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Mandatory Disclosure, Greenhouse Gas Emissions and the Cost of Equity Capital: UK Evidence of a U-shaped Relationship

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Abstract:

This paper examines the effects of disclosing greenhouse gas (GHG) information mandatorily on the cost of equity capital (COC) using a longitudinal unbalanced panel database of the UK's FTSE 350 firms for the period 2011 – 2016. Following Powell (2016), we use a non-linear panel quantile regression (PQR) model to examine the relationship between GHG disclosure (GHGD) and COC in the UK. This technique was supplemented by conducting a two-step generalised method of moment (GMM) estimation to address any concerns related to the potential existence of endogeneity problems. Our findings suggest that high-level GHGD appeared to be negatively associated with COC up to a certain level, which is known as the turning point; then, any increase in GHGD is likely to increase the COC. This means that the non-linear association between GHGD and COC is evidenced in our study and takes a U shape. Likewise, our findings are associative of a moderating effect of the 2013 carbon disclosure regulation (CDR) on the GHGD-COC nexus. We argue that mandatory GHG disclosure and GHG risk are linked so that those companies that are associated with higher GHG risk have a tendency to be better disclosers. Consequently, we urge regulators to design GHG disclosure regulations in a way that mirrors corporate environmental risk and lead to a lower COC in order to align the interests of corporations with those of the society at large.

Keywords: Carbon Disclosure Regulation, Cost of Capital, FTSE 350, GHG Disclosure, Targeted Disclosure Cycle Theory.

1. Introduction:

Previous studies provide evidence that greenhouse gas GHG emissions are expected to severely influence climate change, which can be linked to raising the levels of the sea and other extreme weather phenomena such as floods, hurricanes, droughts and heatwaves (IPCC, 2018). In a global survey of 1000 experts, including different governments, academics, business leaders and non-governmental organisations (NGOs), the Global Risk Report of (2019) considers these extreme weather conditions and the failure to control the magnitude of climate change as top risks (World Economic Forum, 2019). Given this, a number of environmental initiatives have been launched by various international bodies and countries, such as Kyoto Protocol in 1997 and most recently the United Nations Framework Convention on Climate Change (UNFCCC) in 2016 that is also called as Paris accord, in order to cope with the mitigation of GHG emissions and other environmental consequences on humankind (Hassan & Romilly, 2018; Giannarakis et al., 2019; Li et al., 2020). Under the Paris accords, for instance, several countries have pledged to minimise their GHG emissions in an effort to reduce the increases in global temperature by enacting appropriate environmental regulations. Relatedly, more than 40 states have applied a cap-and-trade program, which grants corporations tradable allowances for how much carbon dioxide they can reduce emitting each year (Maaloul, 2018).

Further, policymakers are progressively obliging businesses to disclose information on their GHG emissions (Albarrak et al., 2019). For instance, in June 2013, the UK government enacted a carbon disclosure regulation (CDR) that requires all listed firms and public organisations to report on their GHG emissions mandatorily (Secretary of State, 2013) (*See* section 2 for further details). Surprisingly, nevertheless, a little is known about whether the enactment of related regulations, such as the 2013 CDR in the UK, can contribute to a decline in GHG emissions and lead to a lower COC simultaneously. To fill this gap, we distinctively examine the issue of a GHG disclosure mandate in the UK and how and why GHG disclosure (GHGD) can affect companies' prospects to obtain low-cost access to financial resources, and how and why regulations such as the CDR of 2013 in the UK can moderate the GHGD-COC nexus?

In recent years, companies have undergone growing pressures to provide more information related to their policies to reduce GHG emissions further to their collective climate change plans in the long-term (Flammer, 2013). At a global scale, stakeholders have called for increased transparency, greater disclosure and a consistent approach to GHG emissions (Qian and Schaltegger, 2017). Meanwhile, corporations have stated concerns over the cost of GHG emissions disclosures from the perspective of competitive disadvantage and liability exposure (Weigand, 2010). Others urge balancing this approach by taking both costs and benefits into account (Li et al., 2017). Consequently, today's corporations should be able to determine the appropriate level of disclosure of the costs and benefits linked to GHG emissions (Bui et al., 2020).

Although prior researchers have recently sought to examine the impact of GHG emissions and/or disclosure on COC, in various settings around the world (e.g., Maaloul, 2018; Albarrak et al., 2019; Kumar and Firoz, 2018; Lemma et al., 2018; Bui et al., 2020), the expected effects of disseminating GHG information mandatorily on COC has not been examined, specifically in the UK settings (Alsaifi et al., 2020). For instance, Albarrak et al. (2019) indicate that the association between GHG disclosure and COC is a context-specific, mainly associated with the regulatory environment. Given this, the findings of examining the GHG-COC nexus are primarily linked to differences in the regulatory environment across countries. Also, a study examining the association between GHGD and COC in the UK is virtually non-existent (Broadstock et al., 2018). Additionally, to the best of our knowledge, there is no single study exploring the effect of regulative forces on the GHGD-COC nexus. Therefore, there is a need for more research papers to shed light on the suggested value of corporate engagement in mandatory and voluntary GHG disclosure in reducing the COC for those conformed companies. Thus, our study seeks to uniquely examine the crucial policy questions of why and how GHG disclosure (GHGD) can affect COC in a developed context has recently witnessed substantial changes in its environmental regulations, namely the UK? Furthermore, we examine the potential moderating effect of the 2013 CDR on the GHGD-COC nexus.

In doing so, we contribute to the existing body of literature as follows. First, we provide evidence on the effects of GHGD on the COC in a developed economy. Second, we examine the potential moderating influence of the UK government act of 2013 that requires companies to mandatorily disclose their GHG emissions information on the relationship between GHG disclosure and COC. Third, we suggest that high-GHGD companies face a lower COC up to a particular point where increasing GHGD levels can result in higher COC. Our study, therefore, seeks to identify the turning-point that can lead to a U shape relationship between GHGD and COC. Fourth, we distinctively employ the targeted disclosure cycle (TDC) theory to develop a hypothesis on the effect of GHG emission disclosure on the COC in the UK. Fifth, using a non-linear panel quantile regression (PQR) model, we use the most appropriate estimation method to provide a more comprehensive analysis of the GHG-COC nexus than prior studies that are restricted to the traditional linear regression models such as the least-squares method.

The objectives of our study are three-fold. First, it aims at determining the impact of GHG disclosure on COC in a developing setting, namely the UK. Second, we examine the potential moderating effect of the 2013 regulation that mandatorily requires firms to disseminate their GHG information on the GHG-COC nexus in the UK from 2011 to 2016. In stating these objectives, our study purports that firms, which are deemed to adhere to the 2013 carbon disclosure regulation, are likely to enjoy a lower cost of capital in the UK simultaneously. By doing so, we respond to the recent calls (e.g., Albarrak et al., 2019; Raimo et al., 2020; Bui et al., 2020; Alsaifi et al., 2020) to assess the effectiveness of mandatory GHG disclosures (i.e., 2013 CDR) in reducing a firm's COC, and how these environmental regulations, such as CDR, can moderate the GHGD-COC nexus. Our results are, therefore, expected to help managers, practitioners and policymakers in evaluating the effectiveness of the mandatory nature of GHGD in lowering the COC in the

UK. Third, we attempt to identify the turning-point of the GHGD-COC nexus. Specifically, we argue that in the early stages the increases in the levels of GHGD are expected to lead to a lower COC up to a certain level of GHGD, known as the turning point, and then COC increases as the GHGD increase. Based on the first scenario (first stage), the cost of capital increases the investments in those environmentally sensitive industries. In contrast, the intervention of government via imposing the regulations seemed to improve the quality of the environment (second scenario).

Our findings are three-fold. First, using a comprehensive dataset, and applying a non-linear PQR model, our findings suggest that high-GHGD is negatively associated with COC in the UK up to a certain level known as the turning point; then, any increases in GHGD is likely to increase the COC for those environmentally sensitive sectors. Second, our findings are indicative of a moderating effect of the 2013 carbon disclosure regulations (CDR) on the GHGD-COC nexus. This implies that government decision to force the mandatory disseminating of GHG emission information appeared to lead to enhancing firms' opportunities to gain access to cheaper financial resources. Generally, the econometric models in our paper are robust to a variety of endogeneity issues and alternative GHGD and COC proxies.

The remainder of this article is structured as follows. Section 2 introduces GHGD regulations in the UK. Section 3 reviews the previous GHG emissions and COC previous studies; section 4 presents the research design; section 5 shows and discusses the empirical findings and additional checks; section 6 concludes the research and indicates our limitations and recommendations.

2. Carbon Disclosure Regulations in the UK

As a G7 group member, we focus on the UK institutional setting to examine the GHG-COC nexus because it is considered as one of the most significant GHG emitters in the world (Haque, 2017). Furthermore, the UK government is currently working on developing effective enforcement mechanisms to mitigate the notable effects of climate change proactively (Alsaifi et al., 2020). According to the Carbon Disclosure Project (CDP)[1], for example, more than 97% of the UK listed firms are disclosing information related to Scope 1 and 2 GHG emissions[2] and has

[1] CDP is largest register of corporate carbon disclosures in the world that was founded in the UK in 2000. CDP primary aim is sending an annual survey to listed firms on main stock indices such as the FTSE350 on behalf of investor signatories. This survey gathers information those firms on GHG emissions-related issues.

[2] Scope 1 GHG emissions are direct emissions arising from sources controlled by the disclosing company. Scope 2 GHG emissions are those indirect emissions associated with the generation of energy purchased.

the most significant percentage (96%) of board-level oversight of climate change risk in the world (CDP, 2016).

In 2008, the Committee on Climate Change (CCC)[3] recommended the UK government to set up a reduction plan for GHG emission to be as a minimum as 80% of the 1990s emissions by 2050 (Alsaifi et al., 2020). Later in 2009, the UK government has published voluntary guidelines for measuring and reporting on GHG emissions to persuade listed firms to lower their climate change impact. Most relatedly, in June 2013, the UK government enacted a regulation that requires all listed firms and public organisations to report on their GHG emissions mandatorily (Secretary of State, 2013). This regulation aimed at providing clarity around how firms are managing the amount of their GHG emissions and reporting on GHG information that shareholders have been calling for. Crucially, starting from the 1st October 2013, all listed firms have been compelled to publishing a directors' report of GHG emissions, including the methodology used in measuring these emissions.

Collectively, the UK provides an interesting setting to examine the extent to which the mandatory and voluntary disclosures of GHG emissions can either restrict or enhance companies' opportunities to gain access to low-cost financial resources as proxied by the cost of capital (COC) in developed economies.

3. Literature Review

3.1. Previous studies

Table 1 presents the key prior studies that are examining the relationship between GHG emissions disclosure and the COC in various developed and developing economies.

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Previous studies seemed to have several shortages. First, a few recent studies focused on exploring the GHGD-COC nexus in the context of developed economies such as the US (Albarrak et al., 2019) and Canada (Maaloul, 2018), while others investigated this association in developing settings such as China (Li et al., 2017), India (Kumar and Firoz, 2018), and South Africa (Lemma et al., 2018). On the other hand, a few studies examined the GHGD-COC nexus in the context of multi-countries (e.g., He et al., 2013; Trinks et al., 2017; Bui et al., 2020). This means that there is no enough attention has been devoted to examining the potential effect of disclosing GHG emission-

[3] The Committee on Climate Change (CCC) is an independent, expert, statutory public body formed by the Climate Change Act of 2008 to evaluate how the UK can meet its targets in relation to GHG emissions reduction plans for a period spans from 2020 to 2050.

related information on reducing the COC for committed firms in the context of industrialised economies. Second, to the best of our knowledge, there is no single study investigating the possible effects of the mandatory disclosure of GHG emissions on COC. This limits our understanding of the impact of carbon disclosure regulation (CDR) on the GHGD-COC connection, specifically, in developed economies. Third, a study examining the GHGD-COC nexus in the UK context is virtually non-existent. Fourth, from a methodological perspective, all prior GHGD-COC studies have used the conventional linear regression methods, including the ordinary least squares (OLS) model (Maaloul, 2018; Albarrak et al., 2019; Li et al., 2015; Kumar and Firoz, 2018), a fixed-effects regression model (Trinks et al., 2017; Raimo et al., 2020), a two-stage least squares (2SLS) regression model (Bui et al., 2020), and a three-stage least squares (3SLS) regressions (He et al., 2013; Lemma et al., 2018) (See Table 1). These traditional linear regression models summarize the average association between different dependent and independent variables on the basis of the conditional mean function $E(y|x)$, which provides a partial understanding of the studied relations (Cobb-Clark et al., 2016). Fifth, to the best of our knowledge, the literature of business strategy and the environment lacks any calculations of the turning point that mirrors the U-Shape of the non-linear association between disseminating GHG emission information and the COC in the developed world.

Consequently, our study aims at addressing the deficiency in prior studies and extends the existing body of literature as follows. First, we examine the relationship between GHGD and COC in a developed economy has recently undergone substantial regulatory transformations that are associated with the mandatory requirements of the disclosure of GHG emissions, namely the UK. Second, this study contributes to the body of literature by considering the moderating effect of the 2013 regulation on the relationship between GHGD and COC among a sample of FTSE 350 companies from 2011 to 2016. Third, unlike previous GHG studies, we distinctively apply a non-linear panel quantile regression (PQR) model to examine the GHGD-COC nexus. Contrary to the conventional linear regression models that use the least-squares estimation method to calculate the conditional *mean* of the target across different values of the variables, a non-linear PQR model estimates the conditional *median* of the target (Baum, 2013). This implies that by applying a non-linear quantile estimation method, we offer a more inclusive understanding of the behaviour of the relationship between GHG emissions disclosure and COC for three reasons. First, a non-linear PQR estimation method is more rigorous to outliers than the least-squares regression method. Second, it is deemed as a semiparametric method as it avoids assumptions linked to the distribution of the error procedure parametrically (Cobb-Clark et al., 2016; Baum, 2013). Finally, we distinctively calculate the turning-point of the GHGD-COC nexus. Crucially, we argue that in the early stages the increasing levels of GHGD are expected to lower the COC up to a certain point, which is known as the turning point, then COC increases as the levels of GHGD increase.

3.2. Theoretical Foundation and Hypotheses Development

Drawing on Fung et al. (2007), we employ the targeted disclosure cycle (TDC) theory to develop a hypothesis on the effect of GHG emission disclosure on the COC in the UK. Fung et al. (2007, 54) state that the disclosure of non-financial information can change the behaviour of the users of information and then users' (stakeholders) actions are expected to shape the relevant reactions of disclosers (firms). This means that the main elements of TDC theory consist of (i) disclosure requirements (e.g., regulations); (ii) senders (or disclosers) of the required information; (iii) receivers (or users) of the required information; (iv) receivers' targeted behaviours (actions or decisions); and, eventually, (v) the targeted behaviour or action of disclosers (firms). Figure 1 presents the causal chain through which disclosure regulation can influence firms' actions.

INSERT FIGURE 1 RIGHT HERE

TDC theory generally assumes that corporate disclosure affects its receiver's behaviour, such as shareholders and stakeholders, resulting in tangible consequences (Downar et al., 2019). Corporations as information providers directly respond to the various behaviours of information receivers by adjusting their related decisions. Recently, TDC theory has been applied to examine the different consequences of corporate GHG disclosures (Baboukardos, 2017; Hombach and Sellhorn, 2019). Hombach and Sellhorn (2019), for instance, define the criteria that should be satisfied so that corporate disclosure of GHG emissions can have real impacts. For example, the disclosure regulation is supposed to change the actual disclosure practices indicating effective enforcement mechanisms of a new set of disclosure requirements. Relatedly, the 2013 Act mandates disclosure of GHG emissions information for all listed firms in the UK as a part of the director's report that should be reviewed by the external auditor based on detailed application guidance ensures the comparability of GHGD among companies (Department for Environment, Food & Rural Affairs – DEFRA, 2012).

Similarly, only after mandating GHGD, shareholders and stakeholders are allowed to assess a firm's GHG emissions information and to compare it to those of peers. Thus, the 2013 Act is expected to decrease the cost of stakeholders' information processing in relation to GHG emissions (Downar et al., 2019). Likewise, GHGD in annual reports has boosted public awareness of firms' GHG emissions, which might have been reinforced by social and traditional media coverage that picks up on the GHG emission information and report on it (Baboukardos, 2017). Stakeholders, therefore, tend to have social preferences for low-level GHG emissions beyond their financial risk implications as they do not only care about payoffs but also about firms' ethical behaviours (Kim et al., 2019). Consistently, Amel-Zadeh and Serafeim (2018) suggest that ethical considerations, such as low-level GHG emissions and high-GHG disclosure, can collectively play an essential role in investment decisions and result in lower COC.

Equally, the new GHG emission information for stakeholders ought to be considered in their actions and expectations. Reporting GHG emission information is of prominent importance to stakeholders stemming from its impact on a firm's climate risks, such as (i) reputational risks (ii) regulatory risks, and (iii) litigation risks (DEFRA, 2012). Regulatory risks are associated with future changes in environmental regulations that may incrementally internalize the cost of GHG emissions through taxes and trading schemes, for example, which is expected after a certain point (the turning point) to increase firms' cost of capital (Downar et al., 2019). Reputational risks may result from changing the consumer or market behaviour. Consumers may take action on climate change, such as boycotts, which is deemed to affect firms with high levels of GHG emission (Kölbel et al. (2017) by increasing their financial risk that can increase the probability of stakeholder sanctions (Hombach and Sellhorn, 2019). Additionally, litigation risks might emerge from a growing likelihood of environmental litigation (Erion, 2009). Previous empirical evidence indicates that investors appeared to consider environmental risks in their investment-related decisions as suggested by a positive relationship of environmental risks with COC (Sharfman and Fernando, 2008). This means that if GHG disclosure is attributed to greater carbon risks, this might lead to increasing a firm's COC. Nevertheless,

We argue that the 2013 Act could impose market-value-related penalties for high emitters (Griffin et al., 2017). The market value-penalties of high-emissions firms can constitute a feedback impact of GHG disclosure, which possibly reinforce managers' efforts to reduce GHG emissions because any change in a firm's market value is regarded as an essential determinant of managers' compensation (DEFRA, 2012) and thus, managers are appeared to be aware of stakeholders' actions and responses to high GHG emissions and may reinforce emission abatement efforts in order to gain more access to financial resources and reduce the COC (Baboukardos, 2017). Nevertheless, increasing the reported level of GHG emissions beyond a particular point (the turning point) is expected to maximise a firm's carbon risk, which leads in turn to increasing its COC, simultaneously.

Previous studies indicate that disclosure of GHG emissions is negatively associated with COC in various settings around the world. For example, Albarrak et al. (2019) find that Carbon disclosure is significantly and negatively associated with COC in the US setting. Likewise, in a multi-country study, He et al. (2013) found evidence suggesting that the COC is negatively linked with carbon disclosure. More recently, Bui et al. (2020) provide evidence that corporate carbon disclosure helps reduce the premium required by investors to compensate for poor carbon performance. Other studies, however, argue that high-GHG companies are associated with a higher COC. For example, Maaloul (2018) indicate that GHG emissions increase firms' COC among a selected sample of Canadian companies. Similarly, Kumar and Firoz (2018) suggest that carbon emissions are positively and significantly associated with the cost of debt in India. These mixed results of examining the effect of GHG emissions on COC in various settings around the world motivated our objective to consider a U-shaped relation between GHG disclosure and COC in the UK suggesting a negative association at low-GHG emissions and a positive one at high-GHG emissions. Based on a TDC theoretical framework and the results of previous studies of a similar nature, we hypothesise the following:

H1: The relationship between GHG disclosures and the cost of equity capital in the UK is a U-shaped relationship indicating a negative marginal relationship at low levels of GHG disclosure and a positive marginal relationship at high levels of GHG disclosure.

Prior studies (e.g., Kölbel et al., 2017; Downar et al., 2019; Hombach and Sellhorn, 2019) state that regulatory risks are associated with future changes in environmental regulations that may incrementally internalize the cost of GHG emissions through taxes and trading schemes are expected to affect the association between GHG reporting and firms' cost of capital. Specifically, Albarrak et al. (2019) indicate that regulators are increasingly obliging firms to disclose their GHG information worldwide. In the UK, for example, the government enacted the CDR of 2013 that mandatorily requires all listed companies and other public organisations to disclose information about their GHG emissions (Secretary of State, 2013). Surprisingly, nevertheless, examining whether enacting CDRs can mirror a decline in GHG emissions and result in a lower COC, simultaneously, is very rare. Our study, therefore, examines the following hypothesis:

H2: The UK carbons disclosure regulations (CDR) of 2013 has a moderating effect on the association between GHG emissions disclosure and the cost of capital.

4. **Data and Methodology**

4.1. Sample and Data

To test our hypotheses, we use unbalanced panel data for the FTSE 350 index. The full list of FTSE 350 companies was retrieved from the Bloomberg database for the 31st of December of each year from 2011 to 2016. The choice of the post-crisis period is made to minimize the confounding effects caused by the 2008 financial meltdown. We chose FTSE 350 as the largest listed firms by market capitalisation on the London Stock Exchange (LSE) (Gerged et al., 2020).

All relevant data required for measuring the dependent and control variables were retrieved from the Bloomberg database. To rule out survivorship bias, all firms with available data were included in our sample. After dropping observations of missing data, we were left with 1832 firm-year observations from 406 firms as a final sample from 2012 to 2016. The most notable elimination occurred in the financial sector of approximately 281 firm-year observations that are mostly investment trusts with no publicly available data. **Error! Reference source not found.** details the sample distribution by industry type and year.

INSERT TABLE 2 HERE

4.2. Measuring GHG Disclosure

Table 3 defines our research variables, operationally. Following previous studies (e.g., Li et al., 2017; Albarrak et al., 2019; Bui et al., 2020) this empirical work uses the total Greenhouse Gases (GHG), Total Greenhouse Gas (GHG) Emissions of the company, in thousands of metric tons. Greenhouse Gases are defined as those gases which contribute to the trapping of heat in the Earth's atmosphere, and they include Carbon Dioxide (CO2), Methane, and Nitrous Oxide (Bui et al., 2020). Total GHG Emissions, as defined in this field, equals the total of company Scope 1 and Scope 2 emissions. It does not include Scope 3 emissions (Trinks et al., 2017). Definition of Scope 3 emissions remains subject to much interpretation, and therefore there is significant variability in the company reported data - this could cause undue variation in company Total GHG emissions figure. Emissions reported as CO2 only will NOT be captured in this field. Emissions reported as generic GHG emissions of CO2 equivalents (CO2e) will be captured in this field. The field is part of the Environmental, Social and Governance (ESG) group of fields (Lemma et al., 2018). To make our variables homogeneous, we converted the GHG in natural logarithm (Ln

(GHG)). In order to capture the non-linear relationship, we include the GHG squared as a variable in our model (GHG^2). (*See* Table 3).

INSERT TABLE 3 HERE

4.3. Measuring the Cost of Equity Capital

The cost of equity capital is defined as the minimum rate of return required by equity investors. Since there is no directly precise and observable measure, it is rather estimated based on analysts' forecasts; which is referred to as the implied cost of equity capital (Botosan, 2006). The implied approach is useful in capturing variation in expected returns and, therefore, presents a better alternative to measuring the cost of equity capital (Pástor et al., 2008). The literature has proposed various measures of the implied cost of equity capital. We mainly use Easton (2004)'s price-earnings growth model (PEG) model for this study. The PEG model is widely used in academic research due to its simple application along with the questioned applicability of traditional capital assets pricing model (CAPM) in a disclosure-cost of equity capital test (Botosan, 2006). The PEG model is estimated as follows:

$$PEG = \sqrt{[(EPS2 - EPS1) \div P0]} \ldots\ldots\ldots\ldots\ldots \text{(1)}$$

Where PEG is the implied cost of equity capital, EPS2 is the analysts' consensus of the two-year forward EPS, EPS1 is the analysts' consensus of the one-year forward EPS, and P0 is the firms' share price at the end of the financial year.

However, a mathematical limitation of PEG model is that EPS2 must be greater than EPS1; which is not always the case for all firms. Thus, the MPEG model is used as an alternative measure to check for robustness. Moreover, due to potential bias and measurement errors in the implied estimations of the cost of equity capital (Easton and Monahan, 2005, Blanco et al., 2015), we use the average of the closing bid-ask spread and the volatility of stock returns as alternative measures for extra robustness check (Botosan, 2006; Jacobs and Shivdasani, 2012). (*See* Table 3).

4.4. Control variables

Following prior GHGD-to-COC studies (e.g., Maaloul, 2018; Albarrak et al., 2019; Kumar and Firoz, 2018; Lemma et al., 2018; Raimo et al., 2020; Bui et al., 2020), we included a number of control variables. We control for the disclosure score of environmental, social, and governance practices (ESGScr)[4] given the empirical evidence of its association with the cost of equity capital (Richardson and Welker, 2001, Plumlee et al., 2015, Plumlee et al., 2009). We also control for the market systematic risk (*Beta*), the natural logarithm of the total assets representing the firm size (log*Size*)[5], and firm growth-related risk Book-to-Market ratio (*B2M*) following (Botosan and Plumlee, 2002, Botosan and Plumlee, 2013). Additionally, the financial leverage measured by the total debt to total assets (*Leverage*) and the firm profitability (*ROA*) are controlled for following (Gebhardt et al., 2001; Salem et al., 2020). A binary variable (*High_analyst*) representing high analyst coverage is used to control for the quality of the informational environment (Botosan and Plumlee, 2005, Gode and Mohanram, 2001, Botosan et al., 2011). Analyst coverage represents the number of total analyst forecasts of earnings per share obtained for a given firm from all of its following analysts. The binary control (*High_analyst*) takes the value of 1 for firms who have analyst-following equal or higher than the median observation and 0 otherwise. (*See* Table 3).

The forecasted long-term growth rate of earnings (*Growth)* is added to control for analyst expectations of future growth prospects following (Botosan and Plumlee, 2013, Easton, 2009, Easton and Monahan, 2005, Gebhardt et al., 2001). A binary *R&D* variable is included to control for the level of information asymmetry surrounding heavily explorative-oriented firms (Aboody and Lev, 2000; Dhaliwal et al., 2011). The R&D binary control is 1 for firms who report R&D expenditure and 0 otherwise. We control for proprietary costs as captured by the Herfindahl-Hirschman index (*HH.Index*). The *HH index* is the sum of squared market shares which is derived by squaring the relative of the firm's sales value to the sum of sales for all firms in the same industry for a given year. The index is estimated based on the ten ICB industry classifications. High (low) values of the HH index indicate weaker (stronger) industry competition (Rhoades, 1993). Finally, a binary control for new financing (*New_financing*) is added to take the value one if the firm issued new long-term debt or common stocks and 0 otherwise (Dhaliwal et al., 2011). Firms planning to issue for external financing are better motivated to enhance their disclosures in order to reap the potential benefits of lowering the cost of capital. (*See* Table 3).

[4] The ESG disclosure score is readily available and directly drawn from the Bloomberg database. The ESGScr is a weighted percentage score of three percentage sub-scores, namely environmental disclosure score, social disclosure score, and governance disclosure score.

[5] Due to issues of high collinearity with all disclosure measures, the natural logarithm of total assets is used as a proxy for size instead of market capitalization.

5. Empirical findings and econometric strategy

5.1. Univariate analysis

Table 4 presents a descriptive analysis of our variables. Specifically, COC as mainly measured by the PEG scored a mean value of 0.10 with a median of 0.08 and a standard deviation of 0.05. These figures are consistent with those of Lemma et al. (2018) that indicates a 0.095 mean and a 0.09 median for the COC in South Africa. Nevertheless, COC proxied by av. Bid-ask spread% has recorded a 0.26 mean, a 0.20 median and a 0.19 standard deviation. These results are in line with the findings of Li et al. (2017) that report a mean value of 0.20 for COC in China. Regarding the Total GHG in thousands of tones, our results recorded a mean of 2810.40, a median of 81.23 and a standard deviation of 10622.35. Our findings are aligned with those of Broadstock et al. (2018) that recorded a mean value of 2637 and a standard deviation of 9814.67 for GHG emissions in the UK.

INSERT TABLE 4 HERE

5.2. Bivariate analysis

Table 5 presents the matrix of correlations for the primary research variables in order to test the multicollinearity assumptions. It shows the coefficients of correlation. The nature of coefficients suggests that any residual non-normally distributed data in the research variables may be mild, which are similarly comparable to those indicated by previous studies (e.g., Albarrak et al., 2019; Raimo et al., 2020; Bui et al., 2020; Alsaifi et al., 2020). Our correlation findings, therefore, are suggestive of no major impact of multicollinearity issues on the rigour and reliability of the findings of regression analysis.

INSERT TABLE 5 HERE

5.3. Econometrics strategy

To examine the effect of GHG reporting on the cost of equity capital, we estimate the following models using Panel Quantile Regression (PQR). The first model estimates the non-linear relationship between GHG and cost of capita without the moderating effect of regulation as follows in the equation (2):

$$COC_{i.t} = \beta_0 + \beta_1 Ln(GHG)_{i.t} + \beta_2 GHG_{i.t}{}^2 + \beta_3 CDR_{i.t} + \beta_4 Control\ Variables_{i.t} + \varepsilon_{i.t} \qquad (2)$$

Then, the second model re-estimates this relationship in the presence of a moderation effect between regulation and GHG variables as it is formulated in equation (3) as follows:

$$COC_{i.t} = \beta_5 + \beta_6 Ln(GHG)_{i.t} + \beta_7 GHG_{i.t}{}^2 + \beta_8 CDR_{i.t} + \beta_9 GHG * Regulation_{i.t} + \beta_{10} Control\ Variables_{i.t} + \varepsilon_{i.t} \qquad (3)$$

Where COC is the proxy of the cost of capital for firm i at time t, this paper adopts two different measurements of the COC; namely, PEG, which is the price-earnings growth estimates of the cost of equity capital of firm (*i*) in the year (*t*). Also, we use closing bid-ask spread and the volatility of stock returns as alternative measures for the COC. GHG refers to the total Greenhouse gases, and GHG^2 is the square of the GHGH. CDR is the 2013 carbon disclosure regulation that mandates the disclosure of GHG emission information by listed firms on the London Stock Exchange.

Most of past empirical studies applied the Ordinary Least Squares (OLS) estimators (e.g., Maaloul, 2018; Albarrak et al., 2019; Li et al., 2015; Kumar and Firoz, 2018). For example, OLS (Pooled), Generalized Method of Moments (GMM) and Instrumental Variables (IV). One of the key assumptions of the OLS method is Normality. Normality assumes that the errors have normal distribution conditional on the regressors (Hayashi, 2002; Wooldrige, 2010)

$$\varepsilon \mid X \sim \mathcal{N}(0, \sigma^2 I_n). \qquad (3)$$

In other words, conventional linear regression methods summarize the average association between a set of independent variables and the dependent variable based on the conditional mean function $E(y|x)$. This process offers a limited view (partial) of the relationship. Therefore, the above-mentioned estimators are inefficient if one might be interested in examining the relationship at different points in the conditional distribution of the dependent variable. To do so, Koenker and Bassett (1978) introduced the Quantile Regression (QR). Mathematically speaking, quantile regression predicts the conditional median (or other quantiles) of the outcome variable (Y). Median regression is more robust to outliers than least squares regression and is semiparametric as it avoids assumptions about the parametric distribution of the error process. (Cobb-Clark et.al, 2016; Baum, 2013).

Recently, there has been significant attention paid towards combining quantile estimation with panel data. In the traditional panel regression, panel data allow for the inclusion of fixed-effects to capture heterogeneity among groups. Several quantile panel data regressions use an analogous method and include additive fixed-effects. However, the additive fixed-effects change the underlying model (Boumparis et al., 2017). Canay (2011) was the first study that introduced the quantile regression in panel data. This method uses an analogous method and includes additive fixed-effects. Previous studies that apply the quantile egression concerning fixed-effects are mainly concerned with the difficulties in estimating a large number of fixed-effects in a quantile framework and considering incidental parameters problems when T is small (Powell, 2016).

To overcome this issue, Powell (2016) developed a new quantile regression for panel data (QRPD). The key advantage of Powell (2016) regression relative to the current quantile methods with additive fixed-effects (αi) is that it provides estimates of the distribution of $COCit$ given Dit instead of $COCit - \alpha i$ given Dit. Powell's (2016) method offers point estimates which can be interpreted in the same way as the ones coming from cross-sectional regression. It is also consistent for small T. The underlying model is:

$$Ln(COC)_{i,t} = \sum_{j=1}^{15} D'_{i,t}\,\beta_j \quad (U^*_{i,t}) \tag{4}$$

where COC_{it} is the cost of capital for each firm i at time t , β_j is the parameter of interest, D_{it} is the set of independent variables and $U^*_{i,t}$ is the error term that may be a function of several disturbance terms, some fixed and some time-varying.

The model is linear in parameters and is strictly increasing in $D_{i,t}\beta(\tau)$. Generally, for the quantile of τ^{th} quantile regression depends on the conditional restriction:

$$P(Ln(COC)_{i,t}) \leq D_{i,t}\beta(\tau)|D_{i,t} = \tau \tag{5}$$

Equation (5) indicates that the probability of the dependent variable is smaller than the quantile function is the same for all Dit and equal toτ. Powell's (2016) QRPD estimator allows this probability to vary by individual and even within-individual as long as such variation is orthogonal to the instruments. Thus, QRPD relies on a conditional restriction and an unconditional restriction, letting: $Di = (Di, \ldots., DiT)$.

$$P(Ln(Ln(COC)_{i,t}) \leq D_{i,t}\beta(\tau)|D_{i,t} = P(Ln(COC) \leq D_{is}\beta(\tau)|D_{it},$$

$$P(Ln(COC)_{i,t}) \leq D_{i,t}\beta(\tau)|D_{i,t} = \tau \tag{6}$$

As it is mentioned above, the main purpose of this paper is to estimate two models; equation 1 and 2. Moreover, this study attempts to identify (calculate) the turning-point. We argue that in the early stages an increase in the GHG leads to the low cost of capital up to a certain level of GHG (known as the **turning point**) and then COC increases as the GHG emissions increase. Based on the first scenario (first stage), the cost of capital increases the investments in the environmentally-sensitive industries. While the intervention of government via imposing the regulations improves the quality of the environment (second scenario). To calculate these turning points, we take the first derivative of variable COC subject to the GHG as follows;

From equation (1), we have:

$$\frac{\partial COC}{\partial GHG} = 0; \qquad \beta_1 + 2\beta_2 GHG = 0; \tag{7}$$

$$GHG^{*} = -\frac{\beta_1}{2\beta_2} \tag{8}$$

From equation (2), we have:

$$\frac{\partial COC}{\partial GHG} = 0; \qquad \beta_6 + 2\beta_7 GHG + \beta_9 CDR = 0; \tag{9}$$

$$GHG^{**} = -\frac{(\beta_6 + \beta_9\, CDR)}{2\beta_7} \tag{10}$$

$GHG1^{**} = -\frac{(\beta_6+\beta_9)}{2\beta_7}$ when the regulation imposed (regulation =1) (10.1)

$GHG2^{**} = -\frac{\beta_6}{2\beta_7}$ when the regulation is not imposed (regulation =0) (10.2)

Where GHG^{*} and GHG^{**} are the minimum level of Greenhouse gases that will promote environmental quality via increasing the cost of capital and β's are the estimated parameters.

5.4. Empirical findings

Table 6 presents the regression findings of examining the GHGD-COC nexus based on Powell (2016) quantile with non-additive fixed-effects. Our findings refer to a significant negative association between GHG disclosure and COC as proxied by PEG from quantile 0.10 to quantile 0.95. This means that at the initial stages, any increases in GHG disclosure seemed to result in reductions in the COC among the selected sample of FTSE 350 at different levels of quantile from 0.10 to 0.95. This means that H1 has been statistically accepted. This result is in line with those of previous studies that suggest a negative relationship between GHG disclosure and COC in various settings around the world. For example, Albarrak et al. (2019) found evidence suggest that GHG emission disclosure is significantly and negatively associated with COC in the US. Likewise, in their study that was undertaken in the South African context, Lemma et al. (2018) provided evidence that carbon disclosure is associated with lower COC. This suggests that firms could exploit the virtues of carbon disclosure to reduce their overall cost of capital.

INSERT TABLE 6 HERE

From the perspective of the targeted disclosure cycle (TDC) theory, we argue that the 2013 carbon disclosure regulation (CDR) may impose market-value-related penalties for high emitters in the UK (Griffin et al., 2017). These market value-penalties can reinforce managers' efforts to reduce GHG emissions because a change in a firm's market value is deemed as an essential determinant of managers' compensation (DEFRA, 2010); thus, managers seemed to be aware of stakeholders' actions and responses to high GHG emissions and may support emission abatement efforts and increase their GHG disclosure levels in order to reduce their companies' COC (Hombach and Sellhorn, 2019). This theoretically interprets the negative association between GHGD and COC that is evidenced in our study.

To achieve the second objective in our study, we examine the possible moderating effect of the CDR of 2013 on the GHGD-COC nexus. Table 7 presents the regression findings of examining the GHGD-COC nexus based on Powell (2016) quantile with the interaction term (GHG*CDR). We found empirical evidence supports that CDR has a moderating effect on the relationship between GHGD and COC as measured by PEG at the different levels of quantiles from 0.10 to 0.95. This means that after implementing the CDR of 2013 that mandatorily requires listed firms to disclose their GHG emissions information, the notion that high-GHGD is negatively associated with the COC in the UK to a certain level is statistically confirmed at a greater level of statistical significance (1%) than the one that is evidenced in Table 6 (without the interaction term). This gives statistical credibility to our second hypothesis (H2).

INSERT TABLE 7 HERE

INSERT TABLE 8 HERE

In an effort to achieve the third objective of our study, we calculate the turning-point at which GHGD becomes positively attributed to the COC (See Table 8 for more details about how the turning point has been mathematically calculated). Table 7 shows that the turning point at which firms pay attention to GHG emissions before the regulation is 1.711k tones while after the regulation enacted, the turning point became 1.38k tones at quantile 0.10, indicating an increased awareness of environmental performance and disclosure among stakeholders in the UK. Such responsible behaviour is evident across all quantiles of the sample from 0.10 to 0.95. This implies that in the early stages any increases in the level of GHG disclosure lead to a lower cost of capital up to a certain level known as the turning point and then COC increases as the GHG emissions increase. While the governmental intervention through imposing the 2013 CDR seemed to improve the quality of GHG disclosure, this might result after the truing point in increases in the

COC. Figure 2 shows a scatter plot between the cost of capital and GHG emissions that denotes the potential of a U-shape relationship between GHGD and COC.

INSERT FIGURE 2 HERE

Theoretically, TDC theory states that regulatory risks are associated with future changes in environmental regulations that in turn may incrementally internalize the cost of GHG emissions through taxes and trading schemes, which is expected after a certain level of disclosure to increase firms' cost of capital (Downar et al., 2019). Likewise, stakeholders may act on climate change, such as boycotts, which can affect high-GHG firms by increasing their financial risk and the probability of sanctions (Hombach and Sellhorn, 2019; Kölbel et al., 2017). Previous empirical evidence indicated that investors among other stakeholders appeared to consider environmental risks in their investment-related decisions after a particular level of GHG disclosure as suggested by a positive relationship between environmental hazards and COC (Sharfman and Fernando, 2008; Erion, 2009).

Remarkably, nevertheless, not the main focus of our study, the control variables have heterogeneously influenced COC proxies (i.e., PEG and Av.Bid-Ask spread) – noticeably the 2013 CDR is negatively associated with COC, indicating a positive role of government intervention by mandating the disclosure of GHG information in reducing the COC for complied corporations. Likewise, other controls such as leverage (DOA), profitability (ROA), firm size (Ln total assets) and analyst coverage (Ln analyst) are negatively linked to COC in the UK at the different levels of quantile from 0.10 to 0.95. In contrast, ESG is only negatively attributed to COC as measured by PEG at 0.10 and 0.20 quantiles, while it is negatively associated with the Av.Bid-Ask spread proxy of COC at quantiles from 0.10 to 0.95. This is consistent with Raimo et al. (2020) that indicates that increasing levels of ESG score seemed to be leading to better access to financial resources for corporations.

5.5. Additional Analysis

To check the robustness of our findings to different COC measures, we use an alternative proxy for the COC, namely Average of closing bid-ask percentages (See Table 3 for more information about the measurement of Av. Bid-Ask Spread%). We use Powell (2016) non-linear PQR model to conduct these additional tests. Table 9 shows the regression findings of examining the GHGD-COC nexus based on Av.Bid-Ask spread as a proxy for COC. Our findings suggest a significant negative impact of GHG disclosure on COC proxied by Av.Bid-Ask spread from quantile 0.10 to quantile 0.95. This indicates that at the initial stages, any increases in GHG disclosure seemed to lead to lowering the COC among the selected sample of FTSE 350. This is consistent with the results of using the PEG as a proxy for the COC in Table 6. This outcome means that our main findings are robust to alternative COC measures.

INSERT TABLE 9 HERE

Furthermore, Table 10 presents the results of examining the potential moderating effect of the carbon disclosure regulation (CDR) of 2013 on the association between GHG and the COC as proxied by the Av.Bid-Ask spread. Using Powell (2016) quantile model with the interaction term (GHG*CDR), we found evidence indicating that CDR can play as a moderator in the relationship between GHGD and COC as measured by Av.Bid-Ask spread at the different levels of quantiles from 0.10 to 0.95. In line with our earlier results, Table 10 shows that the turning point at which firms pay attention to GHG emissions before the regulation is 54.60 tonnes, while after the regulation enacted, the turning point became 33.12 tonnes at quantile 0.10, suggesting an increasing level of stakeholders' awareness of environmental performance and disclosure in the UK. Such responsible behaviour is evident across all quantiles of the sample from 0.10 to 0.95. This means that our findings are not biased to using alternative proxies for the COC.

Using the main proxy for COC (i.e., PEG), we employ a 2-step GMM estimator as a robustness check to ensure that the primary results of estimating a non-linear PQR model are not severely influenced by the probable occurrence of endogeneity issues. First, we use the Durbin and Wu–Hausman tests to identify the likely incidence of endogeneity problems of individual regressors (Blundell and Bond, 1998). From a theoretical perspective, the independent variable (i.e., GHG disclosure) must not be associated with the error term (residuals), and the Durbin and Wu–Hausman tests can decide whether the residuals are linked with the independent variable (COC as measured by the PEG) (Ullah et al., 2018). The results of conducting Durbin test and Wu–Hausman test indicate that GHG emission disclosure is endogenous rather than exogenous (See Table 12). Therefore, the main results presented in Tables 6 and 7 might be biased, and the endogeneity issue seemed to be a real concern in the findings of carrying out the non-linear PQR models. Our study, therefore, applies a 2-step dynamic generalised method of moment (GMM) regression models to overcome the endogeneity concerns.

Drawing on previous studies (e.g., Gerged, 2020; Gerged et al., 2020; Ullah et al., 2018; Moumen et al., 2015; Reguera-Alvarado et al., 2016; Roberts & Whited, 2011, among others), we use a two-step dynamic GMM regression model as an additional check to address the endogeneity concerns arising from reverse causality association between GHG and COC. Fundamentally, we incorporate the lagged versions of past GHG to make a distinction between a '*static*' and a '*dynamic*' panel data model. We estimate two GMM models, the first is without the interaction term (GHG*CDR), and the other is with it. This comes in an attempt to measure the moderating impact of the 2013 environmental regulation (CDR) on the GHG-COC nexus in the UK. The two-step system GMM models can be specified as follows:

$$COC_{it} = \alpha_0 + \beta_1 \, COC\_PEG_{it-1} + \beta_2 \, COC\_PEG_{it-2} + \beta_3 GHG_{it} + \beta_3 \, CDR_{it} + \sum_{i=1}^{n} \beta_i \, CONTROLS_{it} + \mu_{it} + \varepsilon_{it} \tag{11}$$

$$COC_{it} = \alpha_0 + \beta_1 \, COC\_PEG_{it-1} + \beta_2 \, COC\_PEG_{it-2} + \beta_3 GHG_{it} + \beta_3 \, CDR_{it} + \beta_4 \, GHG * CDR_{it} + \sum_{i=1}^{n} \beta_i \, CONTROLS_{it} + \mu_{it} + \varepsilon_{it} \tag{12}$$

The variables are operationally defined in Table 3. In Equation 11, for example, COC_PEG_{it-1} represents one-year lag of the dependent variable COC proxied by the PEG (previous year's COC), and COC_PEG_{it-2} indicates a second lag of the COC as measured by the PEG, which indicates EDI two years previously. These lagged versions of the dependent variable are regarded as explanatory variables in this 2-step system GMM model. Roodman (2009, p.86) states that 'by using lags of the dependent variable (i.e., COC in our study), the dynamic GMM method controls for endogeneity by transforming the data internally where COC's past value is subtracted from its current value'. In doing so, we reduce the number of observations, and the procedure of internal transformation can improve the efficacy of the 2-step system GMM estimation (Wooldridge, 2016).

In Table 12, we conducted two main post-estimation tests, namely the Sargan test and the Arellano-Bond tests in order to determine the validity of the 2-step GMM model and whether our instruments (i.e., lags of COC in Equation 11 and 13) are appropriately specified or not. Ullah et al. (2018) suggest that a key validity assumption of the 2-step GMM estimation is that instruments (the lagged versions of COC) are exogenous. If the results of the pre-estimation tests appear to be non-significant, this implies that the employed instruments in the dynamic GMM process are exogenous; and subsequently, these instruments are valid. Generally, the 2-step system GMM model turns out to be a proper method to tackle the excepted presence of endogeneity problem in our study as the results of conducting the above-mentioned tests are non-significant (See Table 12).

INSERT TABLE 11 HERE

INSERT TABLE 12 HERE

Models 1 and 2 in Table 11 present the results of carrying out the 2-step system GMM models with and without the interaction term (GHG*CDR), respectively. Crucially, GHG disclosure still seems to be negatively associated with the COC (proxied with the PEG) in the UK at 5% level of significance, although this relationship is much stronger after considering the interaction term (GHG*CCDR) at 1% level of significance. This means that the CDR of 2013 that mandatorily requires UK listed companies to report their GHG emission information has a moderating effect on the GHG-COC nexus in the UK. This suggests that the primary results in our study are not severely influenced by the incidence of endogeneity issues.

6. Conclusion

This study aims at determining the impact of GHG disclosure on COC in a developed setting, namely the UK. Also, we examine the potential moderating effect of the 2013 CDR that mandatorily requires firms to disseminate their GHG emission information on the GHG-COC nexus in the UK from 2011 to 2016. By doing so, we respond to the recent calls (e.g., Albarrak et al., 2019; Raimo et al., 2020; Bui et al., 2020; Alsaifi et al., 2020) to assess the effectiveness of CDR in pushing firms towards more engagement in GHGD and how can CDR moderate the GHGD-CoC nexus. In addition, we attempt to calculate the turning-point of the GHGD-COC nexus. Specifically, we argue that in the early stages the increases in the levels of GHGD are expected to lead to a low COC up to a certain level of GHGD (known as the turning point), and then COC increases as the GHGD increase.

Using a comprehensive dataset, and applying a non-linear PQR model, our findings suggest that high-GHGD is negatively associated with COC in the UK up to a certain level known as the turning point; then, any increase in GHGD is likely to increase the COC. Likewise, our findings are indicative of a moderating effect of the 2013 CDR on the GHGD-COC nexus. This implies that government decision to force the mandatory disseminating of GHG emission information appeared to lead to enhancing firms' opportunities to gain access to financial resources up to the level of turning point where any increase in GHGD levels is likely to result in increasing the COC.

Overall, our non-linear PQR models are robust to various endogeneity problems and alternative GHGD and COC proxies.

Our findings are consistent with those of prior studies that report a negative association between GHG disclosure and COC in different settings around the world. For instance, Albarrak et al. (2019) found evidence suggest that GHG emission disclosure is negatively linked with COC in the US context. Similarly, Lemma et al. (2018) provided evidence suggests that GHG disclosure is attributed to lower COC in South Africa. Theoretically, the targeted disclosure cycle (TDC) theory suggests that the CDR of 2013 may impose market-value-related penalties for high emitters in the UK that in turn can push managers towards reducing their companies' GHG emissions because a change in a firm's market value is expected to affect managers' compensation. As a result of stakeholders expected responses to high GHG emissions, managers might, therefore, support emission abatement efforts and increase their GHG disclosure levels in order to reduce their companies' COC.

Our results also indicate that the turning point at which firms pay attention to GHG emissions before the regulation is 1.711k tones while after the regulation enacted, the turning point became 1.38k tones at quantile 0.10, indicating an increased awareness of environmental performance and disclosure among stakeholders in the UK. Such responsible behaviour is evident across all quantiles of the sample from 0.10 to 0.95. This implies that in the early stages any increases in the level of GHG disclosure lead to a lower cost of capital up to a certain level known as the turning point and then COC increases as the GHG gas increase. While the governmental intervention through imposing the 2013 regulation seemed to improve the quality of the environment and environmental disclosure, this might result after the truing point to increases in the COC. Previous empirical evidence indicated that stakeholders appeared to consider environmental risks in their investment-related decisions after the turning point, suggesting a positive relationship between the increasing levels of GHG emissions and COC (Sharfman and Fernando, 2008; Erion, 2009).

Our findings encourage companies to be more transparent in reporting their GHG emissions-related information. Nevertheless, from a social perspective, these findings are only optimistic if mandatory GHG disclosure mirrors GHG performance. That is, companies that have the best quality of GHG disclosure are also those that are expected to have the lowest GHG risk. Our study indicates that GHG risk and mandatory GHG disclosure are linked so that those companies associated with higher levels of GHG risk tend to be better disclosers on GHG emissions.

Regulators and standards setters should, therefore, design GHG disclosure regulations and standards in a way that is reflective of corporate GHG emissions risk and informative of a clear means to evaluate such risk. This means that high-quality GHG disclosure that is fairly matched with corporate GHG risk and lead to a reduced COC seems to maximise the interests of both corporations and societies simultaneously.

One primary limitation of this study that it does not include examining the effect of GHG risk management and the cost of GHG emissions control on COC that may be of interest to market participants. Further research endeavours could focus on the impact of the cost of GHG emissions control on the COC. Also, further studies can consider the impact of a company's GHG risk management strategy as a mediating or moderating variable in the relationship between mandatory GHG disclosure and COC in the UK.

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Table 1:
A systematic review of previous GHG-to-COC related studies

Authors	Objectives	Context	Methodology	Findings
		Panel A: Previous GHG-to-COC-related studies in developed economies		
Maaloul (2018)	The aim of this paper is to investigate the relation between GHG emissions and the cost of debt and to estimate the cost that lenders are imputing to GHG emissions.	Canada	The study used Bloomberg (2013) calculation method to measure COC and applied the OLS regression model to examine the GHG-COC nexus.	The results of this study indicate that GHG emissions increase firms' COC.
Albarrak et al. (2019)	This study examines whether disseminating carbon information can influence firms' cost of equity (COE).	US	COE is as the average of four COE estimates: (a) Claus and Thomas' model (Claus & Thomas, 2001), RCT; (b) Gebhardt, Lee, and Swaminathan's model (Gebhardt, Lee, & Swaminathan, 2001), RGLS; (c) Ohlson and Juettner-Nauroth's model (Ohlson & Juettner-Nauroth, 2005), ROJ; and (iv) Easton's model (Easton, 2004), RMPEG. OLS regression model has been employed to examine the relationship between carbon disclosure and COE.	This study finds that Carbon disclosure is significantly and negatively associated with COE.
		Panel B: Previous GHG-to-COC-related studies in developing economies		
Li et al. (2017)	This study investigates two mechanisms, namely market liquidity and cost of equity capital, by which the carbon information disclosure of firms can benefit their value creation.	China	The article applied a multivariate regression model to investigate the impact of carbon information disclosure on market liquidity and cost of equity capital and used the reciprocal of price-earnings ratio to measure the COC.	The results show that carbon disclosure have a significant positive impact on enterprise value creation, and cost of equity capital play partially mediating role in it.
Kumar and Firoz (2018)	This paper examines the relationship between carbon emissions and a firm's cost of debt (COD).	India	COD is measured by the ratio of pre-tax interest expenses during the year and the total long-term borrowings at the end of the financial year and is being taken as pre-tax because interest paid on borrowings is tax-deductible. Further, multivariate linear regression is conducted to examine this association.	The study found that carbon emissions are positively and significantly associated with COD.
Lemma et al. (2018)	The study examines the interplay among corporate carbon risk, voluntary disclosure, and cost of capital within the context of South Africa, a "rising power" in the climate policy debate	South Africa	Using a 3SLS regression model, this study examines the carbon disclosure-COC nexus. COC is measured by the capital asset pricing (CAPM) model.	This paper provides evidence that voluntary carbon disclosure is associated with lower COC. This suggests that firms could exploit the virtues of voluntary carbon disclosure to reduce their overall cost of capital.
		Panel C: Previous GHG-to-COC-related studies in a multi-country setting		
He et al. (2013)	This research investigated the interactions among carbon disclosure, carbon performance, and the COC.	International evidence	This study uses the price/earnings to growth (PEG) formula to measure the COC internationally and applies a three-stage least squares (3SLS) regression model to investigate the association between carbon disclosure and COC.	This study found evidence suggesting that the COC is negatively linked with carbon disclosure.
Trinks et al. (2017)	This paper investigates whether firms' GHG intensity of emissions can affect their COC.	International evidence	A panel regression model and a fixed-effects model have been employed to examine the GHG-COC nexus, and this study measures COC by performing the Capital Asset	This study suggests that GHG emissions intensity is positively and significantly linked to COC internationally.

			Pricing Model (CAPM) regressions.	
Bui et al. (2020)	This study examines the collective effect of carbon disclosure and greenhouse gas (GHG) emissions on COC.	International Evidence	COC is operationalised following Easton (2004) model (PEG model), and a two-stage least squares (2SLS) model has been applied to examine this relationship.	This study finds the intensity of GHG emission seemed to be positively associated with COC, although the penalty linked with higher COC is moderated by high carbon disclosure. This research paper provides evidence that corporate carbon disclosure helps reduce the premium required by investors to compensate for poor carbon performance.

Table 2:
Sample selection criteria based on industry type and year

Industry/Year	2011	2012	2013	2014	2015	2016	Total
Basic Materials	34	31	25	22	18	22	152
Consumer Goods	25	26	29	29	29	29	167
Consumer Services	58	58	61	70	71	68	386
Financials	60	65	68	71	77	81	422
Health Care	8	10	12	14	14	15	73
Industrials	62	63	66	65	63	64	383
Oil & Gas	22	19	17	15	11	10	94
Technology	15	15	13	10	8	7	68
Telecommunications	9	8	8	7	6	5	43
Utilities	8	7	7	8	7	7	44
Total	301	302	306	311	304	308	1,832

Table 3:
The operational definition of research variables

Code	Name	Variable Definition	Sources
PEG	Implied cost of equity capital	Easton (2004) model for the implied cost of equity capital. It is derived by square-rooting the ratio of forecast short-term growth in earnings to the current share price.	Easton (2004); Botosan (2006) Pástor et al. (2008)
Av. Bid-Ask Spread %	Average of closing bid-ask percentages	A proxy for liquidity, positively related to information asymmetry. The lower the average of closing bid-ask percentages, the lower the information asymmetry. The Bloomberg-calculated Average Bid-Ask Spread Percentage is "Average of all bid-ask spreads taken as a percentage of the mid-price. The bid/ask points used for the computation correspond to the quotes received for the period indicated by Calc Interval (PX393, CALC_INTERVAL) (default value is five days) ending in the complete trading day prior to the date indicated by End Date Override (PX392, END_DATE_OVERRIDE) (default value is the latest completed trading day). For a trading day to contribute to the calculation, there should be at least ten valid bid/ask spread points on that day. The field returns values only if more than 50% of trading days in the period are eligible to contribute to the calculation. The Calc Interval (PX393, CALC_INTERVAL) override will only support periods from one day (1D) up to 30 days (30D)."	Easton and Monahan (2005); Blanco et al. (2015)
LnGHG		The logarithm of Green House Gases. Total Greenhouse Gas (GHG) Emissions of the company, in thousands of metric tons. Greenhouse Gases are defined as those gases which contribute to the trapping of heat in the Earth's atmosphere, and they include Carbon Dioxide (CO2), Methane, and Nitrous Oxide. Total GHG Emissions, as defined in this field, equals the total of company Scope 1 and Scope 2 emissions. It does not include Scope 3 emissions. Definition of Scope 3 emissions remains subject to much interpretation, and therefore there is significant variability in the company reported data - this could cause undue variation in company Total GHG emissions figure. Emissions reported as CO2 only will NOT be captured in this field. Emissions reported as generic GHG emissions of CO2 equivalents (CO2e) will be captured in this field. The field is part of the Environmental, Social and Governance (ESG) group of fields.	Li et al. (2017); Albarrak et al. (2019); Bui et al. (2020); Trinks et al. (2017)
GHG^2		Square term of Green House Gases	Broadstock et al. (2018)
CDR	Carbon Disclosure Regulation	This variable is called carbon disclosure regulation in our study, which distinguishes our sample based on two periods pre and post the introduction of the 2013 carbon disclosure act. Specifically, this variable scores zero for the period before the implementation of the 2013 carbon disclosure regulation (2011 to 2013) and 1 after this regulation (2013 to 2016).	Secretary of State (2013)
GHG*CDR		The interaction term of carbon disclosure regulation and GHG	
Beta	Historical beta	Raw (historical) beta measures the volatility of the stock price relative to the volatility in the market index. Beta is the percentage change in the price of the stock given a 1% change in the market index. The default setting of the beta calculation is two years of weekly data. Historical beta represents the systematic risk of the firm.	Botosan and Plumlee (2002); Botosan and Plumlee (2013).
B2M	Book-to-market ratio	A proxy for both growth prospects and risk. It is measured as the ratio of the firms' closing book value of equity to the closing market value of equity.	Botosan and Plumlee (2002); Botosan and Plumlee (2013).
Debt2Assets	The ratio of total debt to total assets	A proxy for leverage, measured as the ratio of total debt to total assets.	Gebhardt et al. (2001)
ROA	The ratio of total return to total assets	A proxy for performance, measured as the ratio of return to total assets.	Gebhardt et al. (2001)
R&D.Dummy	R&D information asymmetry	Takes the value 1 if the firm reports R&D expenditure and 0 otherwise.	Aboody and Lev (2000); Dhaliwal et al. (2011)
LGTM_GROWTH	The forecasted long-term growth rate	Received directly from contributing analysts; not calculated by BEst. While different analysts apply different methodologies, the Long-Term Growth Forecast generally represents an expected annual increase in operating earnings per share over the company's next full business cycle. In general, these forecasts refer to a period of three to five years.	Botosan and Plumlee (2013); Easton (2009); Easton and Monahan (2005); Gebhardt et al. (2001).
HH Index	A proxy for proprietary costs via the level of industry competition	The Herfindahl-Hirschman (HH) index is taken as the sum of squared market shares. The market share is calculated by dividing the firm's annual sales value by the sum of sales for all firms in the same industry for a given year.	Rhoades (1993)

ESGScr	Environmental, social and governance disclosure score	The ESG score is a weighted percentage score of three percentage sub-scores, namely environmental, social and governance disclosure scores. "Proprietary Bloomberg score based on the extent of a company's Environmental, Social, and Governance (ESG) disclosure. Companies that are not covered by the ESG group will have no score and will show N/A. Companies that do not disclose anything will also show N/A. The score ranges from 0.1 for companies that disclose a minimum amount of ESG data to 100 for those that disclose every data point collected by Bloomberg. Each data point is weighted in terms of importance, with data such as Greenhouse Gas Emissions carrying greater weight than other disclosures. The score is also tailored to different industry sectors. In this way, each company is only evaluated in terms of the data that is relevant to its industry sector. This score measures the amount of ESG data a company reports publicly and does not measure the company's performance on any data point."	Lemma et al., 2018). (Richardson and Welker, 2001, Plumlee et al., 2015, Plumlee et al., 2009).
LnAnalysts	Analyst coverage	The natural logarithm of the total analyst forecasts of earnings per share obtained for a given firm from all its following analysts.	Botosan and Plumlee (2005); Gode and Mohanram (2001); Botosan et al. (2011)
LnTonAssets		The natural logarithm of the book value of total assets reported by the firm in a given year.	Botosan and Plumlee (2002); Botosan and Plumlee (2013)
New.Financing. Dummy	A binary metric for the issuance of new financings	It would take the value 1 if the firm issued new long-term debt or common stocks and 0 otherwise.	Dhaliwal et al. (2011)

Table 4:
Descriptive Statistics

Stats	N. Of Observations	Mean	Median	ST.DEV	Min	Max
PEG	1688	0.10	0.08	0.05	0.00	0.68
Av. Bid-Ask Spread%	1353	0.26	0.20	0.19	0.02	0.86
TotalGHG in thousands of tones	1356	2810.40	81.23	10622.35	0.07	86000
CDR	1832	0.50	1.00	0.50	0.00	1.00
Beta	1828	0.88	0.83	0.35	0.06	2.36
B2M	1824	0.53	0.41	0.44	-1.14	5.76
Debt2Assets	1832	0.21	0.20	0.18	0.00	1.66
ROA	1824	0.07	0.06	0.14	-0.54	2.35
RDDUMMY	1832	0.31	0.00	0.46	0.00	1.00
LGTM_GROWTH	1409	0.11	0.08	0.26	-3.67	3.03
Competition HH Index	1811	0.55	0.01	2.29	0.00	34.77
ESGScr	1759	0.34	0.32	0.11	0.07	0.69
Ln (Analysts)	1832	13.53	13.00	6.73	0.00	3
Ln (total asset)	1832	32654	2142.91	155982.50	38.54	1923844
newfinancing dummy	1832	0.76	1.00	0.43	0.00	1.00

The research variables are operationally defined in Table 3.

Table 5:
Pairwise correlations

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
(1) PEG	1.000														
(2) Av. Bid-Ask Spread%	0.100*	1.000													
(3) TotalGHGEmissions	0.197*	-0.155*	1.000												
(4) CarbonDisclosur~20	-0.127*	-0.108*	-0.058*	1.000											
(5) Beta	0.215*	-0.262*	0.260*	-0.160*	1.000										
(6) B2M	0.226*	0.013	0.130*	-0.082*	0.216*	1.000									
(7) Debt2Assets	-0.016	-0.056*	0.040	0.070*	-0.032	-0.054*	1.000								
(8) ROA	-0.151*	0.001	-0.076*	-0.010	-0.083*	-0.229*	-0.139*	1.000							
(9) RDDUMMY	-0.094*	-0.037	0.200*	-0.043	-0.013	-0.252*	0.019	0.014	1.000						
(10) LGTM_GROWTH	0.027	-0.034	-0.106*	-0.042	-0.006	-0.045	-0.107*	0.047	-0.041	1.000					
(11) CompetitionHHIndex	-0.016	-0.208*	0.106*	-0.016	0.055*	0.030	-0.007	-0.064*	0.004	-0.035	1.000				
(12) ESGScr	0.009	-0.404*	0.392*	0.052*	0.314*	0.123*	0.141*	-0.099*	0.139*	-0.118*	0.147*	1.000			
(13) Analysts	-0.080*	-0.516*	0.385*	-0.092*	0.332*	-0.017	0.051*	-0.023	0.089*	-0.013	0.178*	0.493*	1.000		
(14) TotAssets	0.058*	-0.202*	0.134*	0.002	0.233*	0.286*	-0.039	-0.089*	-0.071*	0.004	0.107*	0.233*	0.169*	1.000	
(15) newfinancingDummy	-0.145*	-0.140*	0.095*	0.104*	-0.027	-0.070*	0.131*	-0.112*	0.088*	-0.001	0.055*	0.131*	0.133*	0.080*	1.000

* shows significance at the .05 level. The variables of the study are operationally defined in Table 3.

Table 6: the regression findings of examining the GHGD-COC nexus based on Powell (2016) quantile employing PEG as a proxy for COC.

Quantiles	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	0.95
Ln (GHG)	-0.004***	-0.005***	-0.003***	0.000	-0.005***	-0.003***	-0.007*	-0.012***	-0.022***	-0.027***
	(0.000)	(0.000)	(0.000)	(0.001)	(0.001)	(0.001)	(0.004)	(0.001)	(0.000)	(0.000)
GHG^2	0.000***	0.001***	0.000***	0.000	0.001***	0.001***	0.001***	0.002***	0.003***	0.004***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
CDR	0.001	-0.005***	-0.007***	-0.009***	-0.008***	-0.004***	-0.007***	-0.007***	-0.006***	0.001***
	(0.001)	(0.000)	(0.000)	(0.001)	(0.000)	(0.001)	(0.001)	(0.000)	(0.000)	(0.000)
Beta	0.012***	0.006***	0.017***	0.020***	0.020***	0.029***	0.028***	0.025***	0.031***	0.026***
	(0.003)	(0.001)	(0.000)	(0.001)	(0.001)	(0.002)	(0.003)	(0.000)	(0.000)	(0.000)
B2M	-0.008***	-0.009***	0.003***	0.004***	0.009***	0.016***	0.016***	0.025***	0.038***	0.056***
	(0.002)	(0.000)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.000)	(0.000)
Debt to Assets	-0.017***	-0.013***	-0.008***	-0.015***	0.003**	-0.010***	-0.006	0.016***	0.042***	0.032***
	(0.003)	(0.001)	(0.002)	(0.001)	(0.001)	(0.002)	(0.015)	(0.002)	(0.000)	(0.000)
ROA	-0.035***	-0.022***	-0.038***	-0.069***	-0.050***	-0.068***	-0.068**	-0.027***	-0.029***	-0.032***
	(0.004)	(0.001)	(0.001)	(0.004)	(0.003)	(0.008)	(0.027)	(0.004)	(0.001)	(0.000)
R&D Dummy	0.005***	0.002***	0.001	-0.003***	-0.000	-0.000	-0.009***	-0.002**	0.002***	0.001***
	(0.001)	(0.000)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.000)	(0.000)
LGTM_GROWTH	0.013***	0.015***	0.022***	0.032***	0.036***	0.036***	0.032***	0.029***	0.013***	0.016***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.003)	(0.001)	(0.001)	(0.000)
HHI index	-0.000*	-0.000	-0.000	0.002***	0.001***	0.001***	-0.000	0.000***	0.000***	0.001***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
ESG Score	-0.009***	-0.005**	0.009**	0.034***	0.030***	0.027***	0.031***	0.040***	0.027***	-0.013***
	(0.003)	(0.002)	(0.004)	(0.004)	(0.002)	(0.008)	(0.003)	(0.003)	(0.002)	(0.001)
Ln (analyst)	0.001	-0.003***	-0.001***	-0.004***	-0.005***	-0.009***	-0.004***	-0.007***	-0.017***	-0.016***
	(0.001)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.001)	(0.000)	(0.000)
Ln(total asset)	0.000	0.001***	0.000	-0.002***	-0.001**	-0.003***	-0.002***	-0.003***	-0.004***	-0.006***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)
New financing D~y	-0.001	-0.003***	-0.003***	-0.002***	-0.003***	0.002*	-0.000	-0.004***	-0.012***	0.006***
	(0.001)	(0.000)	(0.001)	(0.001)	(0.001)	(0.001)	(0.002)	(0.000)	(0.000)	(0.000)
Obs.	1071	1071	1071	1071	1071	1071	1071	1071	1071	1071
Turning points (GHG* thousands of metric tons)	1.734925	12.182494	57.9476443	122.523973	12.182494	4.4816891	33.115452	20.085537	39.121284	29.224284

Standard errors are in parenthesis *** p<0.01, ** p<0.05, * p<0.1

Table 7: presents the regression findings of examining the GHGD-COC nexus based on Powell (2016) quantile employing PEG as a proxy for COC (with interaction)

Quantiles	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	0.95
Ln (GHG)	-0.005***	-0.003***	-0.003***	-0.002***	-0.002***	-0.009***	-0.012***	-0.018***	-0.038***	-0.030***
	(0.000)	(0.001)	(0.000)	(0.000)	(0.000)	(0.001)	(0.001)	(0.000)	(0.002)	(0.001)
GHG^2	0.000***	0.000***	0.000***	0.000***	0.001***	0.001***	0.001***	0.002***	0.005***	0.004***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
CDR	-0.008***	-0.011***	-0.010***	-0.011***	-0.010***	-0.017***	-0.023***	-0.019***	-0.054***	-0.023***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.003)	(0.003)
GHG*CDR	0.002***	0.001***	0.001***	0.001***	0.001***	0.002***	0.005***	0.005***	0.013***	0.005***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.001)
Beta	0.021***	0.013***	0.018***	0.027***	0.006	0.029***	0.025***	0.028***	0.031***	0.035***
	(0.001)	(0.002)	(0.002)	(0.001)	(0.005)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
B2M	-0.008***	-0.010***	-0.001	0.003***	0.011***	0.014***	0.025***	0.026***	0.048***	0.050***
	(0.001)	(0.001)	(0.001)	(0.000)	(0.001)	(0.001)	(0.001)	(0.001)	(0.005)	(0.001)
Debt to Assets	-0.010***	-0.007***	-0.012***	-0.005***	-0.011***	0.001	-0.001	0.017***	0.003	0.040***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.004)	(0.001)	(0.004)	(0.001)
ROA	-0.022***	-0.029***	-0.047***	-0.063***	-0.048***	-0.076***	-0.062***	-0.031***	-0.010***	-0.024***
	(0.003)	(0.002)	(0.001)	(0.001)	(0.005)	(0.002)	(0.006)	(0.002)	(0.002)	(0.001)
R&D Dummy	0.003***	0.001**	-0.001***	-0.005***	-0.004***	0.003***	-0.003***	0.002***	0.014***	0.007***
	(0.001)	(0.001)	(0.000)	(0.000)	(0.001)	(0.001)	(0.001)	(0.000)	(0.003)	(0.000)
LGTM_GROWTH	0.003***	0.014***	0.023***	0.029***	0.024***	0.031***	0.025***	0.034***	0.017***	0.015***
	(0.001)	(0.001)	(0.000)	(0.001)	(0.003)	(0.001)	(0.002)	(0.001)	(0.001)	(0.002)
HHI index	0.000	0.000*	0.000*	0.000***	-0.001**	0.001***	0.000**	0.001***	-0.000	0.000**
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
ESG Score	-0.002	-0.004	-0.009**	0.007***	0.023***	0.039***	0.048***	0.017***	0.025***	-0.016***
	(0.003)	(0.003)	(0.004)	(0.002)	(0.003)	(0.002)	(0.006)	(0.005)	(0.008)	(0.002)
Ln (analyst)	0.004***	-0.006***	-0.000	-0.002***	-0.007***	-0.008***	-0.005***	-0.007***	-0.019***	-0.018***
	(0.000)	(0.001)	(0.000)	(0.001)	(0.001)	(0.000)	(0.001)	(0.001)	(0.001)	(0.001)
Ln (total asset)	-0.002***	0.002***	0.001**	-0.001***	0.001	-0.003***	-0.004***	-0.003***	-0.002***	-0.006***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
New financing D~y	-0.001	-0.006***	-0.004***	-0.001***	-0.003***	0.001**	0.002	-0.003***	-0.014***	0.002***
	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.001)	(0.004)	(0.000)
Obs.	1071	1071	1071	1071	1071	1071	1071	1071•	1071	1071
Turning points (GHG* thousands of metric tons) (Regulation=1)	1.38030349	14.952759	14.3104478	1.11380474	2.9864694	7.8367447	33.115452	25.79034	12.182494	22.759895
Turning points (GHG* thousands of metric tons) (Regulation=0)	1.71116141	57.820524	54.1352114	1.240561	8.9189998	14.11247	403.42879	90.017131	44.701184	42.521082

Note: The research variables are operationally defined in Table 3. Standard errors are in parenthesis *** p<0.01, ** p<0.05, * p<0.1

Table 8:
The average change (decrease) in turning points of GHG after 2013

PEG CEO	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	0.95
After 2013	1.4	15.0	14.3	1.1	3.0	7.8	33.1	25.8	12.2	22.8
Before 2013	1.7	57.8	54.1	1.2	8.9	14.1	403.4	90.0	44.7	42.5
Diff (After - before)	-0.3	-42.9	-39.8	-0.1	-5.9	-6.3	-370.3	-64.2	-32.5	-19.8
% of diff (Diff/Before *100)	-19.3	-74.1	-73.6	-10.2	-66.5	-44.5	-91.8	-71.3	-72.7	-46.5
Average					**-57.0567 %**					
Av. Bid-Ask Spread	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	0.95
After 2013	33.1	115.6	54.6	244.7	15.6	79.4	33.1	78.0	38.2	15.6
Before 2013	54.6	314.2	90.0	665.1	42.5	168.2	70.1	72.7	78.0	25.8
Diff (After - before)	-21.5	-198.6	-35.4	-420.4	-26.9	-88.7	-37.0	5.4	-39.8	-10.1
% of diff (Diff/Before *100)	-39.3	-63.2	-39.3	-63.2	-63.2	-52.8	-52.8	7.4	-51.0	-39.3
Average					**-45.684535 %**					

Note: All research variables are operationally defined in Table 3.

Table 9: the regression findings of examining the GHGD-COC nexus based on Powell (2016) quantile employing Av. Bid-Ask Spread % as a proxy for COC

Quantiles	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	0.95
LnGHG	-0.010***	-0.019***	-0.018***	-0.011***	-0.013***	-0.017***	-0.031***	-0.057***	-0.058***	-0.040***
	(0.000)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.002)
GHG2	0.001***	0.002***	0.002***	0.002***	0.002***	0.002***	0.004***	0.007***	0.008***	0.006***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
CDR	-0.028***	-0.030***	-0.028***	-0.032***	-0.039***	-0.042***	-0.055***	-0.043***	-0.045***	-0.009*
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.002)	(0.000)	(0.005)
Beta	-0.001	0.009***	0.003***	-0.002***	-0.021***	-0.030***	-0.041***	-0.045***	-0.061***	-0.108***
	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.002)	(0.002)	(0.010)
B2M	0.028***	0.053***	0.045***	0.061***	0.074***	0.099***	0.110***	0.122***	0.102***	0.094***
	(0.000)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.000)	(0.002)
Debt2Assets	0.017***	0.036***	0.022***	0.011***	-0.004***	0.012***	-0.001***	-0.018***	-0.045***	-0.120***
	(0.002)	(0.002)	(0.000)	(0.000)	(0.000)	(0.001)	(0.000)	(0.003)	(0.003)	(0.008)
ROA	-0.147***	-0.084***	-0.117***	-0.098***	-0.102***	-0.129***	-0.154***	-0.156***	-0.246***	-0.303***
	(0.001)	(0.001)	(0.000)	(0.000)	(0.000)	(0.001)	(0.000)	(0.005)	(0.002)	(0.003)
RDDUMMY	0.004***	-0.002***	-0.008***	-0.007***	-0.008***	-0.003***	0.008***	0.018***	-0.002**	0.010***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.001)	(0.002)
LGTM_GROWTH	-0.000	0.013***	-0.001***	-0.028***	-0.039***	-0.046***	-0.042***	-0.043***	-0.069***	-0.074***
	(0.000)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.002)	(0.002)	(0.008)
CompetitionHH~x	-0.003***	-0.001***	-0.002***	-0.002***	-0.001***	-0.002***	-0.002***	-0.003***	-0.006***	-0.005***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
ESGScr	-0.053***	0.005***	-0.002***	-0.036***	-0.058***	-0.071***	-0.089***	-0.242***	-0.455***	-0.347***
	(0.005)	(0.002)	(0.000)	(0.000)	(0.000)	(0.002)	(0.000)	(0.004)	(0.003)	(0.008)
Lnanalyst	-0.030***	-0.042***	-0.048***	-0.064***	-0.074***	-0.089***	-0.114***	-0.118***	-0.157***	-0.108***
	(0.000)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.001)	(0.001)
Lntotalasset	-0.026***	-0.029***	-0.029***	-0.029***	-0.033***	-0.037***	-0.042***	-0.050***	-0.046***	-0.068***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)
newfinancingD~y	0.008***	0.005***	-0.002***	-0.006***	-0.002***	-0.016***	-0.021***	-0.019***	-0.051***	-0.066***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.001)	(0.002)
Obs.	940	940	940	940	940	940	940	940	940	940
Turning points (GHG* thousands of metric tons)	148.4131591	115.58428	90.0171313	15.6426319	25.79034	70.105412	48.182698	58.640675	37.524723	28.031625

Note: Research variables are fully defined in Table 3. Standard errors are in parenthesis *** *p<0.01*, ** *p<0.05*, * *p<0.1*

Table 10: the findings of examining the moderating impact of CDR on the GHGD-COC nexus based on Powell (2016) quantile employing Av. Bid-Ask Spread % as a proxy for COC

Quantiles	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	0.95
LnGHG	-0.016***	-0.023***	-0.018***	-0.013***	-0.015***	-0.041***	-0.034***	-0.060***	-0.061***	-0.039***
	(0.000)	(0.000)	(0.001)	(0.000)	(0.002)	(0.004)	(0.000)	(0.000)	(0.000)	(0.007)
GHG2	0.002***	0.002***	0.002***	0.001***	0.002***	0.004***	0.004***	0.007***	0.007***	0.006***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)
CDR	-0.038***	-0.046***	-0.043***	-0.043***	-0.063***	-0.063***	-0.082***	-0.048***	-0.098***	-0.050***
	(0.000)	(0.000)	(0.001)	(0.000)	(0.003)	(0.002)	(0.000)	(0.001)	(0.001)	(0.007)
GHG*CDR	0.002***	0.004***	0.002***	0.002***	0.004***	0.006***	0.006***	-0.001***	0.010***	0.006***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.001)	(0.000)	(0.000)	(0.000)	(0.001)
Beta	-0.005***	0.002***	0.004***	-0.000	-0.020***	-0.047***	-0.039***	-0.056***	-0.077***	-0.067***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.002)	(0.004)	(0.000)	(0.001)	(0.001)	(0.008)
B2M	0.033***	0.051***	0.047***	0.062***	0.079***	0.107***	0.098***	0.139***	0.098***	0.094***
	(0.000)	(0.000)	(0.001)	(0.000)	(0.003)	(0.002)	(0.000)	(0.000)	(0.001)	(0.001)
Debt2Assets	0.021***	0.033***	0.037***	0.009***	0.008	0.005	-0.003***	-0.039***	-0.076***	-0.159***
	(0.000)	(0.000)	(0.001)	(0.000)	(0.005)	(0.003)	(0.000)	(0.002)	(0.001)	(0.012)
ROA	-0.162***	-0.073***	-0.096***	-0.104***	-0.083***	-0.077***	-0.152***	-0.212***	-0.262***	-0.328***
	(0.001)	(0.000)	(0.001)	(0.000)	(0.008)	(0.009)	(0.000)	(0.002)	(0.001)	(0.005)
RDDUMMY	-0.000	-0.001***	-0.004***	-0.005***	-0.006***	0.019***	0.003***	0.023***	0.003***	-0.004
	(0.000)	(0.000)	(0.001)	(0.000)	(0.002)	(0.005)	(0.000)	(0.000)	(0.001)	(0.007)
LGTM_GROWTH	-0.001***	0.002***	-0.003***	-0.029***	-0.059***	-0.040***	-0.036***	-0.027***	-0.066***	0.035**
	(0.000)	(0.000)	(0.000)	(0.000)	(0.004)	(0.004)	(0.000)	(0.001)	(0.002)	(0.018)
CompetitionHH~x	-0.002***	-0.001***	-0.002***	-0.002***	-0.002***	-0.004***	-0.002***	-0.002***	-0.006***	-0.010***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.000)	(0.000)	(0.000)	(0.001)
ESGScr	-0.013***	-0.001***	-0.022***	-0.033***	-0.063***	-0.164***	-0.105***	-0.139***	-0.340***	-0.476***
	(0.001)	(0.000)	(0.002)	(0.000)	(0.010)	(0.024)	(0.000)	(0.004)	(0.001)	(0.009)
Lnanalyst	-0.025***	-0.043***	-0.049***	-0.065***	-0.083***	-0.089***	-0.117***	-0.127***	-0.143***	-0.152***
	(0.000)	(0.000)	(0.002)	(0.000)	(0.002)	(0.001)	(0.000)	(0.000)	(0.001)	(0.002)
Lntotalasset	-0.028***	-0.028***	-0.028***	-0.029***	-0.032***	-0.032***	-0.039***	-0.052***	-0.050***	-0.053***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.002)	(0.000)	(0.000)	(0.000)	(0.002)
newfinancingD~y	0.001***	0.002***	-0.003***	-0.006***	-0.003*	0.008*	-0.017***	-0.016***	-0.059***	-0.034***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.002)	(0.004)	(0.000)	(0.001)	(0.000)	(0.005)
Obs.	940	940	940	940	940	940	940	940	940	940
Turning points (GHG* thousands of metric tons) (Regulation=1)	33.11545196	115.58428	54.59815	244.691932	15.642632	79.43984	33.115452	78.033862	38.200826	15.642632
Turning points (GHG* thousands of metric tons) (Regulation=0)	54.59815003	314.19066	90.0171313	665.141633	42.521082	168.17414	70.105412	72.654424	78.033862	25.79034

Note: All research variables are operationally defined in Table 3. Standard errors are in parenthesis *** *p<0.01, ** p<0.05, * p<0.1*

Table 11: The findings of examining the GHGD-COC nexus based on a 2-Step GMM model

Models	(1) without interaction	(2) with interaction
Dependent Variable	PEG COE	PEG COE
Ln (GHG)	-0.012**	-0.018***
	(0.006)	(0.006)
GHG2	0.001**	0.002***
	(0.001)	(0.001)
CDR	0.003	-0.018**
	(0.003)	(0.008)
GHG*CDR	-	0.005***
		(0.002)
Beta	0.045***	0.046***
	(0.010)	(0.010)
B2M	0.018	0.019
	(0.014)	(0.014)
Debt2Assets	0.064***	0.066***
	(0.025)	(0.025)
ROA	-0.097***	-0.086***
	(0.030)	(0.030)
RDDUMMY	0.005	0.003
	(0.011)	(0.012)
LGTM_GROWTH	0.012	0.011
	(0.017)	(0.016)
CompetitionHH~x	0.001	0.001
	(0.001)	(0.001)
ESGScr	0.049	0.059
	(0.051)	(0.051)
Lnanalyst	-0.001	0.001
	(0.008)	(0.008)
Lntotalasset	-0.004*	-0.005**
	(0.002)	(0.002)
newfinancingD~y	-0.010	-0.009
	(0.006)	(0.006)
CDR		0.005***
		(0.002)
_cons	0.068**	0.084***
	(0.031)	(0.032)
Obs.	835	835
Arellano-Bond test for AR (1) in first differences (P-value)	0.052	0.035
Arellano-Bond test for AR (2) in first differences (P-value)	0.186	0.159
Sargan test of overid. restrictions:	0.247	0.178
Wald chi2 (p-value)	96.50(0.000)	106.90 (0.000)
Turning points (GHG* thousands of metric tons)	403.42	
Turning points (GHG* thousands of metric tons) (Regulation=1)		9.00
Turning points (GHG* thousands of metric tons) (Regulation=0)		90.01

Note: All research variables are operationally defined in Table 3.

Table 12:
Endogeneity test and Instrumental Variables

Tests of endogeneity Ho: variables are exogenous	
Durbin (score) chi2	1.83383 (p = 0.3997)
Wu-Hausman F(2,818)	.900226 (p = 0.4069)
Tests of overidentifying restrictions	
Sargan (score) chi2	.0648 (p = 0.7991)
Basmann chi2	.063564 (p = 0.8009)

Figure 1: Targeted Disclosure Action Cycle

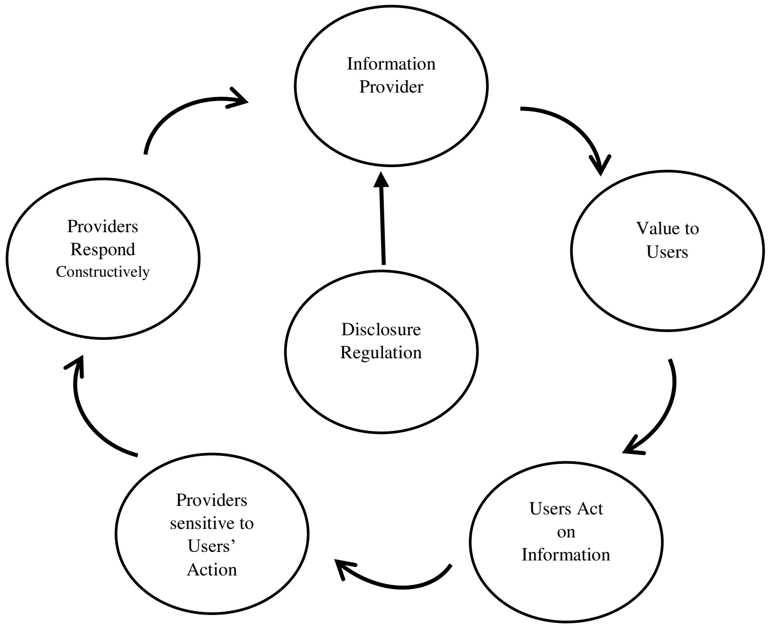
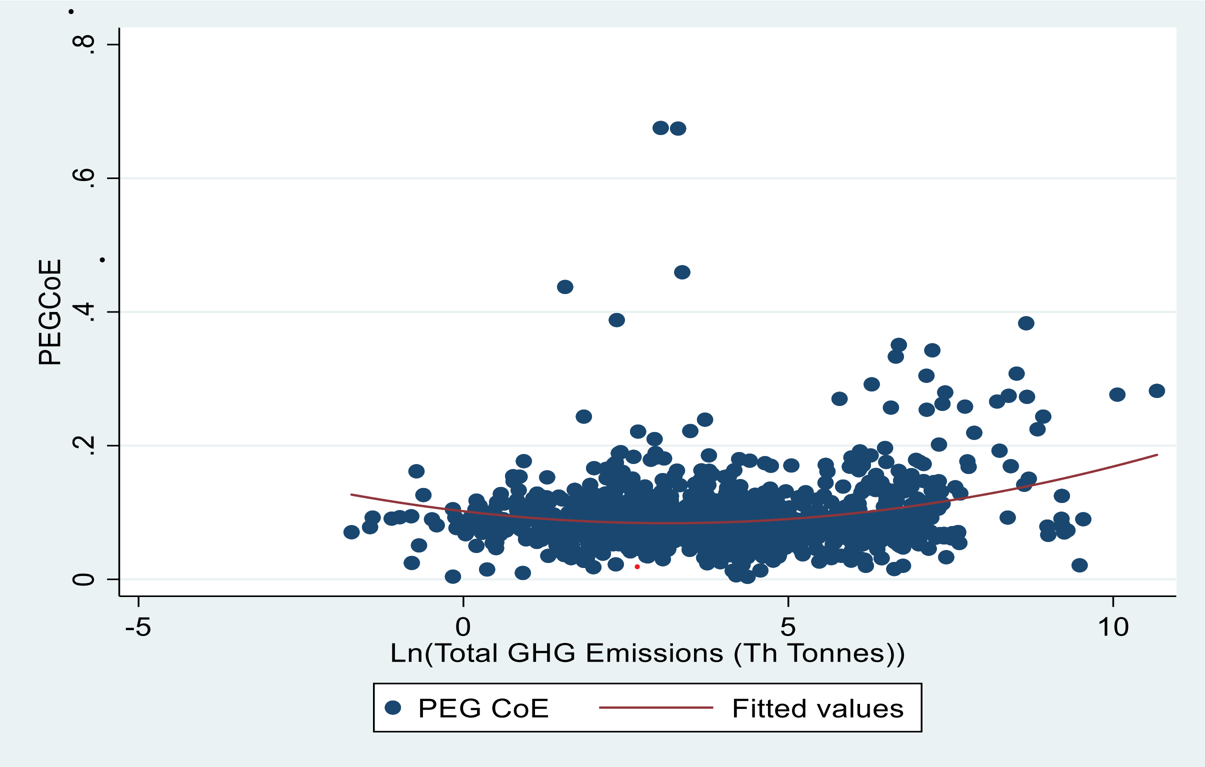


Figure 2: Scatter plot between the cost of capital and GHG emissions: the potential of U-shape relationship



*The cost of capital decrease as the total GHG emissions increase up to a certain level of GHG (the first stage), then the cost of capital increases when the GHG emission rise (the second stage).