Impact of Benchmarking Allocation on Compliance Level of Carbon Emission Reduction: Evidence from Phase 2 of the Carbon Emission Trading Scheme (ETS) in South Korea

By

CHOI, Eunjin

THESIS

Submitted to

KDI School of Public Policy and Management

In Partial Fulfillment of the Requirements

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Committee in charge:

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Abstract

This study examines the impact of carbon permit allocation rules on compliance within the emission trading scheme (ETS), a critical mechanism for controlling greenhouse gas (GHG) emissions. Specifically, it investigates the effect of the benchmarking (BM) allocation method, which is an output-based allocation, on firm non-compliance compared to grandfathering (GF), which is based on historical emissions. This investigation is based on Korean firm-level emission data from 2015 to 2019. The results indicate that BM increased the likelihood of non-compliance, especially among small and medium-sized entities (SMEs) and public corporations, while large private firms were not affected. These findings emphasize the importance of providing support to SMEs and public corporations to ensure the effective implementation of the BM allocation rule and the reduction of carbon emissions.

1. Introduction

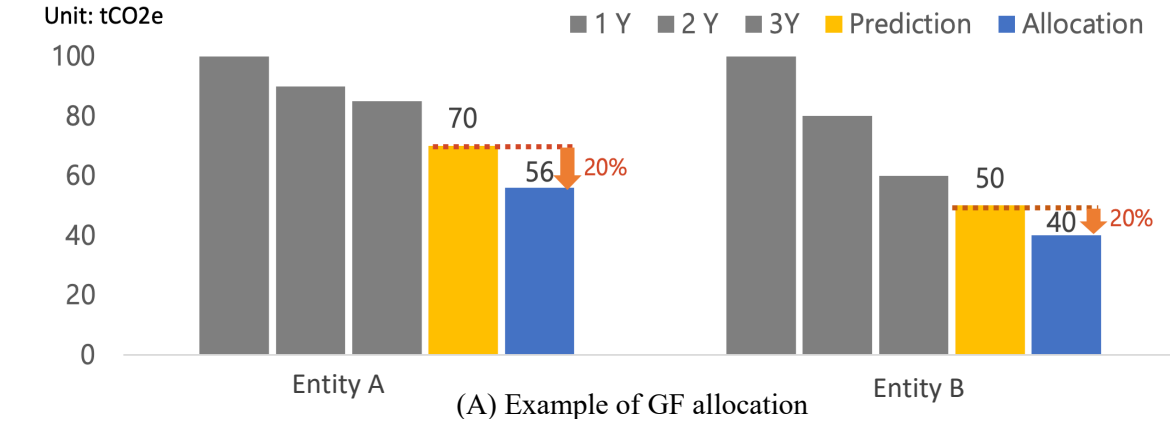
As the climate crisis has accelerated, many countries have gathered consensus on global action to decelerate the crisis. This consensus led to the successful Paris Agreement in 2015, in which the largest number of countries ratified and enacted the first international law on climate change in 2016. Ratified 194 countries have submitted NDC (Nationally Determined Contribution) to the UNFCCC (United Nations Framework Convention on Climate Change) secretaries every five years after 2016. A major way to achieve the reduction target is by either implementing a Carbon Emission Trading Scheme (ETS), imposing a carbon tax, or even employing both regulations simultaneously. According to the World Bank (2022), the Emission Trading Scheme (ETS) regulates a significant share, precisely 17.49%, of global greenhouse gas (GHG) emissions, which amounts to 8.95 gigatons of CO2 equivalent (GtCO2e). This regulation spans across 101 countries, encompassing both national and subnational jurisdictions.

Carbon ETS is a carbon reduction mechanism in which the government allocates carbon emission permits and allows trading it among participants based on a market-based approach. The permit price in the market influences industries regulated by the ETS to either buy permits instead of reducing emissions or sell permits by investing in emission reduction measures. This process may follow the general market rule, the law of supply and demand, in our society, but there is a significant difference. The government exercises control over the supply through allocation methods of permits in this Carbon trading market. Hence, the allocation method becomes a critical factor in the ETS.

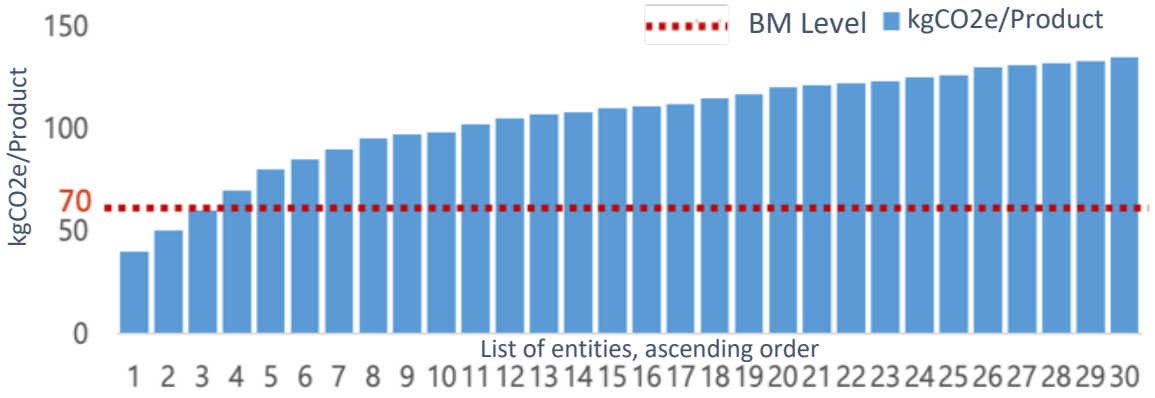
There are four ways to allocate permits: Grandfathering (GF), Benchmarking (BM), Free and Auction allocation. GF is the allocation method based on historical emissions during base years, assuming the entity will follow the same emission trend in the future, considering the economic

situation and reduction target. BM is another allocation method based on the energy intensity of output (product): comparing the products' energy intensity (i.e., Carbon Emissions per unit production of a product) among entities in the same industry. This signifies that entities surpassing the BM level are granted strengthened permits, consequently leading to reduced GHG emissions. Conversely, entities emitting GHGs below the BM level can secure additional permits. This is because they exhibit greater production efficiency compared to their counterparts. Accordingly, they stand to gain an advantage. Whether Grandfathered or Benchmarked, these permits can be allocated through free or auction processes.

Figure 1. Example of the (a) GF and (b) BM allocation.



(A) Example of GF allocation



(B) Example of BM allocation

Notes: The upper graph depicts the (A) GF allocation, an instance of Grandfathering with a 20% reduction target. The government predicts future emissions based on the past three years (1Y ~3Y) and applies the reduction target as total allocation. On the other hand, the lower graph illustrates the (B) BF allocation: an example of Benchmarking with a top 10% Benchmarking level set at the emission level of the fourth company among a total of 30 companies. As a result, the first four entities can secure more permits.

When permits are provided through auction allocation, participant entities in the ETS must decide whether to purchase these permits in the carbon trading market by conducting an internal analysis such as a Cost-Benefit Analysis. This analysis mainly revolves around comparing the cost of buying carbon permits in the carbon trading market with the cost of reducing carbon emissions through the adoption of more carbon-efficient technologies. Therefore, a key aspect of Free and Auction allocations is the control and management of carbon permit prices in the carbon trading market.

Many countries are moving towards increased use of Benchmarking (BM) and Auction allocation in Carbon ETS. This shift is driven by recognition of the effectiveness of BM and Auction allocation in reducing carbon emissions. It's worth noting that BM allocation is stricter, especially for entities exceeding BM efficiency levels, resulting in fewer initial permits. In contrast, Auction allocation offers more flexibility, allowing them to make informed choices based on their analyses of permit purchases and technology investments.

This paper focuses on BM allocation, which is more stringent than auction allocation, and *assesses its impact on achieving level of carbon emission reduction targets*. It also explores *whether this stringent allocation's impact varies based on entity size and changes over time*. This study can offer insights into the ETS's operational strategy, particularly concerning allocation permits and achievement of reduction targets.

The remainder of this paper is structured as follows. The theoretical background for allocation impact in the EU ETS and allocation practice of K-ETS is presented in Section 2. Section 3 describes the methodology of impact evaluation and the data used. The outcomes are explained in Section 4. Eventually, Section 5 summarizes the main findings and concludes with policy implications.

2. Theory, practice, and research questions

2.1 Theoretical Background

Entity behaviors based on the Benchmarking and Grandfathering allocation in EU ETS

Looking into the experiences of the EU, which has been implementing the carbon ETS since 2005 as a frontier of ETS operation, allocation ways have changed over phases. Behaviors for carbon reduction showed differently depending on the Grandfathering (GF) and Benchmarking (BM) allocation period across different industry sectors in EU ETS Phase 1(2005~2007) and Phase 2(2008~2012). When GF was adopted, almost all industries and entities tried to secure more carbon permits and were blamed by other sectors because historically, the more emitted industry gets more permits. Supported by flexibility mechanisms (i.e., banking, borrowing, and offset), the industries banked surplus permits obtained through GF allocation. It has also contributed to setting the low permit price due to permit surplus (Sato et al., 2022).

On the other hand, BM allocation includes green technology investment, ultimately reducing GHG when the permit is provided as auctioning. (Endres et al., 2018; Peng et al., 2022; Chen et al., 2022). From these studies, BM is likely more suitable for meeting the carbon emission reduction as the original purpose of the ETS. Since BM requires high cost in terms of price for administrative implementation to set BM level (i.e., carbon emissions unit for manufacturing one production), criteria scope, and category and conducting extra MRV (Monitoring, Reporting, and Verification) (Gong et al., 2015).

Throughout the extensive history of the EU ETS, a multitude of substantial research studies have undertaken the analysis of ETS implementation outcomes across different phases and the scrutiny of permit prices in the trading market (Bucher & Ellerman, 2006; Abrell et al., 2011 & 2021), as well as investigating the behaviors of entities, with a particular focus on their market

activities and technology adoption. These research endeavors have been committed to comprehensively understanding the attainment of reduction targets. However, there has been a notable lack of empirical analysis regarding the levels of achievement associated with allocation methods (GF and BM). This gap in research can be attributed to the complexities of the international carbon market and the diverse internal regulations within the EU ETS.

Outcome Assessments in the Korea ETS Operation

In comparison to the EU ETS, the Korea ETS has seen fewer impact studies. Nevertheless, there are some remarkable studies, specifically, a recent study by Koo et al. (2019) highlighted the impact of carbon pricing within the Korea ETS. It noted that if the evaluation of different pricing methods does not consider the size of the entities, it can lead to an underestimation of the economic impact. Additionally, the study found that even with mitigated carbon pricing method for large entities, there are negative impacts on small and medium-sized companies. In addition, Kim (2022) researched the energy intensity of sub-industry sectors under the Target Management Scheme(TMS) and ETS in South Korea since 2010, revealing an increase in emission intensity contrary to the objectives of both management schemes.

However, a significant portion of research within the Korea ETS landscape has been conducted by government agencies such as the Korea Energy Economics Institute and the Greenhouse Gas Inventory and Research Center. These studies have predominantly focused on analyzing the outcomes themselves without conducting in-depth impact analyses of the allocation methods. For instance, the analysis has often revolved around assessing the number of permits submitted in comparison to the initial permit targets, evaluating the dynamics of permit price changes, and examining the total number of permits traded. While some of these studies have placed primary emphasis on aspects like carbon pricing method and energy intensity, their scope has generally

been confined to a limited number of industries. It may be due to the relatively short history of Korea ETS operation. Furthermore, there is still a significant lack of research on allocations within the Korea ETS, despite the fact that the Korea ETS employs distinct allocation approaches that can be easily distinguished by phases and offers a simpler operational environment for investigation compared to the EU ETS. This condition provides ample opportunities for various investigations. The study utilized the experience of the Korean ETS to analyze the specific impact of allocation methods.

2.2 Allocation Practice of Carbon Permit in Korea ETS

The Korean Emission Trading Scheme (ETS) was launched in 2015, following the setup of the Carbon Emission Target Management System (TMS) in 2010 as a preparatory step for ETS participation. Similar to the EU ETS, the Korean ETS is divided into phases: Phase 1 (2015-2017), Phase 2 (2018-2020), and Phase 3 (2021-2025)

Implementation of Benchmarking allocation on a sub-industry basis

At Phase 1, 525 entities[1] mandatorily participated in the ETS and were categorized into 26 sub-industries [2] under six sectors: Power, Industry, Waste, Public services, Waste treatment /management, and Transportation (including Domestic Aviation). Table 1 displays the portion of each sector and the number of subsectors in Phase 1 and 2 of K-ETS.

Only three sub-industries (Cement, Oil refining, and Aviation under the Industry sector) were applied to the Benchmarking (BM) allocation, while Grandfathering (GF) allocated the rest of the

[1] It covers yearly average GHG emissions during the past three years ahead of phase: Emitting over the 125,000 tCO2e for entities(entities) or, over 25,000 tCO2e for individual facilities.

[2] A total of 26 industrial sectors were designated in Phase 1. However, the sectors are divided into 62 in accordance with KSCI(Korean Standard Industrial Classification). It matches the current 62 industrial sectors.
Subsectors in the K-ETS changed from 26 in Phase 1 to the departmentalization 62 subsectors in Phase 2. All subsectors listed in this paper are based on Phase 2. For a more detailed list of the subsectors and the number of entities, please refer to *Appendix 1. The subsectors of the K-ETS and their allocation methods in Phase 1 and Phase 2*.

sectors. These 26 subsectors were recategorized into 62 sectors in Phase 2. Based on the changed sector as 62 subsectors, five subsectors adopted BM allocation in Phase 1. Four more subsectors were added to the BM allocation in Phase 2 (2018~2020). In total, nine subsectors with BM allocation cover 52% of the GHG emission in K-ETS in Phase 2. For phase 3 (2021~2025), the subsectors were allocated as BM increased and covered 70% of the GHG emission.

Table 1. Allocation of shares by sectors (K-ETS summary report)

	Phase1 (2015~2017)		Phase2 (2018~2020)	
Number of entities (Average)	592		637	
Sectors (Number of subsectors)	Allocation (KtCO2e)	Portion (%)	Allocation (KtCO2e)	Portion (%)
Industry (47)	918.5	54.47%	942.3	54.79%
Power (3)	717.3	42.53%	704.1	40.94%
Waste (2)	30.4	1.80%	53.3	3.10%
Building (9)	13.1	0.78%	12.3	0.72%
Transportation (1)	4.9	0.29%	5.6	0.33%
Public (1)	2.2	0.13%	2.1	0.12%
Total (62)	1,686.4	100%	1,719.7	100%

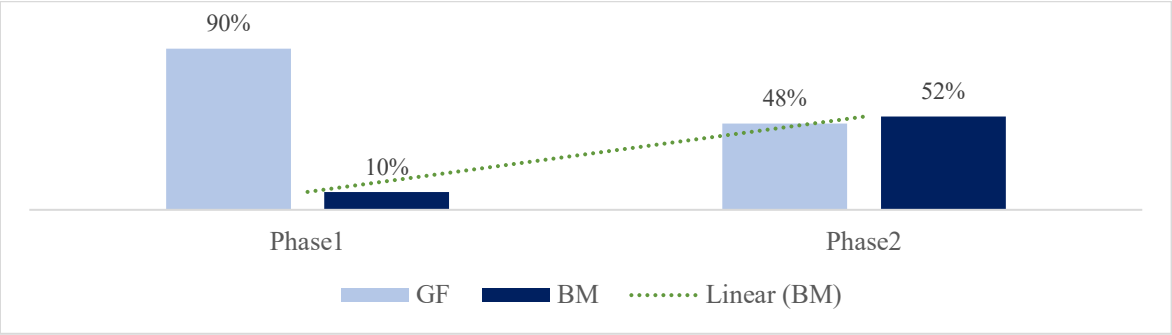
Notes: Total allocation amount is 1.67 MtCO2e, 1.78 MtCO2e Phase 1 and Phase 2, respectively.

In Phase 2 of the Korea ETS, there was a significant increase of 42% in BM allocation compared to the 10% observed in Phase 1. It is presented in Figure 2, encompassing (A) all entities. Although the Korea ETS has operated based on sectors and sub-industry sectors without differentiation based on the scale of entities, a closer examination reveals that the participating entities in the ETS can be classified into two distinct groups: (B) large entities and (C) small and medium-sized entities(SMEs) according to relevant laws and regulations.[3] The group (C) is comprised of various small and medium private entities and public corporations, including city

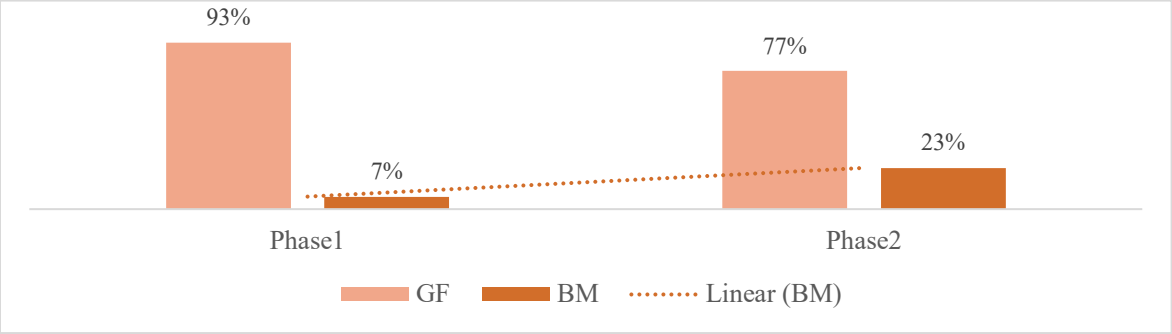
3. Monopoly Regulation and Fair-Trade Act : Special Act on the Promotion of growth and the strengthening of competitiveness of middle-standing enterprises; Framework Act on Small Medium Enterprises.

governments, with the exception of large entities. The allocation shares for each group were as follows: (B) large entities accounted for 43.81%, and (C) SMEs occupied 56.19% of the total allocation.

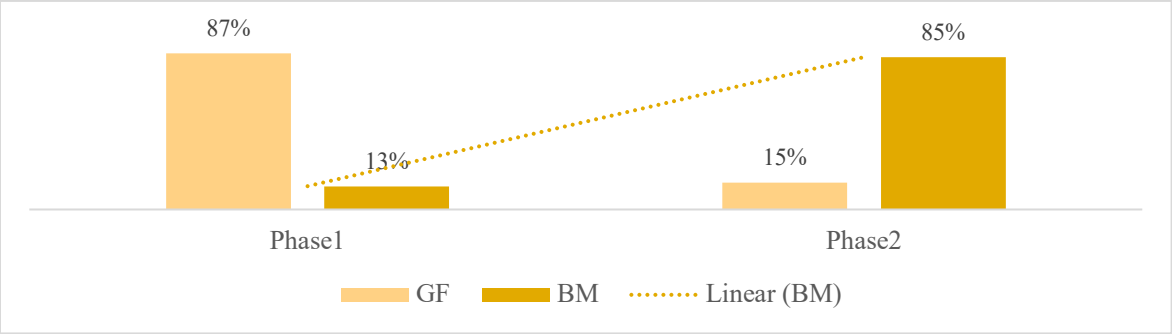
Figure 2. Permit allocation method change from Phase 1 to Phase 2



(A) All entities



(B) Large entities



(C) Small and medium-sized entities (SMEs)

The level of BM allocation criteria hasn't changed in either Phase 1 and 2, as the average emission intensity of each product or heat criterion. In particular, in Phase 2, the LNG complex power plant opted for a more lenient median emission intensity level. This average and median

level of BM value remains in Phase 3. It is significantly less stringent compared to the BM level in the EU ETS, which is set at the top 10% for high-performing energy efficiency.

Implementation of Auction allocation on a sub-industry basis

All permits were provided 100% free in Phase 1, but free allocation decreased to 97% (auctioning 3%) in the next Phase 2. In Phase 3, the free permit was reduced to 90%. Allocation of free permits was determined depending on trade intensity and production cost rates within the subsector basis, the same sub-industrial sector basis used to determine Grandfathering(GF) or Benchmarking(BM) allocation and their BM levels.[4] However, the subsectors designated for auction allocation do not align with the allocated subsectors through BM or GF. In Phase 2, 26 subsectors were included in the auction allocation, whereas only nine subsectors adopted BM allocation.

The auction-allocated permits are not initially allocated in the first stage of the allocation process. Instead, they are obtainable in the carbon permit market when auctioned entities require additional permits. These auctioned permits are usually priced lower than the prevailing market rate. Nevertheless, in Phase 2, the auctioned permits comprised a mere 0.8% of the total 3% of permits designated for all 26 sectors. This suggests that subsectors subject to auctioning often opt for alternative methods of obtaining carbon permits by the end of the year without relying on auctioned permits.

4. Free permit allocated based on the subsectors that whether the (1) over 30% of the trade intensity, (2) over 10% of the production cost rate, or (3) 10% of the trade intensity and over 5% of the production cost rate at the same time. The calculation method is determined in accordance with Appendix 1 of the Enforcement Decree of the Act on the Allocation and Trading of Greenhouse Gas Emission Permits.
- Trade intensity = (Average annual exports of the sector during the base period + Average annual revenue of the sector during the base period) / (Average annual sales of the sector during the base period + Average annual income of the sector during the base period)
- Level of Production cost = (Annual average GHG emissions for the base period of the sector
× price of emission permit in the base period) / average annual value-added production in the base period of the sector

2.3. Research Questions and Hypotheses

This study explores the impact of benchmarking (BM) allocation within the Korea ETS. An important advantage of this investigation is the ease of distinguishing entities within each sub-industry sector during both Phase 1 (2015-2017) and Phase 2 (2018-2020) in the Korea ETS. The specific focus is on the experience of BM allocation in Phase 2, which saw a broader adoption compared to Phase 1.

Effectiveness of Benchmarking allocation

When considering the administrative and industrial aspects related to the implementation of auction and BM allocations within the ETS, BM allocation is considered a more stringent method than auction allocation. Under auction allocation, the government's primary role is to manage the permit price in the market, while entities have a degree of flexibility in choosing between permit purchase and investment activities by internal evaluation process.

In contrast, BM allocation poses significant administrative and industrial challenges, given the requirement to delineate uniform manufacturing scopes and criteria in determining BM values for the allocations. When determining a BM value, despite entities producing the same product, having the exact same process for all entities within the same sub-industry sector is challenging. Gathering process information from both administrative and industrial perspectives is also difficult. In addition, it takes time to compare the scope and have an agreement for all entities. This complexity prompts the research question of *whether the effort invested in establishing BM levels justifies the expected achievement in carbon emission reduction.*

This inquiry leads to Hypothesis 1, which assesses the overall achievement level of carbon emission reduction through BM allocation in Phase 2 of the Korea ETS as called "Baseline analysis".

Hypothesis 1: *BM allocation significantly impacts the likelihood of achieving carbon emission reduction targets through the imposition of stringent initial carbon permits.*

Consistency in the Effectiveness of Benchmarking Allocation Across Entity Scales

Once the BM values are determined through the harsh process and allocated, entities within the same sub-industry must grapple with closing the gap to match top-performing entities in terms of carbon emission efficiency. This situation raises concerns about the consistent effectiveness of this stringent allocation for all entities, regardless of scale, especially when assessing whether BM allocation genuinely assists all entities in achieving their emission reduction targets. Larger entities often possess the resources to adopt green technologies and highly efficient processes, benefiting both emission reduction and overall production efficiency following thorough cost analyses. Smaller entities, on the other hand, may struggle to keep pace due to differing financial conditions and business environments. The strengthened allocation may lead the smaller entities to lose their competitiveness by failing to achieve the allocation target. These concerns resonate with common perceptions and opinions regarding BM allocation, as outlined in year-end reports issued by government agencies (2018& 2022, K-ETS Summary report).

This leads to the second research question (2) *whether the achievement of carbon emission reduction is consistent among all entities, regardless of their size or scale,* and formulated second research hypothesis.

Hypothesis 2: *BM allocation significantly impacts the likelihood of achieving carbon emission reduction targets across entities of varying scales: Large entities and SMEs.*

Hypothesis 2 accounts for the impact of BM allocation on the achievement level of carbon emission reduction by categorized entities based on scale as a sub-sample analysis. These entities are primarily classified into two groups according to Monopoly Regulation and Fair-Trade Act, as

illustrated in Figure 2 and Table 2: Large entities and Small and Medium-sized entities (SMEs), which also encompass public corporations.

Table 2. Allocation of shares and descriptions of entity categories

<table>
<tr><th>Hypothesis</th><th colspan="2">Entity category</th><th>Shared allocation (%)</th><th>Descriptions</th></tr>
<tr><td>Hypothesis 1</td><td colspan="2">All entities</td><td>100</td><td>- Entities emitting over 125 KtCO2e/yr. or individual facilities emitting over 25KtCO2e/yr. on a three-year average.</td></tr>
<tr><td rowspan="4">Hypothesis 2</td><td>Large entities</td><td>Private</td><td>43.81</td><td>- Designated large private entities based on Monopoly Regulation and Fair-Trade Act.</td></tr>
<tr><td rowspan="3">Small and Medium-sized entities (SMEs)</td><td>Private</td><td>15.02</td><td rowspan="3">- SMEs: All other non-large entities.
- SMEs - Private Entities: All non-large, non-public corporation entities.
- SMEs - Public Corporations: Entities falling under the TMS (Target Management System) framework, including public universities, public hospitals, local governments, and other public corporations affiliated with the Korea Electric Power Plant.</td></tr>
<tr><td>Public</td><td>41.17</td></tr>
<tr><td>subtotal</td><td>56.19</td></tr>
</table>

Furthermore, to gain insight into the factors contributing to the outcomes associated with SMEs within the broader context, the study conducts a separate analysis of SMEs, distinguishing between those in the private sector and those owned by public corporations.

By scrutinizing the results of Benchmarking (BM) allocation methods among entities in a real-world context, this investigation sheds light on the effectiveness of this allocation method in driving carbon emission reductions and advancing the goals of the ETS. Additionally, it considers the competitive dynamics among entities of different scales within the same sub-industry sectors.

3. Data and Methods

3.1. Data

The study merged two major datasets: Emission and Allocation data. Primary emission data of each entity for the study was obtained from GIR (Greenhouse Gas Inventory and Research Center)[5], which provides publicly available datasets. A government-qualified third party verifies the annual data, and the verification is a mandatory process of the ETS. Through the verification, six key pieces of information are disclosed in the dataset: names of the entities, verified number of emissions, verifying agency, subsectors, department of the government agency[6] along the subsectors, and year of designation to the ETS.

While the emission data is open to the public, allocation data is typically treated as confidential information. Despite this, a lawmaker requested the Ministry of Environment to disclose the

5. GIR (http://www.gir.go.kr/home/index.do?menuId=37), the GHG emission data by each entity in each year is opened to the public. If an entity wants not to disclose the emission data for security reason, it's possible to apply not open to the public process through the disclosure committee. Six of the entities haven't disclosed their emission data in 2015.

6. Each government agency take a responsibility to ensure the transparency and accuracy of the emission and allocation: Ministry of land, Infrastructure and Transport(Building, Transportation), Ministry for Food, Agriculture, Forestry and Fisheries(Agriculture, Livestock, Food), Ministry of Trade, Industry and Energy (Industry and Power), Ministry of Environment (Waste)

allocation data for public interest purposes in 2021[7]. The dataset also encompasses the names of entities, their allocation data for each year spanning from 2015 to 2019, and the average allocated permit for Phase 3 (2021-2025). It does not reflect the flexible banking, borrowing, and offset mechanisms. Instead, it exclusively considers early reduction credits (permits) prior to the official implementation of the ETS (2010-2014) in 2018.

To construct the dataset for analysis, these two datasets were matched based on the names of entities and years. This process confirmed the presence of missing or canceled data, primarily due to company mergers.[8] During this matching process, additional variables such as allocation methods and the scale of the entities, as defined by the Fair-Trade Commission (FTC) for large entities, were organized. As a result, the dataset identified another six major variables relevant to the research objectives, including allocation and emission data, identification numbers for each entity, subsectors, allocation methods (Grandfathering or Benchmarking, Free or Auction), and the scale of the entities.

The key dependent variables are Allocation, Emission, and Possibility of Non-Compliance. The "Possibility of Non-compliance" is introduced as a key dependent variable to assess the achievement level of carbon emission reduction in both Hypothesis 1 and 2. Additionally, comprehensively supporting Hypotheses, this study also set another two dependent variables , emissions and allocation, which serve as indices of the level of achievement of carbon emission reduction. The new variable (Possibility of Non-compliance) represents the computed actual amount of emission divided by the allocated permit for each entity from 2015 to 2019.

7. Two lawmakers (Hye-Young, Jang and Won Young, Yang-Yi) officially asked the allocation data to the Ministry of Environment. The data upload at NEWSTAPA DATA PORTAL (newstapa.org)

8 . There is an article of permit cancellation and transferring in the ACT ON THE ALLOCATION AND TRADING OF GREENHOUSE-GAS EMISSION PERMITS: Article 17 (Revocation of Allocation of Emission Permits) . The allocation data may not represent all the result of these process.

It would help to provide an overall understanding of reduction and compliance behavior in the K-ETS. If the resulting ratio exceeds 1.0, it indicates an increased possibility of non-compliance for the entity. This situation necessitates additional efforts to align carbon emissions with the allocated permit, potentially incurring extra costs. Accordingly, entities may seek various strategies to address this challenge, such as implementing new technologies to achieve verified carbon reduction, optimizing efficiency in carbon emissions, or acquiring additional carbon permits from the carbon market. By examining these key variables -Allocation, Emission, and Possibility of Non-compliance- the study can evaluate the extent to which allocated permits have indeed decreased and whether emissions have correspondingly decreased in accordance with the allocation methods. Ultimately, it allows the study to check the appropriateness of the allocation methods employed and explore potential behaviors caused by distinctive allocation in the Korean ETS.

To ensure accurate analysis and reliable results, the study eliminates outliers and considers the scale of entities as controlled independent variables. Specifically, outliers are new or merged entities during the middle years of the phases. Only keep the entities with the full five-year dataset for all variables and include the merged entity during Phase 1 and Phase 2 only if it could clearly trace the history with emission and allocation data transfer.

Finally, in organizing the dataset, 396 entities, covering 90.52% of the five-year allocation permit, were utilized to test the empirical analysis. Additionally, the study takes into account entity scales (Large entities, small and medium-sized entities; SMEs) by creating sub-dummy variables.

3.2 Summary Statistics

Prior to exploring the effect of Benchmarking (BM) allocation, a summary statistics overview was conducted, contrasting the treatment group (allocated by BM) with the control group (allocated by Grandfathering; GF) over five years. This summary is presented in Table 3 with three

panels for testing both hypothesis : (A) all entities for Baseline analysis (Hypothesis 1), and (B) Large entities and (C) SMEs categorized by entity size for sub-sample analysis (Hypothesis 2).

Upon comprehensive examination of the five-year dataset, different appearances emerged between BM and GF allocation methods. Specifically, in Panel A (encompassing all entities) and Panel C (the category of Small and Medium-Sized Entities; SMEs) allocated through GF exhibited higher levels of non-compliance possibilities. Conversely, for larger entities, those allocated through BM displayed higher non-compliance possibilities than GF in Panel B. For other dependent variables, such as Allocations and Emissions, although the number of BM-allocated entities is considerably smaller than those allocated through GF, Allocations and Emissions were notably higher than BM-allocated entities for all samples. This observation suggests that BM allocation is primarily directed towards entities with higher emissions profiles. In addition, a particularly intriguing finding emerged in the subsample analysis, where SMEs exhibited significantly higher Emissions and Allocations than Large entity sample, once adopted BM allocation. This is attributed to the inclusion of heavily emitting public corporations, such as Power Plants, within the SME category.

A balance test was also conducted to assess whether there were any disparities between the BM and GF groups during the pre-treatment phase, Phase 1, as depicted at Table 4. The results of this test offer confirmation that no statistically significant differences were detected in any of the dependent variables for all samples through panel A to C. This was consistent even when the categorized entity analyses comparing the treatment and control groups were performed. These findings indicate that there was a balanced baseline between the two groups, ensuring their comparability both before and after the introduction of Phase 2.

Table 3. Summary statistics (2015~2019, Phase 1 and Phase 2)

	All	Benchmarking (BM, Treatment)	Grandfathering (GF, Control)
	Mean (1)	Mean (2)	Mean (3)
A. All entities			
Allocations (KtCO2e)	1,293.434	3,637.733	1,019.734
Emissions (KtCO2e)	1,349.356	3,932.733	1,047.744
Possibility of Non-compliance	1.149	1.059	1.16
Observations	1,980	207	1,773
B. Large entities			
Allocations (KtCO2e)	1,869.781	2,250.483	1,821.926
Emissions (KtCO2e)	1,926.630	2,656.997	1,834.821
Possibility of Noncompliance	1.086	1.132	1.081
Observations	600	67	533
C. Small and medium sized entities (SMEs)			
Allocations (KtCO2e)	1,042.848	4,301.631	674.921
Emissions (KtCO2e)	1,098.368	4,543.264	709.428
Possibility of Non-compliance	1.177	1.024	1.194
Observations	1,380	140	1,240

Notes: The table was analyzed using a total of 396 entities over a five-year period. However, due to data access limitations, the sample was organized based on two conditions. First, both allocation and emission data should be available and matched for all five years, from 2015 to 2019. Second, entities that joined the ETS during the middle of Phase 1 or Phase 2 were excluded from the analysis. Additionally, merged entities that had ambiguous permit cancellations or transfers between entities were also excluded from the study. The standard errors are clustered at the firm level. Statistical significance at the 1, 5, and 10 percent levels is indicated by ***, **, and *, respectively, and the evaluated standard error is robust.

Table 4. Baseline Characteristics by Treatment Status (2015~2017, Phase 1)

	All	Benchmarking (BM, Treatment)	Grandfathering (GF, Control)	Treatment -Control
	Mean (1)	Mean (2)	Mean (3)	Difference (4)
A. All entities				
Allocations (KtCO2e)	1,299.749	2,026.318	1,246.585	-779.733.3 (689.071)
Emissions (KtCO2e)	1,341.215	2,298.953	1,271.136	-1,027.817 (700.097)
Possibility of Non-compliance	1.173	1.056	1.182	0.126 (0.100)
Observations	1,188	81	1,107	
B. Large entities				
Allocations (KtCO2e)	1,880.757	1,981.749	1,873.522	-108.227 (1,546.228)
Emissions (KtCO2e)	1,896.673	2,837.850	1,829.245	-1,008.605 (1,477.420)
Possibility of Non-compliance	1.083	1.217	1.074	-0.143 (0.136)
Observations	359	24	335	-
C. Small and medium sized entities (SMEs)				
Allocations (KtCO2e)	1,048.142	2,045.084	974.533	-1,070.551 (726.978)
Emissions (KtCO2e)	1,100.673	2,072.049	1,028.952	-1,043.097 (773.494)
Possibility of Non-compliance	1.212	0.988	1.229	0.241 (0.131)
Observations	829	57	772	-

Notes: The table was analyzed using a total of 396 entities over a three-year period (Phase 1). However, due to data access limitations, the sample was organized based on two conditions. First, both allocation and emission data should be available and matched for all three years, from 2015 to 2017. Second, entities that joined the ETS during the middle of Phase 1 or Phase 2 were excluded from the analysis. Additionally, merged entities that had ambiguous permit cancellations or transfers between entities were also excluded from the study. The standard errors are clustered at the firm level. Statistical significance at the 1, 5, and 10 percent levels is indicated by ***, **, and *, respectively, and the evaluated standard error is robust.

3.3 Identification Strategy

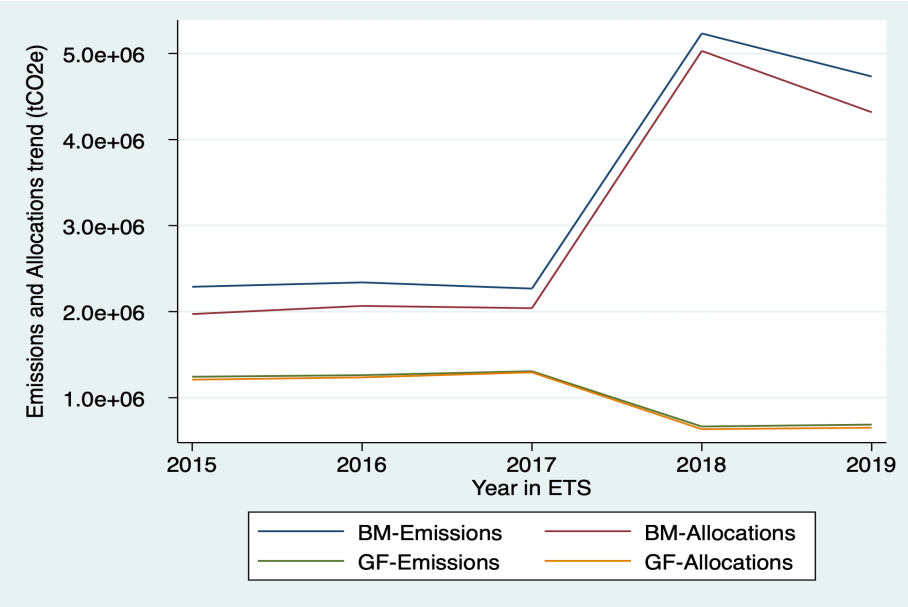
Difference-in-differences (DID) regression methodology is employed to assess the impact of Benchmarking (BM) allocation in two distinct phases: Phase 1 (pre-treatment) and Phase 2 (post-treatment) based on the Hypothesis 1 and 2. The analysis of the effect of BM treatment involves a comparison of the probability of non-compliance ratio before and after the expansion of BM allocation in 2018, represented as the cutoff point. A binary variable distinguishes entities that received BM allocation from those that did not. This analytical approach enables the investigation of the impact of BM allocation on the Probability of non-compliance ratio. This method relies on the assumption that external interferences have minimal impact on both the BM-allocated (treatment) and Grandfathering (GF) allocated (control) groups during the specified years under examination, particularly before and after the introduction of the treatment.

Trend of Allocations, Emissions and Non-Compliance possibilities by allocation methods

Before embarking on the investigation into the impact of BM allocation in Phase 2, the study evaluated the influence of BM and GF allocation on pivotal variables throughout the entire year. This evaluation is presented and illustrated in Figure 3 and Figure 4, which encompass main aspects such as Allocations, Emissions, and Non-compliance possibilities.

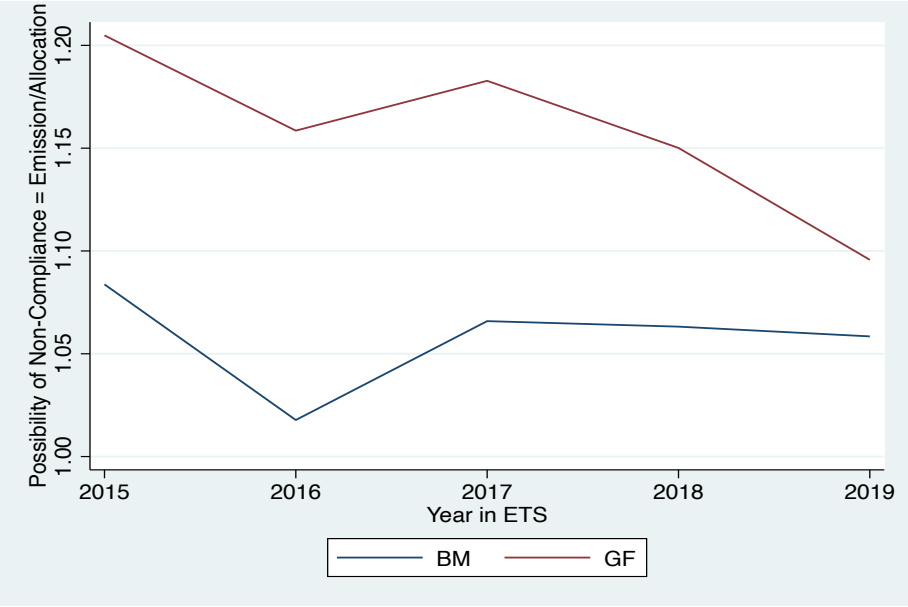
First, Figure 3 provides empirical confirmation of discernible patterns in emissions and allocations between the distinct phases: Phase 1 and Phase 2. In the initial phase, both the BM and GF allocation methods manifest nearly parallel, relatively stable patterns in emissions and allocations. However, as the ETS transitions into Phase 2, a notable departure is observed for both allocation methods, revealing significant disparities in these patterns attributed to the choice of allocation methods.

Figure 3. The trend of means of Allocations and Emissions by treatment in each year.



Regarding the key variable of this investigation, the mean of the Possibility of Non-compliance ratio, it also demonstrates a discernible trend concerning the impact of these two allocation methods. A parallel trend is notably evident during Phase 1, as elucidated in Figure 4. However, this trend takes on a different trajectory in Phase 2.

Figure 4. The Possibility of Non-compliance ratio depends on the allocation methods.



In Phase 1, both allocation methods follow a similar pattern, with the Possibility of Non-compliance ratio exceeding 1.0. However, a significant disparity emerged in the rate of decrease between the two methods starting in 2018, coinciding with the introduction of Phase 2. Specifically, BM allocation displays a gradual and modest declining trend in the possibility of the non-compliance ratio over the years. Conversely, GF allocations exhibit more substantial and notable downward trends in reduced emissions.

These observed divergences in Phase 2 for all major dependent variables lend robust support to the identification of distinctive patterns between the BM and GF allocation methods in both Phase 1 and Phase 2.[9]

The Empirical Model for Evaluating the Impact of BM Allocation in Phase 2

To precisely estimate the impact of BM allocation during Phase 2 (2018-2019) and determine whether more stringent allocation methods have a greater impact, which aligns with the original aim of this investigation, Equation (1) is utilized. This equation takes the form of a DID regression and incorporates individual firm fixed effects and time fixed effects.:

$$(1)\ y_{it} = \beta_1(BM_{it} * Phase_2) + Firm\ FE_i + Year\ FE_t + \varepsilon_{it}$$

y_{it} represents a key dependent variable, the 'Possibility of Non-compliance', for *firm i* in *year t.* To conduct a more comprehensive analysis, the model used two other dependent variables, 'Allocations' and 'Emissions'. BM_{it} a binary indicates whether *firm i* received Benchmarking (BM) allocation in $Year_t$. $Phase_2$ is another binary variable to distinguish the impact of BM allocation on Phase 2, which exhibited significantly different values in major dependent variables according to summary statistics.

[9] For trend of Allocation, Emission and Possibility of Non-Compliance of Large entities and SMEs(Small and Medium sized entities), please refer to the *Appendix Figure1* and *Appendix Figure2.*

An interaction variable is created by multiplying BM_{it} and $Phase_2$. This interaction variable is utilized as a regressor in the empirical model, and it aids in capturing the effect of BM allocation specifically during Phase 2, denoted by coefficient β_1, which is a key result of the empirical model. It quantifies how the Possibility of Non-compliance (y_{it}) changes when BM allocation is received during Phase 2 compared to Phase 1. Moreover, $Auction_{it}$ is included as a control variable. This variable considers the auction allocation method applied to each subsector, which differs from with GF and BM allocated subsectors. Including it as a control variable helps account for potential differences in outcomes related to various allocation methods, allowing us to isolate the effects of BM allocation in Phase 2.

Firm and Year-fixed effects are also introduced into the equation. Firm fixed effect ($Firm\ FE_i$) considers the unique characteristics of each firm, like its size and industry, to control for firm-specific factors. Year fixed effects ($Year\ FE_t$) can capture factors such as economic conditions, regulatory changes, or other time-specific influences. Lastly, the error term at the end (ε_{it}) accounts for unexplained variations in the dependent variable, Y_{it}, which can be due to random or unobservable factors.

4. Results

4.1. Baseline Results:

Effectiveness of Benchmarking allocation for all entities in the ETS

The Possibility of Non-compliance ratio shows 12.9 percentage point increase with Benchmarking (BM) allocation in Phase 2, as shown in Table 4. The adoption of BM allocation, which is a more stringent method, does not lead to a reduction in carbon emissions through the allocation process; instead, it results in a positive relationship in the Possibility of Non-compliance ratio. BM allocation has no significant impact on emissions and allocation itself. These results

support the Hypothesis 1: the impact direction is negative that BM allocation makes decrease the achievement.

Table 4 - BM allocation Effect on Non-compliance, Emission and Allocation

	Allocations (KtCO2e)		**Emissions (ktCO2e)**		**Non-compliance**	
	No controls (1)	Controls (2)	No controls (3)	Controls (4)	No controls (5)	Controls (6)
BM*Phase2	-171.550 (117.682)	-154.831 (108.009)	-147.979 (145.324)	-141.657 (137.736)	0.142** (0.059)	0.129** (0.056)
Controls	N	Y	N	Y	N	Y
Observations	1,980	1,980	1,980	1,980	1,980	1,980
Adj_R^2	0.99	0.99	0.99	0.99	0.49	0.49

Notes: This table contains estimates of the effect of BM allocation in Phase2 on Non-compliance, Emissions, and allocations. The Control in the table is Auction allocation, which differs in its application from BM allocation in Phase 2, representing another stringent factor in the supply of carbon permits. The standard errors are clustered at the firm level. Statistical significance at the 1, 5, and 10 percent levels is indicated by ***, **, and *, respectively, and the evaluated standard error is robust.

4.2. Subsample Results :

Effectiveness of Benchmarking allocation by scale of entities in the ETS

From the baseline analysis, sub-analysis is conducted in Table 5 for testing Hypothesis 2, using entity size dummies for a large entity and small and medium-sized entities (SMEs), shows a significantly different impact on Possibility of Non-compliance ratio.

In Panel A, large entities reveal that BM allocation in Phase 2 contributes to an increase in the Possibility of Non-compliance ratio; the effect lacks statistical significance. On the other hand, SMEs show a significant impact, with the Possibility of Non-compliance ratio increasing by 17.6 percentage points. Table 5 further supports the finding that SMEs primarily drive the increase in the Possibility of Non-compliance ratio of whole entities in Table 4. There is no significant evidence for the impact of BM allocation on both entities' emissions and allocation. However, a

substantial disparity exists in the extent of emission reduction between the large entities and the SMEs. Furthermore, the degree of allocation reduction under BM allocation is even more pronounced in the category of SMEs. These analyses do not support Hypothesis 2, revealing that the impact of the strengthened allocation method varies depending on the entity scale. Specifically, the results show (1) no impact of BM allocation on large entities and (2) a negative impact of BM allocation on SMEs in terms of complying with the allocated permit by reducing emissions, as indicated by the Possibility of Non-compliance ratio.

Table 5. BM Allocation Effect on Non-compliance, Emissions, and Allocations by Entity Size

	Allocations (ktCO2e)		**Emissions (KtCO2e)**		**Possibility of Non-compliance**	
	No controls (1)	Controls (2)	No controls (3)	Controls (4)	No controls (5)	Controls (6)
A. Large entities						
BM*Phase2	-116.674 (248.334)	-85.860 (218.027)	-458.554 (336.978)	-381.677 (287.365)	0.035 (0.077)	0.038 (.074)
Controls	N	Y	N	Y	N	Y
Observations	597	597	597	597	597	597
Adj_R^2	0.99	0.99	0.99	0.99	0.44	0.44
B. Small and medium sized entities (SMEs)						
BM*Phase2	-201.177 (128.937)	-191.520 (120.832)	-6.582 (142.023)	-13.596 (137.685)	0.188** (0.077)	0.176** (0.075)
Controls	N	Y	N	Y	N	Y
Observations	1,380	1,380	1,380	1,380	1,380	1,380
Adj_R^2	0.99	0.99	1.00	1.00	0.50	0.50

Notes: The Large entities dropped 3 singleton observations during analysis. The Control in the table is Auction allocation, which differs in its application from BM allocation in Phase 2, representing another stringent factor in the supply of carbon permits. The standard errors are clustered at the firm level. Statistical significance at the 1, 5, and 10 percent levels is indicated by ***, **, and *, respectively, and the evaluated standard error is robust.

Cause of Effectiveness of Benchmarking Allocation in SMEs:

Private entity vs. Public corporation

This study also conducted a more detailed analysis of the category of SMEs in Table 6. In Table 5, the sub-samples (Large entities and SMEs) were categorized based on the typical classification of large entities as private companies according to Korean law. Consequently, the SME category encompasses all other scales of private entities and public corporations since there are no specific laws to distinguish Public Corporations by size. However, this further analysis of SMEs as dividing two more categories was essential due to the diverse array of participants in the Korea ETS, which includes entities such as the Korea Electric Power Corporation, affiliated enterprises, municipal government agencies, and private establishments.

It's important to note that the Carbon Emission Target Management Scheme (TMS) serves as a preparatory step for the ETS, and the TMS designed exclusively for Public Corporations operates separately. Therefore, conducting additional analysis with a specific focus on distinguishing Public Corporations within this sub-sample of SMEs is essential to comprehensively understand how allocation methods impact and influence behaviors within the context of both TMS and ETS.

The results in Table 6 indicate that BM allocation had a significant impact on emissions reduction in private entities and an increase in non-compliance possibilities among Public Corporations within SMEs

Remarkably, private companies in SMEs (Panel A) experience a significant reduction of 95.3 tons of CO2 equivalent emissions when they adopt BM allocation compared to GF allocation. However, this reduction in emissions does not seem to have a substantial impact on the overall reduction in the Possibility of Non-compliance across all entities and SMEs, as demonstrated in Panels A and C of Table 5.

In contrast, Public Corporations play a dominant role in the observed increase in non-compliance possibilities, particularly in Panel B (SMEs) of Table 5. As Panel B of Table 6 shows, the control group, characterized by its allocation through auctions, exhibits a significant and evident increase of 59.3 percentage points in the variable of Possibility of Non-compliance. The analysis results reveal an intriguing trend of increasing non-compliance possibilities in the entire SMEs category in Table 5, primarily driven by Public Corporations. It can reject the second hypothesis, demonstrating a differing impact of BM allocation between SMEs in the private sector and SMEs owned by public corporations.

Table 6. BM allocation Effect on Non-compliance, Emission and Allocation by entity type

	Allocations (ktCO2e)		**Emissions (KtCO2e)**		**Possibility of Non-compliance**	
	No controls (1)	Controls (2)	No controls (3)	Controls (4)	No controls (5)	Controls (6)
Panel A. SMEs- Private entity						
BM*Phase2	-44.651 (29.233)	-45.282 (29.664)	-97.280** (45.819)	-95.939** (45.510)	0.019 (0.051)	0.024 (0.051)
Controls	N	Y	N	Y	N	Y
Observations	1,140	1,140	1,140	1,140	1,140	1,140
Adj_R^2	1.00	1.00	1.00	0.99	0.74	0.74
Panel B. SMEs-Public Corporation						
BM*Phase2	-758.939 (527.323)	-539.744 (498.223)	297.019 (590.738)	136.444 (640.083)	1.081** (0.380)	0.593** (0.284)
Controls	N	Y	N	Y	N	Y
Observations	240	240	240	240	240	240
Adj_R^2	0.99	0.99	0.99	0.99	0.47	0.49

Notes: The categorization of entities aligns with the TMS framework: Public Corporation – Public university, public hospital, Local government, and other public corporation including affiliated of the Korea Electric Power Plant. The Control in the table is Auction allocation, which differs in its application from BM allocation in Phase 2, representing another stringent factor in the supply of carbon permits. The standard errors are clustered at the firm level. Statistical significance at the 1, 5, and 10 percent levels is indicated by ***, **, and *, respectively, and the evaluated standard error is robust.

4.3 Time-Varying Effect

The impact of Benchmarking (BM) allocation can also vary over the years, offering a more detailed perspective on the effect of Benchmarking on all entities and sub-categorizations. Figure 5 presents the coefficients of BM allocation on the Possibility of Non-compliance ratio, highlighting a distinct trend by years with equation (2).

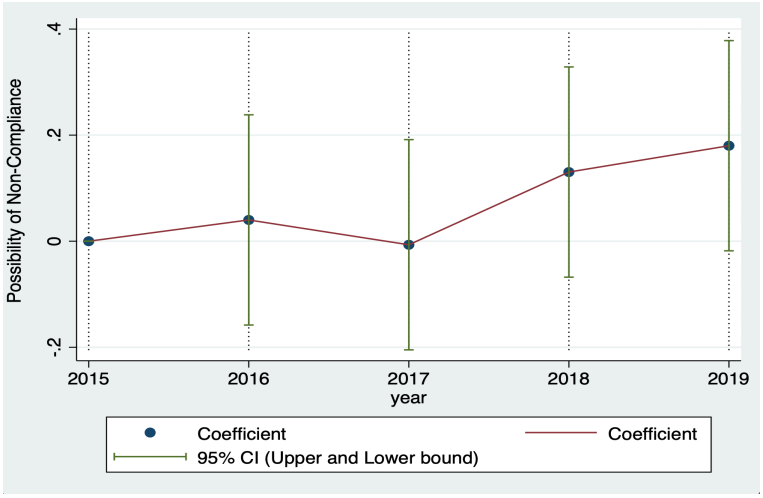
$$(2)\ Y_{it} = \sum_{t} \beta_2 (BM_{it} * Year\ dummy_t) + Firm\ FE_i + Year\ FE_t + \varepsilon_{it}$$

Y_{it} represents the main dependent variable 'Possibility of Non-compliance' for firm *i* in year *t*. The product of BM_{it} and $Year\ dummy_t$ is used an interaction variable in the equation to help us estimate the coefficient β_2 for each year(*t*). This coefficient shows how the dependent variable changes over the years, giving us insights into how BM allocation affects the variable across different years. It also takes into account firm-specific and year-specific fixed effects along with random error.

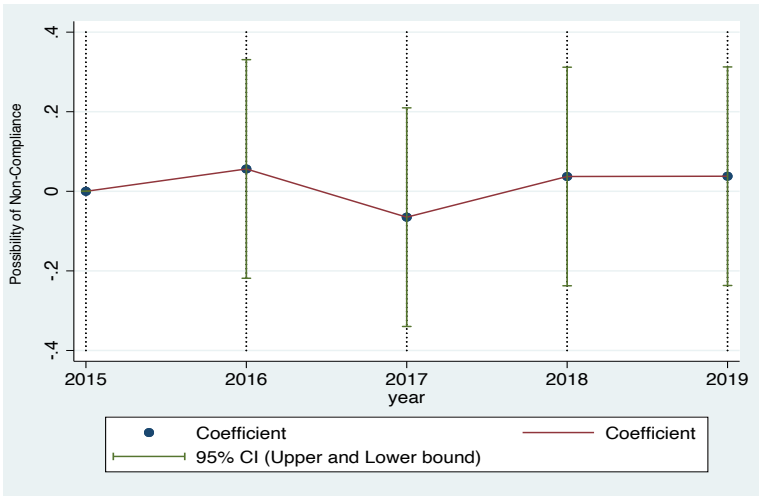
As for all entities (A), in 2018, the initial year of Phase 2, the coefficients of BM allocation were observed to be higher compared to Phase 1 (2015~2017), and they exhibited an ascending trend. The elevated ratios indicate that entities allocated through BM essentially face the imperative to exert extra effort and investment in reducing carbon emissions to reverse the rising emission trend or alternatively procure permits from the carbon market.

Analyzing the sub-sample analyses in Figures (B) and (C), distinguished by the entity size, revealed distinct trends. It can be inferred that the coefficient of the BM allocation significantly increases only for all other entities (C). All sample analyses (A) and (C) exhibit a similar trend. Interestingly, the coefficient for large entities (B) exhibited a negative value in 2017, unprecedented in other sample analyses.

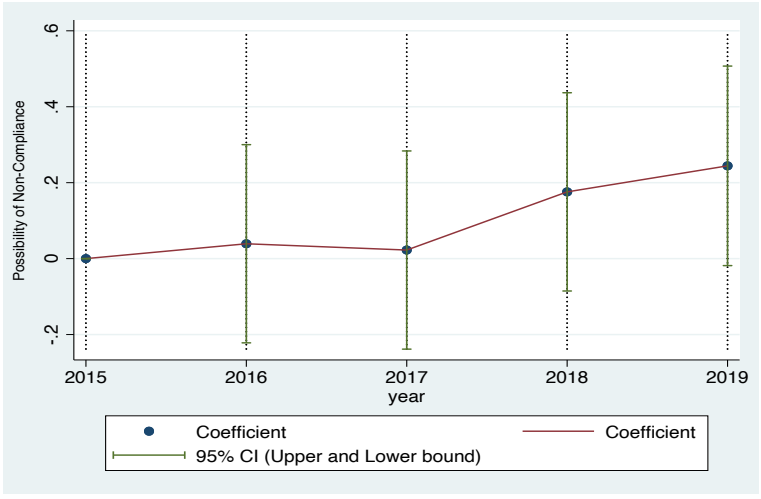
Figure 5. Coefficient of BM allocation on the Possibility of Non-compliance ratio



(A) All entities



(B) Large entities



(C) SMEs

5. Conclusions and Policy Implication

This paper analyzes the impact of Benchmarking (BM) allocation in Phase 2 on the Possibility of Non-compliance ratio, which was computed based on the allocation and emission data of each entity during the period of 2018 to 2019.

5.1 Conclusions

The BM allocation as a stringent method for providing fewer permits affect to the decreased the achievement level of carbon emission reduction. Even the results cannot consist for varying the entity scale, showing negative impact to the small and medium sized entities (SMEs) even though the significant emission reduction showed in the SMEs.

The results show that BM allocation has a statistically significant impact, leading to a 12.9 percentage point increase in emissions compared to the allotted allocation, the Non-compliance possibilities. This increase in the Possibility of Non-compliance ratio is primarily driven by small and medium-sized entities(SMEs), as indicated by the 17.6 percentage point in the sub-analysis.

Conducting extra subsample analysis with private entities and Public Corporations in SMEs, this 17.6 percentage point increase was dominantly given from the Public Corporation, which showed a significant increase of 59.3 percentage points of the Possibility of Non-compliance. Even though the notable emission decrease shown from the Private entities within SMEs couldn't significantly affect the emission decrease in the other results.

The primary discovery of this study indicates that the adoption of BM allocation leads to an elevation in the Possibility of Non-compliance ratio, seceding the original purpose of the stringed allocation. Large private entities did not exhibit any discernible impact on this increasing trend of non-compliance possibilities. Despite the earnest endeavors of small and medium-sized Private entities to curtail carbon emissions through reinforced BM allocation, such efforts did not yield a

proportionate reduction in the Possibility of Non-compliance ratio for these entities. In stark contrast, Public Corporations displayed a contrasting effect with a substantial surge in the possibility of non-compliance ratio, irrespective of the reduction in allocation. This surge was concomitant with a significant uptick in emissions emanating from Public Corporations.

The investigation accentuates the constraints posed by BM allocations across distinct sub-groups: Large private entities, SMEs-Private entities, and SMEs-Public Corporations. The reinforced BM allocation approach scarcely influences substantial large entities' capacity to abate emissions, as they possess the resources to undertake diverse emission reduction strategies. These results align with the conclusions of a recent survey in the Korean Emission Trading System report in 2020, which exposed that significant entities have directed relatively greater resources towards carbon emissions reduction in comparison to small and medium-sized entities (Greenhouse Gas Inventory and Research Center of Korea, 2020).

On the other hand, BM allocation presents challenges for small and medium-sized private entities to meet stringent emission reduction targets. These entities grapple with limitations concerning technology investment and accessing carbon permits from the market despite their concerted attempts to sustain competitiveness. The same survey corroborates this observation, revealing that small and medium-sized entities have registered modest progress in carbon emission reduction, notwithstanding their relatively limited investment endeavors.

Furthermore, Public Corporations participating in the ETS could potentially adopt a passive approach toward carbon emission reduction, as evidenced by a notable increase in emissions under BM allocation. This disposition could be attributed to their position as government entities with practical monopolies within their respective industries, potentially exempting them from the same market competitiveness concerns as private entities. Alternatively, this trend could also indicate a

heightened motivation for increased emission reduction efforts to meet allocation targets, given their status as public entities.

5.2. Policy Implications

Returning to the research questions, it is essential to reconsider how the policy allocates emission permits, considering the capabilities of different entities, fairness, and objectivity of carbon reduction targets, given the administrative costs and efforts of BM allocation. As the ETS gains prominence, applying a uniform allocation method to all entities, regardless of their financial capacity, might make smaller players less competitive in their industries. This becomes especially important in the global context, where carbon reduction standards are becoming stricter, and new regulations like the Carbon Border Adjustment Mechanism (CBAM) or Carbon Tax are emerging.

Small and medium-sized (SMEs)-private entities should certainly contribute to carbon reduction efforts, but they often need more support in terms of resources and technology upgrades. This support can come from the government and larger entities through programs akin to the Joint Implementation (JI) mechanism in the Kyoto Protocol. Such programs make allow larger entities to assist smaller ones in securing more permits. To make this work, the government should play a pivotal role in assessing carbon reduction potential before deciding on allocation methods. This approach can be more effective and administratively efficient than the complex BM allocation method.

Further supporting this idea, it's essential to emphasize the need for a deeper investigation into the specific challenges Public Corporations encounter in complying with their allocated permits and the factors driving the significant increase in emissions under BM allocation. This investigation can provide valuable insights into the factors influencing the behavior of Public Corporations in the ETS. Additionally, the government should actively support emission reduction

initiatives by Public Corporations, going beyond mere profit considerations, as these entities bear significant responsibility. By engaging more proactively, the government can encourage a stronger commitment to carbon reduction and the ETS's objectives.

5.3. Future research

Despite the study's outcomes and implications, there's room for improvement. Incorporating more recent data, like 2020 allocations, could enhance the analysis of Phase 2 (2018-2020). Future research might explore variables like non-compliance ratios, entity sales data, and energy intensity.

Specifically, future investigations could delve deeper into the BM level. The Korea ETS employs a BM level defined as the average carbon emission efficiency across the entire ETS period, while the EU ETS uses a top 10% of efficiency BM level. The choice of BM level significantly impacts allocation results, affecting both the achievement of reduction targets and entity behavior.

Furthermore, allocation practice in Phase 3 (2021-2025), which is beyond the scope of this study, can be a challenge subject for case analysis. Analyzing BM allocation for large entities, as well as its consultation and late adoption for SMEs in Phase 3, can help evaluate its efficiency and effectiveness compared to other methods in terms of carbon reduction emission and administrative processes. By critically addressing the study's limitations and furthering research in this field, particularly within the context of the Korea ETS, another opportunity emerges to enhance the effectiveness of the ETS in achieving its goal of reducing carbon emissions.

Appendix Table 1. The subsectors of the K-ETS and their allocation methods in Phase 1 and Phase 2 based on the Korean Standard Industrial Classification

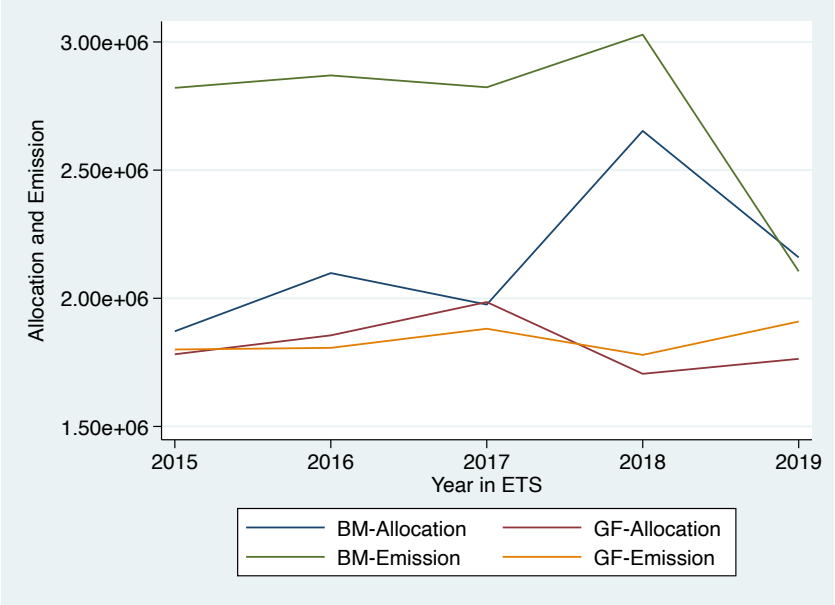
Sector	Phase1			Phase2		
	Subsectors	GF/BM	Free /Auction	Subsectors	GF/BM	Free /Auction
Industry	(1) Industrial complex	GF	Free	(1) Steam, chilled or hot water and air conditioning supply	BM	Free
	(2) Mining	GF	Free	(2) Mining of coal and lignite	GF	Free
	(3) Food and beverage	GF	Free	(3) Slaughtering of livestock, processing, and preserving of meat and meat products	GF	Auction
				(4) Manufacture of vegetable and animal oils and fats	GF	Free
				(5) Manufacture of dairy products and edible ice cakes	GF	Auction
				(6) Manufacture of grain mill products, starches and starch products	GF	Free
				(7) Manufacture of other food products	GF	Auction
				(8) Manufacture of alcoholic beverages	GF	Auction
				(9) Manufacture of ice and non-alcoholic beverages; production of mineral waters	GF	Auction
				(10) Manufacture of tobacco products	GF	Free
	(4) Fibers and textiles	GF	Free	(11) Spinning of textiles and processing of threads and yarns	GF	Free
				(12) Dyeing and finishing of textiles and wearing apparel	GF	Auction
				(13) Manufacture of man-made fibers	GF	Free
	(5) Wood products	GF	Free	(14) Manufacture of wood products	GF	Auction
	(6) Pulp and paper	GF	Free	(15) Manufacture of pulp, paper and paperboard	GF	Free
	(7) Refined petroleum products	BM	Free	(16) Manufacture of refined petroleum products	BM	Free
	(8) Oil and other chemical products	GF	Free	(17) Manufacture of basic chemicals	GF	Free
				(18) Manufacture of plastics and synthetic rubber in primary forms	GF	Free
				(19) Manufacture of fertilizers, pesticides, germicides and insecticides	GF	Free
				(20) Manufacture of other chemical products	GF	Free

				(21) Manufacture of medicinal chemicals, antibiotics and biological products	GF	Free
				(22) Manufacture of medicaments	GF	Free
				(23) Manufacture of rubber products	GF	Free
				(24) Manufacture of plastics products	GF	Auction
	(9) Glass products	GF	Free	(25) Manufacture of glass and glass products	GF	Free
	(10) Ceramic products	GF	Free	(26) Manufacture of refractory and non-refractory ceramic products	GF	Free
	(11) Cement products	BM	Free	(27) Manufacture of cement, lime and plaster	BM	Free
				(28) Manufacture of articles of concrete, ready-mixed concrete and other cement and plaster products	BM	Auction
	(12) Iron products	GF	Free	(29) Manufacture of basic iron and steel	GF	Free
				Casting of metals	GF	Auction
	(13) Non-ferrous metal	GF	Free	(30) Manufacture of basic precious and non-ferrous metals	GF	Free
	(14) Machinery products	GF	Free	(31) Manufacture of structural metal products, tanks, reservoirs and steam generators	GF	Free
				(32) Manufacture of other fabricated metal products; metalworking service activities	GF	Auction
				(33) Manufacture of general-purpose machinery	GF	Free
				(34) Manufacture of special-purpose machinery	GF	Free
				(35) Manufacture of aircraft, spacecraft and its parts	GF	Free
	(15) Semi-conductor	GF	Free	(36) Manufacture of semiconductor	GF	Free
	(16) Display products	GF	Free	(37) Manufacture of electronic components	GF	Free
	(17) Electrical and electronic	GF	Free	(38) Manufacture of batteries and accumulator	GF	Free
				(39) Manufacture of insulated wires and cables	GF	Free
				(40) Manufacture of domestic appliances	GF	Free
	(18) Motor vehicles	GF	Free	(41) Manufacture of motor vehicles and engines for motor vehicles	GF	Free

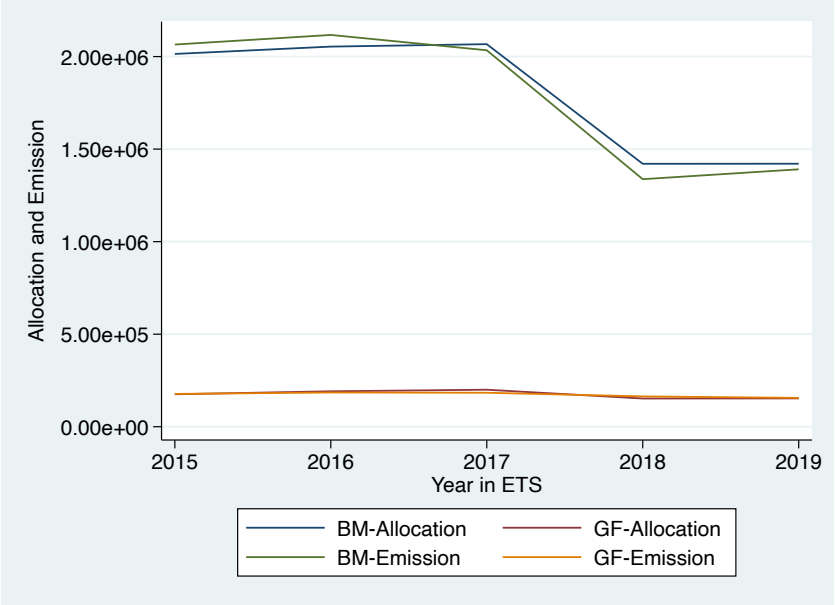
				(42) Manufacture of parts and accessories for motor vehicles(new products)	GF	Free
	(19) Ships and boats	GF	Free	(43) Building of ships and boats	GF	Free
	(20) Telecommunications	GF	Free	(44) Telecommunications	GF	Auction
				(45) Computer programming, consultancy and related activities	GF	Auction
				(46) Data processing, hosting and related activities; web portals	GF	Auction
Power	(21) Power plant	GF	Free	(47) Electric power generation, transmission and distribution	BM	Auction
				(48) Manufacture of gas; distribution of gaseous fuel through mains	BM	Free
	(22) District heating business	GF	Free	(49) Steam, chilled or hot water and air conditioning supply	BM	Free
Waste	(23) Waste	GF	Free	(50) Sewage, wastewater, human and animal waste treatment services	BM	Auction
				(51) Waste treatment and disposal services	GF	Free
Building	(24) Building business	GF	Free	(52) Retail sale in non-specialized stores	GF	Auction
				(53) Support activities for transportation	GF	Free
				(54) General accommodation and accommodation with cooking facilities	GF	Auction
				(55) Insurance business	GF	Auction
				(56) Real estate activities with own or leased property	GF	Auction
				(57) Administration of industrial and social policy of community	GF	Auction
				(58) Higher education	GF	Auction
				(59) Hospital activities	GF	Auction
				(60) Amusement parks and other recreation activities	GF	Auction
Transportation	(25) Aviation	BM	Free	(61) Passenger air transport	BM	Auction
Public/ Others	(26) Water supply	GF	Free	(62) Water Supply	GF	Auction

Appendix Figure 1. The trend of means of Allocations and Emissions of Large entities and Small and Medium-sized entities (SMEs) by treatment in each year.

Figure 1. The trend of means of Allocations and Emissions by treatment in each year.



(A) Large entities

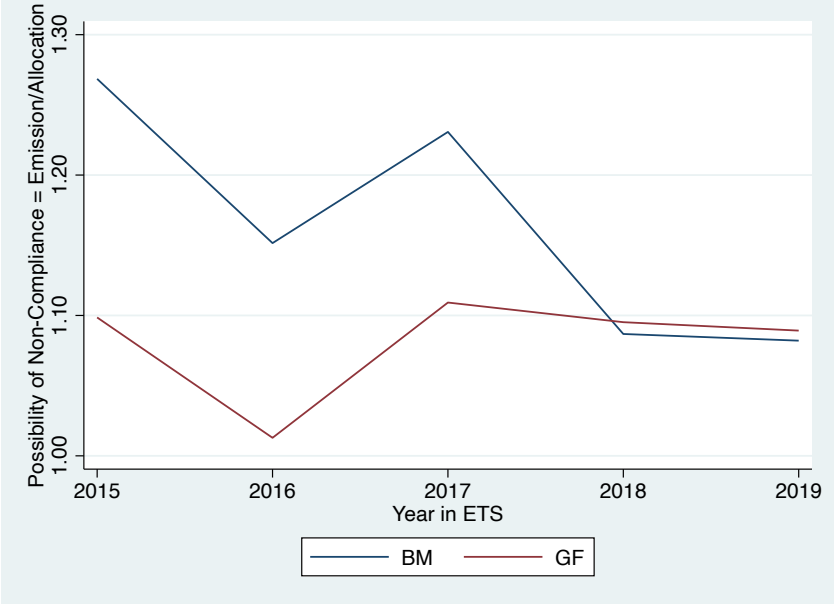


(B) SMEs

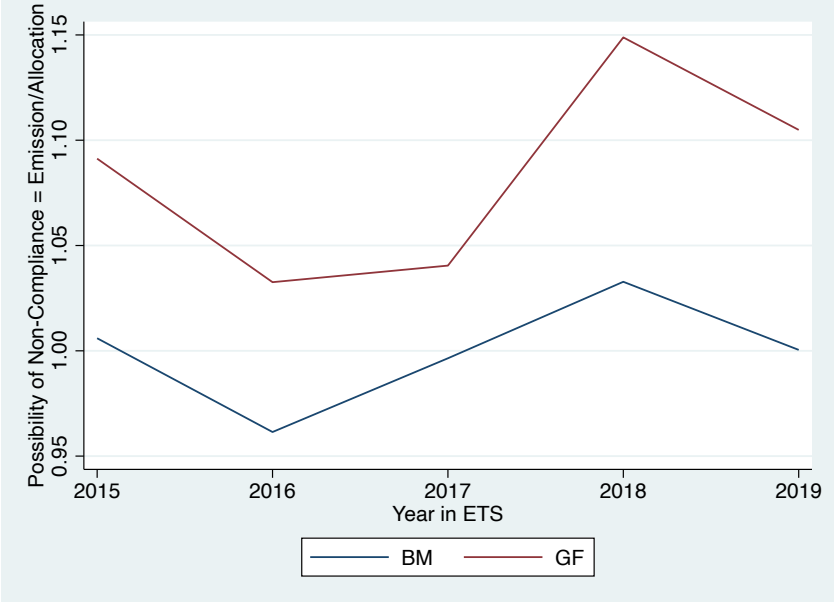
Notes: While they show relatively parallel trends during Phase 1 and distinct trends based on BM and GF allocation, (A) large entities do not provide a clear basis for comparison. (B) SMEs exhibit noticeable differences between Phase 1 and Phase 2.

Appendix Figure 2. The trend of means of Possibility of the Non-compliance of Large entities and Small and Medium-sized entities (SMEs) by treatment in each year.

Figure 2. The trend of means of Possibility of Non-Compliance by treatment in each year



(A) Large entities



(B) SMEs

Notes: Both (A) large entities and (B) SMEs exhibit distinct trends in the possibility of non-compliance. In contrast, during Phase 2, the possibility of non-compliance by BM allocation for large entities decreases, while for SMEs, the possibility increases for both allocation methods.

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