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Relationship between Climate Change Risk and Cost of Capital

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ABSTRACT

In recent years, a global consensus has emerged on the importance of climate change risks. Climate change risk is also known to affect investment decision-making processes, such as those related to the issuance of Green Bonds and the use of ESG investment principles. Given this context, we examine whether there is a relationship between the cost of capital and climate change risk, by focusing on companies under the Target Management Scheme in Korea. Companies with high levels of greenhouse gas emissions or energy use are more likely to be exposed to the uncertainty related to future climate change risks. We measure the climate change risks faced by companies using information on greenhouse gas (GHG) emissions and energy consumption of companies that were announced in the Korean GHG Information Center from 2011 to 2015. We use the weighted average cost of capital provided by NICE Credit Information Co. Ltd., as a proxy for cost of capital. We find that companies with higher risk of climate change have higher cost of capital. In addition, we show that there is a significant positive relationship between climate change risks and cost of capital in high climate change risk industries.

Keywords: Climate change risk, Cost of capital, Greenhouse gas, Energy consumption, Target management scheme

1. Introduction

Greenhouse gas (GHG) emissions play a role in raising the Earth's temperatures, by surrounding the Earth while filling up its atmosphere, which causes climate change problems. The dangers of climate change from the emission of GHGs are a threat to the survival of humans. There is a consensus on this, across the world. According to the Global Climate Risk Index 2017¹⁾ by Germanwatch, a non-governmental

organization that publishes annual reports on climate change risk, more than 528,000 people died due to 11,000 meteorological disasters from 1999 to 2015. In the same period, material damage amounted to \$3 trillion. The report concluded that heavy rains, floods, and landslides are the main causes of damage owing to extreme precipitation accelerated hydrological cycles caused by global warming. Climate change risks have been largely harmful to developing countries. However, if global warming continues with increasing GHG emissions or energy use, the damage is likely to expand globally, in the future. While many other methods are being tried to address the dangers of climate change, the most popular one is to reduce

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1) <https://germanwatch.org/en/12978>

GHG emissions, a major source of climate change risk.

Efforts to reduce GHG emissions can be largely divided into two categories. First, there is a way to designate GHG emissions for each company and to impose penalties if they exceed the set emissions. The other is to allocate GHG emissions for each company, allowing free trade in assigned emissions. Accordingly, it aims to reduce emissions voluntarily by treating GHG emissions as cost-induced items.

Korea is using both these methods. The Target Management Scheme (TMS) was introduced in 2010 to achieve voluntary GHG reduction targets. The TMS provides targets to management companies in the form of reduction goals for GHG emissions and fossil fuel consumption, and verifies the performance of such companies' operations. As a result, companies that are designated as management companies comply with the GHG emissions, energy consumption, and emission facilities based on the procedure, manage the emission register through the GHG information center²⁾, and disclose emission information. The emission trading system has been in effect since 2015.

Policy efforts on climate change risks have also changed the Korean business environment. Based on the figures related to Korea's emission trading system, the average transaction price increased from 10,998 won in 2015, the first year of the system, to 20,023 won in 2017. Therefore, the increase in GHG emissions was directly related to the additional cost of the company. In addition, both, the emission trading system and the TMS have a regulation on fines and penalties, which may result in additional costs due to violations of applicable laws and enforcement ordinances, and failure to implement improvement orders³⁾.

The risk of climate change raises the direct cost to the enterprise, and also significantly affects the corporate financing policy and management strategy. The Carbon Disclosure Project (CDP), an environmental group founded in 2000, has collected climate change

risk information for companies from more than 5,500 companies worldwide. The CDP provides investors with information to avoid climate change risks, while at the same time requiring a long-term and short-term management strategy for climate change. The CDP's signatories, financial institutions around the world, incorporate climate change risk information from the CDP into their investment decisions.

Such international consultations on climate change risks, new domestic policies and changes, and requests for disclosure of climate change information are changing the business environment. In past studies, there has been empirical evidence for the relationship between climate change risk, firm value, and cost of capital (Feldman, Soyka, and Ameer, 1997; Garber and Hammitt, 1998; Wagner, Van Phu, Azomahou, and Wehrmeyer, 2002; Sharfman and Fernando, 2008; Busch and Hoffmann, 2011; Chapple, Clarkson, and Gold, 2013; Chava, 2014; Matsumura, Prakash, and Vera Munoz, 2014; Saka and Oshika, 2014; Plumlee, Brown, Hayes, and Marshall, 2015; Kawk and Choi, 2015; QA, Murni, and Agustiningih, 2015; Park and Noh, 2017).

Capital costs also refer to the minimum rate of return required by investors and creditors on the funds that the company has raised for the costs incurred in the procurement and use process. Thus, from the perspective of investors and creditors, a positive event that could increase their return would reduce the company's capital costs by making it easier to finance the company, thereby reducing the costs in the use process. On the contrary, however, negative events are likely to reduce the return on investments and creditors will increase the cost of capital. Thus, if investors and creditors recognize and evaluate the firm's efforts to reduce GHG emissions and reduce energy use associated with the risk of climate change in the course of making an investment decision, the company's capital costs will vary.

We examine the relationship between climate change risk and cost of capital, focusing on TMS companies.

For the purposes of this study, a proxy of companies' overall climate change risk is calculated using GHG

2) Greenhouse Gas Inventory and Research Center
<http://www.gir.go.kr/>

3) <http://open.krx.co.kr/>

emissions and energy use. More specifically, companies are classified into ten groups according to the amount of GHG emissions and energy consumption per unit of sales. Each group is assigned a value from 0 to 9, and then, the average of the two groups is adjusted between 0 and 1. We use weighted average cost of capital (WACC) provided by NICE Credit Information Co. Ltd. as a proxy for capital cost.

We find that companies with higher risk of climate change tend to have higher costs of capital, and thus, they need to actively manage GHG emissions and energy consumption. In addition, we find that there is a significant positive relationship between climate change risks and cost of capital in high climate change risk industrial groups.

This study is the first to analyze the effect of climate change risk on cost of capital in Korea. This is timely in light of the global interest in climate change risks and Korea's role as a signatory to the Paris Convention. In addition, the use of Korean GHG and energy data as a measure of climate change risk is expected to provide additional evidence in management studies related to carbon risk. Finally, the results of this study that carbon risk, as a part of nonfinancial information, is reflected in the cost of capital, and can contribute to the expansion of empirical studies between existing environmental performance and financial performance.

The structure of this paper is as follows. In section 2, the theoretical background and previous research are described and then a hypothesis is derived. Section 3 explains the definition of major variables and presents a research model. Section 4 presents the results of the empirical analysis and interprets its meaning. The last section summarizes and concludes the findings.

II. Literature reviews and hypothesis

According to the conventional view, corporate environmental activities are unnecessary "costs" for

businesses and should be reduced, as far as possible. Mahapatra (1984) found that spending on environmental pollution control of enterprises not only creates no profit, but also increases production costs and increases the need for additional capital procurement. In this regard, the authors interpreted that the cost of controlling environmental pollution was not considered a positive outcome, as it was recognized as an outflow of available resources.

Busch and Hoffmann (2011) reveal the reasons why climate change is an important issue that causes systematic change in the business environment. First, they point out that various countries are increasingly strengthening their climate policies and that low-carbon, energy-efficient information is used in consumer spending decisions, making this information a major concern for external stakeholders. Second, they argue that fossil fuel prices, which have risen as fossil fuels are gradually depleting, affect the cost of manufacturing, and additional costs are incurred by GHG emissions in various regions and industries. Third, global interests in climate change issues are reflected in corporate strategies to encourage the development of reusable energy and new low-carbon management models. Based on these discussions, recent studies analyzing the relationship between environmental performance and cost of capital, report that the environmental performance of firms leads to a lower cost of capital.

Feldman et al. (1997) found that companies which improved environmental performance by introducing an excellent environmental management system and reducing toxic emissions achieved lower cost of capital. In this regard, they suggested that firms that improve environmental performance can effectively inform systematic risk reduction in capital markets, and reduce stock volatility or systemic risk, due to improved environmental performance. Garber and Hammitt (1998) conducted a study analyzing monthly stock returns of 73 US chemical companies in relation to Superfund⁴⁾ intervention. As a result of the analysis,

4) The Environmental Protection Agency's Superfund program aims to protect human health and the environment by managing the country's hazardous waste areas and coping with nationally

it was confirmed that the cost of capital increases as the Superfund intervention increases. Sharfman and Fernando (2008) predicted that the cost of capital would be lower when uncertainty of the company's future activities declined as the company's environmental risk management improved. To verify this, they used the Toxic Release Inventory disclosure data and cost of capital for 267 US companies. As a result, they confirmed that the improvement of environmental risk management is related to the reduction of the cost of capital. They also found that environmental risk management can gain additional benefits through tax benefits rather than by only reducing the cost of capital.

Chava (2014) found that investors demand significantly lower expected returns on stocks excluded from the environmental screen⁵⁾, and that banks impose higher interest rates on companies with environmental problems than those without environmental problems. For firms with environmental problems, institutional investors have lower stakes, and few banks are involved in loan syndicates. Plumlee et al. (2015) found that there is a positive relationship between the quality of voluntary disclosure and future cash flows, and a positive (+) or negative (-) relationship with the cost of equity capital. They argue that higher the quality of voluntary disclosure, higher is the firm value. Many studies that have directly analyzed the relationship between environmental activities and cost of capital have reported that increasing or improving environmental activities lead to lower cost of capital, which is caused by the elimination of information asymmetry and reduction in the risk of violating legal regulations.

In Korea, there is limited direct analysis of the relationship between environmental performance and cost of capital. However, there is a more comprehensive analysis of the relationship between corporate social responsibility (CSR) and cost of capital. Jang and Choi (2010) found that CSR performance has a

significant positive correlation with the cost of capital. This is contrary to the hypothesis that a firm with superior CSR performance will have a low cost of capital, and the authors concluded that CSR performance does not provide useful information to investors in the domestic capital market. Based on past research that CSR, which is one of the means of communication among stakeholders, has the effect of reducing information asymmetry between management and shareholders (Reverte, 2012), Chun (2012) shows how CSR information affects a firm's cost of capital. According to the results of the analysis, it is found that the cost of capital of a company that performs CSR is lower than that of a company that does not perform CSR, and the cost of capital decreases as the CSR performance improves. Seo and Choi (2015) found that CSR had a negative effect on WACC. In this regard, the authors explained that companies that are actively engaged in CSR activities can easily raise investment funds as the risks in the capital market are reduced. In addition, investors tend to be willing to pay even if their return on investment is low due to investor preference effects. This tendency consequently reduces WACC. Ahn and Choi (2015) found that CSR has a negative correlation with cost of capital and cost of debt at a statistically significant level.

Taken together, recent studies suggest that investors and creditors are positively evaluating corporate efforts to reduce the risk posed by climate change. The stakeholders recognize that a company's active response to climate change risks can help resolve future uncertainties and information asymmetries.

In this study, the risk of climate change is expected to be reflected in the decision-making process of stakeholders, ultimately affecting the corporate cost of capital. The risk of climate change can create new costs in the future. Unlike in the past, when the risk of climate change was perceived as the inevitable consequence of the industrialization process, the reduction of greenhouse gases is recognized as an obligation after the Paris Convention. Therefore, companies facing a higher climate change risk—those with high levels of greenhouse gas emission or energy

important environmental emergencies.

<https://www.epa.gov/superfund>

5) Such as hazardous chemical, substantial emissions, and climate change concerns

use—should reduce their level of emissions or energy use in the near future. This would entail a higher cost to the companies.

In addition, the disclosure by a company that it is managing climate change risks in an appropriate manner can have a positive impact on its reputation. This can help a company to increase its sales volume or secure a better workforce, as well as help it in obtaining finance through instruments such as Green Bonds. Many institutional investors, including pension funds, have announced that this information would be used to exercise their shareholder rights or make investment decisions. In fact, efforts at the international level to institutionalize the risk of climate change in finance have made steady progress since the Paris Convention. Many financial institutions have already begun to ask for information on environmental issues, such as climate change, faced by the companies (CDP, 2017). This means that institutional investors will invest more in companies facing a low climate change risk. Conversely, this also implies that firms with a lower climate change risk can raise funds at a lower cost.

Last, abnormal weather phenomena caused by climate change risks can significantly affect a company's future physical business environment. This increases the uncertainty surrounding the company's operating activities and may affect a company's cost of capital. The uncertainty includes that resulting from the violation of laws and regulations related to climate change or potential litigation costs. Further, a company's low GHG emissions and energy use can be seen as an indication of the company's efficient management of its physical resources. This may be a result of the more advanced technology possessed by the enterprise. Under the carbon emissions trading scheme, a company's low level of carbon emission level can become a cash-generating source. This fact can positively influence the decision-making process of current or potential investors.

Therefore, the following hypothesis is set in this study:

Hypothesis: Climate change risk has a significantly positive relationship with the cost of capital.

III. Study design and sample selection

A. Climate change risk variables

In this study, climate change risk variables are measured using GHG emissions and energy information released by the GHG Information Center. After declaring low-carbon green growth as a new vision of national development in 2008, Korea has been implementing GHG and energy TMS since 2010 as a key means to realize GHG reduction. The controlled entities of the system are corporations and facilities for which the three-year-average GHG emissions and energy consumption as of January 1 of each year, exceed certain threshold levels under the enactment of the Framework Act on Low Carbon, Green Growth. The specific targets are 125,000 tCO₂ (corporate) and 25,000 tCO₂ (facility) by the end of 2011, and 87,500 tCO₂ (corporate) and 20,000 tCO₂ (facility) from 2012. Starting January 1, 2014, it was 50,000 tCO₂ (corporate) and 15,000 tCO₂ (facility). In terms of energy consumption, it was 500 TJ (corporate) and 100 TJ (facility) by the end of 2011, 350 TJ (corporate) and 90 TJ (facility). From 2014, it was 200 TJ (corporate) and 80 TJ (facility). Corporate establishments and facilities are obligated to submit a statement of GHG emissions, energy consumption, and emission facilities annually, and relevant information is expected to be disclosed to the GHG Information Center of the Ministry of Environment.

In this study, we use data on GHG emissions and energy consumption published by the GHG Information Center to measure the risk of climate change faced by enterprises, using the following process. First, we divide the company's GHG emissions (CO₂) and energy consumption (E) into sales, and calculate GHG emissions per sales (CO₂/sales) and energy consumption (E/Sales). This is the adjustment of the size effect of GHG emissions and energy consumption according to past studies (Chapple, Clarkson, and Gold, 2013; Saka and Oshika, 2014; Jung, Herbohn, and Clarkson, 2016; Choi and Noh, 2016) which state that the size of the company and GHG emissions are proportional.

If a company owns multiple business facilities

that are targeted for control, the sum of the GHG emissions and energy consumption from the target management facilities will be the GHG emissions and energy consumption of that company. Further, the value of 0 to 9 is assigned to 10 groups (Decile_CO2/Sales (0~9), Decile_E/ Sales (0~9)) based on the amount of GHG emissions per unit of sales and the amount of energy consumption per unit of sales. The closer this number is to 9, the higher the level of GHG emissions and energy use. Next, the value of the GHG emission and energy consumption groups are averaged and then adjusted to a value between 0 and 1 (CRISK). Therefore, CRISK is an integrated measure of climate change risk taking into account both, the company's GHG emissions and energy use. In addition, the degree of the climate change risk is also strongly influenced by the industry to which the company belongs (Chapple, Clarkson, and Gold, 2013; Saka and Oshika, 2014; Jung, Herbohn, and Clarkson, 2016). Thus, it also considers the measures of climate change risk adjusted by the industry averages (IND_CRISK). IND_CRISK is calculated by subtracting the average of the industry from the value of the individual enterprise. Higher the value, greater is the risk of climate change relative to the industry average. In case of adjusting to the industry average, the industrial classification standard uses the Standard Industrial Classification by Statistics Korea, and excludes industries with less than five industry observations per year.

B. Cost of capital

Cost of capital was measured using WACC provided by NICE Credit Evaluation Information Co. Ltd., according to past Korean research (Park, 2011; Park, Park, and Choi, 2012; Lee, Jung, and Kim, 2015; Ryu, Kim, and Choi, 2015). If we directly calculate WACC, there will be data constraints, which may lead to subjective assumptions. In particular, while estimating the cost of equity capital, there is a need for forecasting information on future profits. Korean financial analysts do not present future earning

forecasts for all publicly traded companies. Therefore, this study minimizes the limitations of measurement and subjective assumptions by using the information of NICE credit rating information.

The specific calculation method of WACC provided by NICE Credit Rating Co. Ltd., is as follows. First, the cost of debt is obtained by dividing the total interest cost by the total debts and then multiplied by 1 minus the effective tax rate, and the cost of equity is based on capital asset pricing model. Here, the risk-free interest rate is based on the 3-year average annual yield of treasury bonds of the immediately preceding year. The beta is obtained by dividing the covariance between the individual stock returns and market returns, which are measured by using the average KOSPI and KOSDAQ index returns divided by the variance of the market returns. WACC is calculated as the weighted average of the cost of debt and cost of equity.

C. Study model cost of capital

This study uses Equation (1) to analyze whether the risk of climate change is reflected in the cost of capital or not.

$$\begin{aligned}
 WACC_{i,t} = & \alpha_0 + \beta_1 Indep_{i,t} + \beta_2 SIZE_{i,t} + \beta_3 LEV_{i,t} + \\
 & \beta_4 ROA_{i,t} + \beta_5 PPE_{i,t} + \beta_6 MB_{i,t} + \\
 & \beta_7 B_{i,t} + \beta_8 GROWTH_{i,t} + \beta_9 AGE_{i,t} + \\
 & \beta_{10} K2_{i,t} + \epsilon_t
 \end{aligned} \tag{1}$$

The dependent variable is the WACC provided by NICE Credit Information Co. Ltd. The key independent variables are CRISK, a measure of climate change risk, and IND_CRISK, an industry adjusted climate change risk measure. CRISK is measured using GHG emissions and energy consumption published in the GHG Information Center of the Ministry of Environment. When the value of CRISK is larger, higher is the risk of climate change due to higher GHG emissions and energy consumption. IND_CRISK is obtained by subtracting the industry average CRISK from the CRISK of individual

companies. Higher the IND_CRISK value, higher the risk of climate change than the industry average. As firms with higher risk of climate change have higher cost of capital, β_1 is expected to have a positive coefficient. In addition, we examine the homogeneous relationship between dependent and independent variables to confirm whether the risk of climate change is reflected in cost of capital or not. In Equation (1), i is an individual company, and t is the year. In this study, regression analysis is performed on pooled firm-year observations, and year and industry effects are controlled using dummy variables.

As control variables, we use variables that are known to be related to capital costs in previous studies and these are as follows. SIZE, which is measured by the natural log of the total assets, is included according to past studies that the market risk is lower as the firm size is larger (Fama and French, 1995; Francis, Khurana, and Pereira, 2005). We include LEV, which is the debt ratio, as higher the leverage ratio, higher is the probability of default (McInnis, 2010). ROA, which measures the profitability of the firm, is included as a control variable as higher the profitability, lower is the risk of defaulting and lower is the cost of capital (Hope, 2009; Ge and Kim, 2010). Tangible assets represent the size of collateral assets that the firm can provide (Hope, Kang, Thomas, and Yoo, 2009), and capital expenditure is lower when the firm's collateral value increases. PPE, which is the proportion of tangible assets to total assets, is included as a control variable. MB, which is the ratio of the market to book value of equity, and GROWTH, the sales growth rate, are included as control variables to control future growth potential (Ahmed, Rasmussen, and Tse, 2008; Dhaliwal, Gleason, Heitzman, and Melendrez, 2008; Fernando, Elder, and Abdel-Meguid, 2008). In past studies, there has been a conflicting relationship between growth potential and capital cost. The systematic risk, BETA, is for the market risk. It is expected to have a positive relationship with the cost of capital (Ahmed, Rasmussen, and Tse, 2008; Hope, Kang, and Thomas, 2009; Ge and Kim, 2010). AGE is included as a control variable in order to control the difference

in management safety and business cycle. This is calculated by considering the natural logarithm of the number of years since the establishment of the enterprise. K2 is the measure of bankruptcy risk, which is widely used in Korea and is expected to be positively related to the cost of capital. Finally, we include year and industry dummies to control the effects of industry differences and overall economic changes on outcomes.

D. Sample selection

To verify whether the risk of climate change is reflected in the cost of capital or not, a sample is selected based on the following conditions:

- (1) Companies that are targets of GHG emissions and energy consumption
- (2) Non-financial companies
- (3) Excluded unlisted companies
- (4) Excluded companies with negative net assets
- (5) Companies able to obtain financial data on cost of capital and control variables

First, we set up the initial samples for Korean companies that can obtain information on GHG emissions and energy use from 2011 to 2015. The reason for selecting 2011 is that the TMS in Korea was introduced in 2010, and related information was released from 2011 onward. There are a total of 4,137 observations of companies subject to the TMS. Among these, 73 companies or businesses do not disclose emission information. Further, 2,527 were non-listed firms. There are 17 cases in which a company has multiple target management facilities.⁶⁾ Excluding the financial industry, the final sample, which contains all the information on control variables, consists of 1,083 company-year observations. All the variables are winsorized at the upper and lower 1% levels,

6) In the case of firms with multiple facilities that are targets of the TMS, the sum of the emissions from the facilities is regarded as the firm's emissions. In addition, it was confirmed that the analysis results were not different even when these samples were excluded.

except for natural logarithmic variables and climate change risk variables (CRISK and IND_CRISK).

IV. Results of the empirical analysis

A. Descriptive statistics and correlation analysis

Table 1 reports the descriptive statistics of the variables used in the model in Equation (1). The average of the WACC for Korean listed firms subject to the TMS for GHG emissions and energy consumption in Korea is 5.39% and the median is 5.17%. As the proxy of the risk of climate change, CRISK is adjusted to have a value between 0 and 1, it is confirmed that the mean and median are the same, and that both sides are symmetrical with respect to the center. As IND_CRISK is a variable indicating the difference between CRISK and the industry average, it is

confirmed that the average is 0. The target companies emit an average 0.391 tCO₂e of GHG per sales and consume 0.01 tJ of energy.

Table 2 shows the Pearson correlation between the variables used in this study. The correlation coefficients between WACC and CRISK and between WACC and IND_CRISK are opposite each other, but the absolute value of correlation coefficient is smaller than 0.1. Among the control variables, BETA is found to have a particularly high correlation with WACC (0.6623), because BETA is used in calculating the capital cost of equity making up the WACC. The correlation between CRISK and IND_CRISK that measures climate change risk, is high. Among the independent variables, the variables whose absolute value of the correlation coefficient is 0.5 or more are ROA and K2, LEV and K2. This is due to the fact that the profitability and the debt ratio are included in the variables for calculating K2 (default risk). Although not shown in the table, as a result of a multicollinearity test, the mean of

Table 1. Descriptive statistics

This table shows descriptive statistics of main variables. The sample consists of the listed firms under the Target Management System from 2011 to 2015.

Variables	mean	sd	p1	p25	p50	p75	p99
WACC	5.39	1.39	3.04	4.4	5.17	6.25	9.1
CRISK	0.45	0.28	0	0.2	0.45	0.7	0.9
IND_CRISK	0	0.2	-0.59	-0.11	0	0.13	0.5
CO2/Sales	0.39	0.84	0.01	0.05	0.12	0.46	4.81
Energy/Sales	0.01	0.01	0	0	0	0.01	0.04
K2	30.79	8.05	10.94	25.93	30.28	34.96	54.06
SIZE	20.86	1.62	17.97	19.63	20.46	22	24.84
LEV	1.33	1.78	0.1	0.41	0.87	1.52	12.4
ROA	0.02	0.07	-0.21	0	0.03	0.05	0.17
PPE	0.39	0.17	0.07	0.26	0.38	0.51	0.85
MB	1.28	1.37	0.23	0.57	0.92	1.46	9.2
BETA	0.81	0.4	0.1	0.5	0.77	1.09	1.78
GROWTH	0.03	0.21	-0.38	-0.06	0.02	0.09	0.76
AGE	3.56	0.67	1.61	3.4	3.81	4.01	4.42

Note. WACC is the weighted average of the cost of capital. CRISK is the climate change risk which measures the average of decile ranks of CO₂/Sales and decile ranks of Energy/Sales. IND_CRISK is the climate change risk compared to the industry average of CRISK. CO₂/Sales is GHG emissions (tCO₂e) per KRW 1 in sales, and Energy/Sales is energy consumption (TJ) per KRW 1 in sales. K2 is distress score. SIZE is the natural log of total asset. LEV is leverage and ROA is net income divided by lagged total asset. PPE is property, plant and equipment divided by lagged total asset. MB is market to book value of equity. BETA is systematic risk in CAPM. GROWTH is sales growth ratio. AGE is the number of years since the firm started.

Table 2. Pearson correlation

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
(1)WACC	1											
(2)CRISK	-0.0820*	1										
(3)IND_CRISK	0.0351	0.7155*	1									
(4)K2	-0.0365	-0.2170*	-0.1037*	1								
(5)SIZE	0.1930*	-0.3985*	-0.0835*	0.3419*	1							
(6)LEV	0.1047*	-0.0089	0.0196	-0.5228*	0.0313	1						
(7)ROA	-0.0149	-0.0849*	-0.0612	0.5746*	0.0815*	-0.4431*	1					
(8)PPE	-0.0770*	0.3686*	0.2367*	-0.2780*	-0.0653*	0.1976*	-0.0690*	1				
(9)MB	0.1964*	-0.2067*	-0.1329*	0.0184	0.0776*	0.2841*	-0.0743*	-0.0314	1			
(10)BETA	0.6623*	-0.1369*	0.0004	-0.0489	0.3541*	0.0815*	-0.0434	-0.0879*	0.1163*	1		
(11)GROWTH	0.0911*	-0.0849*	-0.0557	0.0239	0.0471	-0.0765*	0.2233*	0.0727*	0.0199	-0.0139	1	
(12)AGE	-0.0611*	0.0756*	0.0635*	0.1794*	0.003	-0.1401*	-0.0005	-0.0666*	-0.2109*	-0.0671*	-0.1278*	1

Note. Variable definition is the same as Table 1. * denote statistical significance at the 5% or less level.

VIF is 1.89 and K2 has the highest VIF value of 3.12. Taken together, VIF test results suggest that the multicollinearity problem is not serious.

Table 3 reports industry averages of CRISK for target management companies from 2011 to 2015. Higher the value of CRISK, more are GHG emissions and energy consumption per unit of sales, which is a high risk of climate change. The top five industries with the highest risk of climate change are manufacture of pulp paper and paper products, non-metallic mineral products, wood and wood products, chemicals and chemical products, and primary metals. The top five industries with low risk of climate change are warehouse and transportation related services, construction business, computer programming system integration, wholesale and commodity brokerage, and other transportation equipment manufacturing. These results are largely similar to the classification criteria for GHG emissions per unit of sales and energy consumption per unit of sales.

B. Main analysis

Table 4 shows the result of multiple regression analysis for Hypothesis 1 to verify the relationship between climate change risk and capital cost. Column

(1) shows the results of the analysis of the model using CRISK, which is a measure of climate change risk, and column (2) shows the analysis of the model using IND_CRISK adjusted by industry average. For the robustness of the results, we report the t-value calculated with the standard error corrected for heteroscedasticity. The results in column (1) show that CRISK has a statistically significant positive correlation with WACC at the 1% level. In other words, higher the risk of climate change, higher is the cost of capital. We find that the climate change risk of a firm is reflected in the cost of capital. Similarly, column (2) with IND_CRISK as the main test variable also confirms that there is a statistically significant positive relation between WACC and industry adjusted climate change risk at the 1% level. IND_CRISK represents the degree of climate change risk relative to the industry average, which means that the risk of climate change is higher than the industry average. These results show that companies with higher GHG emissions and energy consumption per unit of sales than the industry average are considered to have a high risk of climate change, and thus, bear high cost of capital. Therefore, companies need to manage climate change risks in order to raise funds at low capital costs.

WACC has a statistically significant positive

Table 3. The average of climate change risks by industry

Industry	N	CRISK	CO2/Sales	E/Sales
Manufacture of pulp paper and paper products	157	0.7838	0.7718	0.0122
Manufacture of non-metallic mineral products	204	0.7222	3.3743	0.0206
Manufacture of wood and wood products; excluding furniture	24	0.695	0.3224	0.0104
Manufacture of chemicals and chemical products;	661	0.5766	0.4435	0.0082
Manufacture of primary metals	456	0.5689	0.41	0.0061
Accommodation	6	0.5667	0.2072	0.0041
Manufacture of coke briquette and petroleum products	30	0.56	0.2538	0.0037
Land transportation and pipeline transportation	72	0.5531	0.3494	0.005
Textile products manufacturing industry; Except clothing	89	0.5293	0.2068	0.004
Beverage manufacturing	64	0.4933	0.4884	0.0043
Manufacture of electronic components, computer image sound and communication equipment	1584	0.4669	0.2404	0.0044
Manufacture of rubber products and plastic products	271	0.4105	0.1238	0.0025
Manufacture of medical materials and pharmaceuticals	616	0.41	0.2896	0.0052
Manufacture of leather bags and shoes	29	0.39	0.1014	0.002
Communication	66	0.3033	0.0684	0.0014
Air transportation	18	0.3	0.1159	0.0017
Automobile and trailer manufacturing	539	0.2948	0.1478	0.0024
Grocery manufacturing	290	0.2939	0.0802	0.0017
Professional Services	502	0.2906	0.0773	0.0015
Electric gas steam and air conditioning supply business	72	0.2526	0.5316	0.0101
Apparel apparel accessories and fur products manufacturing	132	0.25	0.0795	0.0009
Sports and entertainment services	42	0.22	0.0534	0.001
Retailing; Exclude cars	167	0.2143	0.0539	0.0011
Other machinery and equipment manufacturing	826	0.2015	0.1963	0.0024
Electrical equipment manufacturing	327	0.194	0.0679	0.0014
Tobacco industry	6	0.13	0.0329	0.0007
Other transportation equipment manufacturing	132	0.0986	0.0305	0.0005
Wholesale and commodity brokerage	550	0.04	0.0111	0.0002
Computer programming system integration	172	0.03	0.0184	0.0004
Construction business	234	0.016	0.0114	0.0002
Warehouse and transportation related service	30	0	0.0066	0.0001

relationship with the following control variables, namely, debt ratio (LEV), market to book value ratio of equity (MB), systematic risk (BETA), and risk of bankruptcy (K2). WACC has a negative relationship with firm size and profitability. This implies that firms with smaller sizes, higher debt ratios, lower profitability, higher growth potential, higher systematic risk, and higher default risk have to pay higher capital costs

to raise their capital. This is consistent with the results of past studies. Summarizing the results in Table 4, given the ability of companies to manage climate change risks as a result of their environmental activities, the efforts to reduce GHG emissions and energy consumption will reduce the future risk of climate change, lowering the cost of capital. In particular, it is necessary to reduce GHG emissions

Table 4. Climate change risk and WACC - Main analysis

Independent variable:	Predicted Sign.	Dependent variable : WACC	
		(1)	(2)
		CRISK	IND_CRISK
Indep	?	0.34*** (3.24)	0.41*** (3.61)
SIZE	-	-0.05** (-2.48)	-0.06*** (-2.72)
LEV	+	0.08** (2.03)	0.10** (2.47)
ROA	-	-1.48** (-2.17)	-1.46** (-2.10)
PPE	+	0.03 (0.16)	0.11 (0.51)
MB	+/-	0.13*** (4.41)	0.13*** (3.97)
BETA	+	2.21*** (26.09)	2.16*** (23.24)
GROWTH	+/-	0.15 (1.13)	0.03 (0.25)
AGE	+/-	0.02 (0.47)	0.03 (0.62)
K2	+	0.02*** (3.1)	0.03*** (3.34)
Year dummy		YES	YES
Industry dummy		YES	YES
Obs.		1,083	929
R2		0.73	0.75

Note. Variable definition is the same as Table 1. ***, **, * denote statistical significance at the 1, 5, 10% level, respectively.

and energy use for companies with higher GHG emissions and energy consumption per unit of sales than the industry average in order to raise funds at lower costs.

C. Additional and robustness test

Table 5 reports one of the additional analyses. First, based on CRISK, the top 10 industries are classified as high-risk industrial groups and the remaining industries are classified as low risk industrial groups. Further, we examine the relationship between CRISK and WACC by considering both groups. The purpose of this analysis is to observe if there is a significant

difference in the results between industries with high risk of climate change and those with low risk. In the case of companies belonging to industrial groups with high risk of climate change, there is a possibility that the market is perceived as having a high risk of climate change. However, if companies in these industries are actively working to reduce GHG emissions or energy consumption, they will be more positively evaluated by the market for their ability to respond to climate change risks. Therefore, the efforts to reduce climate change risks are expected to be reflected in the cost of capital. Table 5 shows that CRISK and IND_CRISK have a statistically significant positive relationship with WACC, only in the high risk of climate change industrial group. This implies that the relationship between climate change risks and capital costs is prominent in industrial groups with high risk of climate change. Therefore, if a company belonging to an industry with a high risk of climate change actively manages GHG emissions and energy consumption, it can be positively evaluated in the market, thus lowering its capital costs.

As part of further analysis, the following will verify whether voluntary disclosure to the CDP has a significant impact on the relevance of climate change risks to cost of capital. CDP is an environmental group that was established in 2000. On behalf of global financial institutions, CDP collects information on the risk of climate change and long-/short-term environmental management strategies for companies and provides relevant information to investors through the CDP Climate Change Report. Companies that are subject to the CDP survey voluntarily respond to the CDP questionnaire annually, and CDP publishes the report on an annual basis. In Korea, research has been conducted on the top 200 ~ 250 companies with the highest market capital. Choi and Noh (2016) find that the response rate of Korean companies is approximately 30% of the surveyed firms since 2011.

According to past research, voluntary disclosure lowers information asymmetry between managers and investors, and contributes to efficient allocation of asset resources (Healy and Palepu, 2001). In addition,

Table 5. Low / High climate change risk industry

Independent variable:	Predicted sign	Dependent variable : WACC			
		Low climate change risk		High climate change risk	
		CRISK	IND_CRISK	CRISK	IND_CRISK
Indep	?	0.21 (1.11)	-0.09 (-0.53)	0.64*** (4.99)	0.88*** (5.54)
SIZE	-	-0.06** (-2.54)	-0.08*** (-3.04)	-0.07** (-2.28)	-0.08** (-2.06)
LEV	+	-0.04 (-0.08)	0.05 (0.81)	0.10** (2.25)	0.12*** (2.59)
ROA	-	-1.19 (-1.08)	-0.49 (-0.52)	-1.53* (-1.70)	-1.42 (-1.52)
PPE	+	0.1 (0.42)	0.38 (1.48)	-0.28 (-1.15)	-0.21 (-0.76)
MB	+/-	0.14*** (3.75)	0.12*** (2.71)	0.17*** (3.51)	0.16*** (3.06)
BETA	+	2.45*** (26.14)	2.41*** (20.33)	2.19*** (21.63)	2.15*** (18.33)
GROWTH	+/-	0.23 (1.27)	0.13 (0.68)	0.04 (0.24)	0.04 (0.21)
AGE	+/-	0.02 (0.46)	0.08 (1.6)	-0.04 (-0.68)	-0.05 (-0.80)
K2	+	0.02* (1.84)	0.02** (2.03)	0.02* (1.73)	0.02 (1.62)
Year dummy		YES	YES	YES	YES
Industry dummy		YES	YES	YES	YES
Obs.		546	466	537	463
R2		0.73	0.73	0.67	0.67

Note. Variable definition is the same as Table 1. ***, **, * denote statistical significance at the 1, 5, 10% level, respectively.

companies can reduce their cost of capital by reducing future uncertainties through voluntarily disclosure (Diamond and Verrecchia, 1991; Lambert, Leuz, and Verrecchia, 2007; Armstrong, Guay, and Weber, 2010; Beyer, Cohen, Lys, and Walther, 2010). Choi and Noh (2016) find that CDP disclosure is useful in enhancing value relevance and credit relevance. Therefore, this section seeks to further identify the impact of CDP disclosure effects between climate change risks and cost of capital, taking into account CDP disclosure as an active management of the risk of climate change.

Table 6 shows that climate change risk, a key verification variable, is still statistically significant with WACC, regardless of whether CDP disclosure variables are added or not. Based on the results in

column (1) in Table 6, the CDP disclosure effect appears to be negatively related to the cost of capital. In other words, CDP disclosure reduces uncertainty related to information asymmetry on climate change risks between firm and investors, thereby reducing capital costs. However, in column (3), where IND_CRISK is used as a key test variable, CDP disclosure is negatively associated with cost of capital, but not statistically significant. This result can be inferred to be due to the fact that the level of corporate climate change risk compared to the industry average has more impact on capital cost than CDP disclosure does. In columns (2) and (4), we present the results of adding cross terms between CDP disclosure and measures of climate change risk. However, though the coefficient of the cross term has negative value,

Table 6. GHG-energy emissions and the firm value – Main analysis

		Dependent variable : WACC			
Independent variable:	Predicted Sign.	CRISK		IND_CRISK	
		(1)	(2)	(3)	(4)
Indep	?	0.36*** (3.45)	0.38*** (3.13)	0.41*** (3.66)	0.44*** (3.64)
Indep x CDP	?		-0.06 (-0.24)		-0.16 (-0.56)
CDP	?	-0.17** (-2.10)	-0.15 (-1.25)	-0.12 (-1.39)	-0.13 (-1.40)
SIZE	-	-0.03 (-1.15)	-0.03 (-1.12)	-0.04 (-1.61)	-0.04 (-1.59)
LEV	+	0.08** (2.03)	0.08** (2.02)	0.10** (2.45)	0.10** (2.45)
ROA	-	-1.36** (-1.98)	-1.36** (-1.99)	-1.39** (-1.99)	-1.40** (-2.00)
PPE	-	-0.01 (-0.03)	0.00 (-0.01)	0.08 (0.39)	0.09 (0.42)
MB	+/-	0.14*** (4.63)	0.14*** (4.62)	0.13*** (4.13)	0.13*** (3.95)
BETA	+	2.22*** (26.46)	2.22*** (26.29)	2.17*** (23.53)	2.17*** (23.53)
GROWTH	+/-	0.16 (1.16)	0.16 (1.17)	0.04 (0.27)	0.04 (0.29)
AGE	+/-	0.02 (0.43)	0.02 (0.43)	0.02 (0.58)	0.03 (0.6)
K2	+	0.02*** (3.03)	0.02*** (3.03)	0.03*** (3.30)	0.03*** (3.29)
Year dummy		YES	YES	YES	YES
Industry dummy		YES	YES	YES	YES
Obs.		1083	1083	929	929
R2		0.73	0.73	0.72	0.72

Note. Variable definition is the same as Table 1. ***, **, * denote statistical significance at the 1, 5, 10% level, respectively.

it is not statistically significant.

In Table 7, CRISK is calculated using GHG emissions and energy use per unit of total assets, and not sales. This analysis is meaningful in terms of robustness analysis. Except for the method of adjusting the scale effect, the procedure for measuring the risk of climate change is the same as in the previous section. Table 7 shows that even though the scale effect is adjusted by total assets, there is a significant negative relationship between CRISK (IND_CRISK) and WACC at the 1% significant level. In other words, climate change risks are negatively

related to cost of capital, and actively reducing GHG emissions or energy consumption can contribute to lowering the cost of capital. The sign and significance of the control variables are the same as the results in the previous section.

V. Conclusions

In this study, we identified the relationship between

Table 7. The analysis by industry based on the level of climate change risks

Independent variable:	Predicted Sign.	Dependent variable : WACC	
		(1)	(2)
		CRISK	IND_CRISK
Indep	?	0.34*** (2.97)	0.41*** (3.44)
SIZE	-	-0.04** (-2.10)	-0.05** (-2.30)
LEV	+	0.08** (1.99)	0.09** (2.43)
ROA	-	-1.52** (-2.25)	-1.50** (-2.17)
PPE	-	0.03 (0.17)	0.11 (0.50)
MB	+/-	0.13*** (4.41)	0.13*** (3.99)
BETA	+	2.20*** (25.95)	2.15*** (23.14)
GROWTH	+/-	0.14 (1.02)	0.02 (0.12)
AGE	+/-	0.03 (0.64)	0.04 (0.88)
K2	+	0.02*** (2.96)	0.02*** (3.17)
Year dummy		YES	YES
Industry dummy		YES	YES
Obs.		1083	929
R2		0.73	0.72

Note. CRISK is the alternative proxy of climate change risk which measures the average of decile ranks of CO2/Total asset and decile ranks of Energy/total assets. IND_CRISK is the climate change risk compared to the industry average of the alternative proxy of CRISK. Control variable definition is the same as Table 1. ***, **, * denote statistical significance at the 1, 5, 10% level, respectively.

climate change risk and WACC, focusing on GHG and energy target management companies. In order to do this, we used information on GHG emissions and energy consumption of Korean companies announced in the GHG information center from 2011 to 2015. Climate change risk measures were calculated using GHG emissions and energy consumption per unit of sales. The cost of capital is measured as the WACC provided by NICE Credit Information Co. Ltd. A key analysis shows that there is a positive correlation between climate change risk and cost of capital. In other words, companies with high GHG emissions

and energy consumption per unit of sales have higher capital costs. Thus, companies need to actively reduce GHG emissions and energy consumption. In addition, as GHG emissions are heavily influenced by industry characteristics, we also use measures of climate change risk adjusted by the industry average. The analysis also shows that the measures of climate change risk adjusted by the industry average have a positive relationship with cost of capital. Therefore, companies with more GHG emissions and energy consumption than the industry average need to actively reduce their emission and consumption. In addition, we find that there was a significant positive correlation between climate change risks and cost of capital in high climate change risk groups. Therefore, companies that are at high risk of climate change need to actively manage their GHG emissions and energy consumption.

The subject of this study is timely in light of the global interest in climate change risks and Korea's role as a signatory to the Paris Convention. In addition, the use of Korean GHG and energy data as a measure of climate change risk is expected to provide additional evidence in management studies related to carbon risk. Finally, the results of this study that carbon risk as a part of nonfinancial information is reflected in the cost of capital, can contribute to the expansion of empirical studies between existing environmental and financial performance.

In this study, we have confirmed that the climate change risk can be a factor in determining the cost of capital. Companies should actively manage climate change risks not only for sustainable management, but also for more efficient financial strategies. In addition, shareholders or creditors who are willing to fund businesses should continue to be interested in the ability of the company to manage climate change risks and reflect this information in their investment portfolio composition. In addition, policy makers need to actively disclose information on the climate change risks for individual companies and actively use them in assessing CSR.

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