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Carbon premium versus non-carbon premium: Case of the Korean stock market

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Abstract: This study analyzes how the implementation of emissions trading affects the Korean stock market. The South Korean government initiated greenhouse gas (GHG) emissions trading in 2015. Primarily, the scheme increases the cost for carbon emitters. Hence, a stock market investor may be disinclined to invest in the stocks of carbon polluters. However, over-allocation caused a 'windfall profits' problem in the early period of the EU-ETS. Higher cash flows from windfall profits and carbon risk would bring a 'carbon premium.' That is, carbon risk has an ambivalent impact on the stock market. Consequently, we cannot ascertain which effect has a greater influence on the financial market unless we comprehensively analyze the Korean situation. We used panel fixed-effects models and quasi-experimental methods to examine the impact of emissions trading on the stock market, using monthly data from South Korean companies listed on the KRX300. The results indicate that introducing carbon regulations rendered carbon-emitting firms less attractive to South Korean stock market investors. Reversal consequences in several periods were represented due to institutional issues, which were mainly allocation matters and banking restrictions in Korean emissions trading. This finding suggests that the Korean asset market reacts effectively to GHG regulation.
Keywords: *Banking restriction, Carbon premium, Emissions trading, Synthetic control method, Windfall profit.*

1. Introduction

Currently, many countries and regions accept greenhouse gas (GHG) emissions trading schemes (ETS) to achieve their carbon reduction targets. In 2015, approximately 10 years after launching the European Union emissions trading scheme (EU-ETS), the South Korean government introduced this system. This market mechanism provides regulated companies a flexible reduction option, thereby rendering it an efficient policy instrument for addressing climate change. In addition, new regulations on carbon emissions have affected industrial sector. From a regulated firm's perspective, this increases costs. However, the ordinance does not have a negative impact on the costs of non-carbon emitters. Therefore, it is reasonable to expect that implementing emissions trading could decrease carbon-emitting companies' stock prices, while having no effect on non-polluters' stock prices. Consequently, we can anticipate that the stock returns of non-carbon emitters will surpass those of their counterparts after implementing an ETS.

However, considering the burden and backlash from the industrial sector, most emissions initially allocate a free allowance. Moreover, over-allocation frequently occurs during the initial stages. The loose and free allocation leads to "windfall profits" because they earn more money when they sell their affluent allowance to the market. The EU-ETS has encountered a windfall profit issue [1-4]. The Korean ETS experienced similar concerns in the early period [5]. This unexpected profit could positively impact the stock prices of carbon emission sources. In this case, a carbon premium is expected in the stock market.

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Previous literature reveals that an ETS has a bidirectional impact on the financial market. Oestreich and Tsiakas [6] and Wen, et al. [7] demonstrated a "carbon premium" in the stock market after introducing carbon emissions trading. Those studies pay attention to the workings of windfall profits and increased carbon risk that would cause such a "carbon premium." However, a carbon emitter would experience increased costs to comply with regulations; consequently, a stock market investor may not prefer to invest in stocks of carbon emitters. Furthermore, a carbon risk has an ambivalent impact. Carbon risk such as institutional uncertainty, contributes to investors' reluctance to invest in carbon-emitting stocks. Pástor, et al. [8] and Ardia, et al. [9] supported this noncarbon premium. Consequently, we cannot determine the results without a comprehensive analysis.

This study aimed to ascertain which "non-carbon" or "carbon" premium the Korean stock market can delineate when considering implementation of the emissions trading. Free allocation and overallocation concerns were experienced during the initial phase of the Korean carbon-trading scheme. Thus, we anticipated that the stock returns of carbon-emitting portfolios will surpass those of non-carbon-polluting portfolios. The Korean government is committed to decrease GHG emissions and attain a carbon-neutral society by 2050 by enacting relevant legislation. These resolute signals would impact the Korean stock market, as investors would eschew the stocks of carbon-emitting companies. As a result, we cannot ascertain which effect has a greater influence on the stock market unless we comprehensively analyze the Korean situation. To address this research gap, we initially estimated the effect of introducing emissions trading into the stock market by applying a panel fixed-effect model. Subsequently, we verified the results using comparative empirical methodologies, such as comparing portfolio cumulative returns and the synthetic control method.

2. Literature Review

Previous studies have indicated that "non-carbon premium" and "carbon premium" are represented depending on market circumstances. Oestreich and Tsiakas [6] and Wen, et al. [7] demonstrated that a "carbon premium" is observed in the early stage of the ETS. Their hypothesis was based on the following logic. A company with free carbon allocation may experience higher cash flows; thus, there is a high chance of a carbon premium in stock returns for a company that does not receive a free allowance. Furthermore, considering that carbon emitters are exposed to carbon risk[1], they may aim for higher expected returns than companies that do not emit carbon, *ceteris paribus*. Oestreich and Tsiakas [6] used the Fama-French multifactor model to examine how the EU-ETS affected German stock returns based on these arguments. Their empirical results showed that a significant financial alpha exists in a portfolio of companies that receive free allocations. Using the difference-in-differences method, Wen, et al. [7] studied the same topic for Shenzhen's emissions trading system, and the results confirmed the "carbon premium" in China's early ETS. Bolton and Kacperczyk [10] analyzed the carbon premium issue in more extensive study regions by applying a panel regression model. An analysis of more than 14,400 firms in 77 countries revealed a widespread carbon premium in terms of emission levels rather than emission intensity. This premium is more significant in countries with inadequate economic development, fossil fuel reliance, and less inclusive political systems. Sankar, et al. [11] examined the causal relationship between firms' emissions and a carbon premium for the 141 companies among the S&P 500 index. They demonstrated that Scope 1 emissions exhibit a notable carbon premium.

In contrast, other studies have documented positive returns for portfolios that take long and short positions in non-carbon-emitting firms and stocks of carbon emitters, respectively. Pástor, et al. [8] and Ardia, et al. [9] suggested that the stocks of non-carbon emitters may yield higher returns than those of polluters because of increased concerns regarding climate change. Pástor, et al. [8] developed a theoretical model to discuss the role of sustainability preferences in asset markets. It assumes that investors' expectations of the cash flows of green versus brown firms can change because of customers' and regulators' preferences for sustainability solutions. In addition, climate change concerns increase

[1] They experienced uncertain carbon prices since carbon allowance prices fluctuate in an emissions market.

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legislation, thereby harming brown firms, whereas customers prefer sustainable products. Thus, high sustainability preferences lead investors to own green firms. Consequently, an increase in investor preference for non-polluting firms directly influences stock value. Based on this support, their model predicts that green stocks will surpass brown stocks when apprehensions regarding climate change increase. Ardia, et al. [9] provided empirical evidence for the theoretical model proposed by Pástor, et al. [8]. Data from S&P 500 companies between January 2010 and June 2018, shows that green stocks outperformed brown stocks in response to an increase in climate change concerns, as indicated by newspaper articles.

Further studies have reported similar results. Soh, et al. [12] examined the relative financial performance between carbon-efficient and carbon-inefficient companies. Based on U.S. firm data from January 2005 to December 2015, this study found positive abnormal returns since 2010, indicating that the investment strategy of long carbon-efficient firms and short carbon-inefficient firms may yield excess returns of 3.5 to 5.4% annually. Zhang [13] examined U.S. firms and found negative excess returns associated with carbon intensity, suggesting that higher carbon emissions may lead to lower stock returns. Huij, et al. [14] empirically showed a negative correlation between financial returns and carbon emissions in the U.S. stock market. Ding, et al. [15] examined the effects of company carbon emissions on corporate financial distress using data from Shenzhen and Shanghai firms from 2008 to 2018 in the context of China's carbon regulation policy. Their results indicated that increased carbon emissions are correlated with elevated financial crisis risk. Bauer, et al. [16] extensively explored this topic. They showed that green stocks in G7 countries have consistently yielded higher returns than brown stocks in the last 10 years. Hambel and van der Sanden [17] reported similar results. They demonstrated the outperformance of the green firm among 3,500 US companies and 10,000 companies across 90 countries.

In summary, previous studies have shown contradicting findings, showing either a "carbon premium" with brown stocks producing greater returns or the inverse ("non-carbon premium"), with green stocks producing higher returns than brown stocks. Therefore, we cannot determine which effects affect the stock market unless we conduct a comprehensive analysis of the Korean market. This study aimed to address this research gap using a dataset of South Korean stocks from exclusive industrial sectors over a long period. Furthermore, compared to the literature, we adopted a different approach known as a synthetic control method that can produce intuitive and comprehensive results.

3. Emissions Trading in South Korea

The Korean emissions trading scheme (K-ETS) is the primary policy measure for reducing GHG emissions in South Korea. On August 15, 2008, the Korean government declared that two keywords, "low-carbon" and "green growth," would be the new national vision for the next 60 years. Considering this pronouncement, the Korean government drafted laws to enhance its implementation. The Basic Act on Low-Carbon Green Growth was enacted in January 2010. On March 31, 2011, the Ministry of Government Legislation (MOLEG) established and finalized a legislative plan known as the "2011 Laws on Green Growth in Korea[2]." This legislative plan contains the "Act on the Allocation and Trading of Greenhouse-Gas Emission Permits," approved by the National Assembly and promulgated on the May, 14, 2011 [18]. In 2015, the Korean government launched the ETS, the first mandatory nationwide carbon market in Asia.

The principal features and components are as follows: First, the K-ETS was implemented in several phases. Coverage increased in these phases. The first phase, the pilot period, was conducted between 2015 and 2017. A total of 525 entities are under the K-ETS, and the aggregated emissions of these companies account for 66% of the national GHG emissions. Subsequently, the second (2018 to 2020) and third (2021 to 2025) phases followed. In Phase 2, 591 entities were under regulation, and the share of

[2]This plan includes more diverse green growth policy measures in various sectors, such as energy, transportation, construction, agriculture, and waste. However, we discussed the emissions trading system in this study.

their aggregated emissions accounted for 70.2% of the national emissions. From 2021, 93 more entities were expected, for a total of 684 entities, and their aggregated emissions level was 73.5% of the national emissions.

Heavy GHG-emitting industries, such as electricity generation, cement production, steel manufacturing, oil refining, and petrochemicals, are subject to regulations. Specifically, companies that emit more than 125,000 CO_2 tons annually are regulated. Some sectors, such as agriculture and small emitters, are exempt from the system because of challenges in monitoring emissions. The cap of the K-ETS is expected to be stricter in future phases to achieve carbon neutrality by 2050. Discussions are underway to broaden the scope of the scheme to include more industries, such as construction.

The K-ETS allows flexibility mechanisms such as offsets, banking, and borrowing. Carbon emitters can use offset credits, such as, Korean Offset Credits (KOCs), since Phase 1. International credits, such as Certified Emission Reduction (CERs) from the Clean Development Mechanism were available for compliance from Phase 2. Companies may "bank" unused allowances for future application. In addition, they borrowed insufficient allowances within a single trading phase. However, banking has some adverse effects. Participants often retained their allowances as a risk mitigation strategy. This caused less trading activity, ultimately causing low market liquidity. Discussions on banking restrictions began in 2017 to mitigate the adverse consequences and stabilize the market. In June 2018 and June 2019, the market adopted a stricter approach, restricting the permissible banking quantities depending on the volume of allowances traded [19].

This restriction affected prices in the K-ETS. In late 2019 and early 2020, the price of the Korean Allowance Unit (KAU) exceeded that of European Union Allowances (EUA). South Korea and the European Union (EU) aspire to achieve carbon neutrality by 2050. Consequently, they significantly elevated their GHG reduction targets in response to ambitious reduction goals in 2020 and 2021. Consequently, we anticipated an increase in allowance demand, which would lead to price escalations. The EUA price increased significantly, thereby exceeding expectations by two to three times; however, the KAU price exhibited a different trend. The price of KAU declined by approximately one-third during this comparable period. Previous literatureYu and Lee [19] and Yoon [20] indicates that banking restrictions cause a decline in KAU prices. Figure 1 illustrates historical allowance prices.

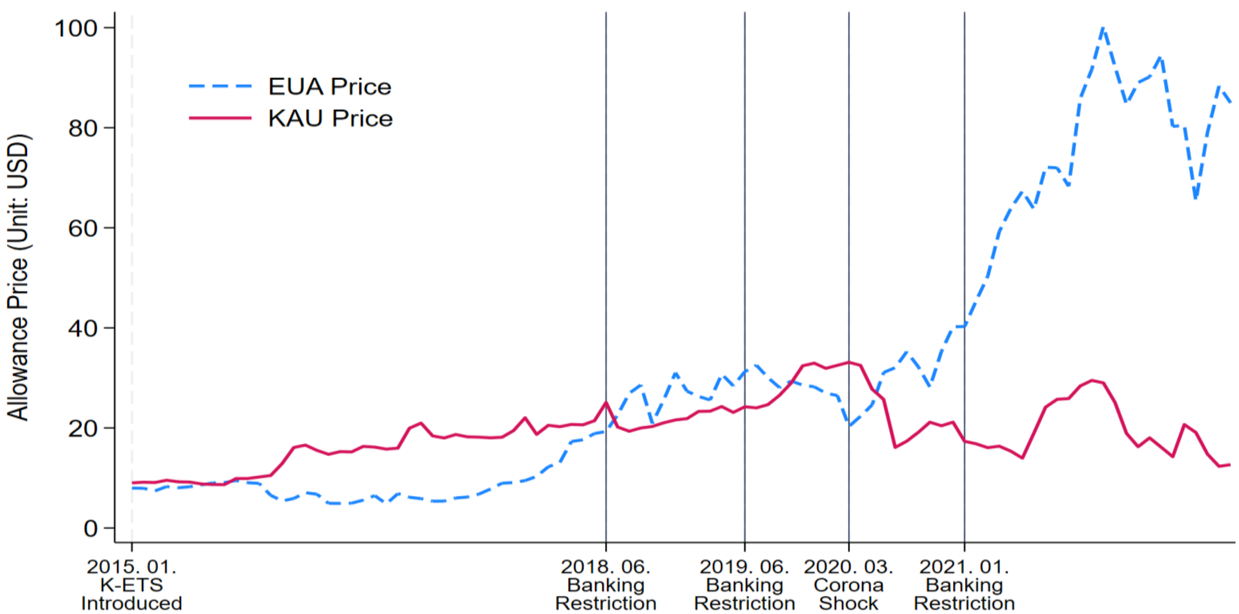

Figure 1.
Historical allowance prices in K-ETS and EU-ETS.
Note: This graph was drawn by the author. Price data were obtained from Investing.com (EUA) and KRX (KAU).

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The Korean government allocates emissions allowances to participating companies, considering the burden on the industrial sector, and allowing them an adaptation period. During the first phase, the "Grandfathering" method granted regulated firms a free carbon emission permit based on their previous GHG emission record. In the second phase, the "benchmarking" method distributed a free allowance to regulated firms based on their prior production levels. The regulatory authority initiated an auction to allocate allowances; however, 3% of the total allocation was allocated in the Phase 2. In the Phase 3, the percentage of auctions increases by 10%. Table 1 summarizes the characteristics of Korea's ETS.

Table 1.
Overview of the Korean ETS.

Trading period	**Phase 1 (2015 ~ 2017)**	**Phase 2 (2018 ~ 2020)**	**Phase 3 (2021 ~ 2025)**
Liable entities	525 entities	591 entities	684 entities
Emissions coverage	66% among national emissions	70.2% among national emissions	73.5% among national emissions
Amount of allocation	1,686 million CO2 ton (3 year total)	1,796 million CO2 ton (3 year total)	3,082 million CO2 ton (5 year total)
Allocation method	100% Free allocation (Grandfathering)	97 % Free allocation (Benchmarking) and 3% Auctioning	90% Free allocation (Benchmarking) and 10% Auctioning
Industry Coverage	Energy, Industrial Processes and Product Use, Building, Waste, Transport (Aviation)		
Flexible mechanism	Offset (KOCs & CERs), Banking, Borrowing		

Note: This table was prepared by the author and refers from.
Source: Greenhouse Gas Inventory & Research Center [21]; Greenhouse Gas Inventory & Research Center [22] and Greenhouse Gas Inventory & Research Center [23]

4. Data

4.1. Sample Period

This study analyzes South Korean companies using monthly data from January 2010 to December 2022 (156 months). On March 31, 2011, the MOLEG announced a legislative plan that included ETA. The National Assembly passed the ETA and promulgated it on May 14, 2011. Finally, K-ETS commenced operations in January 2015. A discussion on banking restrictions commenced in 2017 to address the ETS market liquidity issue. The market imposed stricter banking restrictions in June 2018 and June 2019, which continued throughout Phase 3. Therefore, the time span of the dataset encompassed the period before the K-ETS implementation and external shocks in the regulation.

4.2. Firm Data

We considered KRX300-listed companies in this analysis. The KRX300 is a benchmark stock price index representing the South Korean stock market consisting of 300 stocks selected from those listed on the Korea Composite Stock Price Index (KOSPI[3]) (213 companies) and KOSDAQ[4] (87 companies) markets. Due to the split listings of some stocks, the total number of stocks in our dataset included 302 companies. This accounts for 84.7% of the total market capitalization of the Korean stock market. Although the KOSPI200 concentrates on large manufacturing companies such as Samsung Electronics, Hyundai Motors, and POSCO, the KRX300 includes various industries, such as bio and cultural content, and the share of the industrial sector in the KRX300 is as follows; information technology, financials and real estate, consumer discretionary, and industry 34.2%, 12.4%, 11.6%, and 11.1%, respectively. Monthly stock prices and pertinent accounting data, including ROE (return on equity), sales growth, leverage, and investment, were obtained from FnGuide. Monthly stock returns were calculated as $R_t = \ln(P_t) - \ln(P_{t-1})$.

[3]The 'Korea Composite Stock Price Index,' or KOSPI, is an index that primarily consists of large-cap stocks.
[4]KOSDAQ stands for 'Korea Securities Dealers Automated Quotations,' representing a stock market composed of small and medium-sized venture companies.

4.3. Carbon Emission Allowance Data

All the allowances were freely distributed during the pilot period. Despite the auction for allocation adopted in Phase 2, its share was relatively small. The official government database does not publicly release free allocation data at the installation level but identifies the list of regulated firms. The National Assembly and a media outlet (Newspaper) requested the government to release allocation datasets. Currently, it is available on web media sources[5]. It contains complete information on the GHG allowance in the K-ETS. After the public sector was excluded from the complete dataset[6], 683 installations remained. After manually matching each installation to a KRX300-listed firm, 80 companies were identified as participating in carbon emissions trading and fulfilling their obligations. The companies included in this analysis account for approximately 32.19% of South Korea's total allocation[7]. Table 2 lists the companies that received more than 500,000 CO_2 tons of free allowances annually.

Table 2.
List of companies with annual free allocation over 500,000 CO_2 ton.

Company	**Industry**	**Allowances Granted**	**Company**	**Industry**	**Allowances Granted**
Daesang	Food	627,923	LG Electronics	Electric	1,026,844
Dongkuk Holdings	Iron/ Steel	1,985,866	LG Uplus	Telecommunications	1,076,508
Hanwha Solutions	Chemical	2,076,574	Lotte Chemical	Chemical	5,797,874
Hyosung	Heavy Industry	1,268,513	Lotte Shopping	Retail Distribution	926,745
Hyundai Motor	Auto Manufacturer	1,547,504	OCI Holdings	Chemical	2,542,099
Hyundai Steel	Iron/ Steel	19,835,373	POSCO FUTURE M	Electric/ Chemical	1,741,885
KCC	Chemical	1,440,533	POSCO Holdings	Iron/ Steel	75,113,206
KIA Corp.	Auto Manufacturer	850,434	Samsung Electronics	Semiconductors /Electric	8,903,097
Korea Electric Power Corp.	Utilities	1,268,258	Samsung Heavy Industry	Heavy Industry	502,287
Korea Gas Corp.	Utilities	641,775	Samsung SDI	Secondary Battery/ Electric	722,305
Korea Petrochemical Ind.	Chemical	1,257,442	SeAH Besteel Holdings	Iron/Steel	1,272,619
Korea Zinc	Iron/Steel	3,149,614	SK Hynix	Semiconductors	2,869,722
Korean Air	Airline	552,913	SK Telecom	Telecommunications	762,510
KT	Telecommunications	1,132,159	SKC	Chemical	790,910
Kumho Petrochemical	Chemical	3,066,655	S-Oil	Chemical	6,331,744
LG Chemical	Chemical	7,354,068	Ssangyong CNE	Building materials	11,601,822
LG Display	Electric	5,208,838	Youngpoong	Non-ferrous metals	1,153,581

5. Empirical Strategy

We used three empirical specifications to examine the existence of a carbon premium in the Korean stock market. We estimated the treatment effect using a panel fixed-effects model in the first stage. Subsequently, we confirmed the results using a portfolio approach. According to Bauer, et al. [16] and Huij, et al. [14] we compared the stock returns on brown and green portfolios. We verified the results using the synthetic control method in the final stage. These comparative approaches provide intuitive and comprehensive results. Moreover, they enable us to better understand the treatment effect because

[5]This dataset is available at https://data.newstapa.org/datasets.
[6]The dataset includes the public sector, such as local governments, educational institutions (a university and educational foundations), and some public welfare foundations, in addition to a private company.
[7]It makes sense since government-owned utilities and local governments received a substantial share of the KAU.

they show the variation in treatment effects for the entire analysis period. The following sections discuss these three methodologies in detail.

5.1. Panel Regression Model

Considering the favorable allocation to the regulated industry and windfall profit issue, this empirical analysis hypothesizes that a carbon-emitting firm will outperform a non-carbon emitter after introducing the K-ETS, *ceteris paribus*. We used a panel fixed-effects model to test this hypothesis. First, we classified a firm's category, such as brown (carbon emitter) or green (non-polluter), to specify the effect of carbon emissions regulations. Previous studies considered carbon emission levels [14-16]. Other studies, such as Oestreich and Tsiakas [6] and Wen, et al. [7] used carbon allowance allocation as their criterion. We separated brown and green firms by carbon allowance allocation because this study examines the impact of emissions trading on the Korean stock market. We designated companies that receive free allowances and those that do not as brown and green portfolios, respectively. The panel-fixed effects model takes the following form.

$$\ln(Stock\ Retrun_{it}) = \alpha Brown_{it} + \sum_j \beta_j X_{itj} + \gamma_t + \delta_i + \varepsilon_{it} \quad (1)$$

where the dependent variable is the logarithmic stock return and $Brown_{it}$, is a dummy variable. Specifically, carbon emitters (brown firms) are designated as 1, whereas non-carbon emitters (green firms) take the value of 0. This implies that the brown portfolio outperforms the green portfolio when we have a positive estimate and vice versa. Variable X_{it} includes control variables for accounting information, such as ROE, sales growth, log market capitalization, leverage, and investment. The γ_t are time dummies specifically, year fixed effects. Industry fixed effects have been captured in δ_i. We used 21 industry classifications[8] in the empirical model. The ε_{it} is the error term.

5.2. Portfolio Approach

Bauer, et al. [16] has shown that a non-carbon premium generally exists in G7 countries; however, there are periods in which the opposite result is observed at specific points in time. The stock returns of portfolio results may vary by period owing to policy issues in the K-ETS and other external shocks in the Korean financial market. The portfolio approach can be used as an alternative for observing fluctuating returns throughout a time series. Comparing stock returns among portfolios with heterogeneous characteristics is a widely applied method in empirical finance, especially in asset pricing. To implement this approach, we calculated the average stock returns for each portfolio. The simple spread between these portfolios represents the carbon (or non-carbon) premium.

To verify the robustness of the results, we used five different groups to establish a brown portfolio in terms of allocation amounts. The first brown portfolio, which is the largest emitter group, comprised eight companies that receive an annual allowance of over five million CO_2 tons on average. The second group consisted of 25 carbon-emitting firms that receive over one million CO_2 tons annually. The third group included 34 companies that received more than 500,000 CO_2 tons annually. The fourth brown portfolio comprised 52 firms that receive over 100,000 tons of CO_2 annually, on average. Finally, the fifth brown portfolio included all 80 companies that receive carbon allocations. In contrast, we considered one identical green portfolio that includes all KRX300-listed companies that do not receive allowances. We calculated all portfolio returns for the five cases by considering them equally.

We considered an additional case; the size-adjusted method adopted by Huij, et al. [14]. This practice is a variation of the SMB in the Fama-French multi-model. We used market capitalization as the standard of company scale to establish a return series, as in the Fama-French model; however, we used carbon allocation in this model instead of book-to-market. The specific form is as follows;

[8]There are 44 industry categories for the firms listed on the KRX300 index among 77 KSIC (Korea Standard Industry Code) two-digit level industry classifications. I reclassified those 44 into 21 industry categories, which are metal and non-ferrous manufacturing, plastic and rubber product manufacturing, chemical manufacturing, etc.

$$BmG_t^{Huij} = \frac{R_{Big,t}^B + R_{Small,t}^B}{2} - \frac{R_{Big,t}^G + R_{Small,t}^G}{2} \quad (2)$$

where $R_{Big,t}^B$ denotes portfolio stock returns of large-cap firms and carbon emitters. $R_{Small,t}^B$ refers to the stock returns of small-cap firms receiving a carbon allowance. We classified small and large firms based on their market capitalization. If their market capitalization is larger than the median, they were designated as "big," and vice versa. The allocation of carbon allowances distinguishes between the brown and green groups, similar to the other groups. The two variables in the numerator of the second term on the right side ($R_{Big,t}^G$ and $R_{Small,t}^G$) are the green portfolio counterparts of the first term.

5.3. Synthetic Control Method

We turned to the synthetic control method (SCM). Abadie and Gardeazabal [24] analyzed the economic impact of terrorism and political conflicts in Basque, a region in Spain. They introduced the SCM to estimate the effect of conflict on economic development. Since Abadie, et al. [25] improved the method, the SCM has been used in many quasi-experimental studies [26-32].

The premise of the SCM is that a weighted composite of possible controls can be a proper counterfactual group. We established a weighted average of a green portfolio that replicates the characteristics of brown firms before the introduction of emissions trading. The composite synthetic green portfolio provides an unbiased estimate of the counterfactual if the trend in stock returns of the synthetic control is similar to the trend in stock returns in the brown portfolio for the pre-intervention period.

Adopting the empirical strategy of Abadie, et al. [25] we defined the effect of carbon regulations on the stock market as follows.

$$\alpha_{jt} = R_{jt}^B - R_{jt}^G \quad (3)$$

where α_{jt} is the treatment effect of the carbon regulation policy for firm j at time t. R_{jt}^B, and $R_{j,t}^G$ are stock return of the brown portfolio (treatment group), and that of the green portfolio (counterfactual group), respectively. R_{jt}^B represents the observed stock returns of brown firms (carbon emitters). The stock return from the green portfolio (treatment group) is the stock return from non-carbon emitters, which is a synthetic outcome that would have occurred if carbon regulations had not been implemented. To satisfy the quasi-experimental conditions, the two groups had similar characteristics before the launch of the K-ETS. Let carbon regulation occur in period T_0, and sample firm be represented as $j = 1, 2, 3, \ldots, J + 1$. The first sample ($j = 1$) is the portfolio comprising carbon emitters; j represents the "donor pool" of non-carbon emitters that could be used to estimate the counterfactual. Suppose R_{jt}^G is expressed as follows.

$$R_{jt}^G = Z_j\theta_t + \lambda_t\mu_j + \epsilon_{jt} \quad (4)$$

where Z_j includes relevant covariates unaffected by the intervention[9], θ_t are time-specific parameters, λ_t are unknown common factors, and μ_j are firm-specific unobservables. Define $\mathbf{w}$ as a $J \times 1$ vector of weights such that $0 \leq w_j \leq 1$ and $\sum_{j=2}^{J} w_j = 1$. Suppose that there is a w_j^* such that

$$\sum_{j=2}^{J} w_j^* R_{jt} = R_{jt}^B \text{ for } t = 1, \ldots, T_0 \quad \text{and} \quad \sum_{j=2}^{J} w_j^* Z_j = Z_1 \quad (5)$$

then Abadie and Gardeazabal [24] and Abadie, et al. [25] showed that the effect of interest, α_{1t} for $t > T_0$, can be estimated by the equation

$$\widehat{\alpha_{1t}} = R_{1t}^B - \sum_{j=2}^{J} w_j^* R_{jt} . \quad (6)$$

[9]This model includes total assets and cumulative stock return.

A specific metric was used to estimate w, which is a vector of weights. Let Ω_1 be the vector of pre-intervention characteristics in the treated unit and Ω_0 matrix of pre-intervention characteristics in the counterfactual units. The vector w was selected to minimize the distance

$$\sqrt{(\Omega_1 - \Omega_0 w)' V (\Omega_1 - \Omega_0 w)} \quad (7)$$

where V is a symmetric and positive semidefinite matrix. In this application, V is a diagonal matrix that assigns weights to minimize the mean squared error of the synthetic control estimator. By applying the estimated w, the synthetic outcome can be estimated as $\sum_{j=2}^{J} w_j^* R_{jt}$. This composite outcome which uses weight vector w and non-carbon-emitting firms as the synthetic control group, indicates what the counterfactual group would have been if the carbon regulation had not been implemented. Finally, the treatment effect can be achieved by contrasting the composite outcome with the actual outcome of the carbon emitters.[10]

6. Results and Discussion

The empirical results of the panel analysis are as follows. Most importantly, the estimation results suggest that carbon-emitting firms underperform in the Korean stock market (Table 3). Particularly, the estimates for the brown dummy show consistent and statistically significant results in all the models. The estimation results for the control variables that may affect investors' decisions, such as ROE, sales growth, firm size, leverage, and investment, are generally consistent with theoretical expectations. In general, higher ROE and sales growth translate into higher stock returns, other things being equal. We used the logarithmic value of market cap to explain the effect of firm size, and the estimation results for this variable showed that the larger the firm size, the higher the stock returns. Large-cap stocks outperformed small-cap stocks in the 2010s in the South Korean stock market. The results for the investment variable imply that a firm with more investments has better stock market performance. And the leverage effect is not statistically significant.

Table 3.
Estimation results for the panel regression.

	(1)	(2)	(3)	(4)	(5)
Brown Dummy	**-0.006*** **	**-0.006*** **	**-0.010*** **	**-0.009*** **	**-0.009*** **
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
ROE	**0.000*** **	**0.000*** **	**0.000*** **	**0.000*** **	**0.000*** **
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Sales Growth	-	**0.000*** **	**0.000*** **	**0.000*** **	**0.000*** **
	-	(0.000)	(0.000)	(0.000)	(0.000)
Ln(market cap)	-	-	**0.003*** **	**0.003*** **	**0.003*** **
	-	-	(0.001)	(0.001)	(0.001)
Leverage	-	-	-	-0.003	-0.003
	-	-	-	(0.004)	(0.004)
Investment	-	-	-	-	**0.003* **
	-	-	-	-	(0.002)
Constant	-0.022	-0.023	-0.062	-0.060	-0.060
	(0.041)	(0.041)	(0.046)	(0.047)	(0.047)
R-sq	0.013	0.013	0.014	0.014	0.014
N	31866	31853	31853	31853	31853
Time FE	Yes	Yes	Yes	Yes	Yes
Industry FE	Yes	Yes	Yes	Yes	Yes

Note: Robust standard errors are indicated in parentheses. ***, **, and * indicate statistical significance at the 1 %, 5 %, and 10 % levels, respectively.

[10]This is exactly how we defined the effect of a carbon regulation on stock market as represented in equation (3).

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As discussed in Section 3, loose reduction targets in the early period and banking restrictions influenced the K-ETS participants and stakeholders. In addition, other external shocks to financial markets exist. These shifters may contribute to market fluctuations over time, which we discussed using the portfolio approach results. The results of assessing the relative performances of green and brown stock portfolios in the Korean stock market are as follows. A comparison of brown and green portfolios indicate the effect of introducing emissions trading into the Korean stock market. Briefly, the portfolio spreads revealed that stock returns of green companies consistently outperformed those of brown companies after 2011 (see Figure 2). This finding supports the panel analysis results discussed above. The overall results show a similar trend to those of Bauer, et al. [16]. According to the portfolio groups the return on the green portfolio was approximately 50% to 90% higher than its counterfactuals during the study period. There have been a few temporary partial reversals of this experience before April 2011 and between 2015 and 2016. We will concurrently discuss the analysis of the fluctuations by period with the subsequent SCM results.

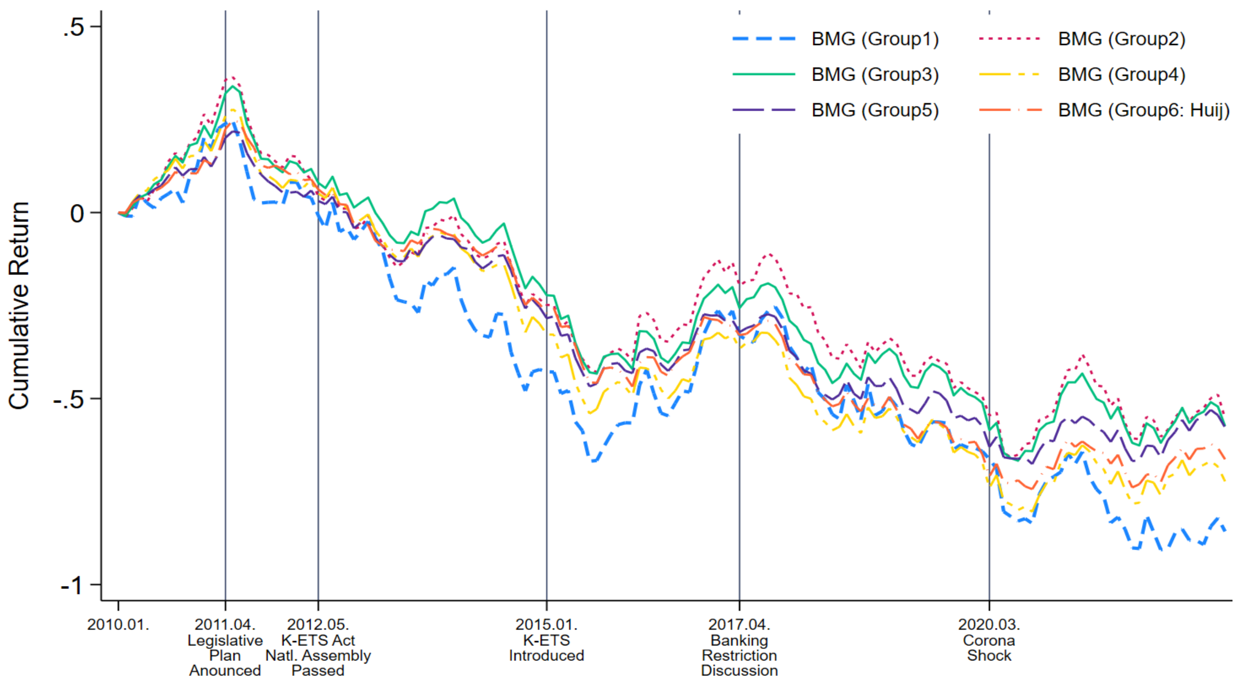


Figure 2.
Portfolio spread results.

We implemented two case studies for the SCM analysis. First, the public announcement of the relative legislative plan for ETA was a crucial juncture for the financial market. The government's declaration informs investors that the adoption of new climate regulations is imminent. Considering this, we used the public announcement release period as the intervention period for the first case study (Case 1). When the ETA passed through the National Assembly the public was convinced that the ETS will be launched. Considering this, we analyzed a separate case with this aspect in time serving as the intervention point (Case 2).

Prior to discussing the SCM results, we assessed whether the synthetic counterfactual group (green portfolio) is well matched to the treatment group (brown portfolio) during the pretreatment period. Table 4 shows the means of the predictive variables used to generate the synthetic control for Case 1.[11] Between the brown portfolio and its synthetic counterpart, the match is good in terms of the total assets

[11]Case 2 had similar results. We skipped the discussion on Case 2 however, the results are available upon request.

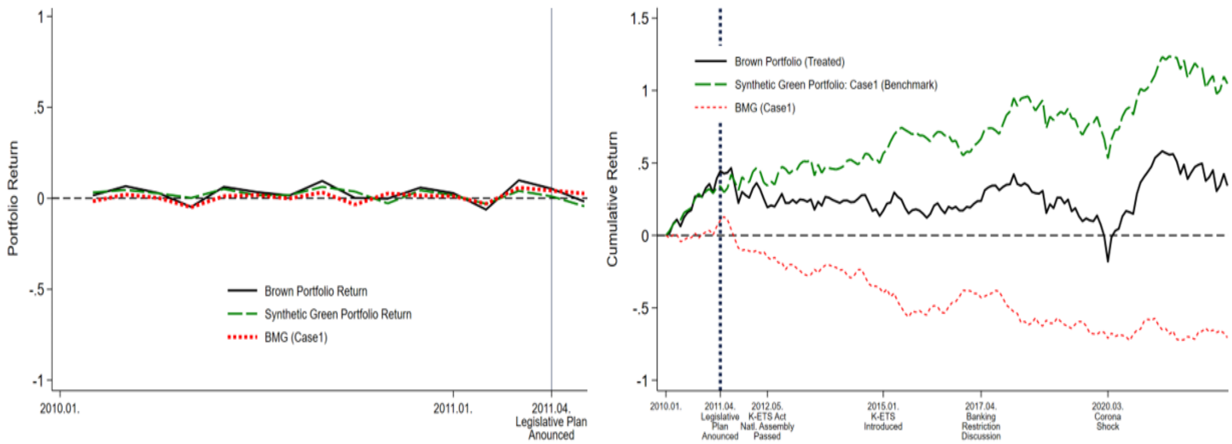
and cumulative returns. Panel (A) of Figure 3 depicts the brown and green portfolio returns and spreads between portfolios. These two portfolios return show a similar pattern; therefore, the spreads fluctuated at zero. Based on the above discussion, the synthetic green and brown portfolios had similar characteristics before the ETA announcement. In other words, the treatment and synthetic counterfactual groups had similar asset size and cumulative returns before the intervention. The only difference is whether or not they had to follow the carbon regulatory policy.

Table 4.
Comparing predictor means between treated and synthetic control groups (Case 1).

	Treated Group (Brown Portfolio)	Synthetic Counterfactual Group (Green Portfolio)
Total Asset (Unit: billion KRW)	15,045	14,944
Cumulative Return	0.208	0.207

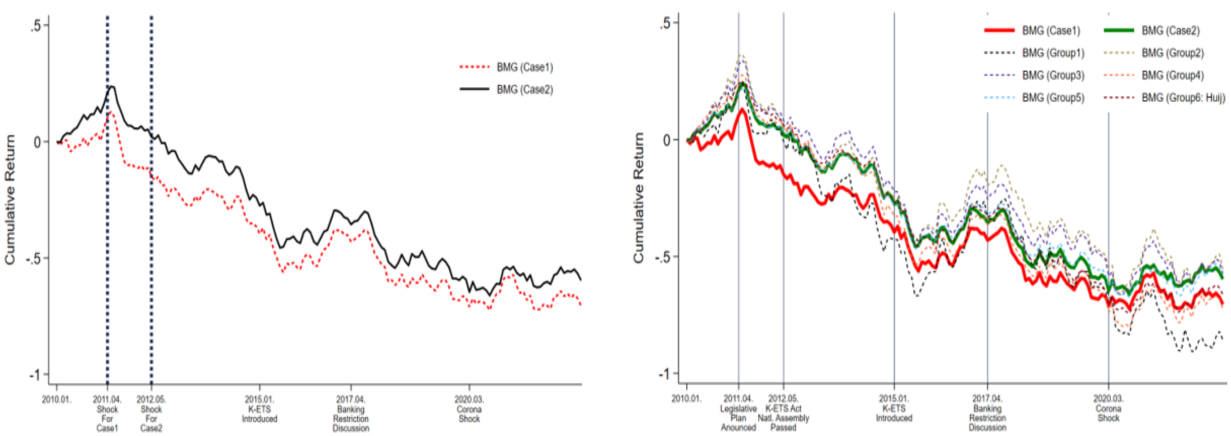
Panel (B) of Figure 3 shows the SCM results for the entire period in Case 1. It contains the cumulative returns and spreads for brown and synthetic green portfolios (brown minus green, or BMG). The BMG moved concurrently before the government's announcement; however, it diverged after an external shock (announcement of the legislative plan). For the remaining period, the green portfolio consistently outperformed the other portfolios, with the spreads reaching approximately 70%. This finding suggests that the K-ETS renders carbon-emitting firms less attractive stocks for investors. The results of the second case study (Case 2) are similar. Panel (A) of Figure 4 reports the spread of Case 2. We combined all BMG trends into a single graph (panel B of Figure 4) to compare the SCM results with those of the previous simple portfolio approach. The SCM results are consistent with the previous results. Figure 3 and Figure 4 show how the non-carbon firms outperformed when the K-ETS was implemented. This finding is consistent with the results of the panel model.

As discussed, all the empirical results show that the brown portfolio underperformed compared to the green portfolio; however, opposite trends were observed in some periods. The BMG results at intervals explain these reversal outcomes. Variations in the return spread by timeframe revealed that several shocks related to emissions trading affect stock markets. Initially, before March 2011, brown firms' performance was superior to that of the green firms. As previously discussed, the MOLEG announced the establishment of the "2011 Laws on Green Growth in Korea" on March 31, 2011. This legislative plan contains the "Act on the Allocation and Trading of Greenhouse-Gas Emission Permits," and implies launching the GHG emissions trading to the market. Indeed, the 2011 declaration upended the direction of the spread between brown and green portfolios. The effect of the shock is evident, and predominance of green portfolio returns continued until June 2015. If a carbon-emitting company is listed under GHG regulations, it has a stigma effect, and less attractive to stock investors.



(a) Portfolio spread trend during the pre-treatment period (b) Cumulative returns of the brown and the green portfolios

Figure 3.
SCM Results for Case 1.



(a) Spreads from the two SCM case studies (b) Spreads from the all-portfolio approach analysis

Figure 4.
Spreads trends from SCM Results.

A few months after the introduction of the K-ETS, the green portfolio's outperformance trend reversed. Allocation matters in Korean emissions trading and external issues in the industrial context may lead to this reversal. The rationale for the allocation is as follows. Considering the burden and backlash from the industrial sector, regulatory authorities freely allocated an allowance of 100% in Phase 1. Furthermore, regulated firms receive sufficient free allowances. In Phase 1 (2015 to 2017), regulated firms received 1,685 million CO_2 tons in free allowances, which was more than the total GHG emissions of 1,669 million CO_2 tons [33]. In addition, as companies' GHG emissions increased, the number of free emission permits allocated increased since the government adopted the "Benchmarking" allocation method from Phase 2. The aggregate GHG emissions from all regulated firms in 2016 increased by 1.9% compared to 2015, and emissions in 2017 increased by 2.9% compared to 2016. However, the free allowances granted in 2016 and 2017 increased by 3% and 3.8%, respectively [34]. Notably, an increase in free allocation exceeds the increase in GHG emissions. Therefore, K-ETS did not bind in the early phases. Based on this, some have indicated that the K-ETS experienced a windfall profit issue [5].

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Second, external shocks in the Korean economy, such as the Middle East Respiratory Syndrome (MERS) epidemic during the spring and summer of 2015, partially contributed to the predominance of the carbon portfolio. Although the MERS epidemic had a minimal macro-level impact on the Korean economy, the effects varied by industry. Private consumption and service industries experienced a noticeable impact, whereas the manufacturing sector experienced limited influence [35]. Brown portfolios include the manufacturing industry rather than the service sector.

In summary, allocation issues such as free and loose allocation indicate that regulations are not strictly binding. Some regulated firms acquire windfall profits from their allowances. These concerns may cause investors to believe that investing in companies that are subject to emissions trading is beneficial. With these allocation issues, the Korean stock market reversed, thereby generating a carbon premium due to the MERS epidemic. This trend continued until 2016, when the stock market favored large-cap stocks whereas industries such as semiconductors outperformed.

Another pivotal event occurred in April 2017. Since emission trading participants often bank their allowances to prepare for future regulation risks, market liquidity in the carbon market remains low. In April 2017, discussions on banking limits began to address this issue. Implementing the “banking restriction” causes emissions trading participants to sell the allowances they hold because the reserved allowances are invalid in subsequent phases. This decreases the allowance price and mitigates the windfall profit advantage. Moreover, participants must deplete their allowances within a given phase if banking is limited. However, future allowance prices are anticipated to escalate because of the increased demand as the Korean government’s GHG reduction targets would be more stringent in pursuit of its ambitious objective of attaining carbon neutrality by 2050. Considering this perspective, “banking restrictions” increase the uncertainty of the carbon trading program in subsequent phases. Consequently, it is prudent to refrain from investing in carbon-emitting companies, and the non-carbon premium in the Korean stock market became evident shortly after April 2017, which coincides with discussions on banking limits.

Furthermore, BMG trends were ambiguous after the COVID-19 pandemic. Stock markets experienced a significant decline in March 2020 (the coronavirus shock). Many governments, including South Korea, have distributed substantial financial resources to address the economic decline through interest rate reduction and quantitative easing (QE). The Korean stock market rapidly rebounded and ultimately maintained a bullish trend when the monetary policy was implemented. The capital influx into the Korean stock market reached approximately 40 billion USD throughout the pandemic [36]. A large influx of new investors in the Korean stock market significantly contributes to stock prices rising. Under such market conditions and the prevalence of irrational behavior during the pandemic, the BMG exhibited no notable trend.

In summary, all empirical results confirm that there was an overall non-carbon premium in the Korean stock market after the introduction of the K-ETS. A few periods show inversions, which are explained by institutional issues, such as loose allocation and banking restrictions. Investors evade investing due to the increased costs and uncertainty related to carbon reduction, which explains the non-carbon premium. Several reports have included survey results on carbon-emitting companies’ concerns regarding high cost and the risk of investing in carbon abatement in South Korea [37, 38].

7. Concluding Remarks

In 2015, the South Korean government introduced the K-ETS, which provides a flexible reduction option to address climate change. This program increases the costs for regulated firms, whereas non-carbon emitters do not experience a negative impact. This can cause a “non-carbon premium” in the stock market. However, higher cash flows by windfall profits and carbon risk cause a “carbon premium,” and it is empirically shown in the early stages of the EU and Chinese ETS [6, 7]. Therefore, we cannot determine which effect has a stronger impact on the stock market without empirical analysis. This study addresses a research gap in the Korean context.

We used panel fixed-effects models and quasi-experimental methods to examine the effect of introducing emissions trading on the stock market. The results of the panel analysis implied that non-carbon emitters exhibit high stock returns compared to carbon-emitting companies in South Korea. The empirical findings from portfolio approaches, such as SCM, support these panel results. In addition, the comparative analysis indicates several periodic reversals (carbon premiums), which can be explained by loose allocation and banking restrictions.

These findings empirically demonstrate that the stocks of non-carbon emitters outperformed those of carbon emitters in the Korean equity market when the K-ETS was introduced. However, before the April 2011 carbon regulations, the brown portfolio produced higher returns than the green portfolio. That is, the introduction of carbon regulations rendered carbon-emitting firms less attractive to South Korean stock market investors. This finding suggests that the Korean asset market reacts effectively to external shocks. In this context, conducting an efficiency test in the K-ETS market is a future research topic.

This study had some limitations. First, the dataset does not include the full list of regulated companies. Although firms in the KRX300 index account for 84.7% of all firms listed on the Korean stock market, their allocation amount is approximately 32.19% of the total allocation in South Korea. Some large polluters such as the five power generation companies are not in the stock market because they are government-owned public companies.[12] In addition to these power companies, large emitters are not listed on the stock market or KRX300 particularly cement manufacturers. Therefore, this analysis does not explain the absence of listed companies. Finally, we used granted GHG allowances, rather than actual GHG emission data, as the criterion for classifying companies into brown and green categories. Whether a company receives a GHG allowance is an intuitive and informative standard for making investment decisions for stock market investors. However, applying actual GHG emissions data and comparing the results with those of this study would be informative in the future.

Transparency:

The author confirms that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.

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