. Example of precise carbon emissions information

Graph B1. Kernel density distribution of the variables used in the entropy balance matching before and after the weighting

Table B1. Carbon emissions disclosure and the cost of capital around the disaster – Propensity score matching

Table B2. Determinants of carbon emissions disclosure – First stage of the propensity score matching

Table B3. Distribution of the historical and forward-looking CO₂ disclosure across time

Table B4. Economic consequences of environmental disclosure around the disaster, separately estimated for historical and forward-looking CO₂ information

Table B5. Environmental disclosure and the cost of capital around the disaster conditional on capital intensity

Table B6. Environmental disclosure and the cost of capital around the disaster conditional on exposure to regulatory risk

Table B7. Sensitivity analysis to the cost of capital measures

Table B8. Carbon emissions disclosure and the cost of capital around the disaster Short-run estimation window [− 1y; + 1y]

Table B9. Carbon emissions disclosure and the cost of capital around the disaster Balanced estimation window [− 3y; + 3y]

Table B10. Environmental disclosure precision and the cost of capital around the disaster, controlling for confounding factors

Table B11. Carbon emissions disclosure and the cost of capital around the disaster

Table B12. Temporal analysis in the cost of capital

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Appendix A

Variable definitions

CO ₂ _DISCLOSURE	Time-invariant dummy variable for firms that have disclosed information on current and target CO ₂ emissions in fiscal year 2009. The data were hand-collected from corporate reports.
POST	Dummy variable that equals one for fiscal years ending after the Fukushima nuclear disaster on March 11, 2011, zero otherwise.
ICC	Yearly average of four implied cost of capital metrics (Claus & Thomas, 2001; Easton, 2004; Gebhardt et al., 2001; Ohlson & Juettner-Nauroth, 2005).
SIZE	Natural logarithm of a firm's total assets at the beginning of its fiscal year.
B_M	Book value to market value of equity ratio at the beginning of the firm's fiscal year.
ROA	Return on assets, computed as the net income before interest and taxes over total assets at the beginning of the year.
LEV	The ratio of the beginning-of-the-year total liabilities to the beginning-of-the-year market value of equity.
RET_VAR	Firm return variability, computed as the standard deviation of monthly stock returns over the last twelve months.
FOLLOWING	Analyst following, computed as the logarithm of the number of analysts that issued forecasts during the year.
ACCRUALS	The difference between net income before extraordinary items and discontinued operations and cash flow from operations, scaled by total assets at the beginning of the year.
ERROR	Forecast bias, computed as the mean one-year-ahead consensus forecast minus actual earnings, scaled by actual earnings.
CO ₂ _PERF	Carbon performance (emission reduction category) score from Asset 4 - Thomson Reuters, which reflects 'corporate effectiveness in reducing environmental emissions in production and operational processes' (ASSET4 ESG Glossary). The score is a relative measure of performance that is normalized to distinguish values and to position the score between 0 and 100 percent. When the variable is missing, we replace it with the year-industry mean using the two-digit industry classification code.
CAP_INTENSITY	Standardized ratio of gross property, plant, and equipment to total assets, measured in the year before the disaster.
CSI	Dummy variable that equals one for firms in industries where carbon pollution is a material issue (SASB, 2017).
#pages	N. of pages of environmental reports.
#words	N. of words in environmental reports.
#numerical words	N. of numerical words in environmental reports.
#long-term words	N. of long-term horizon words in environmental reports.
#horizon	N. of references to future years.
