Regulatory Stringency, ESG Ratings, and Greenwashing: Evidence from Korea's Carbon Market

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Abstract

Carbon pricing regulations are widely expected to improve both firms' environmental performance and their ESG ratings. We show that these two outcomes can significantly diverge. Employing the staggered adoption of Korea's Emissions Trading Scheme (K-ETS) and Target Management System (TMS) across 592 publicly listed firms from 2015 to 2024, we find that entry into the stricter ETS generates a statistically significant and persistent increase in firms' ESG environmental scores, whereas the weaker TMS has no detectable effect. Yet this rating improvement is decoupled from actual emissions outcomes, where ETS adoption is associated with no statistically significant reduction in greenhouse gas emissions. We further determine that gains in environmental scores do not predict subsequent reductions in emissions intensity. This evidence is consistent with regulatory-induced greenwashing, in which firms strategically improve their ESG profiles in response to compliance pressure without undertaking substantive decarbonization. Our findings provide implications for capital market participants with ESG investing, and for policymakers designing carbon regulations: tightening regulatory stringency alone may be insufficient to induce real emissions reductions if it simultaneously creates strong incentives for reputational signaling.

Keywords: Carbon Pricing; Emissions Trading Scheme; Target Management System; ESG ratings; Greenwashing

JEL classification: C33; M14; Q56

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1 Introduction

In recent years, as climate-related physical and transition risks have become more salient, institutional investors increasingly recognize these exposures as financially material factors that require rigorous management (Krueger et al., 2020; Giglio et al., 2021). Consistent with this perspective, many investors now prioritize high-quality climate risk disclosure, frequently viewing such reporting as important as traditional financial information (Ilhan et al., 2023). In this regard, ESG ratings (particularly environment-related rates) have emerged as a key interface between firms and capital markets, shaping how investors assess firms' exposure to climate risk and their commitment to sustainability.

This heightened attention on the ESG disclosure and ratings is not an isolated trend but the culmination of a decades-long evolution in global climate response.[1] Emissions Trading Scheme (ETS) among others emerged as a pivotal policy instrument across the globe. The subsequent adoption of the EU-ETS in 2005 represented a landmark shift in corporate climate regulatory environments, setting the stage for global carbon governance and operating as a market-based policy instrument. Under this framework, firms are required to hold sufficient allowances to cover their CO_2 emissions, which incentivize them to manage their emissions within these predefined limits (Ellerman and Buchner, 2007).[2]

South Korea, which has one of the biggest manufacturing industries and is the second highest country for carbon emission per capita, has implemented the Target Management System (TMS)

[1] Driven by the rapid escalation of climate-driven threats since the 1990s, this evolution has necessitated a transition from theoretical discussion to active risk management. This shift toward active risk management was further solidified by the Kyoto Protocol, which provided the legal architecture for binding emission reductions through specific implementation mechanisms.

[2] If a firm's actual emissions are lower than its allocated cap, it can sell the resulting surplus allowances to other entities in the carbon market. Conversely, firms that exceed their assigned limits must purchase additional allowances from the market to ensure compliance. By utilizing a market-based mechanism, the ETS provides firms with the flexibility to adapt their environmental strategies efficiently within a regulatory framework.

as the country's primary climate policy instrument, which is a command-and-control regulatory framework leading the government to directly set firm-specific targets for greenhouse gas (GHG) emissions and energy consumption.[3] However, aligning with the global shift to the ETS regulation, the country reshaped its climate regulatory landscape in 2015 by initiating the Korea's ETS (K-ETS) as a cornerstone of its carbon neutrality agenda (Asian Development Bank, 2018). Unlike the market-driven EU-ETS, the K-ETS is heavily influenced by a state-centric political structure and features frequent discretionary interventions by the government.[4]

These two regulations (i.e., TMS and ETS) mandatorily apply to firms within a specific GHG emissions range, but their scopes and mechanisms differ.[5] The most critical distinction between them lies in their regulatory stringency and punitive measures. For example, the ETS is assigned to firms with higher GHG emission volumes[6] and requires much larger fines and penalties when violated, than the TMS.[7] For this reason, firms tend to increasingly consider carbon regulations in their ESG strategies, in particular for their core operations (Krueger et

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[3] South Korea's TMS is not unique in its regulatory logic. Similar command-and-control type regimes have been widely adopted internationally, particularly in the early stages of climate and environmental policy, where governments impose mandatory emission standards, technology requirements, or performance targets on firms. Such frameworks have historically played a central role in environmental regulation worldwide, providing a contrast to later market-based instruments such as ETS. For instance, well-known international benchmarks of such frameworks include the technology-based standards under the U.S. Clean Air Act of 1970 establishing technology-based emission standards for industrial sources and the European Union's Industrial Emissions Directive (2010/75/EU), both of which impose prescriptive regulatory obligations on firms rather than market-based flexibility (Wu et al., 2025).

[4] This divergence is strongly driven by path dependency, as the K-ETS is deeply rooted in the nation's previous climate policy (Joo et al., 2023).

[5] Referenced from Act on the Allocation and Trading of Greenhouse-Gas Emission Permits (Act No. 20172, 2024) in Korea. https://elaw.klri.re.kr/eng_mobile/viewer.do?hseq=64708&type=part&key=4; Guidelines on the Operation of the Greenhouse Gas and Energy Target Management System, (Notification No. 2020-3, 2020) in Korea. https://www.law.go.kr/admRulInfoP.do?admRulSeq=2100000186146.

[6] While the TMS imposes firm-specific emissions and energy targets through administrative oversight, the ETS exposes firms to allowance-price risk and market-based compliance. Firms are subject to the ETS regulation if their three-year average annual CO_2 emissions exceed 125,000 tons (or 25,000 tons for a single facility), whereas the TMS regulation apply to slightly smaller entities exceeding 50,000 tons (or 15,000 tons for a single facility).

[7] TMS-regulated firms that violate emission targets face a maximum administrative fine of only 10 million KRW. In contrast, ETS-regulated firms face a surcharge of up to three times the average market price of carbon credits for any excess emissions. Recorded instances of penalties exceeding 2 billion KRW for non-compliant ETS-regulated firms demonstrate that the ETS imposes a far stricter and financially burdensome regulatory environment than the TMS.

al., 2020). This implies that regulatory pressure is expected to translate into improvements in both firms' environmental performance and their ESG evaluations.

However, this expectation relies on a critical assumption that ESG metrics accurately reflect firms' underlying environmental outcomes. If ESG ratings primarily capture disclosure quality or symbolic compliance rather than substantive emissions reduction, firms may have incentives to strategically manage their ESG profiles in response to regulation. Such behavior can give rise to a decoupling between reported environmental performance and actual emissions outcomes. This concern is particularly relevant in the context of carbon regulation, where policy design determines not only compliance costs but also firms' incentives to engage in real mitigation versus reputational signaling. While prior literature has examined the impact of ETS on innovation and GHG emission, relatively little is known about whether stricter regulation improves ESG performance without delivering corresponding environmental outcomes.

To address this gap, we aim to examine the transition from the TMS to the more stringent ETS in Korea. By jointly analyzing ESG environmental scores and firm-level GHG emissions, we test whether regulatory stringency leads to substantive environmental improvements or instead induces a divergence consistent with greenwashing behavior. We employ a regression analysis incorporating firm and year fixed effects and a staggered Difference-in-Differences (DiD) framework to account for the heterogeneous timing of regulatory implementation. Our findings reveal a clear asymmetry between reported and actual environmental performance. While the transition to the more stringent ETS leads to a statistically significant and persistent increase in ESG environmental (E) scores, we find no corresponding reduction in firms' GHG emissions. Further analysis shows that improvements in environmental scores do not precede subsequent emissions reductions, suggesting that these gains are not indicative of real mitigation efforts. In conclusion, the results point to a systematic decoupling between ESG ratings and underlying

environmental outcomes under carbon regulation.

This study contributes to literature threefold. First, we bridge the gap between ESG measurement and real environmental outcomes by linking firm-level ESG ratings to actual emissions data. Second, we show that regulatory stringency may affect not only firms' operational behavior but also their strategic disclosure incentives. Third, we provide new evidence on greenwashing in the context of climate regulation by documenting a systematic divergence between reported and actual environmental performance. It has important implications for investors and policymakers, as it suggests that capital may be allocated based on signals that do not correspond to real decarbonization outcomes. The rest of the paper is structured as follows. Section 2 reviews the literature on ESG management and firm-level carbon regulations, followed by the methodological framework in Section 3. Section 4 describes the dataset and variables used in the study, and the empirical results are addressed in Section 5. We conclude in Section 6.

2 Literature review and hypothesis development

2.1 Sustainability regulation and corporate performance

Porter and van der Linde (1995) hypothesize that well-designed regulations promote competitiveness by incentivizing corporate innovation through flexibility and performance-based goals. This innovative response results in superior productivity and quality, allowing firms to achieve better market positioning; hence this hypothesis challenges the view that environmental regulations are merely costly. Ambec et al. (2013) reinforce this perspective by documenting widespread innovative responses to environmental mandates across various empirical studies. However, they emphasize that such innovation does not automatically translate into enhanced competitiveness or profitability because the outcomes are contingent

upon specific factors including regulatory design, industry characteristics, and available technological opportunities.

From a corporate-level strategic perspective, Hart (1995) extends the Resource-Based View (RBV) by proposing the Natural Resource-Based View (NRBV), which theoretically supports the idea that responding to environmental constraints is not simply a compliance cost, but can become a source of sustainable competitive advantage through organizational capabilities such as pollution prevention, product responsibility, and sustainable technology development. In this context, Russo and Fouts (1997) show that a firm's environmental performance can be related to profitability, and that its economic benefits can be greater in environments with high industrial growth, suggesting that environmental response can function as a stronger competitive advantage.

Building on this, the effect of sustainable management becomes substantial when integrated into core organizational processes rather than treated as a one-time activity. By embedding environmental and social priorities into goal setting, reporting, and governance, firms can transform regulatory compliance into substantive corporate capacity. Eccles et al. (2014) claim that such institutionalization leads to unique performance patterns, implying that ESG can function as a comprehensive organizational system rather than a short-term cost. Furthermore, Lins et al. (2017) report that firms with high Corporate Social Responsibility (CSR) ratings demonstrate high stock returns and profitability during shocks such as the financial crisis. By interpreting this from the perspective of intangible assets such as social capital and trust, they support the idea that sustainable management can function as a risk buffer in times of crisis.

2.2 Two-sided impacts of carbon regulations

Given the increasing importance of ESG management for corporations, the literature reviewed in the previous section raises a central question: whether carbon regulations induce substantive

operational changes or primarily strengthen firms' visible ESG signals. Resolving which effect prevails under what institutional conditions is key to understanding the real-world effectiveness of carbon regulations. Previous studies of the impact of the ETS on corporate behavior and performance reveal a lack of consensus, with findings varying by region or compliance mechanisms.

For example, Jiang et al. (2024) find that China's pilot ETS reduces both absolute carbon emissions and emission intensity, suggesting that the ETS can act as an institutional catalyst transforming Carbon Management Systems (CMS)[8] from symbolic to substantive practices promoting low-carbon innovation. In a similar vein, Colmer et al. (2025) provide firm-level causal evidence from the EU ETS that regulated manufacturers reduce CO_2 emissions by 14 to 16 percent across two trading phases, with no detectable contraction in economic output or employment. In particular, the authors find no evidence of carbon leakage through outsourcing or trade. Instead, regulated firms increase capital investment in cleaner production technologies; hence carbon pricing can induce genuine operational transformation rather than mere compliance activity.

However, such positive effects are not universal. Calel and Dechezleprêtre (2016) show that while the EU ETS generates statistically significant increase in low-carbon patents among regulated firms, its economy-wide technological redirection for green productions remains modest. This result raises the question of whether ETS participation reflects actual operational commitment or merely symbolic compliance. Using a national firm-level survey, Yang et al. (2016) show that firms' ETS participation is driven primarily by public relations and government pressure rather than their commitment to a reduction in GHG emissions or green-

[8] The CMS is a firm-level framework encompassing practices such as emissions reduction activities, energy structure management, and green development initiatives (Jiang et al., 2024).

technological innovation. More directly, Adamolekun et al. (2025) argue that ETS membership increases corporate climate risk, particularly in carbon-intensive industries following the 2015 Paris Climate Agreement, as firms appear to improve outward-facing indicators through disclosure and ratings management rather than actual decarbonization. One typically calls this corporate action *greenwashing*, where a discrepancy between the compliance for decarbonization and actual emissions is observed.

Against this backdrop, South Korea offers a particularly compelling research setting. The country's sequential implementation of the TMS and the K-ETS provides a quasi-experimental environment for a direct comparison of their relative effectiveness (Nyonho et al., 2023). Furthermore, South Korea is one of the rare institutional settings, where mandatory GHG disclosure and voluntary ESG disclosure coexist, enabling a multi-dimensional examination of how carbon regulation affects both firms' environmental performance and market valuation (Kim and Kim, 2024).

Existing Korean evidence largely points toward symbolic rather than substantive firm responses. Kim and Kim (2024) demonstrate that voluntary ESG disclosure under the TMS significantly mitigates negative market valuation effects, suggesting that disclosure serves a reputational rather than an operational function. Nyonho et al. (2023) find that the K-ETS does not significantly reduce firm-level emissions relative to the TMS, as compliance is largely achieved through allowance purchases rather than direct operational changes.[9] Park et al. (2024) further reveal a notable discrepancy between improved environmental ratings and actual emissions under the K-ETS, with firm value declining significantly due to heightened carbon allowance cost uncertainty.

[9] This finding is based on the analysis for the first phase of the K-ETS between 2015 and 2017, where most participants comply with the regulation. A detailed overview of the K-ETS phase is provided in Appendix A.

A related question is whether this pattern of decoupling between ESG ratings and actual GHG emissions persists or shifts under heightened regulatory pressure. Jonghe et al. (2020) show that corporate responses to the 2017 EU ETS tightening are heterogeneous: emission efficiency improves most sharply among firms facing the steepest compliance costs, whereas those with free allowance allocations show little change. A similar dynamic may apply in Korea, where the transition to Phase 3 of the K-ETS in 2021 raised the proportion of auctioned allowances to 10%, concentrating compliance costs among high-emitting firms and potentially generating the kind of heterogeneous behavioral responses observed in the European context.

Drawing on these studies, our study addresses a critical gap in literature. While prior research has examined the effects of emissions trading schemes on firm value and GHG abatement, studies that examine the effectiveness of heterogeneous regulatory intensities in corporate GHG management remain scarce, and direct empirical evidence of greenwashing in this context is largely absent. Table 1 illustrates what make the present study and relevant literature differ and clarify the contributions of this study.

Table 1. Comparison of Relevant Literature with the Present Study

	Evidence of Substantive Environmental Effectiveness		Decoupling: Symbolic Compliance over Real Reductions		The Case of Korea		Present Study
	Colmer et al. (2025)	Jiang et al. (2024)	Adamolekun et al. (2025)	Calel and Dechezleprêtre (2016)	Nyonho et al. (2023)	Park et al. (2024)	
Region	France	China	Global (65 countries)	EU	Korea	Korea	Korea
Sample size	2,348 firm-year	7,936 firm-year	32,752 firm-year	16,979 firm-year	1,314 firm-year	10,699 firm-year	5,920 firm-year
Focus of study	Impact of the EU ETS on reducing carbon emissions without economic contraction or carbon leakage.	Impact of the ETS on carbon performance and the moderating role of Carbon Management Systems (CMSs)	The impact of the ETS membership on corporate climate risk and its moderating factors	Impact of the EU ETS on direct technological change	Impact of the first phase of the K-ETS on environmental performance relative to the prior TMS	Impact of the K-ETS on corporate performance, value, and risk	Firm-Level environmental performance under the K-ETS and TMS, distinguishing real reductions from strategic responses
Main findings	The EU ETS reduced CO2 emissions by 14-16% with no detectable loss in output or employment, with reductions driven by cleaner production investment rather than carbon leakage	The ETS incentivizes low-carbon innovation and enables Carbon Management Systems (CMS) to function as substantive emissions reduction tools	The ETS membership significantly elevates climate risk in carbon-intensive sectors, paradoxically suggesting firms may use participation for reputational purposes rather than genuine emission reduction	The EU ETS increased low-carbon patents by approximately 9% among all regulated firms, and up to 36% among matched firms, though overall technological impact remained modest due to limited sectoral coverage	The K-ETS did not significantly reduce absolute GHG emissions, as firm prioritized compliance through allowance and offset purchases rather than direct operational mitigation, though energy efficiency improved in some sectors.	While K-ETS participation improved environmental disclosure ratings, it failed to reduce actual emissions and significantly decreased Tobin's Q due to carbon price uncertainty, despite modest short-term profitability gains.	While the transition from the TMS to the K-ETS led to a significant rise in environmental scores, this improvement reflects a decoupling effect as reporting gains did not align with actual GHG reductions.

2.3 Hypothesis development

The theoretical framework suggests that while environmental regulations can catalyze corporate innovation and competitiveness (Porter and van der Linde, 1995), the actual outcome may depend heavily on the regulatory design. Compared to the rigid mandates of the TMS, the stricter ETS imposes stronger compliance pressure and provides market-based flexibility and information incentives, which may encourage firms to integrate environmental management more deeply into their organizational processes (Eccles et al., 2014). Since high ESG ratings function as a signal of social capital and a risk buffer in capital markets (Lins et al., 2017), ETS-regulated firms can have stronger incentives to enhance their external environmental profiles to meet market expectations. Thus, we propose:

H1. The transition to the ETS leads to more significant improvements in corporate environmental scores than staying with the TMS.

However, as highlighted by Yang et al. (2016) and Adamolekun et al. (2025), there is a substantial risk of decoupling where firms prioritize reputation management over operational change. When the costs of substantive carbon reduction exceed the marginal benefits of permit compliance, firms often resort to symbolic management. This practice involves improving disclosure frameworks to boost ratings while bypassing the heavy capital expenditures required for an actual reduction in GHG emissions (Nyonho et al., 2023; Park et al., 2024). This can imply that the improvement in environmental scores may be a form of rational greenwashing rather than a reflection of physical environmental impact. Based on this, we hypothesize:

H2. Despite improvements in environmental scores following ETS entry, ETS adoption does not lead to a statistically significant improvement in firms' GHG emissions.

Another question can be whether this decoupling persists under heightened regulatory pressure. The reform of the ETS into the third phase in 2021 raises the proportion of paid allowances to

10%, increasing compliance costs unevenly across firms. As Jonghe et al. (2020) show regarding the EU ETS, corporate responses to this reform can be heterogeneous. Firms facing the greatest compliance burden drive the most pronounced efficiency gains, whereas those with free allocations show little change. Likewise, high-emitting firms under the third phase of the K-ETS may have stronger incentives to pursue both disclosure improvements and actual reductions in GHG emissions, whereas low-emitting firms near compliance thresholds face less pressure. This heterogeneity may emerge even without a detectable aggregate difference between regulated and non-regulated firms:

H3. High-emitting firms in the ETS market experience significantly greater improvements in environmental scores and larger reductions in GHG emissions following the third phase transition than low-emitting firms do.

3 Methodological framework

In this study, we first employ a Two-Way Fixed Effects (TWFE) Difference-in-Differences (DiD) framework to examine how firms under the ETS and the TMS can demonstrate their environmental performance. Our baseline model is specified as follows:

$$Y_{i,t+1} = \beta_1 Post_{i,t} + \beta^T Controls_{i,t} + Firm\ FE + Year\ FE + \epsilon_{i,t}, \quad (1)$$

where $Y_{i,t+1}$ represents the outcome variables for firm i in year $t+1$.[10] The outcome variables include environmental performance measures such as environmental scores of ESG ratings, log-transformed GHG emissions, GHG intensity, and the percentage change in GHG emissions (see Table 2 for variable description). $Post_{i,t}$ is a time-varying indicator that equals one if firm i is subject to regulation in year t, and zero otherwise.[11] $Controls_{i,t}$ denote a vector of time-

[10] We use next year's outcomes to allow for delayed effects of regulatory adoption.

[11] $Post_{i,t}$ varies across different specifications, that is, it is defined as an indicator variable that equals 1 if firm i is subject to the ETS, the TMS, or both regulations in year t.

varying firm-level control variables that are specified in Table 2. To account for unobserved heterogeneity, we include firm and year fixed effects, which control for time-invariant firm characteristics and common temporal shocks, respectively.

While the TWFE estimator is a traditional tool for the DiD analysis, its validity rests on the assumption of homogeneous treatment effects. However, recent econometric literature highlights that the TWFE estimator can be severely biased in a model for staggered adoption, where firms enter regulation at different points in time.[12] This bias can arise because earlier treated units serve as controls for those treated later.[13] When treatment effects are dynamic, using previously-treated units as controls causes their evolving post-treatment outcomes to be subtracted from the estimator, which can lead to significant bias.

To diagnose the extent of these potential biases, Goodman-Bacon (2021) provides a decomposition approach that breaks down the aggregate TWFE estimator into a weighted average of all possible 2×2 DiD comparisons.[14] This decomposition verifies the robustness of our results by identifying potential bias from already-treated comparisons. If such bias is significant, it justifies the use of more advanced staggered DiD estimators. Given the limitations of the TWFE model and the potential for bias identified through the Goodman-Bacon decomposition, this study employs a more robust estimation strategy to identify the causal impact of environmental regulations.

To address the pitfalls of heterogeneous treatment effects across different cohorts, we utilize the interaction weighted (IW) estimator developed by Sun and Abraham (2021). This method

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[12] De Chaisemartin and d'Haultfoeuille (2020) demonstrate that when treatment effects are heterogeneous across groups or over time, the TWFE estimator becomes a weighted sum of individual treatment effects where some weights may be negative.

[13] This can distort the estimates, potentially producing negative coefficients even when the true treatment effect is positive. Borusyak et al. (2024) point out that the TWFE for modeling a staggered adoption identifies treatment effects by leveraging all possible comparisons within the data. This process inevitably involves comparing units that are newly treated against those that were already treated.

[14] Appendix C provides details on the Goodman-Bacon decomposition.

is specifically designed for staggered Difference-in-Differences settings, where firms are subjected to regulations at different points in time. This approach enables to isolate cohort-specific effects, thereby preventing the contamination that occurs in standard TWFE models when previously-treated units are used as controls for later-treated units. The specification of this model is defined as follows:

$$Y_{i,t} = \sum_{e \in E} \sum_{l \neq -1} \delta_{e,l} \left(1\{E_i = e\} D_{i,t}^{l}\right) + \beta^T Controls_{i,t} + Firm\ FE + Year\ FE + \epsilon_{i,t}, \quad (2)$$

where E_i denotes the calendar year in which firm i first receives treatment; hence firms sharing the same value of E_i form a treatment cohort e, and the indicator of $1\{E_i = e\}$ equals one accordingly if firm i belongs to cohort e and zero otherwise, where it enables to isolate comparisons within each cohort and avoid the contamination problem documented by Sun and Abraham (2021). The variable $D_{i,t}^{l}$ is a relative-time indicator equal to one if $t - E_i = l$, meaning that period t falls exactly l periods away from firm i's initial treatment date, and zero otherwise. Negative values of l correspond to pre-treatment periods and are used to assess the validity of the assumption on parallel trends, while non-negative values capture the dynamic evolution of the treatment effect after adoption.[15]

The coefficient $\delta_{e,l}$ in equation (2) captures the cohort-specific average treatment effect on the treated (CATT), representing how much the outcome changes on average for cohort e during the relative period l compared to the never-treated group for the same relative time period. Because $\delta_{e,l}$ is estimated separately for each cohort e and relative period l, the specification allows treatment effects to differ freely across cohorts and to evolve over time, rather than

[15] The period $l = -1$ is omitted from the summation to serve as the baseline reference period, normalizing all estimates relative to the year immediately preceding treatment.

imposing the homogeneity restriction embedded in a standard two-way fixed effects regression.[16]

To explore evidence on greenwashing, we employ an event study framework that shows how environmental scores and GHG emissions can change relative to the onset of regulation. By observing the coefficients across relative periods l, we test the assumption of parallel trends in the pre-treatment phase and identify if the decoupling between improvements of environmental scores and reductions in GHG emissions is present. This dynamic perspective provides the granularity needed to distinguish between immediate compliance shocks and symbolic management.

We further implement a continuous DiD framework[17] to examine the heterogeneous effects of regulatory stringency on firm-level emissions. Unlike the canonical DiD that relies on a binary treatment, the continuous approach allows us to capture the intensity of the regulatory impact based on each firm's baseline characteristics. The model can be specified as follows:

$$Y_{i,t} = \sum_{\tau \neq 2020} \beta_\tau (Exposure_i \times 1\{t = \tau\}) + \beta^T Controls_{i,t} + Firm\ FE + Year\ FE\ +\ \epsilon_{i,t}\,, \qquad (3)$$

where $Y_{i,t}$ is the outcome variable of firm i in year t, capturing environmental performance across four measures: the environmental score, log-transformed GHG emissions, GHG intensity, and the percentage change in GHG emissions. $Exposure_i$ represents the average GHG emissions of firm i over the period from 2015 to 2020, prior to the 2021 implementation which marks the

[16] Interacting with relative-time indicators $E_{i,t}^{l}$ with the cohort dummies $1\{E_i = e\}$ ensures that each $\delta_{e,l}$ is identified from within-cohort variation only, thus already-treated units are never used as implicit controls for later-treated units. Aggregate estimates of treatment effects (i.e., the average effect at a given relative period across all cohorts) can then be defined as a weighted average of $\delta_{e,l}$ using cohort-share weights.

[17] The continuous DiD framework is widely used in contemporary empirical research to capture the heterogeneous effects associated with varying levels of treatment intensity (Duflo, 2001; Pierce and Schott, 2016; Goodman-Bacon, 2018; Xu, 2022). This approach offers a more granular analysis compared to the canonical binary DiD by identifying how the magnitude of impact scales with the degree of exposure to a policy or regulation.

commencement of the Phase 3 in the K-ETS. This measure remains constant over time, serving as a firm-specific proxy for baseline regulatory exposure. Firms with higher pre-policy emission levels are expected to face greater compliance burdens under more stringent regulations. $1\{t = \tau\}$ is an indicator equal to one if the year t corresponds to calendar year τ and zero otherwise, where τ indexes each year in the sample period. We designate 2020 as the reference year, which is therefore excluded from the summation.

The coefficients of interest, β_τ, capture the impact of regulatory stringency at each point in time, exploiting the interaction between the time-invariant firm-level exposure and year indicators to trace differential responses across firms with varying baseline emission level. We also include firm fixed effects to control for time-invariant unobserved firm characteristics and year fixed effects to account for macroeconomic shocks common to all firms. We then conduct the Granger causality analysis to investigate the dynamic predictive relationship between environmental scores and GHG intensity. This analysis facilitates to determine whether changes in a specific variable make an independent contribution to explaining the future behavior of another, beyond what is captured by the variable's own history.[18] While the preceding DiD analyses identify the causal effect of regulatory stringency on firms' environmental outcomes, this analysis further examines whether environmental scores actually reflect underlying environmental performance, as captured by GHG intensity, or whether they are decoupled from actual emissions outcomes.[19]

[18] This method helps examine temporal precedence, which posits that causality exists if past values of one variable provide statistically significant information to predict future values of another (Granger, 1969).

[19] Following Treepongkaruna et al. (2024), we conduct panel unit root tests based on Levin et al. (2002) and Im et al. (2003). Given the short time dimension of our panel data, we restrict the maximum lag length instead of relying on automatic lag selection to prevent excessive loss of degrees of freedom. Furthermore, based on the Dumitrescu and Hurlin (2012) Granger non-causality test results, we determine an optimal lag length of one for our main models. For detailed test statistics, please refer to Appendix D.

4 Data

To examine the effects of carbon regulations, we collect firm-year ETS-regulated and TMS-regulated coverage as well as reported GHG emissions for Korean publicly listed firms between 2015 and 2024 from the National Greenhouse Management System (NGMS).[20] Data on GHG emissions are used to construct a direct measure of firms' actual environmental performance. We then obtain annual ESG ratings from the Korea Institute of Corporate Governance and Sustainability (KCGS), which is the biggest ESG rating agency with the membership of capital market institutions including the Korea Exchange (KRX).[21] Since carbon regulations are designed to incentivize corporate green transitions, we focus on the environmental pillar score of the ESG ratings as a primary proxy for firms' environmental efforts, where higher scores represent more proactive environmental management and engagement.

To mitigate potential omitted-variable bias, we control for a comprehensive set of firm-specific features and governance attributes that may influence both regulatory compliance and environmental strategies. Governance variables, such as board composition and the presence of specialized committees, are constructed based on the Data Analysis, Retrieval and Transfer System (DART) filings.[22] To account for scale, profitability, and financial constraints, we include the variables of firm size, return on asset (ROA), leverage, and asset turnover.

We further control asset tangibility and liquidity using the variables of property, plant and

[20] The identification of firms subject to the ETS and the TMS is determined in accordance with the Act on the Allocation and Trading of Greenhouse Gas Emission Permits, Act No.20172 (2024), and the Guidelines for the Operation of the Greenhouse Gas and Energy Target Management System, Notification No. 2020-3 (2020), of the Republic of Korea.

[21] The ESG scores provided by the KCGS is known as the standard for ESG measurement in the Korean market and has been extensively adopted in prior studies on Korean firms (see, e.g., Seo and Choi, 2025; Kim et al., 2026). See Appendix B for a detailed discussion of the validity of KCGS as an ESG measure and the scoring structure of the Environmental pillar.

[22] DART, operated by Korea's Financial Supervisory Service (FSS), provides public access to mandatory corporate filings submitted by listed firms, including financial statements and periodic reports. It is the primary source of firm-level governance data in the Korean capital market.

equipment (PPE) and cash, respectively. Because investment intensity and market valuation may be related to ESG strategies, we include the variables of CAPEX ratio, market-to-book ratio (MTB), R&D intensity, and advertising expense. Finally, we control for board characteristics that may shape strategic decision-making, including board size and outside directors, as well as female directors and the presence of an ESG committee. Table 2 provides detailed definitions for all variables.

Table 2. Variable Description

Variables	Definition	Source
E score	The overall environmental performance score of the company	KCGS
Regulated	Indicator variable: 1 if the firm is subject to the ETS or the TMS, 0 otherwise	NGMS
ETS	Indicator variable: 1 if the firm is subject to the Emissions Trading Scheme, 0 otherwise	NGMS
TMS	Indicator variable: 1 if the firm is subject to the Target Management System, 0 otherwise	NGMS
GHG Change (%)	The percentage change in GHG emissions, calculated as (Prior Year Emissions – Current Year Emissions)/Prior Year Emissions × 100	NGMS
Ln(GHG)	The natural logarithm of the total GHG emissions	NGMS
GHG intensity	The GHG emissions per 100 million KRW of sales	NGMS
Firm Size	The natural logarithm of total assets	FnGuide
ROA (%)	Net income divided by total assets × 100	FnGuide
Leverage (%)	Total liabilities divided by total assets × 100	FnGuide
Cash (%)	Cash and cash equivalents divided by total assets × 100	FnGuide
CAPEX ratio (%)	Capital expenditure (CAPEX) divided by total assets × 100	FnGuide
PPE (%)	Property, Plant and Equipment (PPE) divided by total assets × 100	FnGuide
Asset Turnover	Sales divided by total assets	FnGuide
MTB	Year-end stock price divided by Book-value Per Share (BPS)	FnGuide
R&D (%)	R&D expenses divided by sales × 100	FnGuide
Advertising (%)	Advertising expense divided by sales × 100	FnGuide
Board Size	The total number of directors on the board	DART
Outside Directors	Ratio of outside directors on the board	DART
Female Directors	Indicator variable: 1 if at least one female director is on the board, 0 otherwise	DART
ESG committee	Indicator variable: 1 if the firm has an ESG committee under the board, 0 otherwise	DART

Note: KCGS refers to the Korea Institute of Corporate Governance and Sustainability, the provider of ESG ratings for this study. NGMS stands for the National Greenhouse Gas Management System, which tracks emissions for entities under the ETS and the TMS. FnGuide is one of the largest financial data providers in South Korea. DART represents the Data Analysis, Retrieval and Transfer system, South Korea's electronic repository for official corporate filings.

Table 3 presents the descriptive statistics of the variables. To ensure a stable comparison group from an unbalanced panel of 968 firms and facilitate the implementation of a staggered Difference-in-Differences (DiD) framework, we apply two primary restrictions. First, we restrict the sample to a balanced panel by retaining only those firms observed continuously throughout the entire sample period. Following Sun and Abraham (2021), we implement this restriction to maintain a consistent sample composition over time, thereby preventing potential biases arising from the entry or exit of firms during the estimation of dynamic treatment effects.

Table 3. Summary Statistics

	N	Min	Median	Mean	Max	Std
E score	5,920	0.000	26.970	27.619	82.279	24.187
Regulated	5,920	0.000	0.000	0.317	1.000	0.465
ETS	5,920	0.000	0.000	0.257	1.000	0.437
TMS	5,920	0.000	0.000	0.060	1.000	0.238
GHG Change (%)	1,179	-45.268	-0.006	0.162	45.651	12.395
Ln(GHG)	1,310	7.271	11.769	12.111	15.941	1.601
GHG intensity	1,310	0.028	3.210	23.357	146.069	33.106
Firm Size	5,920	1.596	27.039	27.290	31.821	1.596
ROA (%)	5,920	-19.129	3.520	3.675	22.653	5.831
Leverage (%)	5,920	6.207	44.045	43.813	89.660	19.758
Cash (%)	5,920	-24.818	5.450	5.351	26.489	7.150
CAPEX ratio (%)	5,920	-18.376	3.270	4.430	31.561	6.535
PPE (%)	5,920	0.625	31.940	32.455	80.617	17.958
Asset Turnover	5,920	0.080	0.840	0.910	2.658	0.479
Ln(MTB)	5,920	0.182	0.610	0.729	2.579	0.440
Ln(R&D) (%)	5,920	0.000	0.086	0.462	3.263	0.693
Ln(Advertising) (%)	5,920	0.000	0.114	0.434	2.591	0.607
Board Size	5,920	3.000	6.000	5.737	11.000	2.012
Outside Directors (%)	5,920	18.182	37.500	40.518	75.000	14.068
Female Directors	5,920	0.000	0.000	0.193	1.000	0.395
ESG committee	5,920	0.000	0.000	0.133	1.000	0.340

Note: The sample size for Ln(GHG) and GHG intensity is 1,310 firm-year observations, primarily constrained by data availability. The sample size for GHG Change is further restricted to 1,179 observations due to the one-year lag required to calculate emissions changes relative to the following period. We apply logarithmic transformations to GHG emissions, MTB, R&D expenses, and advertising costs to address skewness, where variables containing zero values such as R&D and advertising cost add one to their values to avoid undefined number. All remaining variables comprise 5,920 firm-year observations.

Second, following Sun and Abraham (2021), we define the treatment status as an absorbing state, where once a firm transitions to a more stringent regulatory regime (i.e., from the TMS to the ETS), the firm is assumed to stay in that regime for the remaining sample period, without allowing for any reversals or exits from the regulation. To ensure data quality and mitigate the influence of extreme outliers, observations with missing values are excluded and, all continuous variables are winsorized at the 1st and 99th percentiles. After these procedures, the final sample consists of 592 firms with 5,920 firm-year observations, where approximately 25% of firm-year observations correspond to the ETS firms and 6% to the TMS firms.

5 Results

5.1 Carbon regulations and corporate environmental performance

To evaluate how carbon regulations affect firms' environmental performance, we implement a series of panel regressions using the KCGS environmental score as a proxy for corporate environmental performance. Our empirical design captures both the adoption of regulation and the subsequent tightening of the regulatory framework through the transition from the TMS to the ETS. This framework allows us to assess whether these changes lead to substantive shifts in corporate environmental behavior.

To this end, we employ three distinct models that differ in their treatment definitions, control group compositions, and sample restrictions, as summarized in Table 4. In the first model, we compare the treatment group with the indicator of the ETS with the control group comprising both TMS-regulated and never-regulated firms, thereby estimating the average effect of ETS adoption. The second specification includes both indicators for the ETS and the TMS, restricting the control group to never-regulated firms only, where it estimates the independent effect of each regulatory regime relative to the absence of any regulation. Finally, we restrict

the sample to regulated firm-years only in the last model and compare firms that transition from the TMS to the ETS against those that remain under the TMS throughout the sample period. This framework enables to isolate the marginal effect of the ETS relative to the TMS. Since the ETS and the TMS are mutually exclusive by construction, no firm-year observation is simultaneously assigned to both treatment categories.

Table 4. Model Structure

Model specification	Treatment Group	Control Group
ETS vs. Non-ETS	• ETS-regulated	• Non-ETS firms (TMS-regulated and Never-regulated)
ETS & TMS vs. Never-regulated	• ETS-regulated • TMS-regulated	• Never-regulated
ETS vs. TMS	• ETS-regulated	• TMS-regulated

Table 5 shows empirical evidence that both entry to the ETS and transition from the TMS are associated with improvements in firms' environmental scores. Specifically, the coefficient of the ETS variable is positive and statistically significant in the first column, where ETS-regulated firms and non-ETS firms are compared, implying that ETS-regulated firms exhibit higher environmental performance scores. This pattern is also observed in Column (2), where ETS-regulated and TMS-regulated firms are jointly compared with the never-regulated firms. The ETS coefficient remains positive and statistically significant, whereas the TMS coefficient shows no statistical significance. This result provides evidence that the ETS regulation works more effectively to lead firms to manage their environmental performance than the TMS regulation. The last model in column (3) restricting the scope into two regulations shows higher environmental scores among ETS-regulated firms than TMS-regulated firms.

Table 5. Results of Regulatory Impact on Environmental Performance

Variables	Dependent variable: $E\ Score_{i,t+1}$		
	(1) ETS vs. Non-ETS	(2) ETS & TMS vs. Never-regulated	(3) ETS vs. TMS
ETS	9.471***	10.945***	13.273***
	(3.508)	(3.797)	(3.757)
TMS		2.059	
		(4.008)	
Firm Size	4.945***	5.273***	4.274
	(1.764)	(1.825)	(3.369)
ROA	-0.137	-0.140	-0.366**
	(0.103)	(0.104)	(0.160)
Leverage	0.071	0.068	0.143*
	(0.060)	(0.059)	(0.076)
Cash	0.128*	0.140*	0.347**
	(0.072)	(0.073)	(0.163)
CAPEX ratio	-0.085**	-0.085**	-0.003
	(0.040)	(0.041)	(0.076)
PPE	0.054	0.055	0.085
	(0.057)	(0.056)	(0.083)
Asset Turnover	4.956**	4.925**	9.737**
	(2.361)	(2.373)	(4.332)
Ln(MTB)	-5.035***	-5.044***	-4.492**
	(1.579)	(1.587)	(1.926)
Ln(R&D)	-0.703	-0.722	1.025
	(1.692)	(1.688)	(3.055)
Ln(Advertising)	3.106*	3.138*	-12.982**
	(1.922)	(1.903)	(6.100)
Board Size	0.904**	0.903**	1.348**
	(0.381)	(0.382)	(0.579)
Outside Directors	0.132**	0.132**	0.166**
	(0.057)	(0.057)	(0.064)
Female Directors	0.136	0.147	3.633***
	(1.202)	(1.203)	(1.383)
ESG committee	18.590***	18.595***	12.078***
	(2.753)	(2.755)	(2.022)
Observations	4,761	4,761	1,386
Year FE	YES	YES	YES
Firm FE	YES	YES	YES
R-squared	0.134	0.153	0.219

Note: "FE" stands for the fixed effect. We apply logarithmic transformations to MTB, R&D expenses, and advertising costs to address skewness, where variables containing zero values such as R&D and advertising cost add one to their values to avoid undefined number. *, **, and *** indicate significance levels of 10%, 5%, and 1%, respectively. Standard errors are reported in parentheses. Standard errors are two-way clustered by firm and year.

Regarding the effects of control variables, firm size, asset turnover, and cash holdings are found to have significant positive effects on environmental performance. Literature has documented that larger firms facing greater scrutiny from external stakeholders and possessing more abundant resources tend to exhibit better environmental performance (Drempetic et al., 2020).

Firms with higher asset turnover and greater cash holdings are more likely to be able to allocate resources toward environmental management, leading to higher environmental performance. These results are backed by evidence from CAPEX and MTB ratios that have significant negative effects on environmental performance, implying that firms with higher CAPEX and MTB ratios tend to be less capable of allocating resources toward environmental management. One possible explanation is that capital expenditures are focused on physical asset expansion, and higher market valuations reflect growth opportunities; hence environment-friendly actions may not be of importance for such firms.

With respect to governance-related control variables, board size, the proportion of outside directors, and the presence of an ESG committee are all found to have significant positive effects on environmental performance. Firms with larger boards or a higher proportion of independent directors tend to strengthen the monitoring function over management, which can increase pressure toward environmental risk management and responsible corporate actions (De Villiers et al., 2011). Moreover, firms that have established a dedicated ESG committee are more likely to exhibit better environmental performance, as the committee can provide specialized oversight and guidance over corporate environmental strategy (Dixon-Fowler et al., 2017).

While the estimates of a typical TWFE offer an informative baseline, possible staggered nature of regulatory adoption raises a question of whether the aggregate coefficients reflect a weighted average of heterogeneous 2×2 comparisons[23], some of which may use already-treated units as implicit controls for late-treated cohorts. To assess the extent to which this structure affects our

[23] In a staggered adoption setting, Goodman-Bacon (2021) shows that the TWFE estimator can be decomposed into a weighted average of all possible 2×2 difference-in-differences (DiD) comparisons across different treatment cohorts and time periods. These comparisons are heterogeneous in that they vary by which units serve as the treated and contorl groups and at which point in time the comparison is made. Some of these implicit 2×2 comparisons use already-treated units as control groups for later-treated cohorts, which can introduce bias if treatment effects evolve over time.

estimates, we apply the decomposition proposed by Goodman-Bacon (2021), the approach that divides the TWFE coefficient into all underlying pairwise 2×2 DiD comparisons across treatment cohorts and time periods and assigns a specific weight determining its contribution to the overall estimate. Table 6 presents the results of this decomposition employing a single binary treatment indicator. Since the model in column (2) includes both ETS and TMS indicators as separate treatments, we instead apply the decomposition to TMS vs. never-regulated separately as reported in column (2) of Table 6. This test allows us to evaluate whether our TWFE estimates are reliable.

Table 6. Goodman-Bacon Decomposition

Type	(1) ETS vs. Non-ETS		(2) TMS vs. Never-Regulated		(3) ETS vs. TMS	
	Weight	Average estimator	Weight	Average estimator	Weight	Average estimator
Both Treated	0.009	12.406	0.007	-1.080	0.020	4.304
Later vs. Always Treated	0.246	19.373	0.048	5.255	0.859	16.504
Treated vs. Untreated	0.746	11.777	0.945	-0.208	0.121	13.350

We find in Table 6 that for columns (1) and (2), the variation is predominantly attributable to the Treated vs. Untreated component, with weights of 0.746 and 0.945, respectively. Given that the majority of the TWFE estimates are driven by the comparison between treated and untreated, the result supports that the risk of bias arising from contaminated within-estimator comparisons appears limited. The specification that the later-treated group is compared with the always-treated group shows a weight of 0.859 for column (3), suggesting that the estimate largely reflects comparisons in which already-treated units serve as implicit controls for later-treated cohorts; hence the estimate of the model (ETS vs. TMS) may be contaminated by heterogeneous treatment effects, as the implicit control group has already-undergone regulatory treatment. To address this concern and further ensure robustness against any residual heterogeneity in treatment timing, we reexamine the relationship between regulatory shifts and

corporate environmental performance using a staggered DiD approach, excluding always-treated firms that do not provide a valid counterfactual in this framework (Sun and Abraham, 2021).

Table 7 presents the estimated dynamic effects of carbon regulations on environmental scores relative to the year of initial treatment. We assess the assumption on parallel trends and see whether the effects persist over time. We again implement three specifications, mirroring the treatment-control comparison in the baseline analysis: (1) ETS vs. Non-ETS, (2) TMS vs. never-regulated, (3) ETS vs. TMS firms.[24] The first model comparing ETS-regulated with non-ETS firms in column (1) shows that environmental scores increase after the ETS adoption, with statistically significant gains emerging from one year after adoption and growing further in later post-treatment years. The pre-adoption coefficients are not statistically significant, supporting the assumption on parallel trends and suggesting that the two groups are on similar trends prior to treatment.[25]

[24] A model between ETS-regulated and never-regulated firms is not considered due to the structure of Korea's environmental regulatory system, in which ETS coverage is determined based on GHG emission thresholds. Firms emitting at levels sufficient for ETS designation are typically already TMS-regulated prior to the ETS adoption, thus it is rare to see the cases from never-regulated status directly to the ETS. Such cases are largely confined to firms designated at the initial introduction of the ETS in 2015, which are classified as always-treated and excluded under the staggered DiD framework.

[25] One may have a concern that the regulatory assignment is determined by GHG emission thresholds, implying that regulated and never-regulated firms may differ systematically in characteristics such as firm size, industry composition, and capital intensity. Such differences could confound the estimated treatment effect. We address this concern through the staggered DiD event study framework, which relies on the parallel trends assumption that treated and control firms would have followed similar trajectories in the absence of regulation. The validity of this assumption is supported by the event study results, in which the coefficients of pre-adoption are statistically insignificant. This result implies that post-treatment divergence can be attributed to the regulatory intervention rather than firm-specific differences (Sun and Abraham. 2021).

Table 7. Dynamic Treatment Effects of Environmental Regulations on Environmental Scores

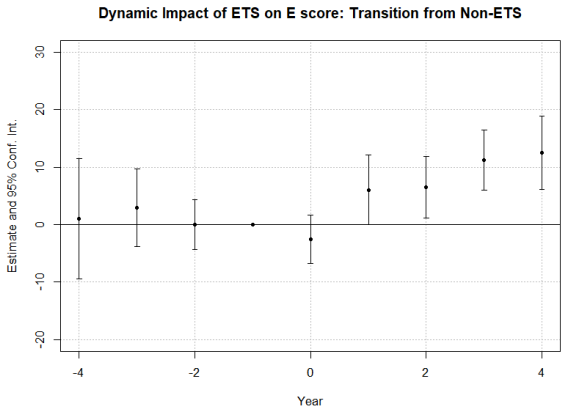
Variables	Dependent variable: E score		
	(1) ETS vs. Non-ETS	(2) TMS vs. Never-Regulated	(3) ETS vs. TMS
$Post_{t-4}$	1.048	2.906	-6.759
	(5.314)	(1.886)	(6.680)
$Post_{t-3}$	2.963	-0.995	-2.661
	(3.453)	(1.481)	(5.615)
$Post_{t-2}$	0.023	-2.509*	-4.214
	(2.224)	(1.339)	(3.164)
$Post_t$	-2.449	-3.059**	1.869
	(2.141)	(1.266)	(3.467)
$Post_{t+1}$	6.030*	1.033	7.950*
	(3.073)	(2.238)	(4.095)
$Post_{t+2}$	6.499**	0.821	6.947
	(2.713)	(2.614)	(4.302)
$Post_{t+3}$	11.216***	5.361	7.246
	(2.659)	(4.753)	(4.806)
$Post_{t+4}$	12.510***	-2.638	20.601***
	(3.264)	(6.409)	(4.475)
Controls	YES	YES	YES
Observations	4,010	3,710	260
Year FE	YES	YES	YES
Firm FE	YES	YES	YES
Within R-squared	0.168	0.174	0.360

Note: To prevent bias from dynamic treatment effects, the full set of relative time indicators is included in the estimation.[26] The two-way fixed effects specifications use the full available sample, whereas the staggered Difference-in-Differences estimators exclude always treated units to mitigate bias, which explains the differences in sample sizes. Specification (4) uses a more restricted sample, comprising only firms that transitioned from TMS to ETS and those that remained under TMS throughout the sample period, resulting in a substantially smaller number of observations. The year t-1 relative to treatment is the omitted reference period. "FE" stands for the fixed effect. *, **, and *** indicate significance levels of 10%, 5%, and 1%, respectively. Standard errors are reported in parentheses. Standard errors are one-way clustered by firm.

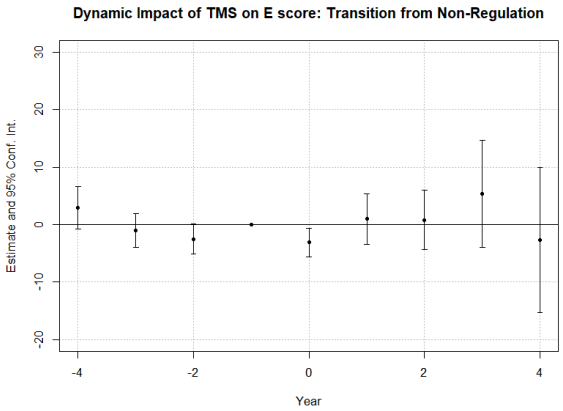
The second specification with the comparison of TMS-regulated and never-regulated firms claims that post-adoption effects under the TMS are generally insignificant. Furthermore, the pre-adoption coefficient at t-2 is statistically significant, indicating that the assumption on parallel trends does not hold. In contrast, the comparison between ETS-regulated and TMS-

[26] As recommended by Sun and Abraham (2021) and Baker et al. (2022), fitting the complete set of possible relative time indicators is necessary to avoid contamination problems. This study maintains the full estimation even when displaying only a specific window for reporting purposes, as trimming or binning distant indicators can lead to biased results. However, only a subset of these indicators is reported for visual clarity.

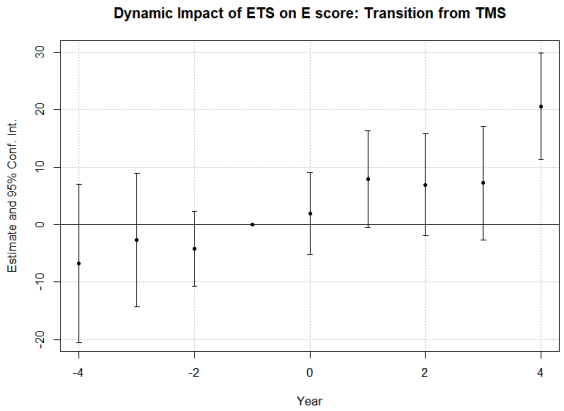
regulated firms shows higher environmental scores for ETS-regulated firms after the regulatory adoption than TMS-regulated firms. The pre-adoption coefficients show no statistical significance, again supporting the validity of this comparison. These patterns are visually summarized in Figure 1, where panel (a) through (c) display the event-study coefficients for each comparison group. In conclusion, these findings support *H1*, suggesting that the transition to the ETS leads to more significant improvements in corporate environmental performance compared to the TMS.



(a) ETS vs. Non-ETS



(b) TMS vs. Never-Regulated



(c) ETS vs. TMS

Figure 1. Dynamic Impacts of Regulation on Environmental scores. The graphs display the dynamic effects of regulatory transitions on corporate environmental scores using the Sun and Abraham (2021) staggered Difference-in-Differences estimator. X-axes represent years relative to the treatment year, with t-1 serving as the omitted reference period. Panel (a) presents the transition from Non-ETS to ETS. Panel (b) illustrates the shift from never-regulated to TMS. Panel (c) highlights the specific transition from TMS to ETS. The vertical bars represent 95% confidence intervals. Standard errors are one-way clustered by firm.

5.2 Evidence on greenwashing

Having shown that the compliance with a stronger regulation (i.e., the ETS) raises environmental scores relative to less strict regulation (i.e., the TMS), we next test whether these rating gains translate into measurable emissions mitigation. Specifically, to evaluate whether the observed improvements in environmental scores represent actual environmental progress we investigate the impact of the transition to the ETS on GHG emissions.[27] Table 8 reports the results of the TWFE DiD estimation that examines the effect of the ETS regulation on actual GHG emissions. We find that the coefficient of the ETS in column (1) is statistically insignificant in explaining changes in GHG emissions (i.e., GHG change), indicating no discernible improvement in emission reduction rates following the ETS entry. This result is consistent in column (2), where no significant effect of the ETS on total GHG emissions. Regarding the unit intensity of GHG emissions by sales (i.e., GHG intensity), we show a positive and marginally significant coefficient of the ETS, which exhibits anecdotal countereffect of carbon pricing regulation.

These results provide evidence that a decoupling between improvements in environmental management scores and tangible emissions is present. To address potential bias arising from heterogeneous treatment timing in the TWFE estimator, we further implement a staggered DiD approach following Sun and Abraham (2021). Table 9 shows the estimates of the dynamic treatment effect, where the pre-treatment coefficient at $t - 3$ in column (1) for changes in GHG emissions is statistically significant. This result indicates that the assumption on parallel trends is violated, suggesting that ETS-regulated and TMS-regulated firms are already on diverging trajectories in terms of emission reductions prior to ETS entry. This suggestion may reflect

[27] Note that data on GHG emissions reported through the NGMS are available only for firms subject to the ETS or the TMS regulation, as reporting obligations are imposed exclusively on regulated entities. For this reason, the analyses in this section are necessarily restricted to regulated firm-years.

systematic differences in the baseline emission profiles or abatement capacities of the two groups.

Table 8. Results of the Greenwashing Effect with TWFE DiD

Variables	(1) $GHG\ Change_{i,t+1}$	(2) $Log(GHG)_{i,t+1}$	(3) $GHG\ intensity_{i,t+1}$
ETS	2.509	0.073	4.217*
	(3.876)	(0.081)	(2.226)
Firm Size	6.550	0.377***	-14.775***
	(3.621)	(0.108)	(5.568)
ROA	-0.045	-0.003	0.061
	(0.064)	(0.007)	(0.100)
Leverage	-0.043	-0.003	-0.084
	(0.064)	(0.002)	(0.053)
Cash	-0.237	0.006	-0.014
	(0.237)	(0.008)	(0.105)
CAPEX ratio	-0.191	-0.004**	0.208
	(0.085)	(0.002)	(0.100)
PPE	0.046	0.010**	-0.081
	(0.103)	(0.005)	(0.087)
Asset Turnover	13.170	0.408*	-4.921
	(4.807)	(0.213)	(3.350)
Ln(MTB)	0.549	-0.166	-3.700
	(1.790)	(0.137)	(1.831)
Ln(R&D)	-1.814	0.352	-0.853
	(2.826)	(0.315)	(3.904)
Ln(Advertising)	-1.490	-0.045	-3.554
	(3.551)	(0.161)	(3.230)
Board Size	0.036	0.025	-0.213
	(0.319)	(0.019)	(0.630)
Outside Directors	-0.075	0.003	-0.025
	(0.042)	(0.002)	(0.090)
Female Directors	2.063	-0.128**	0.125
	(0.515)	(0.060)	(0.800)
ESG committee	-0.877	-0.091	3.326**
	(1.533)	(0.083)	(1.324)
Observations	1,147	1,179	1,179
Firm FE	YES	YES	YES
Year FE	YES	YES	YES
R-squared	0.030	0.108	0.137

Note: "FE" stands for the fixed effect. *, **, and *** indicate significance levels of 10%, 5%, and 1%, respectively. Standard errors are reported in parentheses. Standard errors are two-way clustered by firm and year.

Column (2) similarly exhibits a marginally significant pre-trend at $t-2$, showing that the assumption on parallel trends is not satisfied. Therefore, these results in first two columns of Table 9 imply that a potential causal effect of the ETS entry on aggregate GHG emissions is not empirically guaranteed. In contrast, we identify anecdotal evidence in column (3) that no

statistical significance of both pre- and post-treatment coefficients is observed in explaining the GHG intensity with the assumption on parallel trends holding. This null result supports evidence that the ETS regulation does not generate differential pressure on emissions beyond what is already induced by the TMS regulation.

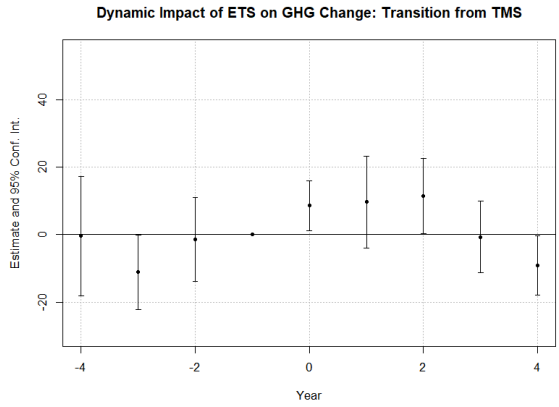
Table 9. Results of The Greenwashing Effect with Staggered DiD

	(1) GHG Change	(2) Ln(GHG)	(3) GHG intensity
$Post_{t-4}$	-0.394	-0.088	-2.362
	(8.501)	(0.068)	(2.154)
$Post_{t-3}$	-11.172**	0.024	-1.594
	(5.302)	(0.061)	(1.632)
$Post_{t-2}$	-1.434	-0.049*	-1.686
	(6.015)	(0.027)	(2.143)
$Post_{t}$	8.625**	-0.003	-0.220
	(3.546)	(0.027)	(0.428)
$Post_{t+1}$	9.742	0.017	-1.381
	(6.561)	(0.064)	(1.857)
$Post_{t+2}$	11.471	-0.006	-2.206
	(5.375)	(0.078)	(2.220)
$Post_{t+3}$	-0.684	0.147	-1.821
	(5.122)	(0.108)	(2.365)
$Post_{t+4}$	-9.100**	0.269**	0.885
	(4.243)	(0.122)	(1.017)
Controls	YES	YES	YES
Observations	198	220	220
Year FE	YES	YES	YES
Firm FE	YES	YES	YES
Within R-squared	0.485	0.519	0.428

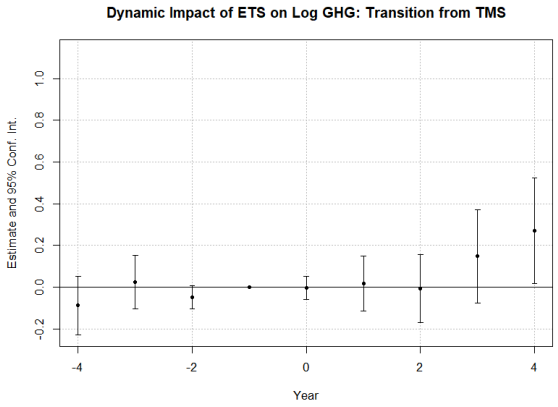
Note: The analysis is further restricted to firms that transitioned from TMS to ETS, with always-treated firms excluded as they do not provide a valid counterfactual in staggered DiD frameworks (Sun and Abraham, 2021), and firms that remained under TMS throughout the sample period serving as the control group. The resulting sample is substantially smaller, reflecting both this restriction and the limited availability of greenhouse gas emission data, which is reported only for firms subject to carbon regulation. The year t-1 relative to treatment is the omitted reference period. “FE” stands for the fixed effect. *, **, and *** indicate significance levels of 10%, 5%, and 1%, respectively. Standard errors are reported in parentheses. Standard errors are one-way clustered by firm.

One possible explanation for this null result is that firms may have complied with ETS obligations primarily through the purchase of carbon offset credit rather than through operational emission reductions. As documented in Nyonho et al. (2023), most of the regulatory compliance during the first phase of the K-ETS was fulfilled through offset credits, providing firms with an alternative pathway to satisfy their obligations without making direct

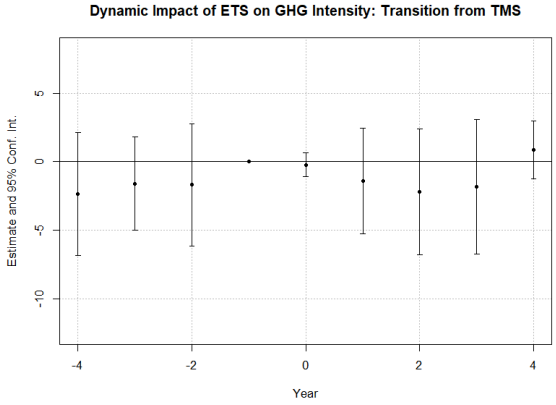
operational changes. This corporate behavior may be partly attributable to the relatively low cost of acquiring carbon offset credits compared to undertaking capital-intensive investments in emission-reducing technologies or processes. When the cost of purchasing credits falls below the cost of abatement, firms may be financially incentivized to alter their operations.



(a) GHG Emission Reduction Rate



(b) Log-transformed total GHG Emissions



(c) GHG Emission Intensity

Figure 2. Dynamic Impacts of ETS Entry on GHG Emissions: Transition from the TMS. The graphs display the dynamic effects of transition from the TMS to the ETS on three GHG emissions outcomes using the Sun and Abraham (2021) staggered Difference-in-Differences estimator. The horizontal axis represents years relative to the treatment year, with t-1 serving as the omitted reference period. The vertical bars represent 95% confidence intervals. Standard errors are one-way clustered by firm.

International Energy Agency (2025) supports this interpretation in that the K-ETS carbon price stood at approximately 18 USD per ton of CO_2-equivalent in 2024, the level that is far below the EU ETS price of 87 USD over the same period. The report further argues that the dominance

of freely allocated allowances has undermined price discovery and disincentivize firms to pursue emission reductions. Under such conditions, the impact of the carbon pricing regulation such as the ETS may be limited to actually reduce GHG emission intensity.

In summary, we identify that despite the notable gains in environmental scores documented in preceding sections, ETS-regulated firms do not appear to achieve meaningful reductions in emissions. This implies that the improvements in environmental ratings may reflect enhanced disclosure and reporting practices rather than substantive operational changes.[28] While this pattern is suggestive of decoupling, our models help address the causal effect of regulatory assignment on each outcome separately, yet do not directly investigate the dynamic relationship between the two measures themselves (i.e., environmental scores and GHG emissions). This raises the question of whether improvements in environmental scores can be forward-looking signals that anticipate future emissions reductions. If this is the case, the absence of a contemporaneous effect of the carbon pricing regulation on GHG outcomes would not necessarily imply greenwashing.

To test this concern, we further examine the temporal predictive relationship between environmental scores and GHG emissions intensity using a panel Granger causality framework. Specifically, we test whether past improvements in environmental scores provide statistically significant incremental information to predict future reductions in GHG emissions intensity, above and beyond what is explained by emissions' own history. The results in column (1) of Table 10 illustrate that past environmental scores with one year lag are positively and significantly associated with future environmental scores, whereas past GHG intensity does not significantly predict future environmental scores. However, past GHG intensity in column

[28] These divergent results are supported by the results of Park et al. (2024), who show that while the ETS transition motivates firms to enhance their reported environmental performance, it has yet to drive the substantive emissions reductions required for a meaningful low-carbon transition.

(2) is found to predict future GHG intensity, consistent with the persistence of emissions over time. More importantly, past environmental scores are positively and significantly associated with future GHG intensity, indicating that higher scores may even be associated with persistently higher emissions.

Table 10. Granger Causality Between Environmental scores and GHG intensity

	(1) $E\ score_{i,t}$	(2) $GHG\ intensity_{i,t}$
$E\ Score_{i,t-1}$	0.333***	0.054**
	(0.028)	(0.026)
$GHG\ intensity_{i,t-1}$	0.018	0.142***
	(0.024)	(0.043)
$Firm\ Size_{i,t}$	2.639	-0.104
	(2.021)	(0.139)
$\text{Leverage}_{i,t}$	0.067	-0.002
	(0.058)	(0.001)
$Cash_{i,t}$	0.092	0.002
	(0.084)	(0.004)
$CAPEX\ ratio_{i,t}$	0.011	0.000
	(0.043)	(0.002)
$PPE_{i,t}$	0.078	0.003
	(0.066)	(0.002)
$Asset\ Turnover_{i,t}$	4.174	0.114
	(2.759)	(0.127)
$Ln(MTB)_{i,t}$	-3.993**	-0.107
	(1.786)	(0.074)
$\text{Ln(R\&D)}_{i,t}$	0.577	0.114
	(1.879)	(0.122)
$Ln(Advertising)_{i,t}$	-10.567**	-0.030
	(4.605)	(0.095)
$Board\ Size_{i,t}$	0.804**	-0.002
	(0.399)	(0.009)
$Outside\ Directors_{i,t}$	0.152***	0.001
	(0.057)	(0.001)
$Female\ Directors_{i,t}$	3.029***	-0.108**
	(0.958)	(0.050)
$ESG\ committee_{i,t}$	8.681***	-0.070*
	(1.942)	(0.039)
Observations	1,265	1,265
Year FE	YES	YES
Firm FE	YES	YES
R-squared	0.428	0.355

Note: "FE" stands for the fixed effect. *, **, and *** indicate significance levels of 10%, 5%, and 1%, respectively. Standard errors are reported in parentheses. Standard errors are two-way clustered by firm and year.

These findings are consistent with the results of Treepongkaruna et al. (2024) that firms with higher scores of the environmental pillar are associated with greater carbon emissions. The

authors argue that ESG ratings function more as a publicity tool than a commitment to emissions reduction. In other words, improvements in environmental scores appear to reflect enhanced disclosure practices or reputation management rather than signaling substantive environmental progress, a pattern that represents symbolic environmental management consistent with the legitimacy theory and the greenwashing hypothesis.

5.3 Robustness check

The preceding analyses show a consistent pattern: ETS entry raises environmental scores significantly and persistently, yet leaves GHG emissions and intensity largely unchanged, a divergence that the Granger causality results further characterize as a failure of disclosure improvements to anticipate actual abatement. One may then question whether this decoupling reflects a fundamental feature of the K-ETS or instead an artifact of the relatively low regulatory stringency that is featured by the scheme's early phases. If our null result on emissions is driven primarily by the weak compliance incentives of two early phases, where nearly all allowances were freely allocated and carbon prices remained far below those of the EU ETS, one would then expect the decoupling to reverse as regulatory pressure intensifies.

To support robustness of these findings on this observed decoupling, we analyze how increased regulatory strictness may affect actual emission reduction versus superficial efforts. We examine the impact of Phase 3 of the K-ETS, where the intensity of the regulation is lifted with an increase in paid allocation to 10%. To implement the analysis, we investigate the firms consistently regulated under the ETS from 2015 to 2024 with a continuous DiD approach represented in equation (3).[29] Table 11 presents the results with three different dependent variables: environmental scores, GHG intensity and log-transformed total GHG emissions.

[29] The key to this analysis is the construction of the exposure variable, defined as each firm's average GHG emissions over the pre-Phase 3 period from 2015 to 2020. This measure is time-invariant and captures the firm's structural position within the regulatory distribution prior to the policy change in 2021. Firms with

Table 11. Continuous DiD on Exposure Amount

	(1) $E\ score_{i,t}$	(2) $GHG\ intensity_{i,t}$	(3) $\mathrm{Ln}(GHG)_{i,t}$
$Exposure_i \cdot Year_{2016}$	0.559	0.992	0.085
	(0.868)	(0.737)	(0.072)
$Exposure_i \cdot Year_{2017}$	0.510	-0.050	0.106
	(0.936)	(0.666)	(0.069)
$Exposure_i \cdot Year_{2018}$	0.698	-0.296	0.065
	(0.884)	(0.590)	(0.044)
$Exposure_i \cdot Year_{2019}$	0.659	-0.221	0.018
	(1.157)	(0.471)	(0.034)
$Exposure_i \cdot Year_{2021}$	0.107	-1.989***	-0.275
	(0.850)	(0.472)	(0.199)
$Exposure_i \cdot Year_{2022}$	2.104*	-3.944***	-0.700**
	(1.107)	(0.870)	(0.341)
$Exposure_i \cdot Year_{2023}$	0.845	-3.648***	-0.697**
	(1.617)	(0.910)	(0.336)
$Exposure_i \cdot Year_{2024}$	-0.304	-3.850***	-0.754**
	(1.538)	(0.922)	(0.346)
Controls	YES	YES	YES
Observations	1,152	1,152	1,152
Year FE	YES	YES	YES
Firm FE	YES	YES	YES
R-squared	0.208	0.069	0.168

Note: $Exposure_i$ denotes the firm-level average GHG emissions during the pre-policy period (2015-2020), before the Phase 3 implementation of the K-ETS effective in 2021. "FE" stands for the fixed effect. *, **, and *** indicate significance levels of 10%, 5%, and 1%, respectively. Standard errors are reported in parentheses. Standard errors are one-way clustered by firm.

Column (1) with environmental scores shows that the disparity in environmental scores between high exposure and low exposure firms widened significantly in 2022, which immediately followed the implementation of stricter regulations. This isolated significance in 2022 implies a temporary and strategic response to the regulatory tightening, though this effect did not persist in subsequent years. This temporary response is observed more prominently to reductions in GHG emissions, as shown in columns (2) and (3) where immediate and statistically significant declines in GHG intensity and total GHG emissions are present right from 2021 and 2022, respectively. The reductions for both remain robust through the end of

higher baseline emissions face a larger gap between their unconstrained emission level and the tightened cap, and therefore bear disproportionately higher compliance costs under the increased requirement. By interacting this continuous exposure measure with year indicators, the continuous DiD in Table 11 identifies whether firms with greater regulatory exposure respond differently to the Phase 3 tightening relative to low-exposure firms, tracing the differential trajectory of each outcome variable before and after 2021.

the sample period. These findings indicate that high-exposure firms tend to initiate and maintain their efforts to actually reduce GHG emissions in operations by responding to the heightened regulatory pressure. Collectively, these results support *H3*, demonstrating that higher-emitting firms under the ETS regulation are more likely to simultaneously achieve greater improvements in environmental scores and reduce GHG emissions following the stricter Phase 3 transition than lower-emitting counterparts.

5.4 Discussion

The findings of this study reveal a notable divergence between corporate environmental disclosure quality and actual GHG emission performance in response to regulatory pressure. While the ETS participation is associated with significant improvements in environmental scores, this does not translate into meaningful reductions in GHG emissions. This result implies that the current regulatory framework in Korea has yet to generate sufficient incentives for substantive emissions abatement.

A key explanation for this decoupling lies in the structural design of the K-ETS. First, the relatively low price of carbon allowances in Korea disincentivizes firms to invest in emissions reduction but highly motivates them to purchase additional allowances. When the marginal cost of abatement exceeds the market price of allowances, profit-maximizing firms benefit from purchasing additional allowances to comply with the regulation rather than investing in carbon reduction technologies or relevant efforts. Second, free allowance allocations as the primary market measure further weakens abatement incentives. Consistent with Nyonho et al. (2023), a substantial share of compliance in the early K-ETS period was fulfilled through offset credits, thus firms easily satisfied their regulatory obligations without undertaking reductions in GHG emissions. Under such conditions, regulated firms face marginal financial pressure to alter their production processes or energy use in ways that would lower actual emissions.

This dynamic can function as a major driver of symbolic environmental management, wherein firms respond to regulatory and stakeholder pressure by improving observable indicators of environmental commitment, such as ESG ratings, without making corresponding changes to their underlying environmental performance. Our results of the Granger causality analysis support this interpretation, as the temporal relationship between environmental scores and GHG emissions does not conform to a pattern in which disclosure improvements precede or drive actual emission reductions.

Nonetheless, our analysis for ETS-regulated firms since its introduction in 2015 provides evidence that regulatory stringency matters. Following the increase in the paid allowance share to 10% in 2021 (i.e., Phase 3 of the K-ETS), these firms exhibit not only improvements in environmental scores but also declining trends in GHG emission intensity and total emissions. This contrasts with the pattern observed before the policy change, suggesting that the decoupling between environmental scores and actual emissions is not an unavoidable outcome of market-based regulation itself, but rather reflects the fact that regulation was not stringent enough to drive real behavioral change.

These findings offer important implications for policymakers. The evidence from Phase 3 of the K-ETS demonstrates that higher regulatory pressure can begin to bridge the gap between disclosure improvements and actual emissions reductions. In other words, among firms with persistently high emission exposure, the tightening of auctioned allowance requirements in Phase 3 is associated with both improvements in environmental scores and meaningful reductions in GHG intensity. This is not in contradiction with the broader finding that the K-ETS has yet to drive aggregate emissions reductions across the regulated population. Rather, it suggests that the direction of the regulatory design is appropriate, but that its current stringency and coverage remain insufficient to generate economy-wide abatement.

Importantly, however, the Phase 3 analysis is necessarily restricted to firms continuously subject to ETS regulation throughout the sample period (i.e., 2015 to 2024) and therefore does not represent the large share of Korean firms currently exempt from mandatory carbon obligations. Extending regulatory coverage to a broader set of firms, particularly in carbon-intensive sectors that currently fall below ETS designation thresholds would be a natural complement to deepening the stringency of existing obligations. With respect to the design of existing regulations, our findings depend on two parameters that jointly determine the effectiveness of market-based carbon policy: the price of carbon allowances and the share of allowances subject to paid allocation. The current levels of both appear insufficient to overcome the cost advantages of purchasing allowances over investing in abatement. Gradual increases in the auctioned allowance share policy measures that support a more robust carbon price could strengthen the financial incentive for firms to reduce actual emissions.

6 Conclusion

This study investigates how Korean firms react to the country's primary carbon pricing regulations (i.e., the TMS and the K-ETS) in their environmental management represented by ESG ratings provided by the largest ESG rating provider in Korea. Using a comprehensive dataset of 592 listed firms from 2015 to 2024, our analysis reveals that firms regulated by the more stringent K-ETS than the TMS tend to have higher environmental scores. However, these improvements do not translate into a robust decline in GHG emissions, indicating a clear decoupling between rated performance and substantive mitigation.

To clarify the underlying economic mechanisms, we employ Granger Causality tests to uncover the incentives behind this decoupling. We find that past environmental scores positively and significantly predict future GHG intensity, which implies that firms with higher environmental ratings engage in symbolic environmental management. In addition to this observation, we

determine that past environmental scores are positively and significantly associated with future GHG intensity, indicating that higher scores are likely to be linked with persistently higher emissions. These results provide a possible explanation on greenwashing actions in that firms strive to improve observable indicators of environmental commitment as a positive market signal without making corresponding reductions in actual emissions.

This study provides useful insights into how a regulatory design for corporate carbon emissions can shape corporate environmental responses and what structural factors can drive the divergence between reported and actual environmental performance. Beyond this regulatory design implications discussed above, our findings may be linked to practical implications for some stakeholders. For institutional investors and asset managers, the evidence of potential decoupling between ESG ratings and actual GHG emissions suggests that commercial rates used as a primary screen for climate-conscious capital allocation may systematically misdirect investment toward firms that are skilled at managing their environmental image rather than their actual carbon footprint.

For ESG rating agencies, the systematic decoupling points to a methodological vulnerability resulting from evaluation frameworks that assign disproportionate weight to, e.g., disclosure quality, reporting completeness, and governance structures relative to verified physical outcomes. Incorporating forward-looking emissions intensity targets and verified abatement track records as mandatory rating components would strengthen the signaling value of environmental scores as a proxy for climate performance.

Several directions remain open for future studies. Although the use of KCGS environmental scores as a proxy for corporate environmental effort is well-established in the Korean context, one could explore whether similar patterns emerge under alternative rating providers or evaluation methodologies. Moreover, including Scope 3 emissions, which capture indirect

emissions across the value chain, would provide a more comprehensive assessment of corporate carbon exposure and abatement effort, particularly for firms deeply embedded in carbon-intensive supply networks. A related limitation concerns the relatively low liquidity of the Korean carbon market during the study period, which may have limited price volatility and made it difficult to fully capture how firms respond to carbon price fluctuations.

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Appendix A. K-ETS Phase Design and Allocation Rules

The Korea Emissions Trading System (K-ETS), established under the Framework Act on Low Carbon Green Growth (2010) and the Act on the Allocation and Trading of Greenhouse Gas Emissions Allowances (2012), was launched in January 2015 as the first mandatory, nationwide emissions trading system in East Asia (International Carbon Action Partnership, 2024). The system operates across distinct allocation periods, each reflecting progressively more stringent climate targets and broader sectoral coverage. Table A1 summarizes the key design features of the K-ETS across its three allocation periods, highlighting the progressive tightening of emission caps, the expansion of sectoral coverage, and the shift from full free allocation toward market-based mechanisms.

The first allocation period (2015 to 2017) served primarily as an introductory phase focused on system stabilization. All allowances were distributed free of charge, with the majority of sectors allocated based on historical emissions using a grandfathering approach. Only three sub-sectors, namely grey clinker, oil refining, and domestic aviation, received allowances through benchmarking. The total cap for this period was set at 1,689.2 $MtCO_2e$, covering 23 sub-sectors across five sectors including heat and power, industry, buildings, waste, and transportation.

The second allocation period (2018 to 2020) marked the transition to a more active reduction phase. The sectoral scope was expanded to six sectors by disaggregating the public and waste sectors, increasing the number of covered sub-sectors to 62. The free allocation share was reduced to 97% for entities subject to auctioning, while regular auctions began in 2019 with a 3% auction share. The total cap was set at 1,777 $MtCO_2e$, and market makers were introduced to improve liquidity in the secondary market.

The third allocation period (2021 to 2025) represents the most comprehensive phase to date, designed in alignment with the Paris Agreement and Korea's 2030 Nationally Determined

Contribution (NDC). The scope was further widened to 69 sub-sectors through the inclusion of freight, rail, passenger transport, maritime shipping, and construction industries, raising the share of national GHG emissions to reach 73.5%. The free allocation share was reduced to a maximum of 90% for eligible sectors, with the auctioning share raised to at least 10%. The total cap for this period is 3,048.3 $MtCO_2e$, corresponding to an average annual cap of 610 $MtCO_2e$, reflecting a 4.7% decrease compared to the 2017 to 2019 baseline.

Table A1. Comparative Overview of K-ETS Allocation Periods

Category	Phase 1	Phase 2	Phase 3
Duration	2015-2017	2018-2020	2021-2025
Number of Sectors	five	six	six (expanded)
Number of Subsectors	23	62	69
Total CAP ($MTCO_2e$)	1,689.2	1,777.0	3,048.3
Free Allocation Share	100%	97%	90%
Allocation Method	Grandfathering (majority); benchmarking for 3 sub-sectors	Grandfathering and benchmarking	Grandfathering and benchmarking
Auctioning	None	3% (from 2019)	At least 10%

Appendix B. KCGS ESG Score Robustness

The Korea Institute of Corporate Governance and Sustainability (KCGS) ESG ratings are the most widely utilized metrics for assessing the non-financial performance of Korean listed firms. KCGS stands as South Korea's leading ESG evaluation body, having pioneered corporate governance assessments in 2003 and introduced integrated ESG ratings in 2011. Currently, KCGS ratings serve as the official foundational data for the Korea Exchange (KRX) in calculating Socially Responsible Investment (SRI) indices, such as the KRX ESG Leaders 150, underscoring its high public institutional authority. Since KCGS rates virtually all KOSPI-listed companies and selected KOSDAQ firms, the use of KCGS data mitigates the sample selection bias that is common in studies relying on global ESG rating agencies, which tend to cover only a subset of listed firms (KCGS, 2026).

The primary variable of interest in this study is the Environmental pillar score provided by KCGS, which represents a firm's overall environmental performance as assessed through a comprehensive and structured evaluation framework. Specifically, environmental score is constructed as a composite score aggregating three large categories: Environmental Management, Environmental Performance and Stakeholder Responses. Each category consists of multiple medium-level indicators that collectively capture distinct dimensions of a firm's environmental engagement. The detailed indicator structure underlying each category is presented in Table B1.

Recent high-impact studies, summarized in Table B2, have employed these ratings to explore the nexus between ESG performance, firm value, and investor behavior in the Korean market. Beyond their widespread use in the literature, the validity of KCGS ratings as a measure of ESG performance in the Korean market is further supported by several methodological considerations.

Table B1. Environmental Evaluation Indicators in Corporate ESG Management Activities

Large category	Medium Category
Environmental management	Establish goals and plans
	Eco-friendly supply chain management
	Clean production system
	Environmental risk management
	Environmental Accounting
	Environmental performance management
	Environmental audit
Environmental performance	Resources
	Climate change
	Environmental regulations
Stakeholder response	Green products and services
	Environmental report
	Stakeholder response

Table B2. Summary of Prior Literature Utilizing KCGS ESG Ratings

Study	Research Question	Key findings and implications
Kim et al. (2026)	How does ESG activity contribute to firm value?	ESG as Information Signal: ESG scores reduce information asymmetry and interpretative uncertainty. Firm value increases when ESG performance is coupled with active communication.
Seo and Choi (2025)	How do investors respond to ESG rating changes?	Market sensitivity: Institutional investors react swiftly to KCGS rating changes. This confirms that KCGS ratings serve as a critical signal for market participants in Korea.
Thompson (2025)	Does ESG performance mitigate stock price crash risk?	ESG as Risk Mitigation: Higher ESG scores significantly reduce crash risk by preventing bad news accumulation. This aligns with our view of ESG as a downside risk management tool.

Lee et al. (2025) suggest that domestic ESG rating agencies exhibit significant differences from international agencies regarding information utilization. While global agencies primarily evaluate firms using market-exposed or standardized external data, including analyst reports, credit ratings, and export ratios, domestic agencies, including KCGS, rely heavily on public disclosures issued directly by companies, such as sustainability reports. This methodological approach suggests that domestic agencies more precisely incorporate the unique corporate governance structures and environmental specificities inherent to the Korean market into their evaluation frameworks. This specialized focus is further validated by empirical data. The

correlation between domestic rating agencies is notably higher than that between domestic and international agencies. Specifically, KCGS demonstrates high correlation coefficients with other domestic evaluators, such as KRESG (0.718) and SUSTINVEST (0.700), proving that it most effectively represents the ESG values and standards prevalent in the Korean market.

Furthermore, Lee (2021) provides a logical basis for these characteristics by comparing the evaluation traits of KCGS and Sustinvest. An analysis of the rating transition matrices reveals that while Sustinvest experiences frequent rating changes within a single year, KCGS maintains relatively stable rating transitions. This stability indicates that KCGS reflects a firm's fundamental ESG capabilities rather than overreacting to short-term issues or market noise, making its data particularly suitable for time-series analysis and long-term corporate value research. The study also notes a philosophical distinction: while Sustinvest operates a model focused on the investment interests of pension funds and institutional investors, KCGS performs evaluations with a more public-interest character, considering a broader range of stakeholders.

Finally, an analysis of correlations by evaluation pillar reveals that the Environmental (E) pillar shows a high correlation of 0.74, as both agencies utilize objective metrics such as GHG emissions. In contrast, the Governance (G) pillar shows a lower correlation of 0.33. While this suggests that pillars requiring qualitative judgment may lead to divergent views, the high correlation in the Environmental pillar validates the objectivity and reliability of the indicators used. Moreover, the divergence in Governance scores can be interpreted as evidence that KCGS is interpreting the complexities of the Korean market through an independent and specialized methodology.

Appendix C. Goodman-Bacon Decomposition

This decomposition reveals that the weights assigned to each 2×2 term are proportional to two factors: 1) the relative size of each subsample and 2) the variance of the treatment dummy within each pair. A critical insight from this approach is that treatment variance is maximized for groups treated in the middle of the panel and minimized for those treated at the extremes. Consequently, the TWFE estimator may be disproportionately influenced by certain groups regardless of their theoretical importance. Applying this decomposition allows researchers to empirically confirm whether the aggregate estimate is distorted by forbidden comparisons, particularly those in which previously treated units serve as controls. This process clarifies the identifying assumptions and the practical validity of the general DiD model.

The OLS estimator from a TWFE DiD design, $\hat{\beta}^{TWFE}$, is formally expressed as:

$$\hat{\beta}^{TWFE} = \sum_{k \neq U} s_{kU} \hat{\beta}_{kU}^{2\times2} + \sum_{k \neq U} \sum_{l > k} s_{kl} \left[\mu_{kl} \hat{\beta}_{kl}^{2\times2,k} + (1 - \mu_{kl}) \hat{\beta}_{kl}^{2\times2,l} \right], \tag{C1}$$

where s_{kU} and s_{kl} represent the weights assigned to each comparison, and μ_{kl} denotes the relative weight within timing groups.

The decomposition identifies three primary types of comparisons that constitute the aggregate estimator. The first is the comparison with never treated units, $\hat{\beta}_{kU}^{2\times2}$, which evaluates the timing group k against the never treated group U. This involves comparing the change in group k from the PRE period to the $POST$ period against the stable baseline of group U. This represents the cleanest form of DiD identification because the control group remains untreated throughout the entire panel, effectively avoiding the issue of dynamic treatment effects:

$$\hat{\beta}_{kU}^{2\times2} = \left(\bar{y}_k^{POST(k)} - \bar{y}_k^{PRE(k)} \right) - \left(\bar{y}_U^{POST(k)} - \bar{y}_U^{PRE(k)} \right), \tag{C2}$$

Within the timing groups, the methodology further distinguishes between two directional comparisons based on the sequence of treatment. The comparison of an early group k against a later group l as control, $\hat{\beta}_{kl}^{2\times2,k}$, is generally considered valid. It utilizes the period when group l is still in its PRE or MID phase as a counterfactual to evaluate the initial impact on the early group k:

$$\hat{\beta}_{kl}^{2\times2,k} = \left(\bar{y}_k^{MID(k,l)} - \bar{y}_k^{PRE(k)}\right) - \left(\bar{y}_l^{MID(k,l)} - \bar{y}_l^{PRE(k)}\right), \tag{C3}$$

In contrast, the comparison of a later group l against an already treated group k, $\hat{\beta}_{kl}^{2\times2,l}$, is termed a forbidden comparison. Since the control group k is already in its own $POST$ period when group l begins its treatment, any time-varying or dynamic changes in the treatment effect of group k are subtracted from the estimate of group l. This process can lead to significant bias, potentially even flipping the sign of the aggregate $\hat{\beta}^{TWFE}$ if these problematic weights are sufficiently large:

$$\hat{\beta}_{kl}^{2\times2,l} = \left(\bar{y}_l^{POST(l)} - \bar{y}_l^{MID(k,l)}\right) - \left(\bar{y}_k^{POST(l)} - \bar{y}_k^{MID(k,l)}\right), \tag{C4}$$

Appendix D. Stationary, Granger Causality Test Results

Table D1 reports panel unit root test based on Levin et al. (2002) and Im et al. (2003). And Table D2 reports Dumitrescu and Hurlin (2012) Granger non-causality. The Dumitrescu-Hurlin test examines Granger non-causality under the null that no individual unit exhibits a predictive relationship, whereas the panel regression in Table 10 identifies the average within-firm association after controlling for firm and year fixed effects. The two approaches therefore need not yield identical inferences.

Table D1. Panel Unit Root Test

Variables	Levin-Lin-Chu (z-stat)	p-value	Im-Pesaran-Shin (tbar)	p-value
E score	-10.285***	0.000	-6.1728***	0.000
GHG intensity	-8.692***	0.000	-2.0834**	0.018

Table D2. Granger Non-causality Test

Null Hypothesis (H_0)	Z-tilde	p-value	Decision
E score does not Granger-cause GHG.intensity.	0.7450	0.4563	Do not reject H_0
GHG.intensity does not Granger-cause E score.	5.4369***	0.000	Reject H_0

Note: Optimal number of lags (BIC) is 1 (lags tested: 1 to 2).

Reference for Appendices

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