# Environmental Disclosure and the Cost of Capital:

# Evidence from the Fukushima Nuclear Disaster

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**Abstract**

We study the relation between environmental disclosure and the cost of capital by exploiting the Fukushima nuclear disaster as a source of variation in the demand for environmental information. Using a large, hand-collected sample of Japanese firms, we find that firms with high disclosure precision within their environmental reports experience a lower increase in the cost of capital than firms with low disclosure precision. Cross-sectional analyses suggest that effect on the cost of capital is driven by the increase in investors' uncertainty about the energy supply shortage rather than about future regulatory costs. Consistent with environmental disclosure being related to the cost of capital changes, we find that after the disaster firms with low disclosure precision in the pre-disaster period increase their environmental disclosures to a greater extent relative to high disclosure precision firms. Taken together, our results provide insights on the dynamics between non-financial and unregulated disclosure and the cost of capital.

**Keywords:** Environmental disclosure; Cost of capital; Disclosure reaction.

**JEL classification***:* G01, G12, G14, G30, M41, M42.

## 1 Introduction

The literature suggests that environmental disclosure informs a broad range of stakeholders about the environmental impacts of corporate activities (GRI, 2013; Roberts, 1992). However, evidence on whether environmental disclosure improves investor information, and, ultimately, affect the cost of capital remains mixed. First, the voluntary, unregulated, nature of environmental disclosure and the absence of penalties for misreporting raise concerns about the usefulness of these disclosures because of credibility issues and low litigation costs (Blacconiere and Patten, 1994; Cho and Patten, 2007). Second, the literature documents that environmental disclosure reduces the cost of capital only for firms with good environmental performance (Dhaliwal et al., 2011). While this evidence is consistent with the notion of environmental disclosure being a signal for future environmental performance (Lys et al., 2015), it does not directly speak about the informational effects of such disclosures. Third, the endogeneity of the relation poses severe empirical challenges that concur to explain the mixed empirical evidence (Plumlee et al., 2015; Richardson and Welker, 2001).

In this paper, we examine the relation between environmental disclosure and the cost of capital using the Fukushima nuclear disaster (henceforth, “the disaster”) as a source of exogenous variation in the demand for environmental information, and as such, a shock to the cost of capital for Japanese firms. On March 11, 2011, a tsunami disabled the power supply and cooling of the Fukushima Daiichi reactors, causing the meltdown of all the nuclear cores in the following three days. We argue that investor uncertainty about the economic implications of the disaster grew into an upsurge in the demand for environmental information and, specifically, about how firms were exposed to the disaster (CSRwire, 2011). We identify two mechanisms through which environmental information disclosed by firms before the disaster is linked to the change in investors' uncertainty about the economic implications of the disaster and, as a result, to the shock to the cost of capital.

First, in the aftermath of the disaster, the closures of all nuclear reactors across the country caused a considerable energy supply shortage (Hayashi and Hughes, 2013; Vivoda, 2012). This, in turn, boosted investor uncertainty about how exposed Japanese firms were to the shortage and, hence, increased the related demand for information about how firms manage their energy policies. Second, the reduction in the production of nuclear energy caused a substantial increase in pollution, as "clean" nuclear power started to be replaced with fossil fuels[1] (Srinivasan and Gopi Rethinaraj, 2013; Vivoda, 2012). Since combating pollution has always been a priority for Japan (Duffield and Woodall, 2011), the disaster increased the threat of regulatory actions for pollution abatements. Consequently, it also increased investor uncertainty about the ability for firms to face future regulatory costs (Blacconiere and Patten, 1994). Given that environmental disclosure typically covers information about firm energy policies and pollution levels (GRI, 2013), we argue that the shift in investor uncertainty, and thus the magnitude of the shock to the cost of capital around the disaster, is related to environmental disclosure in the pre-disaster period (Diamond and Verrecchia, 1991; Easley and O'Hara, 2004; Lambert et al., 2007).

In this context, we specifically focus on environmental disclosure relating to carbon emissions. The environmental economics literature suggests that the disclosure of carbon emissions conveys information about both energy policies (Apergis et al., 2010; Sim et al., 2003) and firm pollution levels (Davis and Caldeira, 2010). Thus, it can reduce investor uncertainty about how a shortage in energy supply can impact a firm's cash flows and, ultimately, its cost of capital.

[1] Nuclear energy is deemed to be cleaner than fossil energy sources because of the lower level of carbon emissions (Apergis et al., 2010; Menyah and Wolde-Rufael, 2010; Sim 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 comparable to most renewables at near zero. Hence nuclear power generation is an effective GHG mitigation option" (Sim et al., 2003, p. 1317).

It further allows investors to better estimate a firm's exposure to future compliance costs related to pollution abatements (Blacconiere and Patten, 1994; Griffin et al., 2017), reducing investor estimation risk and thus the cost of capital. Finally, theory suggests that the negative relation between disclosure and the cost of capital increases in disclosure precision (Diamond and Verrecchia, 1991; Lambert et al., 2012)[2]. Carbon emission information within an environmental report increases the precision of environmental disclosure as it provides quantitative and verifiable information about a firm's environmental performance (Clarkson et al., 2008). Therefore, our hypothesis is that firms that *continuously* disclose carbon emissions information in the pre-disaster period experience a lower increase in the cost of capital after the disaster than firms that do not disclose such information.

In the first part of the paper, we examine whether firms that disclose carbon emissions information within their environmental reports in the pre-disaster period react differently to the disaster from firms that do not disclose carbon emissions information. Our identification strategy is akin to a difference-in-differences design in which we exploit the disaster as a source of time-series variation in the demand for environmental information and whether or not a firm discloses carbon emission information in the pre-disaster period as a source of cross-sectional variation. This specification compares the change in the cost of capital around the disaster for firms disclosing and non-disclosing carbon emissions information.

Our empirical setting alleviates many endogeneity concerns because the timing of the disaster is exogenous to firm characteristics and performance. However, the identification of the effect of environmental disclosure on the cost of capital is challenging for at least two additional reasons. First, firm environmental disclosure choices in the pre-disaster period are likely to be

[2] Baginski and Rakow (2012) document a negative relation between management earnings forecast precision and firms' cost of capital.

associated with other firm characteristics (e.g., operating risk), which may correlate with heterogeneous changes in the cost of capital around the disaster. We address this issue by employing firm fixed effects, and thus focusing on within-firm changes in the cost of capital only to estimate the cost of capital consequences of environmental disclosures. Further, to address the concern that firms with different disclosure choices have different economic characteristics, we reduce the degree of observable heterogeneity between firms disclosing and non-disclosing carbon emissions by relying on an entropy balance matching (EBM) design (Hainmueller, 2012).

Second, the disaster has likely affected firm cost of capital not only through an informational channel (i.e., by increasing investor uncertainty about firm cash flows), but also by potentially affecting its future cash flows (e.g., by lowering firm growth prospectus, or by increasing costs or reducing revenues, etc.). Therefore, to alleviate the concern that changes in firm cost of capital around the time of the disaster also reflect concurrent revisions in firm future cash flows, we employ estimates of firm implied cost of capital. Since our implied cost of capital metrics are based on prices and analyst earnings forecasts, their use allows us to directly control for revisions in firm future cash flows (Hail and Leuz, 2009), and thus allows us to better estimate the informational consequences associated with the disaster. Finally, to assess both the economic consequences and the informational consequences of the disaster conditional on firm environmental disclosure, we also estimate market reactions to the disaster conditional on the presence of carbon emission disclosure.

We start the empirical analysis by graphically examining whether the disaster is associated with a shift in the weight that investors place on environmental information in discounting firm future cash flow. Such evidence would be consistent with the idea that firm environmental-related information was more relevant in discounting firm future cash flows after the disaster. We use the sensitivity of the cost of capital to environmental performance as a proxy for the weight that investors place on environmental information. Environmental performance is measured as the carbon emission reduction score from Thomson Reuters ASSET4. The idea for this test is that the covariance between environmental performance and cost of capital captures the extent to which information about a firm environmental performance is used by investors to assess a firm's cost of capital. We document that the cost of capital was not sensitive to environmental performance before the disaster. However, we observe a sharp increase in the sensitivity of the cost of capital to environmental performance after the disaster. Although descriptively, this analysis provides preliminary evidence on how the disaster is associated with an increase in the weight investors place on environmental information.

We then estimate the average market reaction to the disaster and the average cost of capital change around the disaster, unconditional on firm disclosure choices. We document a substantial negative market reaction (CAR[0,1]) to the disaster for all firms of around a 2.5 percent of a firm market capitalization, and an increase in firm cost of capital of around 200 basis points. These preliminary tests provide evidence that the disaster is associated with substantial economic consequences and with an average increase in the firm cost of capital.

We next turn to our main analysis and explore whether firms that disclose carbon emissions in the pre-disaster period experience a lower increase in the cost of capital than firms not disclosing carbon emissions. We find that firms disclosing carbon emissions experience a lower increase in their cost of capital of around 120 basis points. The results hold and are comparable in magnitudes in the entropy balance matching specifications, and when we allow the coefficients on the control variables to vary between the pre- and post-disaster period, which suggests that we are not simply picking up spurious correlations driven by heterogeneity between disclosing and non-disclosing firms. In terms of the overall economic significance, we document that firms disclosing carbon emissions experience a less negative market reaction of around 2.9 percent.

We then explore two mechanisms that can drive the differential cost of capital changes between disclosing and non-disclosing firms. In particular, we examine whether the differential cost of capital changes are associated with an increase in uncertainty about a firm's ability to face the energy supply shortage and to face future regulatory costs. First, we examine whether the effect of carbon emission disclosure on the cost of capital depends on firm capital intensity – our proxy for firm exposure to the energy shortage. Firms with high capital intensity are more energy dependent and thus more likely to be affected by the energy shortage that followed the disaster. Therefore, if investors face an increase in uncertainty about a firm's ability to manage the energy supply shortage, then the effect of carbon emission disclosures on the cost of capital should be greater for firms with high capital intensity than for firms with low capital intensity. Consistent with this intuition, we find that, conditional on the level of capital intensity, disclosing firms experience a lower increase in the cost of capital relative to non-disclosing firms. Then, we consider whether the cost of capital shock is associated with an increase in uncertainty about future regulatory costs. If this were the case, we would then expect the effect of carbon emission disclosures on the cost of capital to be greater for firms in industries prone to future regulatory actions for pollution abatement, i.e. carbon sensitive industries (CSI) (Patten, 2002; SASB, 2017), relative to firms in other industries. We do not document that the effect of carbon emission disclosure varies across CSI and non-CSI industries, suggesting that this channel is less likely to play a role in our setting.

Next, we explore whether the differential cost of capital reactions to the disaster that we ascribe to an information channel are instead driven by firm's 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' cash flows associated with the disaster, we would then expect the effect of environmental disclosure on the cost of capital to be concentrated among firms that are headquartered close to the Fukushima nuclear site. This approach is in the spirit of a non-parametric matching design, in which we match firms according to their distance to the site of the disaster. We document that the cost of capital effects do not disappear as we gradually restrict our analysis on firms further away from the site of the disaster.

We conduct further cross-sectional analyses to rule out alternative explanations. First, we examine whether our results are driven by heterogeneity in firm carbon emission levels. Firms that disclose information about carbon emissions are more likely to report good news and therefore experience a less severe increase in the cost of capital around the disaster. We do not find evidence that heterogeneity in carbon emission levels drives our results. Second, we consider several confounding factors that may concur to explain the differential cost of capital reactions around the disaster (i.e., press release disclosure, operating risk, and cash flow revisions around the disaster). However, we do not find evidence that these factors are the major driver of our results.

In the second part of our analysis, we examine whether firms change their environmental disclosure after the disaster. The intuition is that if the disaster has changed the cost-benefit trade-off underlying firms' disclosure choices, then firms would adjust their disclosure policy to the new cost-benefit tradeoff. However, whether and how firms change their disclosure after the disaster remain empirical question. On one hand, non-disclosing firms experienced a greater increase in the cost of capital than disclosing firms and, thus, a greater increase in the demand for environmental information – they are therefore expected to react strongly (Leuz and Schrand, 2009). On the other hand, disclosing firms are likely to be timelier in reacting to the change in the demand for environmental information, given the lower marginal cost they face to adjust their disclosures (Balakrishnan et al., 2014). We find that non-carbon emission disclosing firms react more strongly to the disaster and thus to the cost of capital shock by increasing the length of their environmental reports and the precision and forward-looking nature of the information disclosed relative to carbon emission disclosing firms. This result is consistent with the idea that firms that were most affected by the disaster changed their disclosures to a greater extent than their less affected counterparts.

Our paper makes three contributions to the literature. First, we contribute to the growing stream of research on corporate social responsibility (CSR) reporting by providing insights on the dynamics of voluntary environmental disclosure beyond the economic consequences of CSR reporting adoption (Dhaliwal et al., 2011) and we provide evidence that the capital market reflects concerns about environmental risks (Barth et al., 1997). Given the limited regulatory guidance, non-comparability, and credibility concerns (Dhaliwal et al., 2011; Clarkson et al., 2013; Plumlee et al., 2015), the relation between CSR reporting and the cost of capital is theoretically unclear and empirically challenging. We document that firms experience shocks to their cost of capital according to the precision of the information they disclose in the pre-disaster period, and that firms change their disclosures according to the new cost-benefit trade-off.

Second, we contribute to the literature on the effects of CSR disclosure on the cost of capital in three ways. While prior literature has provided mixed evidence on these effects, we exploit firm-level heterogeneity in disclosure precision and show that environmental disclosure has cost of capital effects that are unconditional on the underlying environmental performance. Furthermore, our identification strategy, which relies on quasi-natural experimental variation in the demand for environmental information, helps to mitigate endogeneity concerns. Third, we use an innovative setting that allows us to shed light on an additional underlying mechanism, energy dependence, through which environmental disclosure affects the cost of capital, complementing prior evidence on environmental disclosure and regulatory costs (Blacconiere and Patten, 1992). We also contribute to the literature on the relevance of carbon emission disclosures (Griffin et al., 2017; Ioannou et al., 2016; Matsumura et al., 2014). 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 assess firm energy dependence.

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

The next section provides a description of the empirical setting. Section 3 reviews the literature and presents our hypotheses. The research design is presented in Section 4, while Sections 5 and 6 present the data and main results, respectively. Sections 7 report the analyses on firms' disclosure reaction. Finally, we conclude in Section 9.

## 2. Research Setting

The Japanese setting is particularly relevant and powerful from a research design perspective for three reasons. First, Japan does not have any formal and comprehensive environmental disclosure regulation and environmental reporting is thus a voluntary corporate activity, which provides us with substantial variation in firms' disclosure choices.[3] However, environmental reporting in Japan is aligned with international and U.S. practice. Environmental disclosures are reported in stand-alone CSR reports, prepared in accordance with voluntary international reporting guidelines, such as the Global Reporting Initiatives.

Second, despite the lack of mandatory environmental reporting, Japan has a long-standing commitment to combating global warming, since the Rio Summit in 1992, and thus toward pollution abatements. In July 2008, Japan introduced an "*Action Plan for Achieving a Low-carbon Society*" and as part of the Copenhagen Accord in 2009, it pledged to reduce GHG emissions 25% 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 ($CO_2$) from fossil fuels a 30% below 1990 levels; and introduced a bill for the "Basic Act on Climate Change Countermeasures", which contemplated the introduction of a tax for climate change countermeasures (on fossil fuels) and a feed-in tariff for renewable energy.[4] Hence, in the Japanese setting, regulatory interventions to control pollution are not unusual. Therefore, investors are likely to demand information allowing them to estimate firm exposure to future regulatory costs.

Third, Fukushima is the largest nuclear accident since Chernobyl (Barletta et al., 2016). Radioactive materials contaminated the air, soil and water with lasting impact on the environment (Steinhauser et al., 2014) and serious consequences for human health (Oppenheim and Franklin, 2016). Such effects are likely to have increased the demand for environmental information in

[3] Based on a recommendation by the OECD, the Japanese Ministry of the Environment had introduced a Pollutant Release and Transfer Register (PRTR) in 1999 as part of the Act on Promotion of Global Warming Countermeasures. Under this Act, *plants* of only certain industries that use more fuel that 1500 kiloliters of crude oil yearly or that emits more than 3000 tons of CO2 are required to report the CO2 emissions to the PRTR. However, there are no requirements to provide any information at the firm level. Our main evidence remains unaffected if we control for whether plants belonging to any firms in our sample report to the PRTR.
[4] Specifically, the Basic Energy Plan approved in 2010 included a target of a 30 percent reduction in energy-related CO2 emissions coupled with a doubling of the percentage of electricity generated by clean resources (renewables and nuclear power), all by 2030 (Duffield and Woodall, 2011).

general. Most importantly for our purpose, Fukushima represents a shock to the supply of clean energy – and thus to expected pollution levels. The shutdown of the Fukushima reactors and subsequent closures of all other nuclear reactors across the country caused nuclear power to drop from 31.2% in February 2011, to 12.4% in August 2011 and zero in May 2012 (Hayashi and Hughes, 2013), and consequently raised investors' concerns (and demand for information) about firm energy policies. Furthermore, the reduction in clean nuclear energy increased $CO_2$ emissions by 2.1% in 2011, with at-the-time estimates of a further increase by 5.5% in 2012 and tension over the ability of Japan to reach the Kyoto Protocol 2020 targets for reducing $CO_2$ emissions (Srinivan and Rethinaraj, 2013; Vivoda, 2012). Given that low emission levels have always been a priority for Japan (Duffield and Woodall, 2011), Fukushima has increased the threat of regulatory action for pollution abatements – and, as such, investors' demand about firms' ability to face future regulatory costs (Blacconiere and Patten, 1994).

## 3. Prior literature and hypothesis development

### *3.1. Prior literature*

Extant research documents a negative relation between voluntary disclosure and the cost of capital.[5] Theory predicts that firms can affect the cost of capital by committing ex-ante to disclose information ex post, regardless of the content disclosed (Diamond and Verrecchia, 1991; Lambert et al., 2007; Leuz and Verrecchia, 2000; Verrecchia, 2001). In the environmental disclosure setting, there are at least two non-mutually exclusive explanations to expect a negative relation between environmental disclosure and the cost of capital. First, if environmental

[5] In line with analytical models, disclosure transforms private information into public information. Easley and O'Hara (2004) show that, if the amount of private information about a firm is larger than that of other firms, its cost of capital is higher. However, Easley and O'Hara (2004) analyze a single-firm world, so it is not possible to infer whether the effect of disclosure will survive the forces of diversification. Lambert et al. (2007) demonstrate that the effect of disclosure on the cost of capital is not diversifiable, as it is related to the assessed covariance of the firm's cash flow with all the other firms' cash flows.

disclosure provides information about a firm's impacts on the environment, then market participants will face less uncertainty in estimating a firm's future cash flows. For example, environmental disclosure serves as a source of information to forecast the costs arising from potential regulatory actions for pollution abatements and the risks associated with future compliance requirements (Blacconiere and Patten, 1994; Patten and Trompeter, 2003). Second, environmental disclosure provides information about firm environmental policies, which in turn improves investor information base and reduces a firm's cost of capital (Diamond and Verrecchia, 1991; Easley and O'Hara, 2004; Lambert et al., 2007).

Although it is empirically challenging to document a causal relation (Leuz and Schrand, 2009; Clinch and Verrecchia, 2015), extant research provides insights into how environmental disclosure affects the cost of capital (Clarkson et al., 2013; Dhaliwal et al., 2011; Plumlee et al., 2015; Richardson and Welker, 2001). Richardson and Welker (2001) examine the relation between social disclosure and the cost of capital and find that social disclosure and cost of capital are positively related. Using a lead-lag approach, Dhaliwal et al. (2011) investigate whether initiating stand-alone CSR reporting affects the cost of capital and find a negative relation between the first-time issue of CSR reports and the subsequent cost of capital. However, this result holds only for firms with good CSR performance. Clarkson et al. (2013) find that voluntary environmental disclosure has additional explanatory power over current environmental performance (i.e., the Toxic Releases Inventory emissions) for firm market value but not for firm cost of capital. Plumlee et al. (2015) examine in cross-section how voluntary environmental disclosure quality is related to firm market value, and while they find a positive association between environmental disclosure and firm value after controlling for environmental performance, they do not find a significant association between environmental disclosure quality and cost of capital. However, when they classify the sample based on the type (soft/hard) and the nature (positive/neutral/negative) of the information being disclosed, they document that soft/positive environmental disclosure is associated with a lower cost of capital, whereas soft/negative environmental disclosure quality is positively related to the cost of capital.

These studies rely mainly on cross-sectional designs. In the cross-section, the relation between disclosure and the cost of capital can be positive, negative, or null (Clinch and Verrecchia, 2015; Leuz and Schrand, 2009; Nikolaev and van Lent, 2005). Indeed, disclosure choices are based on reasons related to the information environment and the cost of capital. For example, a firm may issue environmental disclosure as a reaction to a deteriorating information environment or to an increase in investor uncertainty, either of which may lead to a positive cross-sectional association between disclosure and the cost of capital. Alternatively, firms may start disclosing after experiencing growth shocks, making it difficult to separate the effect on the cost of capital driven by the change in disclosure from the one driven by the shock to expected cash flows.

*3.2. Hypothesis development*

Our main research question is whether environmental disclosure reduces firm cost of capital. Although the absence of penalties for misreporting raises concerns about the usefulness of environmental disclosure because of credibility issues and low litigation costs, such disclosure is likely to be credible and persistent for at least two reasons. First, given that environmental disclosure may reveal proprietary information about a firm's exposure to environmental risks and future regulatory costs (Blacconiere and Patten, 1994; Patten and Trompeter, 2003), it is costly and potentially self-enforcing (Gigler, 1994). Second, once started, environmental disclosure is persistent because the decision of stopping disclosure in case of bad performance will decrease the credibility and thus the economic benefits of future disclosure (Einhorn and Ziv, 2008; Stocken, 2000). In addition, firms that cease disclosing environmental information cannot claim to be uninformed, thereby lowering the market penalty associated with that decision. Hence, once the firm starts disclosing, investors infer that the firm has proprietary information and expect the disclosure to continue over time (Dye, 1985; Jung and Kwon, 1988).

In our setting, we argue that the disaster has increased investor uncertainty about how firms were exposed to the shortage in the nuclear energy supply and to future regulatory actions on pollution abatements, and thus created a shock to the Japanese firms' cost of capital. Information about firm energy policies (Matsumura et al., 2014) and potential exposure to future regulatory and compliance costs (Blacconiere and Patten, 1994; Patten and Trompeter, 2003; Griffin et al., 2017) is typically disclosed within voluntary environmental reports (Dhaliwal et al. 2011). As such, we predict that the magnitude of the shock to the cost of capital following the disaster is related to the presence of environmental disclosures in the pre-disaster period. However, since theory predicts that the negative relation between disclosure and cost of capital increases in the precision of the information being disclosed (Diamond and Verrecchia, 1991; Easley and O'Hara, 2004; Lambert et al., 2007), our hypothesis is that firms that disclose precise information within their environmental reports experience a less severe change than those that do not, formulated as follows:

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

We proxy for the precision of environmental disclosure using carbon emission information for three reasons. First, prior literature shows that carbon emission information is value relevant (Matsumura et al., 2014; Griffin et al., 2017), and easily integrated by investors into valuation models (Eccles et al., 2011). Second, carbon emission information within an environmental report increases the precision of environmental disclosure as it provides quantitative and verifiable information about a firm's environmental performance (Clarkson et al., 2008). Third, studies in environmental economics and energy policy document the existence of a link between energy consumption and carbon emissions levels (Apergis et al., 2010; Menyah and Wolde-Rufael, 2010; Sim et al., 2003)[6], suggesting that carbon emission disclosures convey to investors information about both energy policies and pollution levels. In the Fukushima setting, we thus argue that information about carbon emissions affects the cost of capital because it conveys information about: (i) firm energy policies, reducing investor uncertainty about future cash flows during shocks to the supply of energy (Matsumura et al., 2014); (ii) firm exposure to future regulatory costs, providing investors with information about firm pollution levels and thus about firm ability to face future regulatory costs (Griffin et al., 2017).

## 4. Research design and data

### *4.1. Empirical strategy*

In our main empirical tests, we examine whether firms that disclose carbon emission information within their environmental reports in the pre-disaster period experience a lower shock to the cost of capital relative to firms that do not disclose information about their carbon emissions. We consider the cost of capital for two reasons. First, theory predicts a direct link between disclosure precision and the cost of capital (Diamond and Verrecchia, 1991; Leuz and Verrecchia, 2000). Second, we focus on the implied cost of capital to better disentangle estimation-risk effects from cash-flow effects due to revisions in firm future cash flows. To further assess whether the

[6] Specifically, carbon emissions depend on the consumption of energy and the type of energy source. This implies that, conditional on the source of energy, higher $CO_2$ emissions are associated with a greater energy use. Therefore, carbon emissions disclosures convey to investors information about firm energy policies, which are relevant to assess the impact of the energy supply shortage on a firm's future operations. At the same time, $CO_2$ emissions are a key indicator for firm pollution levels (Davis and Caldeira, 2010), which are relevant to assess the exposure to future regulatory costs.

overall economic consequences of the disaster is predicated by differences in firm pre-disaster environmental disclosure, we examine whether the disclosure of carbon emissions in the pre-disaster period is associated with heterogeneous market reactions to the disaster.

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

$$ICC_{i,t} = \alpha_i + \phi_t + \gamma POST_t \times CO_2\_DISCLOSURE_{i,PRE} + \beta_1 X_{I,t} + \beta_2 POST_t \times X_{i,t} + \varepsilon_{i,t}\ , \tag{1}$$

where *ICC* stands for the implied cost of capital, $\alpha_i$ is a non-observable firm fixed effect, and $\phi_t$ is a year fixed effect.[7] $POST_t$ is a binary variable equal one for the fiscal years ending after the disaster (i.e., March 11, 2011). In this model, we assume that firms set their environmental disclosures in the pre-disaster period according to a cost and benefit trade-off. We thus define a dummy variable, $CO_2\_DISCLOSURE_i$, which captures pre-disaster variation in environmental disclosure precision. In particular, $CO_2\_DISCLOSURE_i$ is a dummy variable equals to one if a firm provides historical and forward looking quantitative information about their carbon emissions at least since the year before the disaster (i.e., 2009), zero otherwise. Our hypothesis is that the magnitude of the shock to a firm cost of capital depends on the precision of a firm environmental disclosure in the pre-disaster period. More specifically, we predict that firms that disclose information about their carbon emissions experience a lower increase in the cost of capital relative

[7] In 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 code industry classification). 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.

to firms that do not disclose carbon emission information. The vector $X_{i,t}$ includes a set of observable firm characteristics that are likely to correlate with both firms' cost of capital and disclosure choices.

To reduce heterogeneity between firms disclosing and not disclosing information about their carbon emissions, we employ an entropy balance matching strategy (Hainmueller, 2012). Such matching strategy allows us to minimize the degree of observable heterogeneity between disclosing and non-disclosing firms by imposing 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 that the mean of the determinant variables' distributions between firms disclosing and firms not information about their carbon emissions to be equal, with the additional condition of minimum differences in variance and skewness.[8]

Operationally, we proceed as follows. We first condition the sample to firms that issued an environmental report at least since 2009. Then, we take the firm-specific average of each of the disclosure precision determinant variables over the three years before the disaster (i.e., 2007-2009). We consider the following variables as determinants of a firm degree of disclosure precision: (1) size (*SIZE*), measured as the logarithm of the firm's total assets at the beginning of the fiscal year; (2) leverage (*LEV*), measured as the ratio between the firm's total liabilities and the market value of its common equity at the beginning of its fiscal year; (3) return on assets (*ROA*), computed as the ratio between the firm's income before interest and taxes at the beginning of its fiscal year; (4) book-to-market ratio (*BM*), measured as the ratio between the firm's book value of

[8] Entropy balance matching is widely used in labor economics when the researcher does not have a clear understanding of the assignment into treatment rule or when the researcher does not have a suitable counterfactual (Athey and Imbens, 2017)

its common equity and the market value of the common equity at the beginning of its fiscal year; (5) return variability (*RET_VAR*) measured as the standard deviation of monthly stock returns over the previous twelve months; (6) total accruals (*ACCRUALS*) 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; (7) analyst following (*FOLLOWING*) computed as the logarithm of the number of analysts that issued a forecast during the year; (8) forecast error (*ERROR*) computed as the mean one-year-ahead consensus forecast minus the actual earnings; and (9) environmental performance (*ENV_PERF*), proxied by the emission reduction category score from Thomson Reuters ASSET4, measuring corporate effectiveness towards reducing environmental emissions in the production and operational processes on a scale that varies between 0 (not effective) and 100 (very effective). 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 code industry classification, and obtain the firm-specific weights which satisfy the pre-determined moment conditions.[9]

Another source of concern is that other firm characteristics that are associated with disclosure choices and that vary around the year of the disaster, correlate with the changes in the cost of capital, and thus may explain the differential cost of capital effects between disclosing and non-disclosing firms. For example, firms that experienced a lower increase in return variability around the time of the disaster may have been more likely than others to disclose information about their carbon emissions. In this case, the OLS estimates will be biased if the changes in firms' operating risk correlate with changes in the cost of capital. Hence, we propose a flexible

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

specification in which we allow the coefficients of the vector of the control variables to vary around the time of the disaster (i.e., $D*X_{i,t}$) 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 to allow any arbitrary within-firm correlation over time.

### *4.2. Implied cost of capital computation*

We follow prior literature and rely on accounting-based valuation models to estimate the implied cost of capital (Claus and Thomas, 2001; Easton, 2004; Gebhardt et al., 2001; Hail and Leuz, 2006; 2009; Ohlson and 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 the actual share price and the time series of the 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 flow effects. To address concerns over 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. The details of the computation of the four metrics are reported in Appendix A. In additional specifications, we gauge the extent to which our main results are robust to the use of each single implied cost of capital measure.

### *4.3. Environmental disclosure*

Our underlying argument is that the changes in the cost of capital around the disaster are associated with differences in firm disclosure precision when the disaster hit. Firm environmental reports are hand-collected from the Japanese Ministry of Economy, Trade and Industry[10] and corporate websites. We exploit cross-sectional variation in firm disclosure choices by splitting the sub-sample of disclosing firms into non-overlapping groups according to whether firms included historical *and* forward-looking (i.e., targets) information on carbon emissions since at least 2009. This choice is based on several reasons. First, the disclosure of carbon emissions provides information about the ability for firms to manage shortages in the supply of energy and related transitory arrangements, and the exposure to future compliance and regulatory actions. Second, the disclosure of historical *and* forward-looking information is a good proxy with which to capture firms' ex-ante environmental commitment and effort (Ioannou et al., 2016). Third, using firm disclosure of carbon emissions is aligned with anecdotal evidence.[11] Therefore, we employ a dummy variable that equals one if the firm provided both historical *and* target carbon emissions at least since 2009, zero otherwise (i.e., $CO_2\_DISCLOSURE$). The disclosure data is hand-collected from corporate reports.

*4.4. Control variables*

We include a set of control variables that are likely to vary systematically with firm cost of capital and environmental disclosure choices. Following prior research (Fama and French, 1992, 1993; Hail and Leuz, 2006), we expect the cost of capital to be negatively associated with firm

[10] Data has been collected from http://www.ecosearch.jp/en/

[11] We found anecdotal evidence on corporate reactions to the disaster in carbon sensitive industries, such as the energy industry. For example, in NOK Corp's (an oil seal manufacturer) 2012 CSR report, the CEO message states, "*The earthquake and consequent nuclear accident made us drastically change the consciousness of all over the world how essential the stable energy resources are. We re-acknowledge how important to build the sustainable society, where we can effectively utilize the limited energies and other resources. […], because global warming countermeasures are very important environmental challenges for the development of sustainable society, […] NOK is implementing the 3–year plan form FY2011 setting its environmental policy as 'reduce the adverse environmental impacts and build up the information control system of environmental hazardous substances globally by promoting environmental management'*". Furthermore, evidence can also be found for other industries, such as the food and health industries, as shown in the KIRIN Group's 2013 Sustainability Report: "*After the Great East Japan Earthquake in March 2011, we found people becoming more and more conscious about the social issues that they saw around them and we realized the tremendous expectations placed on us by society. It was not long before we determined that addressing social challenges as part of our business of providing products and services would benefit our business in the long run.*"

size and positively associated with the book-to-market ratio and beta. 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 the firm's book value to the market value of equity at the beginning of its fiscal year. We also consider traditional controls for risk (Hail and Leuz, 2006). Return variability (*RET_VAR*) is measured as the standard deviation of monthly stock returns over the previous twelve months. Firm leverage (*LEV*) is the ratio between firm beginning-of-year total liabilities and the beginning-of-year market value of equity. We also control for firm profitability (*ROA*) using return on assets, computed as the net income before interest and taxes over total assets. We consider proxies for the quality of financial reporting, as it is likely to be correlated with firm environmental disclosure strategy and cost of capital. We include total accruals (*ACCRUALS*) 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 issued 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, computed as the mean one-year-ahead consensus forecast minus the actual earnings (*ERROR*). We finally control for firms environmental performance (*ENV_PERF*), proxied by the emission reduction category score from Thomson Reuters ASSET4, measuring corporate effectiveness towards reducing environmental emissions in the production and operational processes on a scale that varies between 0 (not effective) and 100 (very effective).[12]

Appendix B lists the definition of all variables employed in this study.

[12] ASSET4 does not cover about 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 the performance variables using industry-year means (with the two-digit SIC code industry classification) to increase the power of our tests.

## 5. Data and descriptive statistics

The sample is comprised of 4,216 firm-year observations from 392 unique firms during the 2002-2013 period.[13] To be included in the sample, a firm must be listed in the First Section of the Tokyo Stock Exchange for the 2002-2013 period and with data available to compute the implied cost of capital metrics, disclosure and control variables. We do not require a firm to be continuously listed over the entire sample period, but a firm has to be listed at least two years before and 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 has been hand-collected from the "*Tokyo KeizaiShinpo-Sha*" which reports analyst consensus outstanding 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 analyst forecasts for one year ahead and two years ahead 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 1 percent of the observations at the top of the sample distribution of the yearly average of the four cost-of-capital models (Claus and Thomas, 2001; Easton, 2004; Gebhardt et al., 2001; Ohlson and Juettner-Nauroth, 2005). Table 1 summarizes the sample selection procedure, and provides the breakdown of the sample by year and by industry.

[Insert Table 1 about here]

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

[13] The fiscal year end of all the firms included in the sample is March 31st.

before and after the entropy balance matching procedure, separately for firms disclosing and not disclosing carbon emissions. The panel shows that before the entropy matching weighting, the variable distributions between the two sub-groups are systematically different. Firms disclosing carbon emissions are larger, with lower growth prospectus, 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 between the disclosing and non-disclosing firm group, 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.

[Insert Table 2 about here]

## 6. Results

### *6.1. Preliminary evidence*

We start our empirical analysis by providing descriptive evidence on whether the disaster has triggered a shift in the demand for environmental information. Although we cannot directly observe the shift in the demand, we can however investigate whether the disaster is associated with a change in the weight that investors place on environmental information in discounting firm cash flows; that is, we can measure the extent to which the disaster is associated with an increase in the sensitivity of the cost of capital to firm environmental performance. Such evidence would be consistent with the idea that firm environmental-related information was more relevant in discounting firm future cash flows after the disaster. We thus regress firm cost of capital on the Thomson Reuters ASSET4 emission reduction score (*ENV_PERF*, our measure for environmental performance) and the set of control variables for the pre- and post-disaster periods, separately. Figure 1 plots the coefficients on the emission reduction score conditional on the percentiles of the score distribution, separately for the two periods. The figure shows a sharp increase in the sensitivity of the cost of capital to environmental performance after the disaster, since for any percentile of the emission reduction score, the cost of capital sensitivity is higher in the post- relative to the pre- disaster period. While only suggestive, this evidence is consistent with the idea that the disaster has increased investor demand for environmental information.

[Insert Figure 1 about here]

Then, we estimate the average change in firm cost of capital and the market reaction to the disaster unconditional on firm environmental disclosure. Such analysis provides evidence about the magnitude of the economic and cost of capital consequences associated with the disaster irrespective of firm disclosure choices.[14] Table 3, Panel A reports that, on average, the disaster is associated with an increase in firms' cost of capital of around 200 basis points. Panel B reports the market reaction around the disaster for the 392 unique firms in our sample. Operationally, we compute abnormal returns based on the market model for each firm in the sample, estimated for the 253 trading days ending 127 trading days before the disaster day [trading day 0]. Market returns are those of the Japan NIKKEI 225. We document negative abnormal returns at the disaster date (i.e., *AR[0]*) of around -0.012, implying a 1.2 percent average decrease in firms' market capitalization. The average 2 and 3 trading days cumulative abnormal returns (i.e., *CAR[0,1]* and *CAR[0,2]*) around the disaster date are still negative, significant, and higher in magnitude than the abnormal returns at the disaster date, suggesting that returns do not reverse after the disaster. Taken together, evidence from Table 3 supports the argument that the disaster is associated with substantial economic and cost of capital consequences for the firms in our sample.

[Insert Table 3 about here]

*6.2. Main analysis*

[14] Given that there is no control group in this specification, we replace year-fixed effects with a time-trend variable.

Our hypothesis is that firms disclosing 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 on *POST* × $CO_2$*_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 flexible model with the entropy balance matching. Table 4, Panel B report the market reaction results. We find evidence that firms disclosing information about their carbon emissions experience a less negative market reaction relative to firms not disclosing information about their carbon emissions.[15] Overall, evidence from Table 4 supports the hypothesis that firms that disclose more information about their carbon emissions suffer a less intense cost of capital increase after Fukushima relative to non-disclosing firms.

[Insert Table 4 about here]

We next exploit cross-sectional variation in firm characteristics to explore the underlying mechanisms driving the documented pattern in the cost of capital changes. Specifically, we consider whether the change in the cost of capital after the disaster depends on (i) how the shortage in the energy supply impacts firms' future cash flows, and / or (ii) firm exposure to future regulatory actions.

We first examine whether firms with different degree of capital intensity experience differential cost of capital changes. The underlying idea of this cross-sectional analysis is that firms with higher levels of capital intensity are more likely to be affected by the energy shortage caused by the disaster because of their higher levels of energy dependence. However, conditional on capital intensity, firms disclosing information about their carbon emissions are expected to

[15] The market reaction to the disaster for firms disclosing carbon emissions not economically nor statistically different from zero (*CAR[0,1]* equals to 0.01, p-value=0.545).

experience a lower increase in their cost of capital if disclosure about carbon emissions lowers the uncertainty that investors face about firm ability to manage the energy supply shortage. We measure a firm capital intensity in the year before the disaster (*CAPITAL_INT*) as the standardized ratio between property, plant and equipment and total assets as the beginning of the year. Then, we augment equation (1) with interaction terms between *CAPITAL_INT, POST*, *POST*×$CO_2$*_DISCLOSURE.* Table 5, panel B reports the estimation results. We find that firms disclosing carbon emission information experience a lower increase in their cost of capital after the disaster. Most importantly, conditional on capital intensity, firms disclosing information about carbon emissions experience a lower increase in the cost of capital relative to non-disclosing firms, as the coefficient on the interaction term, *POST*×$CO_2$*_DISCLOSURE*×*CAPITAL_INT* is negative and significant. This evidence is consistent with the argument that carbon emissions disclosure reduces investor uncertainty about firm usage of energy around the disaster.

We then examine whether the relation between carbon emission disclosures and the cost of capital is stronger in carbon sensitive industries (CSI). The underlying argument for this test is that firms in CSI industries (e.g., mining, chemical, and metals) are more likely to be affected by future regulatory actions towards pollution abatements (Patten, 2002). However, if the disclosure of carbon emissions reduces investors' uncertainty about the cash flow implications of future regulatory actions, then CSI firms disclosing information about carbon emissions should experience a less pronounced increase in their cost of capital relative to disclosing firms in other industries. Because of our specific setting, we define carbon sensitive industries (*CSI*) as those industries where carbon pollution is a material issue (SASB, 2017; Khan et al., 2016).[16] Then, we augment equation (1) with interaction terms between *CSI, POST*, *POST*×$CO_2$*_DISCLOSURE.*

[16] We also adopt a different classification of environmentally sensitive industries as in Cho and Patten (2007). This does not change our evidence, nor does it change if we exclude firms in the oil and gas industry (un-tabulated).

Table 5, panel B reports the estimation results. We do not find evidence that firm exposure to future regulatory costs, proxied by *CSI*, differently affects the relation between environmental disclosure and the cost of capital.

[Insert Table 5 about here]

*6.3. Additional analyses*

Previous analyses provide evidence supporting the existence of a negative association between environmental disclosure and the cost of capital and shed light over the mechanism through which carbon emission information disclosed before the disaster reduces investor uncertainty about the implications of the disaster. However, our specifications may still pick up spurious associations between unobservable firm characteristics that correlate with firm disclosure choices. Our empirical strategy, based on firm fixed effects, entropy balance matching, and extensive interaction terms, address this concern only partially. Therefore, we conduct several additional analyses to rule out alternative plausible explanations.[17]

First, environmental disclosure is bundled with several firm characteristics which may explain why firms react differently to the disaster. For example, firms with good environmental performance are more likely than other firms to disclose environmental information because these firms are more likely to disclose good environmental news. As a consequence, the documented differential cost of capital changes may not be attributable to the disclosure of carbon emissions, but rather to differences in firm performance that correlates with firm disclosure choices. To empirically address such issues, we collect data on firm emissions reduction effort (*ENV_PERF*) from Thomson Reuters ASSET4 ESG. Then, we augment equation (1) with interaction terms

[17] In un-tabulated analyses, we also rule out the possibility that our results are driven by specificities of the institutional setting. Our evidence is robust when we control for firms voluntarily participating in the Japanese emission-trading scheme (in which participants adopt emission reduction targets and receive emission allowances) or greenhouse gas accounting system (according to which plants emitting above a defined threshold must report their emissions to the government).

between *ENV_PERF POST*, *POST×*$CO_2$*_DISCLOSURE*. Table 6 reports the estimation results. We find that firms disclosing information about their carbon emissions experience a lower increase in their cost of capital after the disaster, irrespective of the underlying performance, and the coefficient on *POST×*$CO_2$*_DISCLOSURE* is below the conventional level of significance in all specifications except for the flexible one (i.e., model 3). In un-tabulated results, we run a similar test using firm self-reported carbon emissions scaled by total assets as an alternative proxy for environmental performance and obtain evidence consistent with those reported.

[Insert Table 6 about here]

Then, we address another empirical challenge. Given the nature of the Fukushima nuclear disaster, the event has likely affected firm cost of capital not only through an informational channel (i.e., by increasing investors' uncertainty about firms' future cash flows), but also by directly affecting firm future cash flows (e.g., by lowering firms' growth prospectus, or by increasing costs or reducing revenues, etc.).

We thus test whether the differential cost of capital reactions to the disaster that we ascribe to an information channel are instead driven by a firm's 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 firm 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 Fukushima nuclear site. Operationally, we split the sample into three groups according to the firms' distance from the Fukushima nuclear site (i.e., less than 250 km radius, between 250 and 600 km radius, more than 600 km radius) and then we run equation (1) for each of the three groups, separately. This approach is in the spirit of a non-parametric matching design, in which we match firms according to their distance to the site of the disaster.

Table 7 reports the results. Inconsistent with the idea that our cost of capital estimates mainly reflect heterogeneous economic consequences of the disaster, we document that the cost of capital effects do not disappear as we gradually restrict our analysis on firms further away from the site of the disaster.

[Insert Table 7 about here]

We also directly account for other sources of disturbance that stem from heterogeneity in changes in firm expected performance and operating volatility between disclosing and non-disclosing firms around the disaster. We thus augment equation (1) with two partitioning variables that capture the magnitude of the cash flow revisions around the disaster (*Delta E[CFO]*) and firm operating risk in the year before the disaster (*Operating risk*), respectively. We compute the magnitude of the revisions in future cash flows at the time of the disaster by using the standardized short-term growth, measured as the difference between the one-year and one-year-ahead earnings per share estimates over the one-year-ahead earnings per share estimate. We consider one-year and one-year-ahead earnings per share estimates issued after the disaster. We measure as the standard deviation of the firm's rolling five-year cash flow from operations, Liu and Wysocki, 2008). The estimations results are presented in Table 8, columns (1) – (4)[18]. We do not find evidence consistent with the idea that our findings are driven by changes in firms' revisions of future cash flows or by differences in operating risk across firms, as the main effects ($POST \times CO_2\_DISCLOSURE$), unconditional on the partitioning variables, are still negative and significant.

[Insert Table 8 about here]

Next, we address concerns related to another confounding factor that may drive the association between environmental disclosure and the cost of capital. Firm disclosing information

[18] For brevity, we report only two specifications (flexible with firm fixed effects and flexible with firm fixed effects for the PSM sample). Results remain consistent when using the other specifications presented in the main analysis.

about their carbon emissions may be quicker in reacting to the cost of capital shock by, for instance, issuing press releases. As a result, the documented cost of capital pattern may be attributable to firm initial reaction to the disaster rather than to firm disclosure choices in the pre-disaster period. To account for this possibility, we consider another additional partitioning variable that captures firm initial disclosure reaction through environmental press releases (measured as log of the number of environmental press releases issued within the 9 months after the disaster). The evidence in Columns (5) – (6) of Table 8 does not support the idea that our results are driven by firm initial disclosure reactions.

We finally gauge the extent to which our main results are robust to the use of each single implied cost of capital measure. In the main analyses, we take the yearly average of the four cost of capital metrics to address measurement error concerns related to the use of a single measure. Table 9, panels A-D show that our main results hold for each individual cost of capital metric.

[Insert Table 9 about here]

## 7. Disclosure reaction

So far, we have shown that the Fukushima nuclear disaster is associated with a shift in the demand for environmental information – and thus to firm cost of capital – and that the magnitude of such a shift depends on firm environmental disclosure in the pre-disaster period. We now move on to investigate how firms adjust their disclosure policy to the new cost-benefit trade-off. Extant research shows that a change in the disclosure equilibrium affects firm disclosure supply. Leuz and Schrand (2009) use the Enron scandal as a source of variation in the credibility of financial reporting and document 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 the information-related shocks by increasing the supply of managerial earnings forecasts. Ioannou and Serafeim (2017) investigate the effect of a shift in the demand for environmental, social, and governance issues (e.g., introduction of *mandatory* CSR disclosure regulations) on firm disclosure practices and find that the disclosure supply of firms that have less extensive disclosure before the shift do not catch up with firms that have more extensive disclosure before the shift. Rather, disclosure differences widen as a result of the shift in demand.[19]

Our empirical tests so far show that firms disclosing their carbon emissions experience a less severe cost of capital increase after Fukushima, suggesting a less intense demand shock for these firms. Coherently, if the cost of increasing disclosure is the same across firms, then we would expect that firms experiencing the most severe shock will react more and thus increase their disclosure to a greater extent. However, given that environmental information is likely to be costly to collect (Ioannou and Serafeim, 2017), especially in the short run, how firms change their disclosures after Fukushima is an empirical question.

Ideally, one would like to examine whether firms initiate the disclosure of their carbon emissions. Unfortunately, firms are unlikely to be able to initiate this type of disclosure in a timely manner, especially in the aftermath of the disaster. Thus, to explore how firms change their disclosures after the disaster, we measure disclosure following Muslu et al., (2015) and collect the following disclosure data from environmental reports for the years 2009-2012: *length* (number of pages and number of words), *degree of hardness* (number of numerical words), and *horizon* (number of references to future years, and number of long-term horizon words).

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

We first take the average of the disclosure metrics in the pre- and post-disaster period and collapse the sample to the firm level, i.e., one observation per firm. Next, we take the difference between the post- and pre-Fukushima period of each of the disclosure metric. Then, we regress the change in the number of pages, number of words, number of long term words, number of numerical words, and number of references to future years, on the *$CO_2$_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 not disclosing information about their historical and forward-looking carbon emissions react more strongly, then we expect the coefficient on *$CO_2$_DISCLOSURE* to be negative. Table 10 reports the estimation results. We find that firms that do not disclose historical and forward-looking information about their carbon emissions in the pre-Fukushima period, and thus experience a larger increase in their cost of capital, increase the length of their disclosure and the precision and forward-looking nature of the information disclosed relative to firms that include carbon emissions information in their environmental reports.

[Insert Table 10 about here]

## 8. Conclusion

We use a large, hand-collected sample of environmental information disclosed by Japanese firms over the 2002-2013 period to investigate whether heterogeneity in firm pre-disaster environmental disclosure precision explains differences in the changes to the cost of capital after the Fukushima nuclear disaster. We document that firms disclosing carbon emissions experience a lower increase in the cost of capital than firms not disclosing information about their carbon emissions. Our evidence further ascribes the effect of disclosure on the cost of capital to carbon emission being informative about the firm's exposure to the energy supply shortage rather than to future regulatory costs for pollution abatement. Finally, our empirical analysis suggests the disclosure reaction in the post-disaster period is higher for firms on the extensive margin, i.e. firms that were not disclosing carbon emissions information before the disaster.

Overall our findings provide insights about unregulated, non-financial information provide benefits to firms when they are hit with economic shocks, complementing prior evidence on the relation between financial disclosure and the cost of capital (Leuz and Schrand, 2009) and on the effect of managerial forecasts on market liquidity (Balakrishnan et al., 2014). We document that environmental disclosure mitigates the increase in the cost of capital, and we shed light on the underlying mechanism, energy dependence, through which environmental disclosure affects the cost of capital, complementing prior evidence on environmental disclosure and regulatory costs (Blacconiere and Patten, 1994).

Despite the consistency of our results across the alternative specifications, our findings are subject to several caveats. First, the absence of a control sample does not allow us to properly control for concurrent events that might affect the cost of capital around the disaster. However, to affect our results, these potential confounders should be correlated with the timing of the shock and with firm environmental disclosure precision choices in the pre-disaster period. Second, disclosure choice is endogenous, and we are unable to properly instrument it. We address this concern in several ways, but we recognize that these approaches do not allow us to identify the effect of environmental disclosure on cost capital. However, for an omitted variable to affect our results, it should be correlated with the timing of the shock and with firm environmental disclosure strategy, and it should differentially affect disclosing and non-disclosing firms. These caveats should be considered when interpreting our findings.

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**Figure 1. Sensitivity of cost of capital to environmental performance**

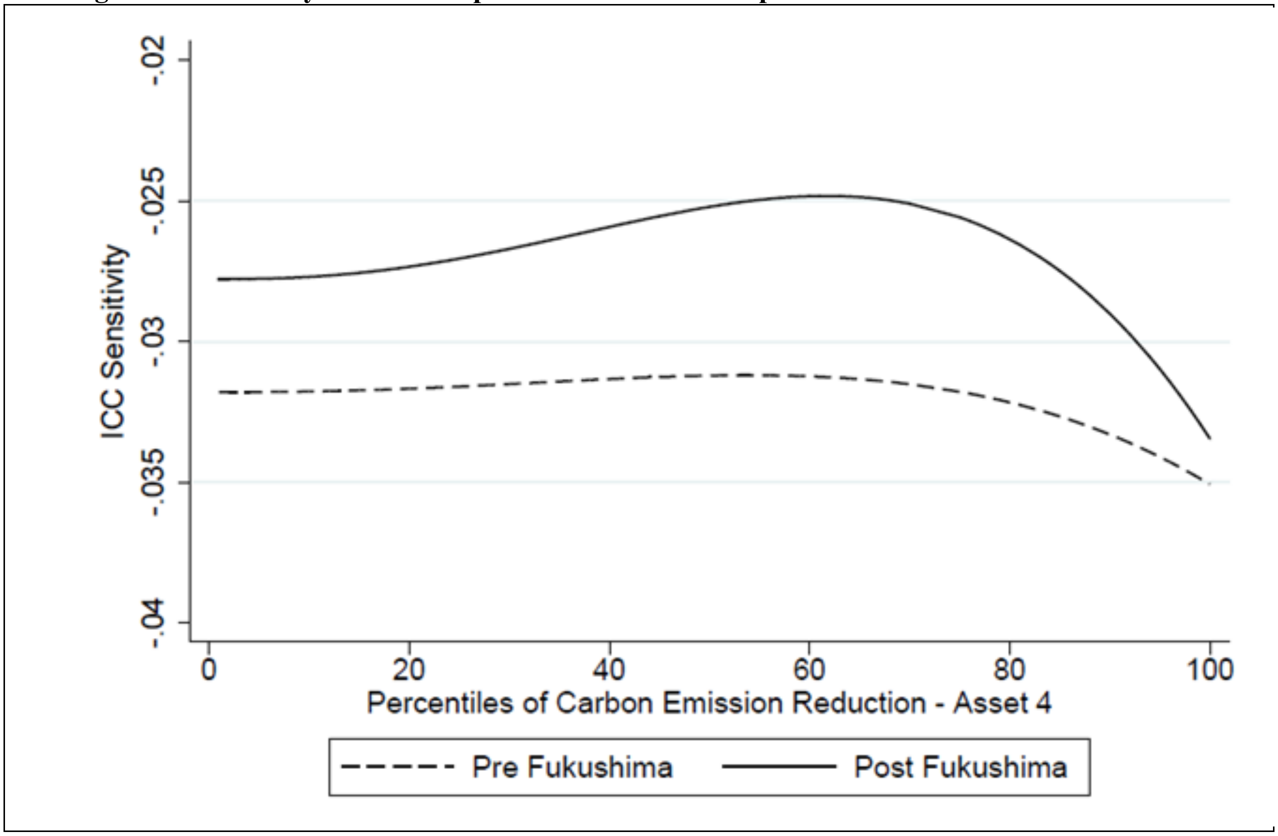


Figure 1 plots the sensitivity of the cost of capital, measured as the yearly average of the four cost of capital models, conditional on environmental performance, measured as the Carbon Emission Reduction Score from Asset4, for the pre- (dash line) and post-disaster (continuous line) periods separately. All variables are defined in Appendix B.

**Table 1. Sample characteristics**

*Panel A. Sample selection*

| | |
|---|---|
| Firms-years listed in the First Section of the Tokyo Stock Exchange (2002-2013) | 12,958 |
| *Less firm-years in missing data to compute the implied cost of capital* | 6,226 |
| *Less firms-years non-continuously listed between 2003 and 2013* | 2,070 |
| *Less firms-years non-continuously issuing environmental reports* | 446 |
| **Final sample** | 4,216 |

*Panel B. Number of times a firm appears in the sample*

| # times | # firms | N |
|---|---|---|
| 4 | 1 | 4 |
| 6 | 5 | 24 |
| 7 | 13 | 91 |
| 8 | 50 | 400 |
| 9 | 31 | 279 |
| 10 | 18 | 180 |
| 11 | 50 | 550 |
| 12 | 224 | 2688 |

*Panel C. Distribution of firm-year observations by year*

| Year | N | % |
|---|---|---|
| 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 | 7.02 |

**Table 2. Descriptive statistics**

*Panel A: Descriptive statistics - Overall sample*

| Variable | N | Mean | p5 | p25 | p50 | p75 | P95 | SD |
|---|---|---|---|---|---|---|---|---|
| ICC | 4,216 | 0.130 | 0.070 | 0.055 | 0.085 | 0.112 | 0.154 | 0.089 |
| SIZE | 4,216 | 7.733 | 1.559 | 5.362 | 6.609 | 7.583 | 8.733 | 9.896 |
| B_M | 4,216 | 1.051 | 0.587 | 0.350 | 0.638 | 0.931 | 1.315 | 1.823 |
| ROA | 4,216 | 0.022 | 0.035 | -0.032 | 0.009 | 0.022 | 0.039 | 0.061 |
| LEV | 4,216 | 0.538 | 0.194 | 0.209 | 0.390 | 0.547 | 0.694 | 0.791 |
| RET_VAR | 4,216 | 0.094 | 0.057 | 0.038 | 0.060 | 0.082 | 0.110 | 0.149 |
| FOLLOWING | 4,216 | 1.704 | 0.793 | 0.693 | 1.098 | 1.609 | 2.397 | 2.833 |
| ACCRUALS | 4,216 | -4.144 | 4.482 | -11.811 | -6.581 | -4.040 | -1.588 | 1.084 |
| ERROR | 4,216 | 0.460 | 1.659 | -1.030 | 0.041 | 0.150 | 0.383 | 1.017 |

*Panel B: Covariate balancing*

*Before entropy balance weighting*

| | *CO2_DISCLOSURE = 1* | | | | *CO2_DISCLOSURE = 0* | | | |
|---|---|---|---|---|---|---|---|---|
| Covariate | N | mean | variance | skewness | N | mean | variance | skewness |
| SIZE | 644 | 8.431 | 2.036 | 0.009 | 3,572 | 7.094 | 1.933 | 0.745 |
| B_M | 644 | 1.099 | 0.264 | 1.771 | 3,572 | 1.333 | 0.337 | 0.769 |
| ROA | 644 | 0.014 | 0.001 | -0.271 | 3,572 | 0.013 | 0.001 | -0.395 |
| LEV | 644 | 0.549 | 0.034 | -0.368 | 3,572 | 0.512 | 0.046 | -0.105 |
| RET_VAR | 644 | 0.112 | 0.002 | 0.954 | 3,572 | 0.111 | 0.002 | 1.326 |
| FOLLOWING | 644 | 2.019 | 0.591 | -0.452 | 3,572 | 1.392 | 0.447 | 0.766 |
| ACCRUALS | 644 | -0.045 | 0.021 | 0.312 | 3,572 | -0.045 | 0.021 | -0.292 |
| ERROR | 644 | 0.608 | 1.716 | 1.18 | 3,572 | 0.454 | 1.433 | 3.493 |
| ENV_PERF | 644 | 81.08 | 377.4 | -1.922 | 3,572 | 75.67 | 619.2 | -1.353 |

*After entropy balance weighting*

| | *CO2_DISCLOSURE = 1* | | | | *CO2_DISCLOSURE = 0* | | | |
|---|---|---|---|---|---|---|---|---|
| Covariate | N | mean | variance | skewness | N | mean | variance | skewness |
| SIZE | 644 | 8.431 | 2.036 | 0.009 | 3,572 | 8.431 | 2.983 | -0.001 |
| B_M | 644 | 1.099 | 0.264 | 1.771 | 3,572 | 1.099 | 0.232 | 1.307 |
| ROA | 644 | 0.014 | 0.001 | -0.271 | 3,572 | 0.014 | 0.001 | -0.345 |
| LEV | 644 | 0.549 | 0.034 | -0.368 | 3,572 | 0.549 | 0.044 | -0.452 |
| RET_VAR | 644 | 0.112 | 0.002 | 0.954 | 3,572 | 0.112 | 0.002 | 1.829 |
| FOLLOWING | 644 | 2.01 | 0.591 | -0.452 | 3,572 | 2.01 | 0.576 | -0.399 |
| ACCRUALS | 644 | -0.045 | 0.021 | 0.312 | 3,572 | -0.045 | 0.021 | -0.309 |
| ERROR | 644 | 0.608 | 1.716 | 1.186 | 3,572 | 0.608 | 1.975 | 3.363 |
| ENV_PERF | 644 | 81.08 | 377.4 | -1.922 | 3,572 | 81.08 | 431.8 | -2.071 |

Table 1, panel A reports descriptive statistics on the variables used in the entropy balance matching. Table 2 Panel B presents the descriptive statistics of the variables used in the entropy balance matching. We split the sample with respect to whether firms disclose or not carbon emissions at least since 2009, before and after the entropy balance matching. All variables are defined in Appendix B.

**Table 3: Economic consequences of the disaster**

*Panel A: Average effect on cost of capital*

| | ICC | |
|---|---|---|
| | BASE | FLEXIBLE |
| | (1) | (2) |
| **POST** | **0.028*****<br>**[0.005]** | **0.021*****<br>**[0.007]** |
| SIZE | -0.010***<br>[0.002] | -0.003<br>[0.008] |
| B_M | 0.022***<br>[0.005] | 0.029***<br>[0.006] |
| ROA | -0.298***<br>[0.071] | -0.307***<br>[0.069] |
| LEV | 0.085***<br>[0.011] | 0.100***<br>[0.030] |
| RET_VAR | 0.198***<br>[0.035] | 0.070***<br>[0.025] |
| FOLLOWING | 0.012***<br>[0.003] | 0.011**<br>[0.005] |
| ACCRUALS | -0.001**<br>[0.000] | 0.001<br>[0.000] |
| ERROR | 0.001<br>[0.001] | 0.001<br>[0.001] |
| ENV_PERF | -0.010**<br>[0.005] | -0.008*<br>[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 |

*Panel B: Market reaction to the disaster*

| | AR [0] | CAR[0,1] | CAR[0,2] |
|---|---|---|---|
| | (1) | (2) | (3) |
| | **-0.012*****<br>**[0.004]** | **-0.025*****<br>**[0.007]** | **-0.044*****<br>**[0.007]** |
| Observations | 392 | 392 | 392 |

Table 3 Panel A 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. Panel B reports market reactions to the disaster unconditional on firms' environmental disclosure policies. Column 1 reports the abnormal returns at the disaster date. Columns 2 and 3 report the 2 and 3 trading days cumulative abnormal returns, respectively. All variables are defined in Appendix B.

***, ** and * denote significance at 1 percent, 5 percent and 10 percent levels (two-tailed), respectively.

**Table 4: Economic consequences of environmental disclosure precision around the disaster**

*Panel A: Environmental disclosure precision and the cost of capital*

| | ICC | | | |
|---|---|---|---|---|
| | BASE | EBM | FLEXIBLE | EBM & FLEXIBLE |
| | (1) | (2) | (3) | (4) |
| **POST × $CO_2$_DISCLOSURE** | **-0.012**$^{**}$ | **-0.015**$^{**}$ | **-0.014**$^{*}$ | **-0.017**$^{**}$ |
| | **[0.006]** | **[0.008]** | **[0.008]** | **[0.008]** |
| SIZE | -0.003 | | -0.008$^{***}$ | |
| | [0.008] | | [0.002] | |
| B_M | 0.029$^{***}$ | | 0.021$^{***}$ | |
| | [0.006] | | [0.006] | |
| ROA | -0.308$^{***}$ | | -0.234$^{***}$ | |
| | [0.069] | | [0.060] | |
| LEV | 0.100$^{***}$ | | 0.083$^{***}$ | |
| | [0.030] | | [0.012] | |
| RET_VAR | 0.069$^{***}$ | | 0.192$^{***}$ | |
| | [0.024] | | [0.039] | |
| FOLLOWING | 0.011$^{**}$ | | 0.008$^{**}$ | |
| | [0.005] | | [0.004] | |
| ACCRUALS | 0.001 | | -0.001 | |
| | [0.000] | | [0.000] | |
| ERROR | 0.001 | | 0.001 | |
| | [0.001] | | [0.001] | |
| ENV_PERF | -0.013$^{**}$ | | 0.007 | |
| | [0.005] | | [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 | 0.262 | 0.403 |

Table 4 Panel A reports the result from regressing the yearly average of the four cost of capital metrics on the interaction between an indicator variable marking firms disclosing historical carbon emissions and carbon emissions targets at least since 2009 or earlier without stopping over the course of their history (*$CO_2$_DISCLOSURE*) and *POST*, as well as controls and fixed effects. The table reports OLS coefficient estimates and (in parentheses) robust standard errors clustered at the firm-level. All variables are defined in Appendix B.

***, ** and * denote significance at 1 percent, 5 percent and 10 percent levels (two-tailed), respectively.

*Panel B: Environmental disclosure precision and market reaction*

| | CAR[0,1] | |
|---|---|---|
| | BASE | EBM |
| | (1) | (2) |
| **$CO_2$_DISCLOSURE** | **0.029**$^{**}$ | **0.025**$^{***}$ |
| | **[0.011]** | **[0.009]** |
| SIZE | 0.016$^{***}$ | |
| | [0.005] | |
| B_M | -0.020 | |
| | [0.017] | |
| ROA | -0.321 | |
| | [0.344] | |
| LEV | -0.029 | |
| | [0.033] | |
| RET_VAR | 0.175 | |
| | [0.248] | |
| FOLLOWING | -0.007 | |
| | [0.010] | |
| ACCRUALS | 0.003$^{**}$ | |
| | [0.001] | |
| ERROR | -0.000 | |
| | [0.003] | |
| ENV_PERF | -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 days cumulative abnormal returns on an indicator variable marking firms disclosing historical carbon emissions and carbon emissions targets at least since 2009 or earlier without stopping over the course of their history (*$CO_2$_DISCLOSURE*), as well as control variables and fixed effects. The table reports OLS coefficient estimates and (in parentheses) robust standard errors that are clustered at the firm level. All variables are defined in Appendix B.
***, ** and * denote significance at 1 percent, 5 percent and 10 percent levels (two-tailed), respectively.

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

*Panel A: Environmental disclosure precision and the cost of capital conditional on energy dependence*

| | BASE | EBM | FLEXIBLE | EBM & FLEXIBLE |
|---|---|---|---|---|
| | (1) | (2) | (3) | (4) |
| **POST × $CO_2$_DISCLOSURE** | **-0.017$^{**}$** | **-0.016$^{**}$** | **-0.015$^{*}$** | **-0.016$^{**}$** |
| | **[0.007]** | **[0.007]** | **[0.008]** | **[0.007]** |
| **POST × $CO_2$_DISCLOSURE × CAP_INTENSITY** | **-0.014$^{**}$** | **-0.012$^{**}$** | **-0.020$^{***}$** | **-0.012$^{**}$** |
| | **[0.006]** | **[0.005]** | **[0.006]** | **[0.005]** |
| **POST × CAP_INTENSITY** | **0.005$^{*}$** | **0.004** | **0.007**** | **0.001** |
| | **[0.003]** | **[0.003]** | **[0.003]** | **[0.003]** |
| SIZE | -0.007$^{***}$ | | -0.009$^{***}$ | |
| | [0.002] | | [0.002] | |
| B_M | 0.017$^{***}$ | | 0.021$^{***}$ | |
| | [0.006] | | [0.006] | |
| ROA | -0.338$^{***}$ | | -0.236$^{***}$ | |
| | [0.074] | | [0.059] | |
| LEV | 0.068$^{***}$ | | 0.083$^{***}$ | |
| | [0.012] | | [0.012] | |
| RET_VAR | 0.129$^{***}$ | | 0.192$^{***}$ | |
| | [0.029] | | [0.040] | |
| FOLLOWING | 0.010$^{***}$ | | 0.008$^{**}$ | |
| | [0.004] | | [0.004] | |
| ACCRUALS | -0.001$^{***}$ | | -0.001 | |
| | [0.000] | | [0.000] | |
| ERROR | 0.000 | | 0.001 | |
| | [0.001] | | [0.001] | |
| ENV_PERF | -0.011$^{**}$ | | -0.001 | |
| | [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 | 0.230 | 0.421 | 0.264 | 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 disclosing historical carbon emissions and carbon emissions targets at least since 2009 or earlier without stopping over the course of their history (*$CO_2$_DISCLOSURE*), *POST,* and the standardized ratio of the gross property, plant, and equipment to total assets (*CAP_INTENSITY*). The table reports OLS coefficient estimates and (in parentheses) robust standard errors that are clustered by firm. All other variables are defined in Appendix B.

***, ** and * denote significance at 1 percent, 5 percent and 10 percent levels (two-tailed), respectively.

*Panel B: Environmental disclosure precision and the cost of capital conditional on exposure to regulatory risk*

| | ICC | | | |
|---|---|---|---|---|
| | BASE | EBM | FLEXIBLE | EBM & FLEXIBLE |
| | (1) | (2) | (3) | (4) |
| **POST × $CO_2$_DISCLOSURE** | **-0.019*** | **-0.023**** | **-0.023**** | **-0.025**** |
| | **[0.010]** | **[0.010]** | **[0.011]** | **[0.010]** |
| **POST × $CO_2$_DISCLOSURE × CSI** | **0.015** | **0.016** | **0.017** | **0.017** |
| | **[0.012]** | **[0.013]** | **[0.013]** | **[0.013]** |
| **POST × CSI** | **0.001** | **-0.001** | **0.001** | **0.001** |
| | **[0.005]** | **[0.006]** | **[0.006]** | **[0.006]** |
| SIZE | -0.003 | | 0.002 | |
| | [0.008] | | [0.009] | |
| B_M | 0.029*** | | 0.028*** | |
| | [0.006] | | [0.008] | |
| ROA | -0.308*** | | -0.238*** | |
| | [0.069] | | [0.067] | |
| LEV | 0.101*** | | 0.077*** | |
| | [0.030] | | [0.029] | |
| RET_VAR | 0.069*** | | 0.089*** | |
| | [0.024] | | [0.031] | |
| FOLLOWING | 0.011** | | 0.009 | |
| | [0.005] | | [0.005] | |
| ACCRUALS | 0.001 | | 0.001 | |
| | [0.000] | | [0.000] | |
| ERROR | 0.001 | | 0.001 | |
| | [0.001] | | [0.001] | |
| ENV_PERF | -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 disclosing historical carbon emissions and carbon emissions targets at least since 2009 or earlier without stopping over the course of their history (*$CO_2$_DISCLOSURE*), *POST,* and a binary variable that equals 1 for firms in industries where carbon pollution is a material issue (*CSI*). The table reports OLS coefficient estimates and (in parentheses) robust standard errors that are clustered by firm. All other variables are defined in Appendix B.
***, ** and * denote significance at 1 percent, 5 percent and 10 percent levels (two-tailed), respectively

**Table 6: Environmental disclosure precision and the cost of capital around the disaster conditional on environmental performance**

| | ICC | | | |
|---|---|---|---|---|
| | BASE | EBM | FLEXIBLE | EBM & FLEXIBLE |
| | (1) | (2) | (3) | (4) |
| **POST × $CO_2$_DISCLOSURE** | **-0.016**$^{**}$ | **-0.015**$^{**}$ | **-0.012** | **-0.015**$^{*}$ |
| | **[0.008]** | **[0.007]** | **[0.009]** | **[0.008]** |
| **POST × $CO_2$_DISCLOSURE × ENV_PERF** | **-0.002** | **-0.002** | **-0.004** | **-0.004** |
| | **[0.008]** | **[0.008]** | **[0.0014]** | **[0.009]** |
| **POST × ENV_PERF** | **0.001** | **-0.001** | **0.002** | **-0.000** |
| | **[0.002]** | **[0.002]** | **[0.002]** | **[0.002]** |
| **ENV_PERF** | **0.000** | **0.000** | **-0.001** | **-0.002** |
| | **[0.003]** | **[0.002]** | **[0.002]** | **[0.002]** |
| SIZE | -0.003 | | -0.009$^{***}$ | |
| | [0.008] | | [0.002] | |
| B_M | 0.029$^{***}$ | | 0.021$^{***}$ | |
| | [0.006] | | [0.006] | |
| ROA | -0.308$^{***}$ | | -0.234$^{***}$ | |
| | [0.069] | | [0.060] | |
| LEV | 0.100$^{***}$ | | 0.083$^{***}$ | |
| | [0.030] | | [0.012] | |
| BETA | 0.069$^{***}$ | | 0.191$^{***}$ | |
| | [0.025] | | [0.040] | |
| FOLLOWING | 0.011$^{**}$ | | 0.008$^{*}$ | |
| | [0.005] | | [0.004] | |
| ACCRUALS | 0.001 | | -0.001 | |
| | [0.000] | | [0.000] | |
| ERROR | 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 | 0.262 | 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 disclosing historical carbon emissions and carbon emissions targets at least since 2009 or earlier without stopping over the course of their history (*$CO_2$_DISCLOSURE*), *POST,* and the environmental performance score from ASSET4 (*ENV_PERF*). The table reports OLS coefficient estimates and (in parentheses) robust standard errors that are clustered by firm. All other variables are defined in Appendix B.
***, ** and * denote significance at 1 percent, 5 percent and 10 percent levels (two-tailed), respectively.

**Table 7: Environmental disclosure precision 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 | EBM & FLEXIBLE | FLEXIBLE | EBM & FLEXIBLE | FLEXIBLE | EBM & FLEXIBLE |
| | (1) | (2) | (3) | (4) | (5) | (6) |
| **POST × $CO_2$_DISCLOSURE** | **-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 |
| POST × 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 | 1,280 | 1,280 |
| 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 disclosing historical carbon emissions and carbon emissions targets at least since 2009 or earlier without stopping over the course of their history (*$CO_2$_DISCLOSURE*), *POST,* conditional on the distance between a firm headquarter and the Fukushima Nuclear site. Control variables are included but not reported for brevity. The table reports OLS coefficient estimates and (in parentheses) robust standard errors that are clustered by firm.

***, ** and * denote significance at 1 percent, 5 percent and percent levels (two-tailed), respectively.

**Table 8: Environmental disclosure precision and the cost of capital around the disaster - Controlling for confounding factors**

| | ICC | | | | | |
|---|---|---|---|---|---|---|
| | Delta E[CFO] | | Operating risk | | Environmental Press Releases | |
| | FLEXIBLE | EBM & FLEXIBLE | FLEXIBLE | FLEXIBLE | EBM & FLEXIBLE | FLEXIBLE |
| | (1) | (2) | (3) | (1) | (2) | (3) |
| **POST × $CO_2$_DISCLOSURE** | **-0.016$^{**}$** | **-0.017$^{**}$** | **-0.018$^{**}$** | **-0.016$^{**}$** | **-0.017$^{**}$** | **-0.018$^{**}$** |
| | **[0.007]** | **[0.007]** | **[0.007]** | **[0.007]** | **[0.007]** | **[0.007]** |
| **POST × $CO_2$_DISCLOSURE × PARTITIONING VARIABLE** | **0.004** | **0.003** | **0.003$^{*}$** | **0.004** | **0.003** | **0.003$^{*}$** |
| | **[0.003]** | **[0.003]** | **[0.002]** | **[0.003]** | **[0.003]** | **[0.002]** |
| Partitioning variable | Yes | Yes | Yes | Yes | Yes | Yes |
| POST × Partitioning variable | Yes | Yes | Yes | Yes | Yes | Yes |
| CONTROLS | Yes | No | Yes | Yes | No | Yes |
| POST × CONTROLS | Yes | Yes | Yes | Yes | Yes | Yes |
| EBM | No | Yes | No | No | Yes | No |
| YEAR FE | Yes | Yes | Yes | Yes | Yes | Yes |
| FIRM FE | Yes | Yes | Yes | Yes | Yes | Yes |
| Observations | 4,169 | 4,169 | 4,143 | 4,169 | 4,169 | 4,143 |
| R-squared | 0.418 | 0.423 | 0.417 | 0.418 | 0.423 | 0.417 |

Table 8 reports the results from regressing the yearly average of the four cost of capital metrics on interaction terms among an indicator variable marking firms disclosing historical carbon emissions and carbon emissions targets at least since 2009 or earlier without stopping over the course of their history (*$CO_2$_DISCLOSURE*), *POST,* and partitioning variables for whether firms issued environmental press releases in the two months after the disaster or not (models 1 and 2), operating risk (models 3 and 4), and expected change in cash flow (models 5 and 6), and the relative interactions. Control variables are included but not reported for brevity. The table reports OLS coefficient estimates and (in parentheses) robust standard errors that are clustered by firm.

***, ** and * denote significance at 1 percent, 5 percent and percent levels (two-tailed), respectively.

**Table 9: Cost of capital sensitivity analysis**

*Panel A: Claus and Thomas ICC metric*

| | BASE | EBM | FLEXIBLE | EBM & FLEXIBLE |
|---|---|---|---|---|
| | (1) | (2) | (3) | (4) |
| **POST × $CO_2$_DISCLOSURE** | **-0.009** | **-0.009$^{*}$** | **-0.012$^{**}$** | **-0.009$^{*}$** |
| | **[0.006]** | **[0.005]** | **[0.006]** | **[0.005]** |
| YEAR FE | Yes | Yes | Yes | Yes |
| FIRM FE | Yes | Yes | Yes | Yes |
| CONTROLS | Yes | No | Yes | No |
| POST × CONTROLS | No | No | Yes | Yes |
| EBM | No | Yes | No | Yes |
| Observations | 4,066 | 4,066 | 4,066 | 4,066 |
| R-squared | 0.320 | 0.336 | 0.323 | 0.343 |

*Panel B: Modified PEG ratio model by Easton ICC metric*

| | BASE | EBM | FLEXIBLE | EBM & FLEXIBLE |
|---|---|---|---|---|
| | (1) | (2) | (3) | (4) |
| **POST × $CO_2$_DISCLOSURE** | **-0.006** | **-0.013$^{*}$** | **-0.013$^{*}$** | **-0.015$^{**}$** |
| | **[0.006]** | **[0.007]** | **[0.007]** | **[0.007]** |
| YEAR FE | Yes | Yes | Yes | Yes |
| FIRM FE | Yes | Yes | Yes | Yes |
| CONTROLS | Yes | No | Yes | No |
| POST × CONTROLS | No | No | Yes | Yes |
| EBM | No | Yes | No | Yes |
| Observations | 3,735 | 3,735 | 3,735 | 3,735 |
| R-squared | 0.541 | 0.506 | 0.547 | 0.540 |

*Panel C: Ohlson and Juettner-Nauroth ICC metric*

| | BASE | EBM | FLEXIBLE | EBM & FLEXIBLE |
|---|---|---|---|---|
| | (1) | (2) | (3) | (4) |
| **POST × $CO_2$_DISCLOSURE** | **-0.016** | **-0.019$^{**}$** | **-0.019$^{**}$** | **-0.020$^{**}$** |
| | **[0.010]** | **[0.010]** | **[0.010]** | **[0.010]** |
| YEAR FE | Yes | Yes | Yes | Yes |
| FIRM FE | Yes | Yes | Yes | Yes |
| CONTROLS | Yes | No | Yes | No |
| POST × CONTROLS | No | No | Yes | Yes |
| EBM | No | Yes | No | Yes |
| Observations | 3,828 | 3,828 | 3,828 | 3,828 |
| R-squared | 0.451 | 0.395 | 0.460 | 0.431 |

*Panel D: Gebhardt et al. ICC metric*

| | BASE | EBM | FLEXIBLE | EBM & FLEXIBLE |
|---|---|---|---|---|
| | (1) | (2) | (3) | (4) |
| **POST × $CO_2$_DISCLOSURE** | **-0.029$^{*}$** | **-0.025$^{*}$** | **-0.030$^{**}$** | **-0.027$^{*}$** |
| | **[0.015]** | **[0.015]** | **[0.015]** | **[0.015]** |
| YEAR FE | Yes | Yes | Yes | Yes |
| FIRM FE | Yes | Yes | Yes | Yes |
| CONTROLS | Yes | No | Yes | No |
| POST × CONTROLS | No | No | Yes | Yes |
| EBM | No | Yes | No | Yes |
| Observations | 4,005 | 4,005 | 4,005 | 4,005 |
| R-squared | 0.308 | 0.262 | 0.310 | 0.276 |

Table 9 presents the results from regressing the different cost of capital metrics on the interaction between an indicator variable marking firms disclosing historical carbon emissions and carbon emissions targets at least since 2009 or earlier without stopping over the course of their history (*$CO_2$_DISCLOSURE*) and *POST*, as well as control variables and fixed effects. Computation of each implied cost of capital is reported in Appendix A. The table reports OLS coefficient estimates and (in parentheses) robust standard errors that are clustered by firm. Control variables are included but not reported for brevity.
***, ** and * denote significance at 1 percent, 5 percent and 10 percent levels (two-tailed), respectively.

**Table 10: Disclosure response around the disaster**

| | ICC | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Δ#pages | | Δ #words | | Δ #numerical words | | Δ #long term words | | Δ horizon | |
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) |
| **$CO_2$_DISCLOSURE** | **-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]** |
| SIZE | 0.238 | | -45.059 | | -39.393 | | 1.144 | | 0.221 | |
| | [0.531] | | [53.327] | | [47.176] | | [3.379] | | [2.771] | |
| B_M | 1.569** | | 117.423** | | 104.997** | | 8.043* | | 6.685* | |
| | [0.603] | | [52.632] | | [46.504] | | [3.696] | | [3.093] | |
| ROA | 15.145 | | -81.513 | | 4.222 | | -73.845 | | -48.246 | |
| | [15.589] | | [1,961.185] | | [1,786.817] | | [86.431] | | [74.428] | |
| LEV | 0.191 | | 756.868 | | 675.397 | | 12.663 | | 18.019 | |
| | [3.329] | | [750.296] | | [690.498] | | [27.679] | | [21.887] | |
| BETA | 12.329* | | 807.537 | | 693.269 | | 102.130 | | 63.878 | |
| | [6.568] | | [1,492.453] | | [1,326.166] | | [109.111] | | [83.393] | |
| FOLLOWING | 2.457** | | 116.104 | | 102.654 | | 7.138 | | 6.134 | |
| | [0.861] | | [99.759] | | [91.553] | | [5.989] | | [4.391] | |
| ACCRUALS | -0.002 | | 19.047 | | 16.962 | | 0.834 | | 0.660 | |
| | [0.152] | | [12.825] | | [11.433] | | [0.509] | | [0.419] | |
| ERROR | -0.080 | | -76.647 | | -68.283 | | -2.110 | | -1.807 | |
| | [0.366] | | [74.503] | | [68.355] | | [1.895] | | [1.613] | |
| INDUSTRY FE | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| EBM | 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 10, report the results from regressions of the firm-specific changes between 2010 and 2011 in the following disclosure variables: number of pages [columns (1) – (2)], number of words [columns (3) – (4)], number of numerical words [columns (5) – (6)], number of long-term words [columns (7) – (8)], horizon (sum of the number of references to future years and horizon references) [columns (9) – (10)] on an indicator variable marking firms disclosing historical carbon emissions and carbon emissions targets at least since 2009 or earlier without stopping over the course of their history (*$CO_2$_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 B.

***, ** and * denote significance at 1 percent, 5 percent and 10 percent levels (two-tailed), respectively.

**Appendix A: Implied cost of capital computation**

The computation of the implied cost of capital models requires the use of the following variables:

- $p_0$: stock price, measured seven months after the fiscal year-end from *Datastream.*
- $bv_0$: current book value of equity per share, measured as of the fiscal year-end from *Compustat Global*;
- $e_t$: expected future earnings per share for year t, computed as the mean analyst earnings per share forecasts. Analyst forecasts have been hand-collected from the "*Tokyo KeizaiShinpo-Sha*" which reports the monthly analysts' consensus outstanding for all firms listed on the Tokyo Stock Exchange. Analyst earnings forecasts are measured as of month +7 after the fiscal year end.
- $d_t$: expected future dividends per share for year t, from *Compustat Global*;
- $bv_t$: expected book value of equity per share for year t, from *Compustat Global;*
- $g$, $r_{gst}$, $r_{glt}$: expected perpetual, short-term, and long-term growth rate;
- $k$: average dividend payout ratio over the past three years ($k$ is required to be bounded between 0 and 1), from *Compustat Global*. If $k$ is missing for a given firm-year, we replace it with the industry-year median.

A.1 Claus and Thomas (2001)

$$p_0 = bv_0 + \frac{e_1 - r_{CT} \times bv_0}{(1 + r_{CT})} + \frac{e_2 - r_{CT} \times bv_1}{(1 + r_{CT})^2} + \frac{e_3 - r_{CT} \times bv_2}{(1 + r_{CT})^3} + \frac{e_4 - r_{CT} \times bv_3}{(1 + r_{CT})^4}$$

$$+ \frac{e_5 - r_{CT} \times bv_4}{(1 + r_{CT})^5} + \frac{(e_5 - r_{CT} \times bv_4) \times (1 + g)}{(r_{CT} - g)(1 + r_{CT})^5} \quad \text{(A.1)}$$

$$bv_t = bv_{t-1} + e_t - e_t \times k$$

If $e_3$, $e_4$, or $e_5$ is missing, it is replaced with $e_3 = e_2 * (1 + r_{glt})$, $e_4 = e_3 * (1 + r_{glt})$, or $e_5 = e_4 * (1 + r_{glt})$, respectively, where $r_{glt}$ is the analyst forecast for the long-term growth rate. The inflation rate is used as a proxy for $g$.

A.2 Gebhardt et al. (2001)

$$p_0 = bv_0 + \frac{e_1 - r_{GLS} \times bv_0}{(1+r_{GLS})} + \frac{e_2 - r_{GLS} \times bv_1}{(1+r_{GLS})^2} + \frac{e_3 - r_{GLS} \times bv_2}{(1+r_{GLS})^3}$$

$$+ \sum_{t=4}^{11} \frac{\overline{ROE}_t - r_{GLS}}{(1+r_{GLS})^t} \times bv_{t-1} + \frac{\overline{ROE}_{12} - r_{GLS}}{r_{GLS} \times (1+r_{GLS})^{12}} \times bv_{11} \qquad \text{(A.2)}$$

$$\overline{ROE}_t = \frac{1}{I} \sum_i^I \overline{ROE}_{t,i}$$

$$ROE_{t,i} = e_{t,i} / bv_{t,i}$$

$$bv_t = bv_{t-1} + e_t - e_t \times k$$

Beyond the explicit forecast period of three years, the residual income series is defined by linearly fading the forecasted accounting return on equity to the sector-specific average return. The industry-average return on equity applies to firms in a given year, using Campbell's (1996) industry classification.

A.3 Ohlson and Juettner-Nauroth (2005)

$$p_0 = \frac{e_1}{r_{OJ}} \times (g_{st} + \frac{r_{OJ} \times d_1}{e_1} - g_{lt}) / (r_{OJ} - g_{lt}) \qquad \text{(A.3)}$$

$$g_{st} = (e_2 - e_1)/e_1$$

$$d_1 = k \times e_1$$

Short-term growth ($r_{gst}$) is as defined by Gode and Mohanram (2003). The inflation rate is used as a proxy for $g$.

A.4 Modified PEG ratio model by Easton (2004)

$$p_0 = (e_2 + r_{PEG} \times d_1 - e_1)/r_{PEG}^2 \qquad \text{(A.4)}$$

We use an iterative procedure to back out the internal rate of return. This process identifies the annual firm-specific discount rate that equates the left-hand-side price to the right-hand-side value. We begin iterating the discount rate from 0 to 1 by 0.0001 each time and stop when the absolute difference is less than 0.1 percent of the left-hand-side price. If there is no solution, we relax the 0.1 percent restriction to 1 percent, 5 percent, and 10 percent maximums. We measure each cost of capital metric seven months after the fiscal year-end. Thus, the prices and analyst forecasts collected reflect the consensus outstanding for the fiscal year ending in five months for $e_1$, seventeen months for $e_2$, and so on, while the valuation model assumes discounting for the whole year. Following Hail and Leuz (2006), we move the prices for the seventh month after the fiscal year back to the beginning of the period using the implied cost of capital (i.e., $[1+r]^{-7/12}$) and then use the full year's discounting.

**Appendix B: Variable definitions**

| | |
|---|---|
| *$CO_2$_DISCLOSURE* | Time-invariant dummy variable for firms that have issued environmental targets and information on their current CO2 emissions at least since 2009 without stopping. The data were hand-collected from corporate reports. |
| *POST* | Dummy variable that equals one for the 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 and Thomas, 2001; Easton, 2004; Gebhardt et al., 2001; Ohlson and 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 the beginning of the year total assets. |
| *LEV* | The ratio of the beginning-of-year total liabilities to the beginning-of-year market value of equity. |
| *RET_VAR* | The firm's 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 a forecast 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 period. |
| *ERROR* | Forecast bias as the mean one-year-ahead consensus forecast, minus actual earnings. |
| *ENV_PERF* | Environmental performance (emission reduction category) score from Asset 4 - Thomson Reuters that reflects "corporate effectiveness towards reducing environmental emissions in the production and operational processes" (ASSET4 ESG Glossary). The score is a relative measure of performance, 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. |
| *CAP_INTENSITY* | Standardized ratio of the gross property, plant, and equipment to total assets. |
| *CSI* | Dummy variable that equals 1for firms in industries where carbon pollution is a material issue (SASB, 2017). |
| *Environmental Press Releases* | Log of the number of environmental press releases issued in the 9 months after the disaster |
| *Operating risk* | Standard deviation of the firm's five-year rolling cash flow from operations. |
| *Delta E[CFO]* | Ratio of the difference between the one-year and one-year-ahead estimated earnings per share to the one-year-ahead estimated earnings per share. |