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An Estimate of Internal Carbon Pricing of Korean Companies under the Emission Trading scheme

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Abstract

This paper estimates an internal carbon pricing of Korean companies under the Korean domestic emission trading scheme using firm-level data. Internal carbon pricing is a monetary value putting on GHG emissions, which enables companies to take a measurable approach of carbon management and investment strategy in business operations. The price of emission a company decides to buy the credit considering its marginal GHG abatement cost is used as a proxy for an internal carbon pricing in this study.

The data were collected from 100 respondents mainly from energy intensive industries in Korea. A multiple-bounded discrete choice (MBDC) format was adopted as an analysis method. The results indicate that the range of the internal carbon price on the part of 50% of the samples corresponds to about 12,500~20,000 KRW/t-CO_2 (11.7~18.7 USD/t-CO_2). Using econometric analysis, this study identifies and discusses the determinants that associate to the internal carbon pricing based on an analytical framework developed in this study.

This study contributes to provide insight into a possible method of estimation of corporate internal carbon pricing and its findings have meaningful implications for the government to initiate and assist in company proactive carbon management and further policy improvement.

Key words: internal carbon pricing, emission trading scheme, multiple-bounded discrete choice, company, Korea

1. Introduction

Putting the price on activities emitting greenhouse gases (GHG) is expected to provide a clear signal to guide economic decision-making at the same time as stimulating innovation of low-carbon technologies, which will bring the development paradigm shift to low carbon green economy using less carbon for growth. Correspondingly, carbon pricing as the form of a carbon tax or an emissions trading system has become a tool increasingly used to address climate change by 27 nations and 40 regions (World Bank Group and Ecofys, 2016).

Under these circumstances, there's growing momentum in the private sector. They see the risks of climate impacts as well as pressures of related government policy such as carbon pricing to their businesses. Seeking to manage these weights and not to weaken the competitiveness but turn them as an opportunity of a transition to low-carbon business models, companies are increasingly aware of the need for carbon management and are embedding relevant strategies

Especially, companies use the price of carbon in a different way in their financial planning by adopting an internal carbon price. An internal price places a monetary value on GHG emissions that enables companies to take a measurable approach of carbon management and investment strategy in business operations (CDP, 2017). Internalized price in a company brings the primary benefits that include the opportunity behavior change to drive efficiency and demonstrate responsibility and leadership (Microsoft, 2013). Today, a number of companies around the world taking climate action by instituting their own internal price on carbon has been increasing (CDP (2017), C2ES (2017)).

However, in academic side, there is lack of literatures. Several documents related to internal carbon pricing were released by CDP report in annual base, C2ES (2017), I4CE (2016), Microsoft (2013 and 2015) and etc. These reports clarified the definition of internal carbon pricing, categorized the types of internal carbon pricing, identified its benefits, and showed practical cases of internal carbon pricing implementation. Only few provide the estimation method of internal carbon pricing. Microsoft showed a model of internal carbon fee in a simple way that can be replicable.

However, while the use of internal carbon prices in a company is becoming more common, the core part is 'how a particular internal carbon pricing value is decided upon' and 'how to integrate the cost into the financial strategies?' since they provide insight into factors that may inform and influence in company's carbon strategies and business management.

To answer it, this study attempt to estimate the internal carbon pricing using firm-level data focusing on Korean companies who have undergone carbon market through their domestic emission trading scheme (K-ETS), the first nationwide domestic emission trading scheme in the

North East Asia and has closed the first phase (2015-2017) in 2017. Covering 70% of national GHG emission, the K-ETS targeted mainly industry and power sectors. Companies are required to implement proactive carbon management responding to it. In our previous studies investigating companies' perspectives and responding to the carbon pricing, many of Korean companies conduct activities little deviated from existing energy and environmental management. One of noteworthy findings was the association of companies' internal carbon pricing among those companies implemented proactive carbon-oriented management in the republic of Korea (hereafter Korea) (Suk et al., 2018 to be submitted).

The remainder of this paper is structured as follows: Section 2 provides the different dimensions of pricing on carbon through a literature review. Section 3 explains the research method and materials, including the analytical framework, method models for quantification, and outline of questionnaire survey and samples used in the study. Section 4 presents and discusses the analysis results and finding. Section 5 provides summary and policy implications.

2. Price on carbon

2.1 Carbon price in different dimensions

In economics, climate change is described as a 'market failure'. Related to this issue of market failures is the specific concept of externalities. Environmental externalities generally arise when environmental resources possess the characteristics of a public good. Under the unregulated market they have been overproduced pollutants or overused the natural resource. Because the costs are not priced into the transaction. Carbon is the main cause of the global warming and climate change. To externalize the social cost of carbon, its cost as pollutant is followed by the PPP theory that suggested by Piguo (1920).

The question raised is therefore how much should one unit of carbon cost? Prior to this though, we may need to discuss how to approach price estimation. There are several pathways: one is to capture what are known as the external costs, so-called social cost, of carbon emissions. The social cost of CO_2 is a comprehensive estimate of climate change damages and includes changes in net agricultural productivity, human health, property damages from increased flood risk, and changes in energy system costs, such as reduced costs for heating and increased costs for air conditioning (EPA website).

Stern review (2006) discusses the effect of global warming on the world economy and gave specific figures that is required to be invested to avoid the worst effects of climate change. Several studies have quantitatively calculated the value of carbon. Majority studies focused on the social cost of climate change and estimated the deduction with a certain mitigation target. World Bank (various years), Hamilton and Atkinson (1996), and Hamilton and Clemens (1999) estimated the deduction as the social cost of a country's CO_2 emissions. Notably, the World Bank (2010) used a value of 20 USD/t-C. Arrow et al. (2010) estimated the deduction to be the climate change damage in a particular country as a result of global emissions in a given year. Arrow et al. (2010) and Atkinson et al. (2010) arrived at a value of 50 USD/t-C. A study by Tol (2008) involved an extensive meta-survey of over 200 estimates and indicated a wide range, from -6.6 to 2,400 USD/t-C, which variation is due largely to differences in discount rates.

Analysis by the UK government's Department of Energy and Climate Change and the Carbon Trust estimates that, in a scenario where warming is limited to less than 2 degrees, the global price of carbon is expected to converge at $140 per ton of CO_2 by 2030 and $400 by 2050. The US Environmental Protection Agency (EPA) estimates the social cost of carbon to range between $16-152 by 2020 and $26-212 by 2050 (Goldstandard, 2016). A regulatory carbon price of at least $40-$80 per ton by 2020 and $50-$100 per ton by 2030 will be required to stay well below the 2C degree target (WB group, 2017).

Kwon and Heo (2010) suggested that a carbon tax equivalent to 36,545 KRW/t-CO_2 (about 31 USD/t-CO_2) would be required to achieve Korea's 2020 mitigation target. Calvin et al. (2012) compared the Copenhagen pledges to the results from 23 different models, all of which participated in the Asia Modeling Exercise (AME), and found that of the nine models reporting results for Korea, only two ever attain the pledged amount, with carbon prices of 30–50 USD/t-CO_2.

However, it is difficult to obtain accurate information on social marginal costs, and even if it can be obtained, when it comes to the policy implementation, it is still needed to define what optimal price level is (Morotomi, 2000). In this respect, there are difficulties in calculating carbon price by use of social costs. One solution is to apply a price level to achieve a socially or politically agreed reduction level (Baumol and Oates 1971). Another is considering the acceptable price level by subjects under the policy. Affordable carbon pricing levels for industry in North East Asia, including China, Japan and Korea, are 6.8~13.4, 4.1~10.3 and 2.3~3.4 US$/t$CO_2$, respectively (Liu et al, 2014, Suk et al., 2014).

Governments may refer various carbon pricing in different dimensions in making regulatory decisions of domestic carbon pricing policy

2.2 Internal carbon pricing of company

An internal carbon price has been defined in several documents

CDP (2013) defined as a planning tool to help identify revenue opportunities, risks, and as an incentive to drive maximum energy efficiencies to reduce costs and guide capital investment decisions. United Nations (2014) mentioned it is a financial value given, by a company, to a tonne of carbon dioxide emissions. I4CE (2016) described it as a value that companies voluntarily set for themselves, in order to internalise the economic cost of their greenhouse gas emissions.

Although each report used different terms in the definition of the internal carbon price, they have a common penetration concept that the internal carbon price is a proactive company's carbon management which is step forward the existing environmental management and a monetary tool instituting their own price on carbon in their financial planning which help weigh the risks and opportunities related to climate change.

According to the Carbon Disclosure Project (CDP), a number of companies around the world taking climate action instituted their own internal price on carbon in their financial planning to help weigh the risks and opportunities related to climate change (CDP, 2017).While most of those companies are based in North America and Europe, the sharpest increase is in emerging economies, including India, Brazil, Mexico, and China (*C2ES*, 2017*)*. The use of carbon prices is most widespread among sector, gas and electricity companies, with more than 75% of those in the energy and utilities sectors using an internal carbon price (Hermes, 2017). But the materials and telecom sectors are also heading in that direction, with more than half of companies planning to use an internal carbon price by 2019 (Hermes, 2017).

Especially in Asia including China, India, Japan, Korea, Hong Kong, Taiwan, Thailand and the Philippines, 111 companies was listed who set carbon prices in CDP report (2017). Majority of them are Japanese companies, sharing 44% of the total Asia. Korea is the second, with a share of 18%. The carbon price levels vary in a range of 5.1-908.9 USD. 76% of them is within the range of 3.4-20.5 USD. The report also indicated a list including companies that will set carbon prices within the next two years, in which there are a total of 198 companies in Asia. Among them companies in China and Japan are majority accounting for 35% and 22%, respectively.

Future proofing their companies against government carbon regulations is one of the greatest motivations for many companies adopting an internal carbon price-especially those using a shadow price. Moreover, using internal carbon pricing has several goals as a strategy to manage climate-related business risks and prepare for a transition to a low-carbon economy. Companies that invest in carbon reduction projects want to ensure that the money they invest goes as far as it can. Setting a price on carbon helps translate climate change into financial terms. Firms include assumptions of the price over time in their business decisions, apply it to emissions across the value chain, and embed it within operational as well as capital spend (Cuff, 2017). It enables to test and assess the profitability of projects in different scenarios to make better decisions to future-proof the business and also brings innovative ideas to the table on how to best allocate capital to deliver higher returns in a low-carbon economy (Goldstandard, 2016).

The C2ES report summarized benefits of internal carbon pricing through interviews with 20 global Fortune 500 companies, including: advancing a company's greenhouse gas reduction goals, preparing for future carbon regulations, responding to stakeholder demand for climate-risk disclosure, creating resilient supply chains, building a competitive advantage, and showcasing corporate responsibility.

In practical implementation of internal carbon price, there are varying ways to describe the concept of corporate internal carbon pricing. Existing reports categorized the types of internal carbon price, as indicated by gray color cells in Table 1.

Table 1 Type of internal carbon price

Reference	Type				
	Carbon fee	Explicit carbon price	Shadow price	Internal carbon price	Implicit carbon price
Camuzeaux and Medford (2016)					
C2ES Report (2017)					
I4ce (2016)					
CDP (2016)					

In overall, it can be summarized as, (1) carbon fee (internal tax, internal carbon tax), (2) explicit carbon price based on regulation, (3) shadow price, (4) implicit price considering marginal cost, (5) Internal carbon price, (6) hybrid carbon price.

(1) Carbon fee (internal tax, internal carbon tax)

Carbon fee is a monetary value on each ton of carbon emissions or a proxy measurement in investment in clean energy or energy efficiency measures that goes a step further to actually charge to business unit(s) CDP (2016). It creating a dedicated source of revenue or investment stream to fund projects that help meet a company's greenhouse gas reduction targets C2ES Report (2017). By include a plan for using the revenue or investment stream to fund the company's emissions reduction efforts in clean energy or energy efficiency measures, this can be an effective method for incentivizing more efficient operation.

Microsoft has applied an internal carbon fee of $5-$10 per ton associated with their electricity consumption and employee air travel and $10-$20 per ton, respectively (Microsoft, 2015). Walt Disney Company has set a goal to achieve zero net direct GHG emissions through energy avoidance or reduction, renewable energy, and offsetting and adopted a carbon fee, $10-$20 per ton. The money generated is used to invest in projects that fit their business objectives (C2ES Report, 2017). Ben & Jerry's has set a price of US$10 (or €10) for every metric tonne of GHG emissions and created an internal fund more than US$1 million annually to support investments that help achieve the company's GHG reduction target (Goldstandard, 2016). Consumer goods brand Unilever implemented an internal price on carbon last year of €30/tonne for significant capital expenditure projects (Edie newroom, 2017).

The observed price range for companies using an internal carbon fee is from $5-$30 per metric ton

(2) Explicit carbon price based on regulation

It is not an easy task to identify and determine a specific figure of price which enables the company's carbon strategies to be directed. Thus, a company that is subject to emission trading systems or a regulatory carbon tax in the countries where it operates may use the levels of prices available ***explicit market or regulatory price*** as the lower limit for determining its price (Camuzeaux and Medford, 2016). Under the differences in stringency of regulations, the current actual price implemented in each scheme currently vary significantly, from under 1 USD/tCO_2 in the Shanghai ETS market up to 137 USD/tCO_2 in Sweden. Prices in most countries tend to be lower, clustering under 13 USD/tCO_2

(3) Shadow pricing

Some companies operating in jurisdictions that do not have an explicit government carbon price are adopting ***shadow pricing*** levels. It is a theoretical price on carbon in contrast to an actual fee. It is used to better understand the potential impact in anticipation of future carbon regulations such as potential carbon prices, policies and caps in project planning processes to test the profitability of future investment decision and expenditure (R&D, infrastructure, financial assets, etc.) under a range of different scenarios (C2ES,2017). Testing the sensitivity of investment plans in this way enables companies to improve their risks management relating to future regulatory carbon pricing systems. For example, some company forecast fuel prices such as ones in the energy sector and model carbon prices to lower the risk of stranded assets CDP (2016).This approach to risk management is quite typical for project approval process (I4ce, 2016).

While an internal carbon fee or internal carbon fee aim is assign a value to immediate energy-efficiency initiatives for buildings and transport, shadow price often that can help support longer-term business planning and investment strategies. So that, the price may need to be higher than current government levels and increase over time to affect long-term decisions.

Some companies examined an internal carbon fee to meet their greenhouse gas reduction goals, and a shadow price to guide future investment decisions (C2ES, 2017). Novartis, a Swiss-based global healthcare company, uses a carbon price of $100/t$CO_2$ for its own greenhouse gas emissions target (Camuzeaux and Medford, 2016). ASDA (a Walmart affiliate) was one of the first UK retailers to embed a shadow cost for carbon in all its carbon mitigation investment decisions. The actual price set is confidential (Goldstandard, 2016). BHP uses a shadow price of

$24-$80 per ton to shift investments toward low-carbon options and increase the robustness of its portfolio (C2ES, 2017). UK utilities company Pennon Group gives a spread of $84.24- $324.00, using the UK government's carbon shadow pricing to monetise carbon emissions over the whole life of proposed projects (Confino, 2014). The observed price range for companies using a shadow price varies from $2-$893 per ton.

(4) Internal carbon price

Based on their self-adopted GHG emissions targets, this involves determining an emissions reduction goal and then back-calculating a carbon price that will ensure the company achieves its goal by the target date. This method is a broader approach focused more on significantly reducing emissions while also mitigating the potential future risk of carbon pricing policies (Camuzeaux and Medford, 2016). A fixed value assigned to each metric ton of emissions may reveal hidden carbon risks. When emissions bear a cost in profit-and-loss statements, it helps to uncover inefficiencies and differentiate business units within a company that use innovative design, processes, and sourcing to cut energy use and carbon pollution CDP (2016).

(5) Implicit carbon pricing

It is essentially the marginal abatement cost of the measures and initiatives implemented by a company to reduce its greenhouse gas emissions, including the cost of complying with regulations. Unlike a carbon fee or a shadow price, the implicit price is calculated retroactively based on the measures implemented to mitigate emissions. An implicit carbon price also differs from a shadow price because it is not used to assess the implications of future carbon constraints.

Instead, an implicit price can help a company understand its carbon footprint, improve internal communication, and evaluate the economic cost of a regulation on the company. Some companies use an implicit pricing strategy as a benchmark before formally launching other carbon pricing approaches—be it a carbon fee or a shadow price.

(6) Hybrid approach

A company may use a combination of these approaches.

3. Research Method and Materials

3.1 Outline of questionnaire survey and samples

A questionnaire was designed to fulfill this research purpose and consisted of three major components: general information on a company; status of company carbon management; and, estimation of price of emission credit a company decides to buy in the carbon market.

Data was collected via an emailed questionnaire survey sent to environmental and energy managers at mid-management level at companies from January to February 2017. 100 samples were collected and confirmed as valid, which included 16 petrochemical, 6 cement, 14 iron & steel, 11 paper & pulp, 10 non-ferrous, 5 machinery, 2 refining, 7 electronics and 29 from others. Of the above, 83 were targets of ETS, with non-ETS accounting for the remainder. The distribution of the samples by company size is summarised in Table 2'.

Table 2 Distribution of the valid respondents

Classification criteria		Number of respondents	Percentage (%)
Sector	Petrochemical	16	16
	Cement	6	6
	Steel & iron	14	14
	Paper	11	11
	Non-ferrous	10	10
	Machinery	5	5
	Refining	2	2
	Electronics	7	7
	Others	29	29
ETS	Targeted	83	83
	Non-targeted	17	17
Size	Large	6	6
	L-medium	36	36
	Medium	35	35
	Small	23	23
In total		100	100.0

3.2 Method measuring the tradable emission credit price

In this study, an explicit and implicit internal carbon pricing described in section 2.2 are focused. It is assumed that when a company sets an internal carbon price using a carbon price based on the carbon market price, company selects a market price among the carbon price in the fluctuating market by taking into account the its marginal carbon abatement cost. Therefore, a price of emission a company decides to trade considering its marginal abatement cost is used as a proxy for an internal carbon pricing of Korean company.

In order to estimate it, the multiple-bounded discrete choice (MBDC) is used in this study. The question and format prepared for this survey and an example response from a company is shown in Table 3.

The MBDC format allows respondents to vote on a wide range of referendums and express voting certainty for each referendum and therefore reinforces the quantity and quality of data (Liu et al. 2013). It has been utilized to estimate a company's affordability level of energy increasing due to the introduction of market-based instruments (Suk et al., 2014).

Table 3 The question and an example response of the MBDC format

Q. Considering the marginal cost of unit GHG reduction of your company, indicate the possibility of credit buy of each price of emission credit indicated in the below table for complaining the short allowance.					
Price of emission credit (KRW/tCO_2)	Possibility for purchasing permits				
	Very high	High	Modest	Low	Very low
3,000	√	④	③	②	①
5,000	√	④	③	②	①
8,000	√	④	③	②	①
10,000	⑤	√	③	②	①
12,000	⑤	√	③	②	①
15,000	⑤	√	③	②	①
18,000	⑤	④	√	②	①
20,000	⑤	④	√	②	①
23,000	⑤	④	③	√	①
26,000	⑤	④	③	√	①
30,000	⑤	④	③	②	√
33,000	⑤	④	③	②	√
37,000	⑤	④	③	②	√

A total of 13 thresholds for the carbon credit price are listed for the companies to show their possibility in making a trading decision. The companies are provided with multiple choice options, including 'very high', 'high', 'moderate', 'low' and 'very low' possibility.

Given a carbon price threshold of $PB_{ij,}$ the probability for a company to buy the credit will be

$$P_{ij} = \Pr(V_i > PB_{ij}) = 1\text{-}F(PB_{ij}) \qquad (1)$$

Once P_{ij}, the probability for company *i* to buy under the emission credit price PB_{ij}, is known by assigning numerical values to the verbal MBDC answers, equation (1) can be estimated for each company. Assuming a specific function for $F(PB_{ij})$, such as a normal accumulative distribution with a mean of μ_i, and a standard variance of σ_i, the estimation model can be written as:

$$P\text{ij} = 1 - \Phi\left(\frac{PB_{ij} - \mu_i}{\sigma_i}\right) + \lambda_i \qquad (2)$$

Where, P_{ij} is the probability for company *i* to decide to trade; PB_{ij} is the threshold of emission credit price; μ_i and σ_i is the mean and standard variance of the distribution; λ_i is an error term. Stata 10 was applied for this estimation.

3.3 Empirical model for econometric analysis

(1) Analytical framework

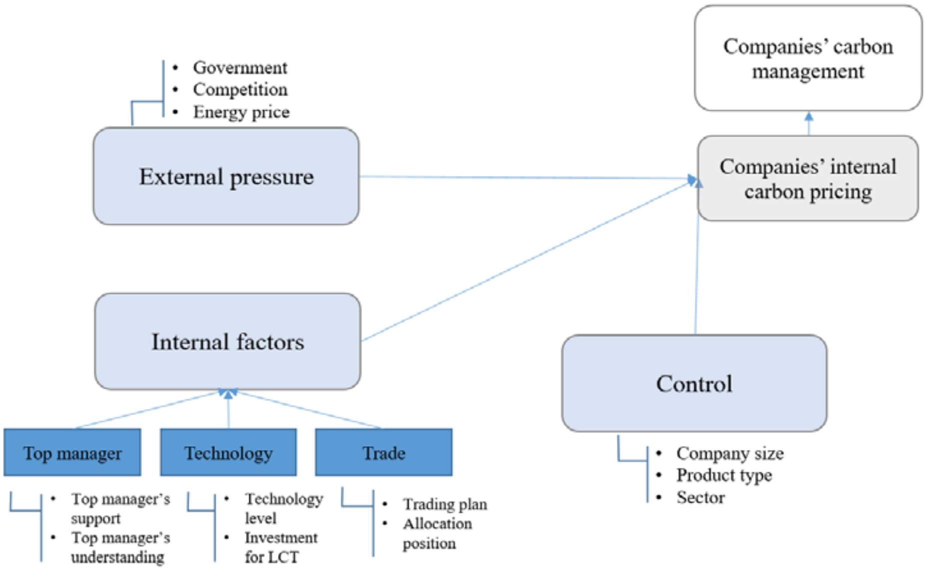

Figure 1 Analytical framework

Company's internal carbon pricing is a part of carbon management. Businesses become motivated to pursue carbon management based on different factors. Referring and modifying the analytical framework by Suk (2018, to be submitted), a theoretical framework was constructed taking into account institutional theory and stakeholder theory (Delmas and Toffel, 2004) that includes internal, external and control variables, as depicted in Figure 1. The difference from Suk (2018) is this framework states the importance of association of allocation position to companies' internal carbon pricing. See Suk (2018, to be submitted) for more detail explanation of determinant and valuation of the variables.

(2) Econometric model

The regression capturing the relationships between the companies's internal carbon pricing, and the classified determinants can be constructed as Eq. (3), where ε represents the error term and β_0 is the constant.

$$Internal\ \ carbon\ \ pricing$$
$$= \beta_0 + \beta_1 External\ \ pressues + \beta_2 Internal\ \ factors + \beta_3 Controls + \varepsilon \qquad (3)$$

4. Results and Discussion

4.1 Allocation position in the third year of the first phase (2015-2017)

Allocation is the key element affecting the trading decisions of ETS-regulated entities. Companies have shown a common tendency to claim that government quota estimates are underestimated (Suk, 2017), which made companies wait-and –see attitude in the early carbon market. In the first year of K-ETS, it was turned out that the allowance of a 40% company was over-allocated (KRX, 2016).

The surveyed companies in this study were asked to indicate whether they would have any part of their emission allowance for the first phase remaining (over-allocated), reasonable or be short (under-allocated), Of the respondents, 58% said that the allowance was under-allocated and there was high possibility of exceeding the allowances if business-as- usual energy strategies were followed in the first phase. 40% of them evaluated their allowance to be reasonable considering their projected emission amount. Remaining of 2% only expected it to be over-allocated.

As a majority of companies believe that their quota may be insufficient, in responding to and preparing for the carbon market, strategies for purchasing in the market are likely to be the main companies are focusing on. While companies said they would rather conduct internal activities and efforts to satisfy the scarce quota than market trading of emissions credits in the first year of the K-ETS, in another year, emissions trading and volume of transactions have increased, which means that securing of emission credits through transactions seems to be an important option for companies to compliance the allowance. Also, through the first phase, companies witnessed market trading patterns. That is, the majority of trade participation occurred after the emission statement was completed, so that the trading volume increased sharply for a short period of time and as a result, the price of the emission rights increased during this period. This would have made the firm to consider the occasional trading strategy.

For this, companies may monitor the market prices as an important determinant of the transaction. The market price of emission company decide to trade will be considered by their own internal carbon price considering the cost reduction of each company and the profit for investment will be an important criterion.

4.2 An estimate of companies' internal carbon price

(1) Statistic results of internal carbon pricing

As shown Figure 2, the average price of internal carbon of all samples is about 16 USD/t-CO_2. There is a difference by industry: Machinery industry is the lowest at 14.4 USD/t-CO_2 and steel & iron is the highest at 21.6 USD/t-CO_2. Most industries (Non-ferrous, electronics, cement, paper, refining, and petrochemical) took values between 15-16 USD/t-CO_2.

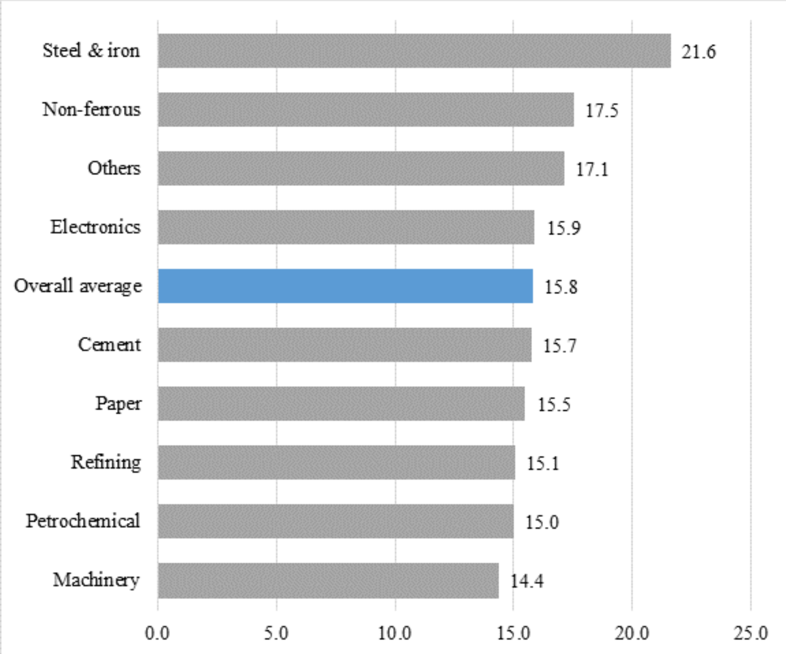

Figure 2 Statistics of companies' internal carbon price by sector

(1) Analysis results using MBDC

A cumulative normal distribution model was applied to the regressions with the aggregative share of the samples as dependent variable and the emission price as independent variable. For this quantitative analysis, available data is 73.

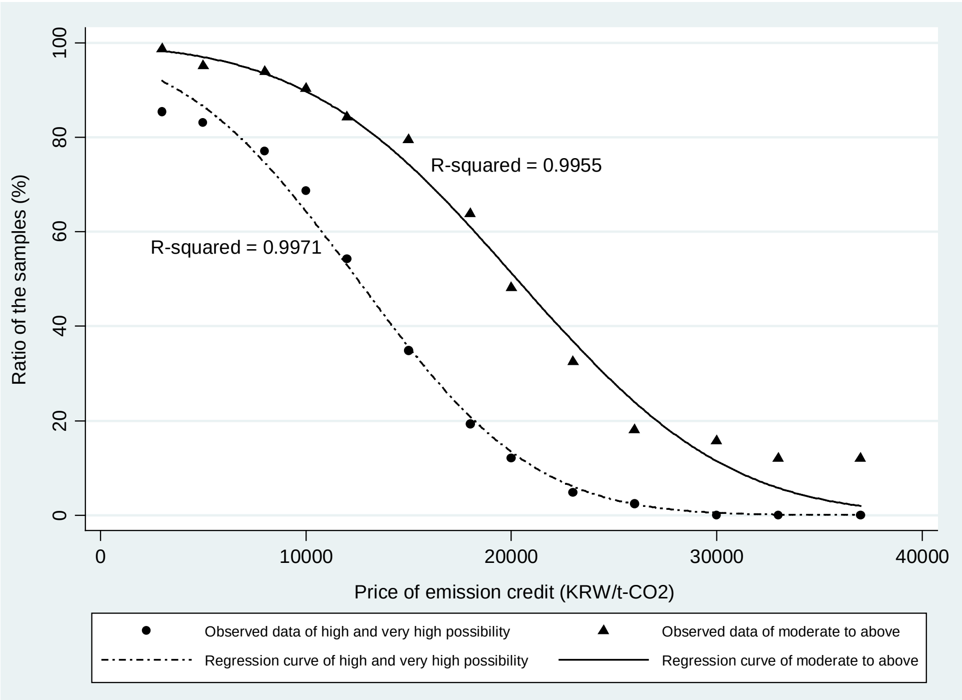

Figure 3 Simulation of companies' internal carbon price (n=73)

As shown in Figure 3 , two groups of data, 'high possibility' and 'very high possibility', and 'moderate' to 'very high possibility' are shown in dotted and solid curve, respectively, because they are meaningful for observing the rough range as decisive emission price ratios for the companies' trading. The R-squared for the regressions of two sets of data is 0.9971 and 0.9955 respectively, indicating a good fit between the observed data and regressions curves.

The range of the emission price on the part of 50% of the samples corresponds to about 12,500~20,000 KRW/t-CO_2 on the two curves, which is equivalent 12-19 USD/t-CO_2. This implies that the mean of emission price in the carbon market for the surveyed companies to buy credits would be between 12 and 19 USD/t-CO_2.These prices are in the range of emission price in the real carbon market under the K-ETS in the first phase, the annual average prices of carbon are 9.9, 15.1 and 19.3 USD/t-CO_2, respectively (MOEK, 2017) and is similar to the internal carbon price of Korean companies, 8.9-20.5USD, in the CDP report (2017).

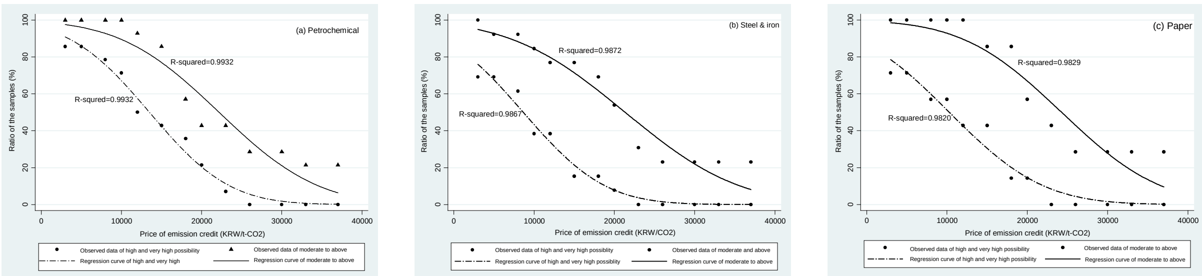

Figure 4 Simulation of companies' internal carbon price by sector (a) petrochemical, (b) steel & iron, and (c) paper

Figure 4 presents the aggregation results of observed data and their regression curves by sector including petrochemical, steel & iron and paper considering their large proportion among samples. The R squared for the regressions of two sets of data for all of them are high, 0.9932 and 0.9837 for petrochemical, 0.9867 and 0.9872 for steel & iron, and 0.9820 and 0.9829 for paper, respectively, confirming the appropriateness of the simulations. For petrochemical sector, the tradable emission price of 50% samples corresponds to 13,494 KRW/t-CO_2 and 22,189 KRW/t-CO_2, individually on the two curves.

This result shows a little bit higher range compared to the average of all samples .The results of steel & iron and paper sectors are 10,297 KRW/t-CO_2 and 24,274 KRW/t-$CO_2$and 8, 662 KRW/t-CO_2 and 21,354 KRW/t-CO_2, respectively, which has a little bit larger range than the average of all and petrochemical sector.

The mean and standard variance of internal carbon pricing were estimated using Eq. (2). Table 4 lists the mean values and percentiles of all the samples and the respondents from chemical, steel & iron and paper considering their large portion of the total.

Table 4 Mean and percentile of internal carbon pricing of samples

Variable	Obs.	Percentile	Centile	[95% Conf.Interval]	
Overall Mean=13,061 Std. dev.=3337	73	10	8792	5183	11307
		30	14635	12054	16337
		50	16954	15744	18487
		70	19287	18371	21321
		90	23849	21600	28229
Petrochemical Mean=17,305 Std. dev.=1571	12	10	4284	2000	13830.39*
		30	13438	3193	16167
		50	15457	10441	22468
		70	18818	14675	32185
		90	31272	18301	33184*
Steel & iron Mean=29,858 Std. dev.=10079	9	10	8654	8654	15776.14*
		30	13959	8654	18402.49*
		50	18168	9256	19378
		70	18999	16818	21354*
		90	21354	18620	21354
Paper Mean=14,945 Std. dev.=2625	5	10	18060	18060	19221.7*
		30	18598	18060	32675.22*
		50	19364	18060	70022*
		70	32493	18596	70022*
		90	70022	20209	70022*
* Lower (upper) confidence limit held at minimum (maximum) of sample					

In this study, a 'very low 'was given a probability value of 0.1% since a value of zero would generate infinity in the model estimation. A simple 'low' was given a value of 25%, 'moderate' 50% and 'high'75%. A 'very high' was presented a value of 99.9% to avoid infinity in the calculation. The mean of internal carbon pricing for all the surveyed companies is 13,061 KRW/t-CO_2. The medium value is 16,954 KRW/t-CO_2. In overall, the internal carbon price of each sector is higher than the mean of total. In particular, the companies from steel & iron industries have comparatively higher means of internal carbon pricing than that of total samples and other sectors. The mean of internal carbon pricing for chemical and paper companies is 17,305 KRW/t-CO_2, and 14,945 KRW/t-CO_2, respectively. However, in terms of the medium values, paper sector shows higher value of internal carbon, 19,364 KRW/t-CO_2, while others, petrochemical and steel & iron, are 15,457 KRW/t-CO_2 and 18,168 KRW/t-CO_2, respectively. This is because some companies in the paper industry showed a much high level of carbon tax about 70,000 KRW/t-CO_2.

4.3 Multivariate regression results of estimated internal carbon pricing

Table 5 presents the results of econometric analysis of estimated internal carbon price to identify associated relationship between pre-listed variables. The robustness of the analysis results were conducted by repeating the regression with omitting independent variables and controls. Five models were adopted. Model 1 includes all the independent variables and controls. In the Model 2, 3 and 5, the group of external pressures, internal factors and controls (production type, size and sector) are individually imported as independent variables. Model 4 is the case of adding 'Trade' and 'Investment'. To see association to allocation position, Model 6 takes in allocation positions, short and over.

Results of multivariate regressions of Model 1, 3 and 4 are statistically significant and are thus discussed here.

The results of this study shows that firms' internal carbon prices are not correlated with external pressures. Meanwhile, top manager’s understanding is associated significantly and positively to the internal carbon pricing. To satisfy the cap of allowance, a company that has emissions trading as a major option has a positive relationship with its internal carbon price. This indicates that trading is likely to occur even at high prices for this company. On the other hand, in Model 4, it shows that the company’s investment has a negative relationship with the carbon price. It is likely because companies that set lower the price of emission credits have a lower marginal cost reductions, which indicates that it may has large reduction potential through low carbon investment and prefer using budget for investment rather than the credit purchasing in the market. Among the production types, the ones that produce the final goods have a positive relationship with the internal carbon price. Small business, chemical, cement. Non-ferrous and electrical and electronic industries showed a positive relationship with carbon prices. Regression analysis confirmed that the assigned position of allocated allowance were not related to companies’ internal carbon pricing

Table 5 Multivariate regression results with internal carbon pricing as dependent variables

Variables		Model1	Model2	Model3	Model4	Model5	Model6
External	Goernment	0.008	-0.050				
	Cmpetition	-0.431	-0.022				
	Eergyprice	0.137	-0.252				
Internal	Top_support	0.264		0.283			
	Top_understanding	0.488^{b}		0.726			
	Tech_level	-0.308		-0.017			
	Trade	1.802^{a}		2.136	0.963^{b}		
	Investment	-0.060		-1.133	-0.651^{c}		
Production type	Raw	-0.673				0.288	
	Inter	-1.369					
	Final					0.622^{b}	
Size	Small	2.544^{b}				0.890	
	Medium	1.142				0.482	
	L-medium	1.308				0.600	
Sector	Chemical	1.488^{b}				0.204	
	Cement	3.408^{b}				0.678	
	Steel	0.768				0.080	
	Paper	1.640				-0.048	
	Non-ferrous	1.616^{c}				0.496	
	Machinery	-8.114				-0.035	
	Refining					1.936^{b}	
	Elec	2.416^{b}				0.202	
Allocation	Short						0.051
	Over						0.033
Obs.		40	73	40	40	73	71
LR chi2(18)		50.47^{a}	0.88	22.75	15.62^{a}	10.6	0.04
Pseudo R2		0.177	0.0014	0.0796	0.055	0.017	0.000

5. Conclusion

Under the climate change risk and policy pressure of carbon pricing, companies faced a momentum for their carbon management. As one of proactive carbon performance, setting own carbon pricing, the internal carbon pricing, is adopted by increasing number of companies as a tool taking measureable approach to carbon management in their business operation.

While lacking of literature on the corporate internal carbon price, this study suggested a possible method of estimation of internal carbon pricing using firm-level data targeting Korean companies under their domestic emission trading scheme.

The analysis results showed the internal carbon prices of companies based on the market transaction prices considering the emission abatement marginal cost the companies indicated were different according to the industry, and the overall average was between 12-19 USD/t-CO_2 which is similar with the actual internal carbon price range proposed by Korean companies in recent CDP report. This study reaffirmed the important role of top manager in implementing carbon management and internal carbon price of company. However It found that firms' investments do not show a positive relationship with internal carbon prices, and companies with high levels of internal carbon prices under the ETS may prefer emissions trading rather than investment to compliance their emission cap.

Nonetheless, there are some shortcomings and limitation of this study to be considered. For instance, questions with 5 scale evaluation were relied on self-reporting by companies. Furthermore, there was some difficulty to collect data and a limited number only usable as the companies were conservative to provide. The small number of sampling may weaken the policy relevance of the estimations and empirical analysis. Expanding the targets and sector, further study may eliminate this study limitation. As subsequent studies, it is necessary to study the effects of internal carbon prices on corporate GHG reduction and low carbon investment. These firm-level works will contribute for companies' carbon management initiative in responding to climate change and related policy as well as government policy direction and design.

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