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The Impact of Climate Change Risks on Firm Value: Evidence from the Korea

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ABSTRACT

This study examines the relationship between climate change risks and firm value using listed Korean companies that are subject to the Target Management System from 2011 to 2015. The proxies of climate change risks are levels of greenhouse gas emissions and energy consumption, and the proxy of firm value is the Tobin's Q. We find that higher levels of greenhouse gas emissions and energy consumption have a greater negative impact on firm value. Moreover, these relationships are stronger in the group of industries with high climate change risks. This study presents evidence that climate change risks may also have an impact on the value of companies in newly industrialized countries. We try to minimize self-selection bias by using greenhouse gas emissions and energy consumption data disclosed in accordance to the local law. Lastly, this study can be used to lay the foundation for policy making by confirming that making efforts to cut greenhouse gas emissions and energy consumption to levels lower than the industry average is important.

Keywords: Carbon trading system; Energy consumption; Firm value; Greenhouse gas emissions; Korea

1. Introduction

The valuation of companies based on financial factors faces many limitations at a time of accelerating industrial development and in the presence of an increasingly complicated managerial environment. This situation has prompted many researchers to utilize natural environmental factors for the valuation of firms. Natural environmental factors gained

popularity in managerial analysis and have now become essential factors for company valuation (QA, Murni, and Agustiningsih, 2015; Honggowati, 2015; Kawk and Choi, 2015). GHG(Greenhouse gas) emissions, in particular, have been the focus of a large number of long-term studies (Busch and Hoffmann, 2011; Iwata and Okata, 2011; Martinez and Bowen, 2013; Matsumura, Prakash, and Vera-Muñoz, 2014; Wang, Li, and Gao, 2014; Talbot and Boiral, 2015; Jung, Herbohn, and Clarkson, 2016; Li, Huang, Ren, Chen and Ning, 2016). The accumulation of research can be largely attributed to the need for establishing regulations on GHG emissions, often seen as the culprit in global warming.

International efforts to cut GHG emissions began

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with the adoption of the 1992 UNFCCC(United Nations Framework Convention on Climate Change) at the Rio Summit. In the 1997 UN Kyoto Protocol, the types of GHGs to be reduced, reduction periods, and reduction targets were defined. The parties agreed to cut their GHG emissions as defined in the Kyoto Protocol; to this end, they decided to adopt emission trading systems and the Joint Implementation mechanism to efficiently meet their reduction targets. The emission trading systems went beyond having a regulatory mechanism to control GHG emissions; it also helped raise the awareness that GHG emission permits can be a financial asset.

The efforts and regulations aimed at reducing emissions at a country level, in line with the UN treaties, are now being implemented at the company level through a voluntary carbon emission reporting system, such as the CDP(Carbon Disclosure Project). Despite numerous debates over corporate responsibility, the fact that corporations are taking voluntary actions to address carbon emissions suggests that the GHG emissions index has become an essential factor that cannot be ignored in today's managerial environment.

Korea ratified the Climate Change Convention in 1993, a quite early step for the country. However, as a developing country, Korea was not bound to the emission reduction obligation. Nevertheless, since the Paris Convention, the country has proactively implemented policies and control systems, including the emission trading system, introduced in 2015 to respond to climate change and keep pace with the international efforts to cut carbon emissions. The country also submitted its Intended Nationally Determined Contributions under the new climate change system to the UNFCCC secretariat, in June 2015. This action plan includes its voluntary target of cutting emissions by 37% from the business-as-usual level by 2030 (Permanent Mission of the Republic of Korea to the United Nations, <http://un.mofa.go.kr/>).

In addition to the GHG emission trading market, South Korea adopted the TMS(Target Management System) to meet its voluntary GHG reduction goal. Companies with high levels of GHG emissions or energy consumption are designated as controlled

entities under this scheme. These entities are given GHG emissions and fossil fuel consumption reduction targets, and their performance is verified and monitored by the government. Such companies maintain records on their GHG emissions, energy consumption, and the status of their GHG emission facilities, following a standard procedure. They also report their information, including their emission information, in the Emission Trading Registry at the Greenhouse Gas Inventory and Research Center (<http://www.gir.go.kr/>).

The international efforts for reducing GHG emissions and the situation in Korea regarding GHG emissions and emission reduction indicate that social and institutional environments are mature for a study on the impact of GHG emissions on firm value. To this end, this study seeks to explore the relationship between GHG emissions and firm value based on GHG emissions and energy consumption data disclosed under the TMS. Data on the amounts of GHG emissions and energy consumption of the publicly listed domestic companies designated as the controlled entities of the scheme are utilized and Tobin's Q is used as a proxy for firm value. The results show that the levels of GHG emissions and energy consumption have a significant negative relationship with firm value. The higher the levels of GHG emissions and energy consumption and the higher the levels of industry-adjusted emissions and energy consumption, the lower the firm value; this relationship is found in the industry group with high levels of GHG emissions.

This study makes the following contributions. It presents additional evidence on the link between GHG emissions and firm value using a new sample of companies in the Korean market, amid the growing global attention to climate change risks. Whereas previous studies have focused on advanced markets, bound to the reduction targets set in the Kyoto Protocol, this study presents evidence that climate change risks may also have an impact on the value of companies in newly industrialized countries. In addition, the results of this study are more reliable because the present analysis is based on objectively

verified data rather than voluntarily disclosed information, such as data from the CDP. This study analyses the aggregate impact of climate change risks on firm value, taking energy consumption level into consideration, along with the amount of GHG emissions. Lastly, this study confirms that significant differences exist between industries regarding the impact of GHG emissions and energy consumption on firm value. It also reveals the importance of cutting emissions to a level lower than the industry average. In addition, this study examines the importance of industry characteristics when analyzing the climate change risks of a company.

2. Literature Reviews and Hypothesis

Previous studies on the impact of GHG emissions on firm value addressed whether natural environmental factors can be used for company valuation. Busch and Hoffmann (2011) look into the relationship between a company's carbon emissions and its financial performance. Their study defines the act of emitting GHGs as a corporate environmental activity, one of many corporate social activities, and explains why climate change is regarded as a critical problem that causes systematic changes in the business environment. First, countries are gradually reinforcing climate policies and consumers are utilizing information about low carbon footprints and energy efficiency in their decision making (Brickman, Hoffman, and Oppenheim, 2008). These trends make such information the primary interest of outside stakeholders. Second, the world is running short on fossil fuels, increasing the price of such fuels (Busch and Hoffmann, 2007). In turn, the higher fuel prices are affecting manufacturing costs, creating extra costs for emitting GHGs in a variety of regions and industries. Third, concerns about the global temperature change are reflected in corporate managerial strategies, promoting the development of renewable energy and new low-carbon business models.

Recent studies that measure a company's environmental performance as the level of carbon emissions report that companies with lower emission levels, those with better environmental performances, usually have a higher firm value (Chapple, Clarkson, and Gold, 2013; Matsumura et al., 2014; Saka and Oshika, 2014).

Wagner et al. (2002) investigate the relationship between the environmental and financial performance of European paper manufacturers using environmental performance indices, namely, ROS(return on sales), ROE(return on equity), and ROCE(return on capital employed). Their study shows that a high environmental performance improves ROCE but does not have a significant impact on ROS and ROE.

Iwata and Okada (2011) point out that environmental problems have traditionally been regarded as conflicts between social interests and individual self-interests, and remain to be solved by government intervention. Their study argues that, in the presence of a positive relationship between environmental and financial performance, a company will be motivated to improve its environmental performance, and this, in turn, may help solve environmental problems without government intervention. The researchers look into the impact of environmental performance on financial performance using Japanese manufacturing industry data from 2004 to 2008 and find that, while discarding wastes does not have a significant effect on financial performance, GHG reduction has a positive relationship with the financial performance of the companies in the entire sample, as well as companies in the clean industry.

Chapple et al. (2013) examine market responses to the level of carbon emissions of 58 Australian companies for which carbon credits are publicly traded. For the analysis, their study defines a company's level of carbon emissions as the total volume of carbon emissions (direct and indirect emissions combined) divided by the total revenue, and classifies companies into two groups according to the calculated level of carbon emission. They find a significant market response whenever an event relevant to the introduction of an emission trading

system happens in the group of high emissions companies. They also look into the relationship between the level of carbon emissions and firm value and find a significant negative relationship between the two.

Matsumura et al. (2014) argue that reports published by environmental organizations encourage companies in many nations, including the United States, to enhance transparency. Companies are encouraged to disclose non-financial information such as carbon emissions, which, in turn, motivates shareholders to ask the management to assess and report the regulations and the situation they face regarding climate change. An analysis of the CDP data of S&P 500 firms shows that, whenever a company sees an increase in its carbon emissions, its firm value decreases, and that companies that disclose their carbon emission volume have a higher value than those in the non-disclosing control group. The researchers interpret this finding as the market imposing a penalty on companies that emit large amounts of carbon or those that do not disclose carbon emission information.

Many studies have concluded that the level of GHG emissions has a negative relationship with financial performance or firm value; however, Wang et al. (2014) believe that the results may be different for Australia, where the economy is concentrated in the resource extraction industry and the investment in corporate social responsibility (CSR) investment is low (Ernst and Young, 2010; Delmas and Nairn-Birch, 2011; Busch and Hoffmann, 2011; Boiral, Henri and Talbot, 2012). In their study of 69 Australian listed companies, they find that higher levels of GHG emissions lead to higher firm value across industries. The researchers believe that their finding is a reflection of Australia's industrial structure, where mining is the biggest sector.

The relationship between GHG emissions and firm value may vary depending on the industry (Wang et al., 2014) as well as the quality of GHG emissions data. Kim and Lyon (2011) point out that most previous studies use voluntarily disclosed information in annual reports and CSR reports, which might have resulted in self-selection bias. In their study, they

used the data generated from the Energy Policy Act established in 1992 and find that participants in the program reported only successful reductions in emissions and did not disclose the overall carbon emission.

Saka and Oshika (2014) perform a study on Japan's mandatory disclosure. Japan legalized the mandatory disclosure of GHG emissions in 1998 and began disclosing the information at a company level in 2006. An analysis of the 89 companies that completed the CDP questionnaires (16 companies refused to complete the questionnaires, and 989 companies did not participate in the surveys from 2006 to 2008) reveals a significant negative relationship between the level of carbon emissions and firm value. The researchers also find that voluntary disclosure positively influences firm value and that the relationship between the two intensifies when a company has a higher level of emissions.

In summary, GHG emissions can be associated with firm value from the following perspectives: first, regulating GHG emissions imposes an environmental cost on companies. Reducing GHG emissions is no longer at a company's discretion, as the effort was initiated with an international convention and has been institutionalized on the country level. Therefore, when a company anticipates that its emissions will exceed the allocated limit, it actively participates in carbon trading to circumvent regulation and seek solutions to cut emissions. This tendency indicates that reducing GHG emissions is an economic factor that imposes costs on companies.

Second, a firm's ability to manage its GHG emissions influences its reputation. Violating environmental regulations or causing environmental incidents could have a negative impact on the future performance of a company because the firm may lose its reputation or its products may be boycotted. On the other hand, if a company enhances its reputation of being environmentally responsible by investing in renewable alternative energy for carbon emission reduction, it can decrease environmental risks and long-run manufacturing costs through positive evaluations from the stakeholders. This result can translate into

more financial benefits from the stakeholders (Simnett, Nugent, and Huggins, 2009; Iwata and Okada, 2011).

Lastly, a company's high level of GHG emissions may increase further in an uncertain business environment. A firm's ability to manage GHG emissions is a scorecard of its ability to respond to climate change risks. If the physical environment becomes exposed to extreme weather caused by climate change, a company that cannot manage climate change risks well will have to face intensified risks. In addition, a company is more likely to be subject to legal sanctions as its emissions move closer to the allotted limit, and thus, the ability to control and manage emissions is closely associated with risk management. This situation may have an adverse impact on firm value. In this context, this study posits the following hypothesis.

Hypothesis: The amount of GHG emissions has a significantly negative impact on firm value.

3. Study design and sample selection

3.1. Definition of variables

3.1.1. Levels of GHG emissions and energy consumption

After the declaration of 'Low-Carbon Green Growth', a new national vision for development, in 2008, South Korea has enforced the TMS in 2010 as a core strategy for achieving its mid-term GHG emission reduction target by 2020. 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 the thresholds set under the Enactment of Framework Act on Low Carbon, Green Growth.

The controlled entities are required to submit reports on their annual GHG emissions and energy consumption and the status of their emission-producing facilities to the relevant authorities every year, and the submitted information are disclosed to the Greenhouse Gas Inventory and Research Center, operated by the Ministry of Environment. This study uses the data in the TMS reports disclosed to the Greenhouse Gas Inventory and Research Center to measure GHG emissions. Since the amount of emissions is generally proportional to the size of a firm, the volume of emissions is divided by revenue, in line with previous studies (Chapple et al., 2013; Saka and Oshika, 2014; Choi and Noh, 2016; Jung et al., 2016). In addition, since GHG emission is largely affected by the characteristics of the industry (Chapple et al., 2013; Saka and Oshika, 2014; Jung et al., 2016) in which a company operates, the emission level is also examined in comparison to the industry average. The amount of energy consumption shown in the reports is also adjusted for total revenue to investigate the link between a company's energy consumption and its value. This study also tests the relationship between firm value and energy consumption in comparison to the industry average.

3.1.2. Firm value

In line with previous studies (Allayannis and Weston, 2001; Davis, 2009; Hu and Wee, 2010; Bartram, Brown, and Conrad, 2011; Chen and King, 2014; Mishra, 2015; Kim, Papanastassiou, and Nguyen, 2017), this study adopts Tobin's Q as a proxy of firm value. Tobin's Q is the market value of assets divided by replacement cost. A higher

Table 1. Thresholds for the controlled entities of the Target Management System (TMS)

	Until Dec. 31, 2011		From Jan. 1, 2012		From Jan. 1, 2014	
	Corporate threshold	Facility threshold	Corporate threshold	Facility threshold	Corporate threshold	Facility threshold
GHG (tCO ₂)	125,000	25,000	87,500	20,000	50,000	15,000
Energy (TJ)	500	100	350	90	200	80

Tobin's Q means a higher ratio of market value to replacement, hence a higher firm value. The Tobin's Q used in this study is as follows:

$$Q = (\text{Ending price of a common stock} \times \text{number of common stocks issued at the end of the period} + \text{face value of a preferred stock} \times \text{number of preferred stocks issued at the end of the period} + \text{total liabilities}) \div \text{total assets}$$

In general, the book value of total assets is used as replacement cost, as replacement cost is impossible to directly measure (Chung and Pruitt, 1994). A company's market value is the sum of the market value of common stocks, book value of preferred stocks, and book value of liabilities. The book value, not market value, of preferred stocks is used to avoid the problems that may arise owing to the lower liquidity of preferred stocks and inefficient market prices (Yon and Park, 2006; Choi, Lee, and Hong, 2009). Book value is used for liabilities because the gap between the market and book value is not significant.

3.2. Study model

This study designs the following model to verify the impact of GHG emission level on firm value:

$$Q_{i,t} = \beta_0 + \beta_1 GHG/Sales_{i,t} + \beta_2 ROA_{i,t} + \beta_3 LEV_{i,t} + \beta_4 PPE_{i,t} + \beta_5 IND_ASSET_{i,t} + \beta_6 SIZE_{i,t} + \beta_7 GROWTH_{i,t} + \beta_8 AGE_{i,t} + \epsilon_t \quad (2)$$

The dependent variable is Tobin's Q ($Q_{i,t}$), a proxy variable for firm value; the level of GHG emissions ($GHG/Sales_{i,t}$), a variable of major interest, is the amount of GHG emissions divided by the revenue of the corresponding year. It is predicted that a higher level of GHG emissions has a negative impact on firm value, and thus, the regression coefficient is expected to be negative. The test variables are the ratio of energy consumption to annual sales ($Energy/Sales_{i,t}$), the level of GHG emissions adjusted for the industry average ($IND_GHG/Sales_{i,t}$), and the level of energy consumption adjusted for the industry average ($IND_Energy/Sales_{i,t}$). We obtain the following model specifications:

$Sales_{i,t}$), the level of GHG emissions adjusted for the industry average ($IND_GHG/Sales_{i,t}$), and the level of energy consumption adjusted for the industry average ($IND_Energy/Sales_{i,t}$). We obtain the following model specifications:

$$Q_{i,t} = \beta_0 + \beta_1 Energy/Sales_{i,t} + \beta_2 ROA_{i,t} + \beta_3 LEV_{i,t} + \beta_4 PPE_{i,t} + \beta_5 IND_ASSET_{i,t} + \beta_6 SIZE_{i,t} + \beta_7 GROWTH_{i,t} + \beta_8 AGE_{i,t} + \epsilon_t \quad (3)$$

$$Q_{i,t} = \beta_0 + \beta_1 IND_GHG/Sales_{i,t} + \beta_2 ROA_{i,t} + \beta_3 LEV_{i,t} + \beta_4 PPE_{i,t} + \beta_5 IND_ASSET_{i,t} + \beta_6 SIZE_{i,t} + \beta_7 GROWTH_{i,t} + \beta_8 AGE_{i,t} + \epsilon_t \quad (4)$$

$$Q_{i,t} = \beta_0 + \beta_1 IND_Energy/Sales_{i,t} + \beta_2 ROA_{i,t} + \beta_3 LEV_{i,t} + \beta_4 PPE_{i,t} + \beta_5 IND_ASSET_{i,t} + \beta_6 SIZE_{i,t} + \beta_7 GROWTH_{i,t} + \beta_8 AGE_{i,t} + \epsilon_t \quad (5)$$

Corporate characteristics have been reported to influence firm value, and, thus, this study utilizes corporate characteristics as control variables. Leverage (LEV), according to the signal hypothesis, is expected to have a positive relationship with firm value (Black, Jang, and Kim, 2006); however, according to the pecking order theory, the relationship may be negative (Myers and Majluf, 1984). Therefore, the signs on the coefficient are not predicted. Previous studies (Waddock and Graves, 1997; Orlitzky, Schmidt, and Rynes, 2003; Cheng, Ioannou, and Serafeim, 2014) have also used leverage to control for risks inherent to a company. ROA represents a company's profitability and generally has a positive relationship with firm value (Gupta and Newberry, 1997; Campbell 2007; Chen et al. 2010; Dhaliwal et al. 2011; Ioannou and Serafeim 2012). The ratio of property, plant, and equipment (PPE) to total assets is used to control for a company's financial factors. Intangible assets (INT_ASSET) refer to the ratio of intangible to total assets, and growth (GROWTH) is measured by growth in sales. Both intangible assets and growth

indicate future growth opportunities and are expected to have a positive relationship with firm value (Burke, Logsdon, Mitchell, Reiner and Vogel, 1986; Morck, Shleifer, and Vishny 1988). The size of a company (SIZE) is obtained by taking the natural logarithm of its total assets. A larger firm size may have a negative effect on firm value (Black et al., 2006), as agency (Demsetz and Lehn, 1985) and political costs increase with size; however, economies of scale may have a positive effect on firm value. Therefore, the signs on the coefficient are not predicted (Gulati, 1995; McWilliams and Siegel, 2001; El Ghoul, Guedhami, Kwok and Mishra, 2011; Ioannou and Serafeim 2012). The age of a company (AGE) is used to control for the effect of a company's life cycle on firm value (Drobetz, Schillhofer and Zimmermann, 2004; Black et al., 2006; Mishra, 2015). A company's GHG emissions are largely affected by the industry, and the relationship between firm value and the amount of GHG emissions may differ accordingly. Therefore, an industry dummy variable is also included in the analysis. Furthermore, firm value may be affected by economic and market conditions. Since there are concerns that particular events, such as the establishment of new regulations on GHG emissions or the introduction of a carbon trading system, may influence the level of GHG emissions and firm value, year dummy variables are used to control measurement errors in each year.

relationship between the level of GHG emissions and firm value. To this end, an analysis is performed on the controlled entities, for which GHG emissions and energy consumption data are made public under the TMS. The sample period is limited to five years, from 2011 to 2015. The analysis period starts in 2011 because the TMS, which contains the GHG emissions and energy data, was enforced in 2010 in Korea and the relevant data have only been released since 2011. The data on the controlled entities' GHG emissions and energy consumption are collected from the Greenhouse Gas Inventory and Research Center, and the financial statements of the entities are collected from TS-2000. The industries are categorized according to the 2-digit code of the Korean Standard Industrial Classification (KSIC). A total of 4,137 observations of the controlled entities are collected from 2011 to 2015, of which 73 observations do not disclose emission information. A total of 2,527 observations are excluded from the sample, as they were from private companies. A total of 17 observations are from companies with multiple controlled facilities. In the case of a company that has multiple facilities under the TMS, the sum of the emissions of the facilities is regarded as the total emission of the company. Excluding the observations of companies in the finance industry as well results in a final sample of 1,134 firm-year observations. Our dataset is unbalanced panel data and the outliers at the top and bottom 1% are winsorized.

3.3. Sample selection

The objective of this study is to examine the

Table 2. Sample selection criteria

Samples	Obs.
Observations from the controlled entities that are subject to disclosure of GHG emissions or energy consumption	4,137
Observations from the entities that refused to disclose information	73
Private companies	2,527
Companies with multiple facilities	17
Financial companies	386
Final samples (firm-year observations)	1,134

4. Results of the empirical analysis

4.1. Descriptive statistics and correlation analysis

Table 3 presents the descriptive statistics of the main variables in this study. The average Tobin's Q value for domestic companies that are subject to the TMS is 1.201, just above 1. GHG/Sales, which is the main test variable, indicates that the average GHG emissions per KRW 1 in sales for Korean companies is 0.391 tCO₂eq. The median value of GHG/Sales is merely 0.122 tCO₂eq/KRW, which means that the average substantially exceeds the median. In particular, companies that are in the top 1% range in the order of the amount of emissions emit 4.808 tCO₂eq per KRW 1 in sales. This result indicates that a small number of companies emit a substantially large amount of GHGs. The average energy consumption per KRW 1 in sales shows a similar pattern. The averages of IND_GHG/Sales and IND_Energy/Sale, indicators of industry-adjusted

GHG emissions and energy consumption, respectively, are both 0, as they are adjusted for the industry average. Both indicators have negative medians, which suggest that a few observations in the same industry have very a high level of emissions.

Table 4 describes the GHG emissions and energy consumption per KRW 1 in sales by industry from 2011 to 2015. Industries are categorized according to the 2-digit code of the KSIC. The table shows that GHG emissions and energy consumption per KRW 1 in sales are generally proportional to each other. The industry with the lowest level of GHG emissions is 'warehousing and support activities for transportation', while 'wholesale trade on own account or on a fee or contract basis' and 'general construction' are the industries with the lowest levels of GHG emissions and energy consumption per KRW 1 in sales. 'Manufacture of other non-metallic mineral products' is the industry with the largest amounts of GHG emissions and energy consumptions; it emits 3.37 tCO₂eq of GHGs and uses 1.0206 TJ of energy per KRW 1 in sales. The top 10 industries in terms

Table 3. Descriptive statistics

	mean	sd	p1	p25	p50	p75	p99
Tobin's Q	1.201	0.871	0.333	0.768	0.963	1.263	6.089
GHG/Sales	0.391	0.836	0.007	0.050	0.122	0.452	4.808
Energy/Sales	0.005	0.007	0.000	0.001	0.002	0.008	0.036
IND_GHG/Sales	0.000	1.041	-3.235	-0.195	-0.024	0.044	5.286
IND_Energy/Sales	0.000	0.011	-0.016	-0.003	-0.001	0.001	0.026
ROA	0.019	0.084	-0.380	0.002	0.026	0.056	0.262
LEV	1.210	1.751	0.005	0.340	0.731	1.383	12.879
PPE	0.300	0.201	0.000	0.142	0.290	0.435	0.862
IntAsset	0.016	0.024	0.000	0.003	0.007	0.017	0.138
SIZE	19.891	1.505	17.029	18.891	19.646	20.648	24.122
Growth	0.049	0.267	-0.582	-0.062	0.026	0.112	1.674
Age	3.528	0.666	1.609	3.332	3.761	3.989	4.500

Tobin's Q is a proxy of firm value and is calculated by dividing the sum of the market value of common stocks, and the book values of preferred stocks and liabilities by total assets. GHG/Sales is GHG emissions (tCO₂eq) per KRW 1 in sales, and Energy/Sales is energy consumption (TJ) per KRW 1 in sales. IND_GHG/Sales is the industry-adjusted value of GHG/Sales and is calculated by subtracting the industry average of GHG/Sales from a company's GHG/Sales. Therefore, a higher IND_GHG/Sales indicates a higher level of GHG emissions per KRW 1 in sales compared to the industry average. IND_Energy/Sales is computed by subtracting the industry average of Energy/Sales from the company's Energy/Sales. Likewise, a higher IND_Energy/Sales means a higher level of energy emissions per KRW 1 in sales compared to the industry average. In the case of the industry-adjusted variables, we exclude the industries with fewer than five observations per year. ROA is obtained by dividing net profit by the average of the current year and previous year total assets. LEV is leverage, and PPE is calculated by dividing property, plant, and equipment by total assets in the previous year. IntAsset is calculated by dividing intangible assets by total assets in the previous year, and SIZE is obtained by taking the natural logarithm of total assets. Growth is the growth rate of sales, and AGE is the natural logarithm of the history of a company.

Table 4. The average level of the GHG emissions and energy consumption by industry

Industry	GHG/ Sales	Energy/Sales
Warehousing and support activities for transportation	0.0066	0.0001
Wholesale trade on own account or on a fee or contract basis	0.0111	0.0002
General construction	0.0114	0.0002
Computer programming, consultancy and related activities	0.0184	0.0004
Manufacture of other transport equipment	0.0305	0.0005
Manufacture of tobacco products	0.0329	0.0007
Sports activities and amusement activities	0.0534	0.0010
Retail trade, except motor vehicles and motorcycles	0.0539	0.0011
Manufacture of electrical equipment	0.0679	0.0014
Postal activities and telecommunications	0.0684	0.0014
Professional services	0.0773	0.0015
Manufacture of food products	0.0802	0.0017
Manufacture of leather, luggage and footwear	0.1014	0.0020
Air transport	0.1159	0.0017
Manufacture of rubber and plastics products	0.1238	0.0025
Manufacture of motor vehicles, trailers and semitrailers	0.1478	0.0024
Manufacture of other machinery and equipment	0.1963	0.0024
Manufacture of textiles, except apparel	0.2068	0.0040
Manufacture of electronic components, computer; visual, sounding and communication equipment	0.2404	0.0044
Manufacture of coke, briquettes and refined petroleum products	0.2538	0.0037
Manufacture of pharmaceuticals, medicinal chemical and botanical products	0.2896	0.0052
Manufacture of wood and of products of wood and cork; except furniture	0.3224	0.0104
Land transport and transport via pipelines	0.3494	0.0050
Manufacture of basic metals	0.4100	0.0061
Manufacture of chemicals and chemical products; except pharmaceuticals and medicinal chemicals	0.4435	0.0082
Manufacture of beverages	0.4884	0.0043
Electricity, gas, steam and air conditioning supply	0.5316	0.0101
Manufacture of pulp, paper and paper products	0.7718	0.0122
Manufacture of other non-metallic mineral products	3.3743	0.0206

Table 4 describes the GHG emissions and energy consumption per KRW 1 in sales by industry from 2011 to 2015. Industries are categorized according to the 2-digit code of the KSIC.

of the amount of GHG emissions are ‘warehousing and support activities for transportation’, ‘wholesale trade on own account or on a fee or contract basis’, ‘general construction’, ‘computer programming, consultancy and related activities’, ‘manufacture of other transport equipment’, ‘manufacture of tobacco products’, ‘sports activities and amusement activities’, ‘retail trade, except motor vehicles and motorcycles’, ‘manufacture of electrical equipment’ and ‘postal

activities and telecommunications’.

Table 5 shows the results of the correlation analysis of the major variables. Some variables used in this study have asymmetric relationships, and thus, the Spearman correlation coefficient (upper) and the Pearson’s correlation coefficient (bottom) are also presented. GHG/Sales, Energy/Sales, IND_GHG/Sales, and IND_Energy/Sales, which indicate the GHG emission level, energy consumption level, industry-

Table 5. Correlation Coefficients

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
(1)TobinQ	1	-0.2809*	-0.2964*	-0.0577	-0.0623*	0.2698*	0.1997*	0.038	0.2509*	0.2150*	0.1807*	-0.2810*
(2)CO2/Sales	-0.1442*	1	0.9770*	0.4740*	0.4109*	-0.0952*	-0.1294*	0.3478*	-0.3012*	-0.4011*	-0.1484*	0.0659*
(3)Energy/Sales	-0.2038*	0.8096*	1	0.4439*	0.4473*	-0.1155*	-0.1337*	0.3510*	-0.3112*	-0.3963*	-0.1548*	0.0671*
(4)IND_CO2/Sales	-0.0289	0.5818*	0.4678*	1	0.8582*	-0.0047	-0.0841*	0.0946*	-0.1229*	0.0212	-0.0593	0.015
(5)IND_Energy/Sales	-0.0406	0.2511*	0.6657*	0.4883*	1	-0.0326	-0.0516	0.0929*	-0.1447*	0.0558	-0.0314	0.0312
(6)ROA	-0.0632*	-0.0534	-0.0986*	-0.1025*	-0.022	1	-0.4755*	-0.1154*	0.0705*	0.0448	0.3066*	-0.0842*
(7)LEV	0.0607*	-0.0363	0.0023	0.1236*	0.0509	-0.3427*	1	0.2173*	0.1016*	0.1325*	0.0325	-0.1867*
(8)PPE	-0.0948*	0.1903*	0.3341*	0.1657*	0.1198*	0.0390*	0.1335*	1	-0.0004	-0.0523	0.0536	-0.0780*
(9)IntAsset	0.1615*	0.0009	-0.1488*	0.0339	-0.0297	-0.0068	-0.031	-0.0277	1	0.3251*	0.1339*	-0.1337*
(10)SIZE	-0.0357*	-0.1074*	-0.1785*	0.0522	-0.0072	0.1429*	0.1236*	0.1153*	0.0521*	1	0.0625*	0.004
(11)Growth	0.0646*	0.0082	-0.0429	0.0235	0.0157	0.2040*	-0.0754*	0.0033	0.0812*	0.0116	1	-0.0139
(12)Age	-0.1127*	0.0309	0.0695*	0.0227	-0.0313	-0.0843*	-0.0316	-0.011	-0.0768*	-0.0031	-0.1054*	1

Table 5 shows the results of the correlation analysis of the major variables. Spearman correlation coefficient (upper) and Pearson's correlation coefficient (bottom) are also presented. * significant at the 5% or 1% level.

adjusted GHG emission level, and industry-adjusted energy consumption level, respectively, are found to have a negative relationship with Tobin's Q, the proxy of firm value. GHG/Sales and Energy/Sales are significant at the 1% and 5% levels, respectively. However, a simple correlation coefficient is a result of examining a linear relationship between two variables without controlling other factors affecting firm value, and thus, it is hard to give a significant interpretation to this coefficient. Therefore, the impact of GHG emissions and energy consumption on firm value should be tested by performing a multi-variable regression analysis, which will be described in the next section.

4.2. Main analysis

Table 6 presents the results of testing the relationship between the levels of GHG emissions and energy consumption of the controlled entities of the TMS and their firm value. Column 1 presents the results of the ordinary least squares analysis on model (2). The estimated coefficient on GHG/Sales is negative and significant at the 1% level, which supports our hypothesis. That is, a company with a higher level of GHG emissions has a lower firm value, and when 1 tCO₂eq of GHG is emitted per KRW 1 in sales,

firm value measured as Tobin's Q decreases by 0.07. Column 2 shows the results of the analysis on model (3), which tests the relationship between energy consumption and firm value. Just like the results presented in Column 1, the level of energy consumption has a statistically significant relationship with firm value at the 1% level, which confirms that a higher level of energy consumption leads to lower firm value. Columns 3 and 4 present the results of verifying the relationship between firm value and industry-adjusted GHG emissions and industry-adjusted energy consumption, respectively. The amount of GHG emissions or energy consumption is largely affected by the characteristics of an industry sector; therefore, the impact of industry-adjusted GHG emissions or energy consumptions on firm value should be examined. The results in columns 3 and 4 also indicate that the estimated coefficients on IND_GHG/Sales and IND_Energy/Sales are negative and significant at the 5% and 1% levels, respectively. This finding suggests that higher levels of GHG emissions and energy consumption compared to the industry average have a negative impact on firm value, while lower levels have a positive impact. The results for the other control variables show that a higher ROA, higher LEV, higher ratio of intangible assets (IntAsset), higher growth, and shorter AGE lead to higher firm

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

TobinQ	Predicted sign	(1)	(2)	(3)	(4)
GHG/Sales	-	-0.07*** (-2.67)			
Energy/Sales	-		-12.38*** (-3.56)		
IND_GHG/Sales	-			-0.07** (-2.36)	
IND_Energy/Sales	-				-11.87*** (-3.31)
ROA	+	1.49*** (4.41)	1.45*** (4.29)	1.42*** (4.20)	1.39*** (4.11)
LEV	+/-	0.07*** (5.60)	0.07*** (5.47)	0.07*** (5.52)	0.07*** (5.56)
PPE	+/-	-0.04 (-0.30)	0.03 (0.19)	-0.03 (-0.23)	0.01 (0.10)
IntAsset	+	5.26*** (4.41)	4.76*** (4.00)	5.40*** (4.54)	4.92*** (4.13)
SIZE	+/-	-0.00 (-0.11)	-0.00 (-0.08)	-0.00 (-0.02)	0.00 (0.14)
Growth	+	0.19** (1.97)	0.11 (1.21)	0.19* (1.94)	0.16* (1.70)
Age	+/-	-0.07** (-2.24)	-0.07** (-2.36)	-0.06** (-2.13)	-0.06** (-2.07)
Year Dummy		YES	YES	YES	YES
Industry Dummy		YES	YES	YES	YES
Obs.		1087	1087	1031	1031
F-statistics		8.13***	7.79***	5.97***	6.23***
Adj. R ²		0.21	0.2	0.13	0.17

Table 6 presents the results of testing the relationship between the levels of climate change risk and their firm value. All estimates are derived from OLS regression analysis. *, **, *** significant at the 10%, 5%, 1%.

value. In contrast, the ratios of PPE to total asset and company size do not have a significant correlation with firm value.

Table 7 shows the results of the analysis on the entire sample classified into high and low climate change risk industries to verify the relationship between the level of GHG emissions and firm value in each group. The criteria for industry classification are the industrial averages of GHG emissions and energy consumption per KRW 1 in sales. The Top 10 industries are defined as industries with high

climate change risks, and the rest are defined as industries with low climate change risks. The industries with high risks are 'warehousing and support activities for transportation', 'wholesale trade on own account or on a fee or contract basis', 'general construction', 'computer programming, consultancy and related activities', 'manufacture of other transport equipment', 'manufacture of tobacco products', 'sports activities and amusement activities', 'retail trade, except motor vehicles and motorcycles', 'manufacture of electrical equipment' and 'postal activities and telecommunications'.

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

TobinQ	Predicted sign	Industries with low climate change risks		Industries with high climate change risks	
		(1)	(2)	(3)	(4)
GHG/Sales	-	-0.18 (-1.00)		-0.05** (-2.17)	
Energy/Sales	-		-15.1 (-1.27)		-10.61*** (-3.18)
ROA	+	0.66 (1.36)	0.65 (1.35)	2.71*** (5.76)	2.59*** (5.51)
LEV	+/-	0.03 (1.45)	0.03 (1.43)	0.13*** (7.46)	0.12*** (7.27)
PPE	+/-	0.21 (0.91)	0.21 (0.93)	-0.24 (-1.57)	-0.14 (-0.89)
IntAsset	+	6.30*** (4.03)	6.12*** (3.89)	2.57 (1.28)	1.90 (0.96)
SIZE	+/-	-0.06 (-0.73)	-0.02 (-0.82)	0.01 (0.81)	0.02 (1.08)
Growth	+	0.07 (0.54)	0.01 (0.04)	0.42*** (2.99)	0.28** (2.09)
Age	+/-	-0.03 (-0.71)	-0.04 (-0.89)	-0.09** (-2.24)	-0.09** (-2.44)
Year Dummy		YES	YES	YES	YES
Industry Dummy		YES	YES	YES	YES
Obs.		545	542	544	543
F-statistics		5.28***	8.22***	4.84***	8.54***
Adj. R ²		0.20	0.22	0.18	0.22

Table 7 shows the results of the analysis for which the entire sample is classified into industries with high climate change risks and those with low climate change risks to verify the relationship between the level of GHG emissions and firm value in each group. The criteria for industry classification are the industrial averages of GHG emissions and energy consumption per KRW 1 in sales. The Top 10 industries are defined as industries with high climate change risks, and the rest are defined as industries with low climate change risks. ***, ***, * significant at the 10%, 5%, 1%, respectively.

When calculating the industry averages of GHG emissions and energy consumption levels, the top 10 industries in both criteria are found to be the same.

The results show that the industry classification is significant. In the industry group with low climate change risks, the estimated coefficients on GHG/Sales and Energy/Sales do not have significant explanatory power over firm value, while the two coefficients are negative and statistically significant at the 5% and 1% levels, respectively, in the industry group with high climate change risks. In other words, higher levels of GHG emissions and energy consumption

have a negative impact on firm value in the industry group with high climate change risks. The coefficients on the levels of GHG emissions and energy consumption adjusted for the industry average are negative and significant only in the industry group with high climate change risks, although this finding is not reported in the table. The regression coefficients (t value) on IND_GHG/Sales and IND_Energy/Sales are -0.17 (-0.97) and -14.01 (-1.18), respectively, in the industry group with low climate change risks, and -0.05 (-1.95) and -11.28 (-3.20) in the industry group with high climate change risks. That is, in the group with high

climate change risks, firms that produce a lesser amount of emissions than the industry average have a higher firm value, while those that emit a larger amount of emissions have a lower firm value. This finding calls for greater efforts of the companies that belong to the high-risk group to reduce GHG emissions and energy consumption.

4.3. Additional and robustness test

The results in the previous section (4.2) confirm that companies with higher levels of GHG emissions, energy consumption, industry-adjusted GHG emissions, and industry-adjusted energy consumption have lower firm value, and the impact of these four variables is stronger in the group of industries with high climate change risks. This section describes the series of additional analyses that are conducted to confirm the robustness of the results presented in the previous section. Year and industry dummies are included in the additional analyses, as in the analyses described in the previous section. In the previous section, the amounts of GHG emissions and energy consumption are divided by sales to adjust for the size of a company. Panel A of Table 8 presents the results of the analysis where GHG emissions and energy consumption are divided by total assets instead. The same analysis was repeated using these variables and the results are consistent with the findings of the previous section. In addition, the coefficients on industry-adjusted GHG emissions and energy consumption are negative and significant at the 5% and 10% levels, respectively.

In Panel B, ROA is used as a measure of firm value (Brown, Crabb, and Haushalter, 2003; Bartram et al., 2009; Choi, Mao, and Upadhyay, 2013; Lau, 2016) to test the robustness of the previous regression analysis where Tobin's Q is used as firm value. The results are consistent with the findings of the previous analysis, showing that higher levels of GHG emissions and energy consumption are more disadvantageous to firm value.

Lastly, in Panel C, the traditional Ohlson (1995)'s model (Boonlert-U-Thai and Duangploy, 2015; Ji,

2017) is used to verify the relationship between firm value and GHG emissions and energy consumption. In this analysis, the dependent variable is per share price of common stock, and the control variables are book value per share (BPS) and earning per share (EPS), and GHG emissions and energy consumption serve as non-financial information. The results show that the regression coefficients on BPS and EPS are positive and significant at the 1% level, confirming the validity of the model. The coefficients on GHG emissions, energy consumption, and industry-adjusted GHG emissions and energy consumption, which are the main variables, are all negative and significant at the 5% level. All the results indicate consistency with the findings from the earlier analyses.

In this research, we examine whether the climate change risks affect firm value. Generally, as the size of the enterprise is larger, the greenhouse gas emissions and energy consumptions are large, so the scale effect may have influenced the result. For this reason, in the previous section, we have used the variable to adjust GHG emissions and energy consumption to sales as a proxy for climate change risks. In addition, table 9 presents the results of analysis using 2 stage least squares regression in order to show more robust results by controlling the possible endogeneity between firm value and climate change risk. As a specific method of 2SLS, firstly, in step 1, estimate the greenhouse gas emissions and energy consumption variables, which are variables of interest. Next, the estimate obtained in Step 1 is included in the two-step regression. The two-step regression model exactly matches equations (2) and (3), except that GHG / Sales and Engery / Sales are estimated values. Explanatory variables for the estimation in Step 1 are selected based on the results of past previous studies measuring environmental performance. As a result of the analysis, it is confirmed that the firm value has a negative relation with the climate change risk, which is the same as the result of the previous section.

Table 8. Additional Analysis

Panel A : Results with changed definitions for the variables GHG emissions level and energy consumption level				
TobinQ	(1)	(2)	(3)	(4)
GHG/TA	-0.12*** (-2.58)			
Energy/TA		-15.50*** (-2.81)		
IND_GHG/TA			-0.09** (-2.01)	
IND_Energy/TA				-8.40* (-1.66)
Obs.	1087	1087	1031	1030
Adj. R ²	0.21	0.21	0.13	0.13
Panel B : Results with ROA as a variable of firm value				
ROA	(1)	(2)	(3)	(4)
CO2/Sales	-0.01** (-2.31)			
Energy/Sales		-0.82*** (-2.62)		
IND_CO2/Sales			-0.01** (-2.00)	
IND_Energy/Sales				-0.74** (-2.26)
Obs.	1107	1107	1044	1044
Adj. R ²	0.31	0.31	0.30	0.30
Panel C : Results of test using the Ohlson model				
P	(1)	(2)	(3)	(4)
CO2/Sales	-3.26** (-2.46)			
Energy/Sales		-432.03** (-2.45)		
IND_CO2/Sales			-3.47** (-2.43)	
IND_Energy/Sales				-411.74** (-2.20)
Obs.	999	999	944	944
Adj. R ²	0.80	0.79	0.78	0.78

Panel A presents the results of the analysis where GHG emissions and energy consumption are divided by total assets instead. In Panel B, ROA is used as a measurement of firm value for the robustness. Lastly, in Panel C, the traditional Ohlson (1995)'s model is used to verify the relationship between firm value and GHG emissions and energy consumption. Year and industry dummies are all included in the additional analyses. The results of the control variable analyses are left out owing to space constraints. *, **, *** significant at the 10%, 5%, 1%.

Table 9. 2SLS analysis to control endogeneity

Independent variable	GHG/Sales and Tobin's Q		Energy/Sales and Tobin's Q	
	(1)	(2)	(3)	(4)
	1 st Stage	2 nd Stage	1 st Stage	2 nd Stage
	GHG/Sales	Tobin's Q	Energy/Sales	Tobin's Q
Pred_GHG		-10.28** (-2.08)		
Pred_Energy				-854.05*** (-3.24)
Lag_Q	-0.08** (-2.03)		-0.00*** (-3.16)	
ROA	-0.60 (-1.45)	-6.26 (-1.16)	-0.00 (-1.46)	-4.13 (-1.34)
LEV	-0.03* (-1.90)	-0.30 (-1.30)	-0.00 (-1.35)	-0.14 (-1.19)
PPE	1.07*** (6.43)	10.97** (1.97)	0.01*** (9.34)	10.24*** (3.04)
IntAsset	3.13** (2.06)	33.01 (1.61)	-0.02 (-1.55)	-14.84 (-1.30)
SIZE	0.02 (1.04)	0.17 (0.86)	0.00 (0.89)	0.08 (0.71)
Growth	-0.38** (-2.46)	-3.59 (-1.43)	-0.00*** (-2.75)	-2.49* (-1.83)
Age	-0.01 (-0.17)	-0.08 (-0.20)	0.00 (0.55)	0.13 (0.51)
Year Dummy	YES	YES	YES	YES
Industry Dummy	YES	YES	YES	YES
Obs.	863	863	863	863
F-statistics	11.76***	-	15.51***	-
Wald X^2	-	6.20		14.60
Adj. R ²	0.33	-	0.40	-

Table 9 presents the results of using 2 stage least square estimation (2SLS) to control endogeneity. Column 1 and column 3 show the first step for 2 SLS. Column 1 estimates greenhouse gas emissions level and Column 2 estimates equation (2) using the results from column 1. In column 3, the energy consumption level is estimated and equation (3) is estimated in column 4 using the estimated results from column 3. *, **, *** significant at the 10%, 5%, 1%, respectively.

5. Conclusions

This study examined the relationship between climate change risks and firm value by performing analyses on listed Korean companies subject to the TMS for a five-year period, from 2011 to 2015. The

proxies for climate change risks are a company's levels of GHG emissions and energy consumption, and the proxy for firm value is Tobin's Q. As GHG emissions and energy consumption are sensitive to the characteristics of industries, industry-adjusted GHG emissions and energy consumption were also examined. This study found that the levels of GHG

emissions and energy consumption have a negative and significant relationship with firm value. That is, higher levels of GHG emissions and energy consumption, which act as climate change risks, have a larger negative impact on firm value. In addition, higher levels of industry-adjusted GHG emissions and energy consumption led to lower firm value, which indicates that making efforts to cut GHG emissions and energy consumption to levels lower than the industry average is important. In addition, these relationships were stronger in the group of industries with high climate change risks. We also performed 2sls analysis to control endogeneity and the results were the same as the previous results. These results are not significantly different from previous studies (Iwata and Okada, 2011; Chapple et al., 2013; Matsumura et al., 2014; Saka and Oshika, 2014) except for the study in Australia (Wang et al., 2014), which has the characteristics of resource extraction industry and low CSR investment.

This study makes several contributions by examining the relationship between Korean companies' GHG emissions and their firm value, following the global trend of valuing businesses using natural environment factors. Unlike many foreign studies that used data voluntarily provided by companies participating in particular programs, this study used GHG emissions and energy consumption data disclosed in accordance with the local law that mandates some companies to report such information, which minimized self-selection bias. In addition, to address the issues raised in the previous studies (Bush and Hoffmann, 2011), this study classified industry groups depending on the levels of GHG emissions and energy consumption, and performed additional analyses using alternative measures for the emissions. Therefore, the present findings that can be used to motivate companies to reduce their GHG emissions and may lay the foundation for policy making.

Despite these contributions, however, this study suffered some limitations. This study analysed companies that are subject to the TMS, not all publicly traded companies in Korea, which means that there may be a bias in the sample selection. Nonetheless,

considering that the companies for which GHG emissions exceed the threshold are subject to the TMS, the emissions of companies that are not monitored under the system are likely to have little impact on firm value.

GHG emissions data will be more widely accumulated as time passes, and thus, future research will be able to present additional evidence that can be further generalized. In particular, the enforcement of the carbon trading system in Korea in 2015 allows researchers to analyse the impact of the carbon trading system on the relationship between climate change risks and firm value. Research on the outcome of the carbon trading system, and changes in firm value and market responses as a result of changes in environmental regulation on climate change, are also expected to be conducted in the future. In addition, a comparative analysis could be performed on the voluntarily disclosed data on GHG emissions, such as the data from the CDP, and the data of the controlled entities of the TMS to see if a bias exists in the voluntarily disclosed GHG emissions data.

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