The Sunshine Effect on Underreporting: Why Facility-Level GHG Transparency Regulation Can Have Real Effects on Firm Behavior*

Dong Gil Kim†

First Draft: May 2022

This Version: Mar 2025

Abstract

This paper draws the causal inference of facility-level GHG transparency on firm behavior by analyzing firms that voluntarily disclosed firm-level emissions before and after the regulation. Using a difference-in-differences design and leveraging the staggered implementation of the initial facility-level disclosure mandate, I find that firms reduce their overall emissions. The standardized and regulatorily overseen facility-level regulation functions as a sunshine mechanism, objectively revealing a firm's true climate impact—such as past firm-level underreporting—triggering negative stakeholder feedback and incentivizing firms to adopt more socially responsible practices. Consistent with the growing influence of climate change on corporate decision-making, I find that although the regulation applies at the facility-level, it heightens firm-level climate concerns and increases negative regulatory sentiment in earnings conference calls, signaling managerial learning. This learning fosters greater investment in low-carbon patent development. Overall, my findings suggest that facility-level GHG transparency regulation has real effects on firm-wide decision-making beyond the regulated facilities.

Keywords: Transparency Regulation, Disclosure Level, Greenhouse Gas Emissions, Sunshine Effects, Feedback Effect, Stakeholder Engagement

JEL Codes: D72, M40, Q54, Q56

*This paper is based on part of my dissertation at Rutgers Business School. I would like to express my gratitude to my dissertation committee: Bharat Sarath, Won Gyun No, Feng Gao, and Sheridan Titman (external advisor). I also thank anonymous reviewers, Simi Kedia, Divya Anantharaman, Kyungha Lee, Sandra Schafhäutle, Philip Joos, Suresh Govindaraj, Svenja Dube, Valentin Dimitrov, Michael Alles, Hilal Atasoy, Bruce Mizarch, Ann Medinets, and seminar participants at the Swiss Accounting Research Alpine Camp, the Korean American Accounting Professors Association, the Korean Accounting Association Summer International Conference, Rutgers Business School.

†Rutgers Business School. Address: Department of Accounting and Information System, 1 Washington Place, Newark, NJ 07102. E-mail: dong.kim@business.rutgers.edu

"*Sunshine is the best disinfectant*". - Justice Louis D. Brandeis 1913.

1 Introduction

Regulators are increasingly adopting disaggregated greenhouse gas (GHG) transparency regulations aimed at enhancing market discipline at the facility level, where a facility encompasses any physical sites such as manufacturing plants, power stations, refineries, and other industrial operations. A key milestone in this regulatory approach was the 2010 launch of the U.S. Environmental Protection Agency's (EPA) Greenhouse Gas Reporting Program (GHGRP). The GHGRP establishes standardized guidelines for facility-level emissions calculations[1] and mandates public disclosure for facilities exceeding specific emission thresholds. To ensure accuracy and reliability, the EPA enforces rigorous monitoring,[2] verification,[3] and compliance measures.[4] Since 2012, the agency has publicly released annual emissions data—including total emissions and facility ownership—for over 8,000 facilities via an accessible online database. By providing objective, standardized, and comprehensive emissions data, the GHGRP serves as a crucial resource for policymakers, investors, environmental groups, and the public, enabling informed decision-making and supporting national climate objectives. Although this granular transparency regulation does not directly require emission reductions, it has significant implications for publicly traded firms that own regulated facilities. Unlike firms without regulated sites, these companies face mandatory annual reporting, exposing them to greater regulatory oversight and intensified stakeholder scrutiny, thereby influencing their environmental strategies and overall approach to managing climate-related risks.

Previous studies (Yang et al. (2021), Tomar (2022)) document that facilities subject to the GHGRP—or firms' aggregated facility-level emissions reported under the program—typically

[1] https://www.ecfr.gov/current/title-40/chapter-I/subchapter-C/part-98?toc=1
[2] https://www.epa.gov/sites/default/files/2017-12/documents/ghgrp_bamm_factsheet.pdf
[3] https://www.epa.gov/sites/default/files/2017-12/documents/ghgrp_verification_factsheet.pdf
[4] https://www.epa.gov/enforcement/enforcement-greenhouse-gas-reporting-program-hfc-importers

achieve greater emissions reductions than control facilities. However, Bartram et al. (2022) identify an unintended consequence within GHGRP firms, demonstrating that financially constrained companies exposed to California's cap-and-trade policy increased emissions at their non-California facilities by 14% more than firms without California operations. Importantly, existing literature lacks direct evidence regarding the firm-wide impact of facility-level transparency regulation. Because regulated facilities represent only a fraction of larger, often multinational organizations, it remains uncertain whether localized U.S. facility-level GHG transparency meaningfully influences broader corporate strategies. This paper addresses this critical gap by examining whether facility-level transparency regulation generates real effects, fundamentally reshaping firm-wide environmental decision-making beyond regulated sites. The key question explored is not merely whether these real effects exist, but how and through which mechanisms they materialize within organizations.

To address causal inference questions, researchers must carefully narrow the scope of their samples, even at the cost of reduced statistical power and external validity (Leuz & Wysocki (2016)). In this study, I focus on firms that voluntarily disclosed their firm-level GHG emissions (e.g., Matsumura et al. (2014), Griffin et al. (2017), Choi & Luo (2021)) both before and after the introduction of the GHGRP, examining differential impacts on firm-level emissions changes in firms with and without regulated facilities. To strengthen the internal validity of causal inferences about the impact of increased facility-level GHG transparency on firm-level emissions, I focus on firms that voluntarily disclose their emissions rather than relying on vendor-estimated data for several key reasons. First, vendor-estimated emissions often diverge significantly from firm-disclosed emissions, raising concerns about estimation errors due to proprietary methods that rely heavily on firm fundamentals (Aswani et al. (2023)). Second, because vendor-estimated data is commercialized, there is often a significant delay in investor access to this information (Zhang (2024)), making it challenging to identify contemporaneous capital market effects on firm behavior. Third, Zhang (2024) finds a perfect correlation between log-transformed vendor-estimated emissions and firm sales, complicat-

ing the distinction between emissions reductions due to actual changes in emissions versus changes in firm sales. In fact, Bauckloh et al. (2023) document an apparent contradiction using vendor-estimated data: while firms affected by the GHGRP do not exhibit greater reductions in their "raw emissions" compared to control firms, they do demonstrate more significant reductions when measured by the "emissions-to-sales ratio."

Climate change increasingly shapes corporate decision-making and business practices (Sautner et al. (2023)). Mandatory facility-level GHG disclosure regulations, characterized by standardized calculation, monitoring, verification, and enforcement procedures, serve as a "sunshine mechanism." This mechanism objectively uncovers the true extent of firms' climate impacts, previously obscured by aggregated firm-level disclosures, by providing precise and comprehensive facility-level emissions data and clearly identifying publicly traded firms responsible for regulated facilities. Such granular transparency elevates stakeholder awareness and amplifies corporate visibility among investors, regulators, and the public, compelling firms to anticipate potential negative feedback and political costs (Watts & Zimmerman (1978, 1990)) associated with disclosing the full scope of their environmental externalities. Aligned with stakeholder theory (Freeman (1984)), which highlights the importance of firms responding proactively to stakeholder interests, the anticipation of negative stakeholder reactions incentivizes firms to adopt more inclusive, responsible, and sustainable strategies. I label this transparency-induced behavioral adjustment the "sunshine effect," whereby firms proactively implement sustainable practices to mitigate negative societal responses triggered by mandatory facility-level disclosures that objectively reveal previously hidden aspects of their environmental impact.

I employ a generalized difference-in-differences (DID) design to assess the impact of the facility-level GHG emissions disclosure mandate on firm-level emissions. Leveraging the staggered implementation of the mandate, which took effect on January 1, 2010, firms are evaluated based on the year they first acquired regulated facilities. The design compares firm-years of newly regulated firms to a control group consisting of firms already subject to

the mandate or not yet exposed. By incorporating firm-fixed effects to account for time-invariant differences between treated and control firms, and industry-year fixed effects to address time-varying industry-level shocks, I estimate the average treatment effect of the granular transparency mandate. Consequently, any alternative explanation for the results would need to coincide with the timing of firms' initial exposure to the facility-level GHG emissions mandate. The findings show that firms subject to the GHGRP reduce their firm-level GHG emissions by 8 to 11% more than unregulated firms in the years following the program's implementation. These results underscore the mandate's effectiveness in driving broader environmental accountability beyond facility-level compliance.

However, alternative explanations for the observed reduction in firm-level emissions must be considered. One possibility is that the decline stems from changes in reporting methodologies—such as adopting new emissions factors, revising measurement standards, or narrowing the scope of reported emissions—rather than reflecting actual operational improvements. Such adjustments could lower reported emissions without indicating genuine environmental progress. Another explanation is that reductions are primarily localized to facility-level emissions, as documented in prior research. While transparency requirements may drive efficiency upgrades or optimized production processes at the facility level, these changes do not necessarily reflect a firm-wide commitment to reducing emissions or integrating sustainability into corporate strategy. I argue that the effectiveness of facility-level transparency regulation in driving firm-wide behavioral change depends on its ability to elevate climate change concerns across the organization through greater disclosure granularity. Crucially, for transparency to translate into substantive firm-level action, managerial learning from heightened climate concerns must lead to tangible, organization-wide adjustments in emissions practices—ones that go beyond localized regulatory compliance and reflect a deeper integration of sustainability into corporate decision-making.

One way to assess managerial learning is by examining its impact on organizational priorities and public messaging, particularly in forums where management interacts with

key stakeholders. Earnings conference calls provide a critical platform for management to discuss firm performance, strategy, and key issues, including environmental, social, and governance (ESG) factors such as climate change. These discussions offer real-time insights into how management frames climate-related risks and opportunities, revealing the extent to which climate concerns permeate the organization and shape strategic decision-making. I find that firms subject to disaggregated emissions regulation exhibit significantly greater climate change concerns and negative regulatory sentiment during earnings calls compared to non-GHGRP firms, as measured by the share of climate-related discussions in earnings call transcripts (Sautner et al. (2023)). These findings suggest that although regulation applies at the facility level, it fosters firm-wide managerial learning, prompting firms to reassess their exposure to climate risks and adjust their strategic priorities accordingly.

Beyond rhetoric, this managerial learning translates into tangible emissions-reduction efforts through innovation. Specifically, firms subject to facility-level regulation develop more green technologies than their non-GHGRP counterparts in the years following the program's implementation. Using data from the United States Patent and Trademark Office (USPTO) linked to public firms' patent records (Kogan et al. (2017)), I find that GHGRP firms generate an average of 11 more low-carbon patents per firm than non-GHGRP firms, with low-carbon patents classified under the Cooperative Patent Classification (CPC) Y02 class (Sautner et al. (2023), Cohen et al. (2024)). To ensure that the increase in patenting reflects genuine emissions reduction efforts rather than broad environmental initiatives or regulatory compliance, I further examine the relationship between emissions reductions and low-carbon patent development. The results reveal a strong link: a 1-unit decrease in fractional firm-level emissions is associated with the development of eight additional low-carbon patents, reinforcing the direct relationship between emissions reductions and innovation in low-carbon technologies.

How does facility-level regulation drive firm-wide managerial learning and ultimately change corporate behavior? I argue that this occurs through negative stakeholder feedback,

triggered by sunshining a firm's true climate impact, which becomes visible only through granular transparency regulation. A concrete example of the sunshine mechanism in facility-level emissions data is its role in revealing underreporting in previously disclosed voluntary firm-level emissions for the same reporting year. Firm-level emissions, disclosed voluntarily and available earlier, lack regulatory oversight, making them inherently subjective. Prior accounting valuation studies (Matsumura et al. (2014), Griffin et al. (2017), Choi & Luo (2021)) find that firms reporting lower total emissions tend to have higher valuations, creating incentives for some firms to selectively define reporting scopes or methodologies to present a more favorable emissions profile. In contrast, facility-level emissions, reported under the EPA's Greenhouse Gas Reporting Program, follow standardized methodologies, undergo rigorous monitoring, and are subject to verification, ensuring greater credibility despite being disclosed later. Since U.S. facility-level emissions represent only a portion of a multinational firm's total emissions, stakeholders generally expect mandatory disclosures to align with or fall below previously reported firm-level figures. However, when facility-level data reveal that total U.S. facility-level emissions exceed previously disclosed firm-level emissions for the same reporting year, stakeholders recognize prior voluntary disclosures as misleading. This discrepancy provokes adverse societal reactions, as mandatory disclosures reveal the full extent of a firm's climate impact—previously obscured at the firm level. As a result, investors, regulators, and the public intensify scrutiny, demand accountability, and adjust their assessments of corporate environmental performance. This heightened pressure acts as a key driver of managerial learning, pushing firms to internalize climate risks, reassess sustainability strategies, and adopt more transparent and proactive environmental practices.

To empirically illustrate the negative feedback firms face from revealing corporate underreporting, I first examine short-term market reaction channel to mandatory facility-level GHG disclosures. Since U.S. facilities represent only a subset of a multinational firm's operations, investors generally expect mandatory disclosures to align with or fall below previously reported firm-level figures. However, when facility-level data reveal firm-level

underreporting—where total U.S. facility-level emissions exceed previously disclosed firm-level emissions for the same reporting year—investors find out prior voluntary disclosures as misleading. I classify this revelation of underreporting as bad news because it signals that the firm's true climate impact is worse than previously expected.Consistent with the role of facility-level regulation as a sunshine mechanism, I find that the revelation of underreporting leads to an average market reaction of -0.49%, corresponding to an estimated market value loss of approximately $49 million.

Next, I examine broader stakeholder responses by analyzing changes in third-party environmental ratings following the introduction of facility-level GHG disclosure regulation. These independent evaluations reflect the perceptions of a wide range of stakeholders, including investors, consumers, and environmental advocacy groups, regarding firms' sustainability practices. By providing granular, standardized emissions data, facility-level disclosures enhance transparency, enabling stakeholders to more accurately assess corporate environmental performance. This heightened transparency exposes previously overlooked corporate shortcomings—such as inconsistencies, reporting gaps, or deliberate misreporting—activating the sunshine mechanism, which objectively reveals firms' true climate impact. As a result, third-party evaluators reassess firms' environmental credibility. When voluntary emissions disclosures conflict with mandatory facility-level data or when emissions exceed stakeholder expectations, firms often experience declines in ESG ratings, reflecting negative stakeholder sentiment. Using MSCI ESG ratings—a widely recognized benchmark in accounting and finance research—I find that firms subject to GHGRP regulation receive significantly lower environmental ratings than their non-regulated peers, despite voluntarily disclosing value-relevant environmental information before and after the regulation, specifically their firm-level GHG emissions. Furthermore, firms that are revealed to have underreported their emissions face even greater declines in ESG ratings. This evidence underscores that mandatory facility-level disclosures not only trigger immediate market reactions but also amplify broader stakeholder pressures, particularly for firms under increased regulatory

scrutiny.

The primary contribution of this paper is to provide evidence and a rationale for how and why facility-level GHG transparency regulation generates real effects at the organizational level, shaping firm-wide decision-making beyond regulated facilities. This addresses a gap in the literature on the real effects of U.S. facility-level GHG transparency regulation (Yang et al. (2021), Tomar (2022), Bartram et al. (2022), Bauckloh et al. (2023)), where direct evidence on firm-wide emissions reductions remains limited. This study extends the literature on disclosure policies and resource allocation (e.g., Kanodia & Sapra (2016), Leuz & Wysocki (2016), Roychowdhury et al. (2019)) by demonstrating that disaggregated GHG disclosure—a subset of organizational reporting—can influence firm-level resource allocation, particularly by fostering green innovation. Although transparency regulation applies at the facility level, its standardized and overseen framework objectively reveals firms' true climate impact, which was previously unavailable at the firm level. This heightened granular transparency fosters managerial learning by elevating firm-level climate concerns, intensifying negative regulatory sentiment in earnings conference calls, and amplifying negative stakeholder feedback. More broadly, this study also contributes to the literature on CSR-related reporting (e.g., Chen et al. (2018), Christensen et al. (2017), Johnson (2020), Rauter (2020)) and feedback effects in financial markets (Subrahmanyam & Titman (2001), Goldstein et al. (2013), Bond et al. (2012)). By examining how facility-level GHG mandates interact with stakeholder reactions—such as investor responses and third-party ESG evaluations of underreporting—this paper offers new insights into the implications of CSR reporting and feedback effects in capital markets.

Second, this study contributes to the literature on the real effects of mandatory firm-level GHG transparency regulation in the United Kingdom (UK). For instance, Downar et al. (2021) analyzed emissions data aggregated from the facility-level European Union's Emissions Trading System (ETS) at the firm level, comparing pre- and post-regulation periods. Their findings reveal that the UK's firm-level GHG transparency regulation led to

significantly greater reductions in aggregated ETS emissions among UK firms compared to their EU counterparts. Jouvenot & Krueger (2019) leveraged vendor-estimated firm-level emissions data available before and after the regulation, showing that UK firms achieved more substantial emissions reductions relative to firms in other EU countries. Similarly, Grewal (2024) examined CDP data from voluntary disclosers and found that the UK's firm-level GHG transparency regulation significantly reduced both total firm-level emissions and emissions intensity. These results are intuitive, as facility-level emissions (ETS emissions) are a subset of total firm emissions, and firm-level GHG transparency regulation is likely to influence either this subset or the organization as a whole. While these studies primarily focus on how increased firm-level GHG transparency impacts facility emissions or overall firm-level reductions, this paper reverses the perspective by examining how increased facility-level GHG transparency drives broader firm-wide emissions reductions. In doing so, it extends the literature on mandatory reporting programs by exploring the multi-level effects of transparency regulations.

Finally, this paper provides policy insights for regulators seeking to enhance market discipline through disclosure regulations (see Leuz & Wysocki (2016) for a comprehensive review). While the U.S. Securities and Exchange Commission's (SEC) recent rule mandating the disclosure of Scope 1 and Scope 2 GHG emissions represents a significant step forward in climate-related transparency (US SEC (2024)), its reliance on firm-specific calculation methodologies undermines comparability both across firms and within the same firm over time. Although firms are required to disclose their methodologies, assumptions, and data sources, the lack of standardization hampers stakeholders' ability to effectively assess environmental performance. In contrast, the Environmental Protection Agency's Greenhouse Gas Reporting Program provides standardized and verified facility-level GHG disclosures, ensuring consistency and comparability. This paper demonstrates that the reliability and comparability established through the GHGRP's regulatory framework activate the "sunshine mechanism," effectively uncovering specific negative externalities and instances of underre-

porting. By equipping stakeholders with objective and standardized data—unlike voluntary disclosures, which often reflect discretionary reporting practices—the GHGRP enables stakeholders to deliver informed feedback, hold firms accountable, and drive meaningful organizational change. As Justice Louis D. Brandeis famously remarked, "Sunshine is the best disinfectant." This study underscores that transparency fosters market discipline only when supported by consistent and comparable data, allowing stakeholders to objectively evaluate environmental performance and provide impactful feedback. Without tangible negative feedback enabled by standardized transparency, firms lack incentives to align with societal expectations.

The remainder of the paper is organized as follows: Section 2 provides a detailed discussion of the institutional context and formulates the hypotheses. Section 3 describes the sample selection process and the data sources utilized in the analysis. Section 4 outlines the empirical methodology and presents the key results. Finally, Section 5 concludes and highlights its broader policy implications.

2 Institutional Background and Hypothesis Development

2.1 Greenhouse Gas Reporting Program by the EPA

In response to growing concerns about greenhouse gas emissions, the Consolidated Appropriations Act of 2008[5] allocated funding to the U.S. Environmental Protection Agency (EPA) to develop a rule mandating the reporting of greenhouse gas emissions across all sectors of the U.S. economy under the Clean Air Act.[6] This initiative led to the creation of the Greenhouse Gas Reporting Program (GHGRP), which took effect on January 1, 2010. The

[5]https://www.govinfo.gov/content/pkg/PLAW-110publ161/pdf/PLAW-110publ161.pdf
[6]https://www.epa.gov/clean-air-act-overview/clean-air-act-text

Table 1: Timeline of important Greenhouse Gas Reporting Program events

Calendar Time	Event
January 1, 2010	Greenhouse Gas Reporting Program was implemented, requiring facilities to measure and report their facility-level emissions to the EPA.
January 11, 2012	Facility-level GHG information for calendar year 2010 was first released to the public.
February 22, 2012	After revision, facility-level GHG information for calendar year 2010 was released again to the public.
February 5, 2013	Facility-level GHG information for calendar year 2011 released to the public.
October 23, 2013	Facility-level GHG information for calendar year 2012 released to the public.
September 30, 2014	Facility-level GHG information for calendar year 2013 released to the public.
October 5, 2015	Facility-level GHG information for calendar year 2014 released to the public.

GHGRP standardizes the calculation of facility-level GHG emissions[7] and mandates the submission of emissions data to the EPA for facilities emitting above specified thresholds, primarily set at 25,000 metric tons of CO2e. These thresholds may vary depending on the facility's source category, such as power plants, refineries, or manufacturing facilities.

To ensure data accuracy, the EPA enforces rigorous monitoring,[8] verification,[9] and enforcement processes.[10] Starting in 2012, annual emissions data for over 8,000 facilities, including total emissions and ownership information, is publicly disseminated through the EPA's Facility Level Information on Greenhouse Gases Tool (FLIGHT) website, promoting transparency and enabling more informed decision-making among societal stakeholders. For a detailed timeline of key events related to the Greenhouse Gas Reporting Program during the sample period, please refer to Table 1. While the GHGRP does not mandate emissions reductions, it has significant implications for publicly traded firms with regulated facilities, as these firms must comply with annual reporting requirements that do not apply to firms without regulated facilities.

[7] https://www.ecfr.gov/current/title-40/chapter-I/subchapter-C/part-98?toc=1
[8] https://www.epa.gov/sites/default/files/2017-12/documents/ghgrp_bamm_factsheet.pdf
[9] https://www.epa.gov/sites/default/files/2017-12/documents/ghgrp_verification_factsheet.pdf
[10] https://www.epa.gov/enforcement/enforcement-greenhouse-gas-reporting-program-hfc-importers

2.2 Voluntary Firm-Level GHG Emission Reporting Before and After GHGRP Implementation

Prior to the introduction of the GHGRP, firms increasingly responded to societal pressure by voluntarily disclosing their firm-level GHG emissions. This pressure extended beyond shareholder concerns, involving various stakeholders—including regulators, investors, consumers, and society at large—who are impacted by the externalities associated with corporate GHG emissions. Non-profit organizations, such as the CDP (formerly the Carbon Disclosure Project), have played a key role in promoting voluntary emissions disclosure. CDP encourages major global corporations to publicly share detailed information about their emissions through dedicated surveys.[11] By 2010, 59% of S&P 500 companies in the U.S. had voluntarily disclosed their firm-level emissions data to CDP (the CDP (2010)).

In addition to CDP surveys, some firms disclosed their emissions through various channels, including annual reports, sustainability reports, ESG data sheets, and their official corporate websites. Most of these disclosures primarily focused on Scope 1 emissions (direct emissions). To address causal inference questions, researchers must carefully narrow the scope of their samples, even at the expense of reduced statistical power and external validity (Leuz & Wysocki (2016)). In this study, I focus on firms that voluntarily disclosed their firm-level GHG emissions (e.g., Matsumura et al. (2014), Griffin et al. (2017)) both before and after the introduction of the program, examining the differential impacts on firm-level emissions changes in firms with and without regulated facilities.

2.3 Hypothesis Development

The increasing adoption of facility-level greenhouse gas (GHG) transparency regulation, such as the U.S. Environmental Protection Agency's (EPA) Greenhouse Gas Reporting Program (GHGRP), has far-reaching implications for corporate environmental behavior beyond

[11] https://www.cdp.net/en/info/about-us/what-I-do

directly regulated facilities. While prior research has predominantly focused on localized emissions reductions at regulated facilities, less attention has been paid to firm-wide effects. This study addresses this gap by examining how and why facility-level transparency regulation can influence firm-wide climate awareness, strategic decision-making, and sustainable business practices.

The first hypothesis builds on the growing literature highlighting climate change as a critical driver of corporate decision-making (Sautner et al. (2023)). As regulatory pressures and stakeholder expectations intensify, firms increasingly reevaluate their environmental strategies and risk management practices. Mandatory facility-level GHG disclosures, characterized by standardized emissions calculations, rigorous monitoring, and stringent verification processes, function as a "sunshine mechanism." This mechanism objectively exposes firms' true climate impacts, previously concealed by voluntary, firm-level disclosures. Prior voluntary reporting allowed firms significant discretion over emissions boundaries, calculation methods, and emission sources, enabling aggregated disclosures that often obscured facility-specific emissions and presented artificially favorable environmental profiles. Facility-level transparency breaks through this opacity by providing standardized, independently verified emissions data, enhancing comparability across firms and industries, and significantly increasing corporate visibility among investors, regulators, and the public. Consequently, firms face greater potential for negative stakeholder feedback and heightened political costs (Watts & Zimmerman (1978, 1990)). Unlike voluntary disclosures, which allowed firms to shape emissions narratives strategically, facility-level transparency delivers objective and verifiable data, amplifying reputational risks, regulatory scrutiny, and investor divestment pressures—particularly for firms with substantial emissions. Consistent with stakeholder theory (Freeman (1984)), anticipating these negative consequences motivates firms to proactively adopt socially responsible practices. Thus, by intensifying external pressures, facility-level transparency drives firms to enhance environmental performance, integrate sustainability into strategic decision-making, and implement meaningful firm-wide emissions-reduction

initiatives.

Despite the potential for facility-level transparency to encourage firm-wide emissions reductions, the extent of its influence remains uncertain for two primary reasons. First, the GHGRP requires disclosure only at the facility level, whereas many firms operate internationally across jurisdictions with varying regulatory frameworks. This raises questions about whether transparency at specific U.S. facilities can meaningfully stimulate broader corporate sustainability strategies or whether firms compartmentalize their environmental responses according to regional regulatory contexts. Second, unlike SEC-mandated financial disclosures—which are formally audited and integrated into 10-K filings—GHGRP emissions data are disseminated through informal channels, such as the EPA's website. Prior research indicates that investors often discount non-financial disclosures provided via informal channels (e.g., Christensen et al. (2017)), viewing them as less credible due to limited regulatory oversight and integration into formal financial reporting frameworks. Together, these factors create uncertainty about the extent to which facility-level transparency effectively shapes investor perceptions and drives firm-wide climate strategies.

H1: Firms subject to facility-level GHG transparency regulation reduce their overall firm-level GHG emissions more than firms without regulated facilities in the years following program implementation.

Reported changes in firm-level GHG emissions must be carefully assessed to distinguish genuine operational improvements from methodological adjustments or localized regulatory compliance. Firms have significant discretion over emissions reporting standards, including measurement criteria, emission factors, and disclosure boundaries, enabling them to potentially lower reported emissions without materially improving environmental performance. For instance, firms may adopt less rigorous measurement approaches, reclassify emission sources, or selectively exclude certain facilities from aggregated totals, resulting in artificially favorable emissions profiles. Additionally, emissions reductions may predominantly reflect localized responses to regulatory pressures at specific facilities (Yang et al. (2021),

Tomar (2022)), rather than broader firm-wide sustainability commitments. Actions such as efficiency upgrades or process optimization at individual facilities might satisfy immediate compliance obligations but do not necessarily represent deeper strategic integration of sustainability into firm-level operations.

I argue that the effectiveness of facility-level transparency regulation in promoting firm-wide behavioral change hinges on its capacity to heighten organizational climate awareness through granular emissions disclosures. A critical indicator of managerial learning about climate change is its visible influence on corporate priorities and public communications, particularly in forums where management interacts directly with stakeholders. Corporate earnings conference calls represent ideal platforms for such engagement, providing management the opportunity to articulate strategic responses to external developments, including regulatory shifts and investor concerns. As transparency at the facility level reveals a clearer picture of the firm's climate impact, stakeholders are likely to increase scrutiny, raising pointed questions about climate strategies, regulatory risks, and preparedness for future policy changes like carbon taxes or emissions caps. Firms facing this intensified scrutiny often proactively expand climate-related discussions during earnings calls, signaling enhanced internal recognition of climate risks and demonstrating a stronger strategic commitment to addressing them. Increased stakeholder attention also amplifies negative regulatory sentiment, especially among investors, analysts, and policymakers who critically evaluate the firm's environmental performance and readiness for tightening regulations. Consequently, firms with significant facility-level emissions experience greater reputational and regulatory pressure, incentivizing proactive, firm-wide sustainability strategies beyond minimal compliance efforts at regulated sites.

H2 :Even though transparency applies at the facility level, firms subject to granular GHG transparency regulation experience a simultaneous increase in firm-level climate change concerns and negative regulatory sentiment in earnings conference calls compared to firms without regulated facilities.

For granular transparency to drive meaningful firm-wide change, managerial learning prompted by increased climate awareness must translate into concrete, organization-wide adjustments in emissions practices. These strategic shifts should surpass mere localized compliance, embedding sustainability firmly within core corporate decision-making processes. A critical indicator of this transformation is greater investment in low-carbon innovation, particularly through increased development of low-carbon patents. Facing intensified regulatory scrutiny, firms gain a deeper understanding of climate-related risks, innovation opportunities, and evolving stakeholder expectations, enabling them to proactively integrate green technologies into their long-term strategies. Such investments represent authentic strategic commitments rather than symbolic responses, positioning firms advantageously within emerging markets and competitive landscapes. Low-carbon patents, indicative of substantial long-term R&D investments, signal that sustainability has become integral to corporate strategy. This perspective aligns with research highlighting that regulatory pressures can stimulate innovation, particularly when transparency simultaneously intensifies external stakeholder scrutiny and internal managerial recognition of climate risks. Consequently, firms prioritizing low-carbon innovation can benefit from improved market valuations, better access to capital, and strengthened stakeholder relationships, particularly as corporate environmental performance increasingly influences investor and policymaker decisions.

H3: Firms subject to facility-level GHG transparency regulation develop more low-carbon patents compared to firms without regulated facilities in the years following program implementation.

Although transparency requirements are associated with increased low-carbon innovation, it remains important to discern whether this innovation is directly driven by genuine firm-level emissions reductions or merely reflects broader environmental initiatives, regulatory demands, or prevailing industry trends. The central question is whether actual reductions in firm-level emissions explicitly stimulate increased patenting in low-carbon technologies, or if innovation occurs independently of actual emissions performance. If firms achieving

meaningful emissions reductions also produce more low-carbon patents, it would indicate that transparency regulations effectively encourage authentic technological advancements, rather than symbolic compliance or passive responses to external pressures.

H3a: Firms subject to facility-level GHG transparency regulation that achieve greater reductions in emissions subsequently develop more low-carbon patents compared to firms without regulated facilities in the years following program implementation.

Conversely, examining the opposite scenario can reinforce this interpretation: if low-carbon innovation genuinely reflects effective emissions management rather than symbolic compliance or mere responses to external pressures, then firms experiencing emissions increases should not demonstrate a corresponding rise in patenting activity. Such evidence would confirm that patenting represents a deliberate strategic effort directly linked to successful emissions reductions, rather than regulatory compliance, symbolic gestures, or general market signaling.

H3b: Firms subject to facility-level GHG transparency regulation that experience greater firm-level emissions increases do not develop more low-carbon patents compared to firms without regulated facilities in the years following program implementation.

How does facility-level regulation drive firm-wide managerial learning and shape corporate behavior? I argue that this occurs primarily through negative stakeholder feedback, triggered when mandatory transparency reveals discrepancies between independently verified facility-level emissions and earlier voluntary firm-level disclosures. Without regulatory oversight, voluntary disclosures allow firms significant discretion in defining emissions boundaries and adopting subjective measurement methodologies, often incentivizing more favorable reporting. Prior research in accounting valuation (Matsumura et al. (2014), Griffin et al. (2017), Choi & Luo (2021)) suggests that lower voluntarily reported emissions can positively influence firm valuation. In contrast, mandatory facility-level disclosures under the EPA's GHGRP provide standardized, credible, and rigorously verified emissions benchmarks. Stakeholders generally expect these disclosures to align with or be lower than prior

voluntary reports. When facility-level data instead reveal higher emissions, they objectively confirm that the firm previously understated its climate impact. This transparency—or "sunshine"—mechanism prompts investors, regulators, and advocacy groups to reassess the firm's environmental credibility, driving managerial learning and firm-wide behavioral adjustments.

Empirically, I first examine stakeholder responses by analyzing short-term stock market reactions to mandatory facility-level GHG disclosures. Because U.S. facilities represent only a subset of a firm's global operations, investors ex-ante expect total facility-level emissions to align with or be lower than previously voluntarily reported firm-level totals. However, when mandatory disclosures reveal unexpectedly higher emissions, investors experience a credibility shock, interpreting the discrepancy as potential misreporting or underestimation of climate risks. This transparency-driven shock negatively affects market valuations as investors reassess regulatory risks, litigation exposure, and reputational damage. Such market reactions exemplify the "sunshine" mechanism, in which transparent and objective disclosures expose previously concealed misreporting, intensifying stakeholder scrutiny and prompting firm-wide managerial learning and strategic adjustments.

H4: Firms that underreport GHG emissions in voluntary firm-level disclosures relative to objective facility-level data experience negative stock price reactions and declines in market value following mandatory transparency revelations.

Beyond short-term market reactions, I further examine broader stakeholder responses by analyzing changes in third-party environmental ratings following the implementation of mandatory facility-level GHG disclosures. Independent ESG ratings capture stakeholder perceptions—including those of investors, consumers, and advocacy groups—regarding corporate sustainability performance and influence investment decisions, policymaking, and sustainability-focused funds. A key question arises: Does mandatory transparency affect ESG ratings even for firms that already voluntarily disclose emissions? At first glance, one might expect minimal impact, given the availability of prior voluntary disclosures, whose

informational value is well-documented in existing literature (Matsumura et al. (2014), Griffin et al. (2017), Choi & Luo (2021)). However, mandatory facility-level disclosures provide standardized, independently verified, and highly granular data, significantly improving transparency compared to voluntary reports, which often allow managerial discretion. This increased objectivity enables third-party evaluators to uncover discrepancies or deliberate underreporting that may have been obscured in voluntary disclosures. Thus, the "sunshine" mechanism activated by mandatory transparency objectively reveals a firm's actual climate impact, prompting ESG rating agencies to downgrade environmental ratings when verified emissions exceed prior voluntary reports. In this way, mandatory disclosures act as a corrective force, enhancing the accuracy and accountability of corporate environmental assessments.

H5: Firms subject to facility-level GHG transparency regulation experience contemporaneous reductions in environmental ratings compared to firms without regulated facilities.

To assess whether declines in environmental ratings genuinely reflect a reassessment of corporate environmental impact following facility-level disclosures, I examine whether larger rating downgrades systematically correlate with prior underreporting in voluntary disclosures. If increased granular transparency drives these declines, firms that previously understated emissions relative to verified facility-level data should face more severe penalties as stakeholders revise their perceptions of environmental credibility. Historically, third-party evaluators and investors relied on voluntary emissions reports, granting firms significant discretion over reporting boundaries, methodologies, and emission sources. This flexibility allowed firms to present more favorable environmental profiles while often obscuring their true carbon footprints. Mandatory facility-level disclosures eliminate this discretion by providing standardized, independently verified data, creating a credible benchmark against which past voluntary disclosures can be evaluated. When facility-level data reveal substantial underreporting, stakeholders recognize material discrepancies, undermining trust in the firm's transparency and sustainability commitments. This erosion of stakeholder con-

fidence increases reputational risks and prompts ESG rating agencies to impose steeper downgrades. Consequently, firms with greater underreporting experience sharper declines in environmental ratings, reinforcing granular transparency's essential role in strengthening corporate environmental accountability.

H5a: Firms that underreport firm-level GHG emissions relative to objective facility-level disclosures experience larger declines in environmental ratings following mandatory transparency revelations.

3 Sample and Data

3.1 Data

The data used in this study is sourced from multiple databases. The sample comprises U.S. publicly listed firms that voluntarily disclosed their GHG emissions both before and after the implementation of the GHGRP policy. Firm-level GHG emissions data, measured in metric tons of carbon dioxide equivalents (CO2e), voluntarily *reported*[12] by the firms, is sourced from Refinitiv Eikon, a leading platform for financial professionals. This data was collected in April 2022. Firm characteristic data are obtained from Compustat, and stock market data are sourced from CRSP. To ensure data quality, only firms with complete information in the Compustat-CRSP merged database are included. Analyst coverage data are retrieved from the I/B/E/S database, and institutional holdings data are sourced from the Thomson Reuters 13F database.

Annual facility-level GHG emissions data, including production quantities and ownership details, is sourced from the EPA's FLIGHT database.[13] This comprehensive resource pro-

[12]Refinitiv Eikon provides firm-level emissions data through a hierarchical process, prioritizing the most accurate source. The primary category, "Reported," uses self-reported CO2 emissions from companies, halting the process at this step if available. If not, emissions are estimated using a CO2-specific model, energy metrics, or, as a last resort, a median-based approach. For this study, only "Reported" emissions data is used to ensure accuracy and reliability.

[13]https://ghgdata.epa.gov/ghgp/main.do

vides emissions data for each facility, measured in metric tons of carbon dioxide equivalents (CO_2e), along with ownership details for the parent entity of each facility. Facilities with missing parent entity information or non-positive emissions are excluded from the analysis. From calendar years 2010 to 2014, the dataset includes 8,437 unique facilities and 31,018 facility-year observations. These facility-level data points are aggregated at the parent entity level to link emissions to corporate entities. The majority of facility-year observations (29,108) are owned by a single parent entity, while 1,910 observations involve facilities jointly owned by multiple parent entities. In cases of joint ownership, emissions are proportionally allocated based on ownership percentages. Given that over 93.8% of facilities in the sample are solely owned, excluding jointly owned facilities or distributing their emissions equally among parent entities does not materially affect the empirical results. To systematically identify publicly traded parent entities of these regulated facilities, I employ a multi-step matching process. First, I use Python-based natural language processing to match the legal names of parent entities to publicly traded firms, leveraging the Levenshtein distance algorithm (Levenshtein (1966)) to measure name similarity. The resulting matches are then carefully reviewed and manually refined to ensure accurate alignment with Compustat identifiers (GVKEY). Next, I integrate CRSP identifiers (PERMNO) via the CRSP/Compustat Merged Database (CCM), linking emissions data to stock market data from CRSP. This approach ensures precise mapping between facility-level emissions and firm-level financial data, allowing for a robust analysis of the relationship between corporate transparency and environmental accountability.

The main panel dataset is constructed by merging fiscal year firm characteristics with calendar year facility-level GHG information. This process generates the main policy variable of interest, GHGRP, a binary indicator set to 1 starting in the year a firm first becomes subject to the GHGRP's implementation and in all subsequent years, and 0 otherwise. The starting year for each firm is staggered, reflecting the timing of the firm's initial exposure to the mandate.

To assess firm-level climate change concerns, I leverage the dataset developed by Sautner et al. (2023), which develops an innovative machine learning-based approach to quantify firm-level climate change exposure using earnings call transcripts. This dataset identifies climate-related keywords and calculates the frequency of discussions on climate topics, encompassing physical risks, regulatory shocks, and opportunities. To integrate this data with firm-level financial and regulatory information, I aggregate the climate exposure measures by CRSP identifier and calendar year.

To analyze firm-level green innovation, I utilize patent data from the United States Patent and Trademark Office (USPTO), linked to public firms' patent records as compiled by Kogan et al. (2017). Following prior research (Sautner et al. (2023), Cohen et al. (2024)), I identify low-carbon patents using the Cooperative Patent Classification (CPC) Y02 class, which categorizes technologies designed for environmental sustainability and climate change mitigation. To integrate this data, I aggregate the total number of low-carbon patents by CRSP identifier and patent application filing year.

For the event study analysis, daily stock data is sourced from CRSP, while factor data is obtained from Ken French's website.

Finally, environmental ratings data is sourced from MSCI ESG ratings, specifically focusing on the Environment Pillar, which evaluates dimensions such as carbon emissions, climate change vulnerability, raw material sourcing, and waste management. The MSCI dataset provides an independent assessment of firms' environmental performance and is widely recognized in accounting and finance research.

In total, the sample comprises 1,890 firm-year observations for 379 unique firms, covering the period from fiscal year 2007 to 2014. To mitigate the influence of outliers, all continuous control variables are winsorized at the 1st and 99th percentiles.

3.2 Descriptive Statistics

Table 2 presents the summary statistics for the key variables. ln(FirmE), representing the natural logarithm of voluntarily disclosed firm-level GHG emissions, has a mean of 13.60 and a standard deviation of 2.28, indicating moderate variability around the average value. The primary policy variable, GHGRP, is a binary indicator with a mean of 0.29, signifying that approximately 29% of the firms in the sample are subject to the GHGRP. ln(FacilityE), which captures the total aggregated facility-level emissions at the firm level, exhibits a mean of 4.15 and a substantially larger standard deviation of 6.66, reflecting significant heterogeneity in emissions across firms.

Table 3 presents the Pearson correlation matrix. Firm-level emissions exhibit strong positive correlations with facility-level emissions, firm size, and capital intensity—factors that reflect a firm's operational scale and industry classification. Furthermore, the positive correlation with climate concerns suggests that higher-emission firms are more actively engaged in climate-related discussions, likely as part of their environmental communication and strategic positioning. The control variables do not display strong correlations.

Table 2: Summary Statistics

	Obs	Mean	STD	Median
ln(FirmE)	1890	13.60	2.28	13.48
GHGRP	1890	0.29	0.45	0.00
ln(FacilityE)	1890	4.15	6.66	0.00
ClimateConcerns	1890	1.58	3.17	0.41
NegRegSenti	1890	-0.22	1.06	0.00
LowCarbonPatents	1890	9.14	37.76	0.00
EnvironmentScore	1730	5.20	1.81	5.21
Size	1890	9.60	1.31	9.51
BM	1890	0.54	0.43	0.42
AI	1890	0.56	0.39	0.49
Leverage	1890	0.25	0.15	0.24
Cash	1890	0.13	0.13	0.09
ROA	1890	0.14	0.08	0.14
Dividend	1890	0.02	0.02	0.02
IO	1890	0.77	0.15	0.79
Analysts	1890	2.79	0.49	2.89

This table provides descriptive statistics for the key variables used in the analysis. ln(FirmE) represents the natural logarithm of voluntarily disclosed firm-level GHG emissions, measured in metric tons of carbon dioxide equivalent (CO2e), capturing the scale of firm-reported emissions. The main policy variable of interest, GHGRP, is a binary indicator set to 1 starting in the year a firm becomes subject to the GHGRP's implementation and remains 1 in all subsequent years, distinguishing treated firms from non-treated firms. ln(FacilityE) represents the natural logarithm of a firm's total aggregated facility-level emissions, measured in metric tons of CO2e, offering a detailed and granular perspective on emissions data. The variables ClimateConcerns and NegRegSenti capture firm-level measures of overall climate change concerns and negative regulatory sentiment, respectively. These measures are based on the proportion of earnings call transcripts focused on these topics, as described by Sautner et al. (2023), and are scaled by multiplying by constant number. LowCarbonPatents reflects the number of firm-level low-carbon patents classified using the Cooperative Patent Classification (CPC) Y02 class, which identifies technologies with environmental benefits (Sautner et al. (2023), Cohen et al. (2024)). EnvironmentScore represents the MSCI Environment Pillar Score assigned to firms, assessing their environmental performance across dimensions such as carbon emissions and natural resource management. SIZE captures firm size and is measured as the natural logarithm of total market capitalization as of December. BM represents the book-to-market ratio, calculated as book equity divided by the market value of common equity at the end of December, reflecting valuation characteristics. AI is measured as the ratio of property, plant, and equipment to total assets, indicating the capital intensity of the firm. Leverage reflects financial risk and is calculated as the sum of long-term and short-term debt divided by total assets. Cash measures liquidity as the proportion of cash holdings to total assets. ROA represents return on assets, a measure of profitability. Dividend reflects the dividend payout ratio, calculated as the sum of common and preferred dividends divided by total assets. IO indicates the proportion of shares owned by institutional investors, while Analysts captures market attention as the natural logarithm of one plus the number of analysts following the firm during the year.

Table 3: Pearson Correlation Matrix

#	Variables	ln(FirmE)	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
2	GHGRP	**0.45**	1	**0.97**	**0.26**	**-0.10**	**0.16**	**-0.14**	**0.22**	**0.16**	**0.35**	**0.17**	**-0.24**	**-0.11**	**0.05**	**-0.14**	-0.0
3	ln(FacilityE)	**0.52**	**0.97**	1	**0.34**	**-0.15**	**0.13**	**-0.18**	**0.24**	**0.20**	**0.41**	**0.17**	**-0.27**	**-0.13**	0.03	**-0.15**	-0.0
4	ClimateConcerns	**0.44**	**0.26**	**0.34**	1	**-0.45**	**-0.05**	**-0.13**	**0.06**	**0.33**	**0.36**	**0.20**	**-0.27**	**-0.22**	**-0.09**	**-0.21**	**-0.1**
5	NegRegSenti	**-0.23**	**-0.10**	**-0.15**	**-0.45**	1	0.03	**0.06**	**-0.05**	**-0.15**	**-0.16**	**-0.06**	**0.11**	**0.09**	**0.05**	**0.10**	**0.0**
6	LowCarbonPatents	**0.08**	**0.16**	**0.13**	**-0.05**	0.03	1	**0.16**	**0.26**	**-0.11**	**-0.08**	**-0.05**	**0.11**	**0.06**	**0.05**	**-0.16**	**0.1**
7	EnvironmentScore	**-0.14**	**-0.14**	**-0.18**	**-0.13**	**0.06**	**0.16**	1	**0.17**	**-0.17**	**-0.24**	**-0.06**	**0.20**	**0.09**	0.04	-0.04	**0.1**
8	Size	**0.48**	**0.22**	**0.24**	**0.06**	**-0.05**	**0.26**	**0.17**	1	**0.26**	0.02	**0.08**	**-0.18**	**-0.17**	-0.00	**-0.30**	**0.3**
9	BM	**0.23**	**0.16**	**0.20**	**0.33**	**-0.15**	**-0.11**	**-0.17**	**0.26**	1	**0.20**	**0.05**	**-0.27**	**-0.51**	**-0.32**	**-0.05**	**-0.1**
10	AI	**0.70**	**0.35**	**0.41**	**0.36**	**-0.16**	**-0.08**	**-0.24**	0.02	**0.20**	1	**0.24**	**-0.44**	**0.07**	0.03	**-0.21**	**-0.1**
11	Leverage	**0.29**	**0.17**	**0.17**	**0.20**	**-0.06**	**-0.05**	**-0.06**	**0.08**	**0.05**	**0.24**	1	**-0.34**	**-0.19**	0.04	**-0.11**	**-0.2**
12	Cash	**-0.48**	**-0.24**	**-0.27**	**-0.27**	**0.11**	**0.11**	**0.20**	**-0.18**	**-0.27**	**-0.44**	**-0.34**	1	**0.17**	0.01	**0.19**	**0.2**
13	ROA	**-0.05**	**-0.11**	**-0.13**	**-0.22**	**0.09**	**0.06**	**0.09**	**-0.17**	**-0.51**	**0.07**	**-0.19**	**0.17**	1	**0.42**	**-0.05**	**0.2**
14	Dividend	**0.05**	**0.05**	0.03	**-0.09**	**0.05**	**0.05**	0.04	-0.00	**-0.32**	0.03	0.04	0.01	**0.42**	1	**-0.26**	0.02
15	IO	**-0.34**	**-0.14**	**-0.15**	**-0.21**	**0.10**	**-0.16**	-0.04	**-0.30**	**-0.05**	**-0.21**	**-0.11**	**0.19**	**-0.05**	**-0.26**	1	-0.0
16	Analysts	-0.04	-0.01	-0.02	**-0.19**	**0.08**	**0.19**	**0.19**	**0.38**	**-0.19**	**-0.14**	**-0.20**	**0.23**	**0.22**	0.02	-0.00	1

This table presents the Pearson correlation matrix among key variables. Correlation coefficients that are significant at the 5% level are highlighted in bold. For variable definitions, refer to Table 2.

4 Empirical Analysis

4.1 H1: The Effect of Facility-Level GHG Transparency Regulation on Firm-Level Emissions

4.1.1 Empirical Design

Following Bertrand & Mullainathan (2003), I employ a generalized difference-in-differences (DID) research design to assess the impact of the granular disclosure mandate on firm-level emissions. This methodology leverages the staggered implementation of the facility-level GHG emissions disclosure mandate, which came into effect on January 1, 2010. A firm's initial exposure to the mandate is determined by the year it first owns regulated facilities. In the analysis, I compare firm-years when a firm first becomes subject to the mandate with other firm-years, including a control group comprising firms already regulated and those not yet exposed in a given year. To ensure robustness, the model incorporates common firm characteristics, firm-fixed effects to account for time-invariant differences between treated and control firms, and industry-year fixed effects to capture time-varying industry-level shocks. This setup enables estimation of the average treatment effect on firms encountering the GHGRP for the first time in a specific year. Consequently, any alternative explanations for the observed effects would need to align temporally with the timing of firms' initial exposure to the facility-level GHG emissions mandate. The generalized DID equation, estimated using the Ordinary Least Squares (OLS) method, is specified as follows:

$$ln(firmE)_{fit} = \alpha_f + \alpha_{it} + \gamma * X_{ft} + \beta * GHGRP_{ft} + \epsilon_{it} \quad (1)$$

Here, f indexes the firm, i represents the Fama-French 12 industry classification, and t denotes the fiscal year. The dependent variable, ln(firmE), is the natural logarithm of voluntarily disclosed firm-level emissions. This logarithmic transformation aids in interpreting results as percentage changes and reduces the influence of outliers. The main policy

variable of interest, GHGRP, is a binary indicator set to 1 starting in the year a firm first becomes subject to the GHGRP's implementation and in all subsequent years, and 0 otherwise. This variable captures contemporaneous changes in firm-level emissions in response to the program. To examine behavioral changes that are likely to occur after the program's implementation, I include lagged values of the GHGRP variable.

Consistent with prior research on mandatory greenhouse gas reporting (e.g., Downar et al. (2021), Yang et al. (2021), Tomar (2022)), the model includes control variables for key firm characteristics, such as firm size, market-to-book ratio, AI, and book leverage. Additional controls account for operating performance, capital structure, IO, and analyst coverage. To address unobservable heterogeneity, firm fixed effects and industry-year fixed effects are included, capturing time-invariant firm characteristics and industry-specific trends, respectively. Standard errors are clustered at the firm level to ensure robust statistical inference.

4.1.2 Main Results

Table 4 presents the findings testing Hypothesis H1, which examines the impact of facility-level GHG emissions transparency regulation (GHGRP) on firm-level emissions (ln(firmE)) over time. The analysis evaluates the contemporaneous and lagged effects of GHGRP to understand how firms adjust their emissions in response to increased transparency.

In Specification (1), the contemporaneous effect of GHGRP (GHGRP(0)) is statistically insignificant ($t = -0.53$), indicating no immediate reduction in firm-level emissions during the year the regulation is implemented. This suggests that firms do not respond instantly to transparency requirements, likely due to the time required for internal assessment and operational adjustments. In Specification (2), the one-year lagged effect (GHGRP(+1)) is significant at the 10% level ($t = -1.82$), with a coefficient of -0.08. This suggests that firms reduce their emissions by approximately 8% one year after their initial exposure to the mandate. The delayed response indicates that firms require time to evaluate compliance requirements and implement emissions-reduction strategies.

By the second year, as shown in Specification (3), the effect becomes highly statistically significant at the 1% level (t = −2.66), with a coefficient of −0.11. This implies that firms reduce their emissions by approximately 11% two years after the regulation takes effect. The increasing magnitude of reductions over time highlights a progressive and sustained response as firms adapt to transparency requirements and external pressures from investors, regulators, and other stakeholders. From an economic perspective, the 8% reduction in emissions after one year and 11% reduction after two years represent substantial behavioral changes. These reductions are likely driven by operational adjustments, increased monitoring, and investments in emissions-reducing strategies, reflecting firms' efforts to align with heightened transparency expectations and mitigate regulatory risks.

Overall, the findings provide strong support for Hypothesis H1, demonstrating that facility-level transparency regulation under the GHGRP leads to significant reductions in firm-level GHG emissions. However, the impact is not immediate—substantial reductions only begin to materialize one year after the regulation's implementation, with a stronger effect in the second year. This delayed but robust response underscores the time firms require to adapt their operations and environmental strategies to increased scrutiny, further affirming the effectiveness of transparency-driven regulatory interventions in influencing corporate environmental behavior.

4.1.3 Dynamic Effects and Goodman-Bacon Decomposition

The difference-in-differences (DID) methodology relies on the assumption of parallel pre-trends between treated and control firms. To validate this assumption, I analyze the dynamic effects of the facility-level GHG information disclosure mandate on firm-level emissions in the years before and after its initial implementation, relative to control firms. Specifically, Figure 1 visually illustrates the estimated coefficients and their 90% confidence intervals for a series of policy dummy variables. These variables represent each of the two years preceding the mandate (T = −2 and T = −1), the year the mandate was first implemented (T = 0),

Table 4: Changes in Firm-Level Emissions Around the Facility-Level GHG Transparency Regulation

	ln(firmE)		
	(1)	(2)	(3)
GHGRP(0)	-0.02		
	(-0.53)		
GHGRP(+1)		-0.08*	
		(-1.82)	
GHGRP(+2)			-0.11***
			(-2.66)
Size	0.64***	0.63***	0.63***
	(6.39)	(6.37)	(6.38)
BM	0.07	0.07	0.07
	(1.00)	(1.01)	(1.01)
AI	0.59*	0.58*	0.57*
	(1.86)	(1.84)	(1.83)
Leverage	-0.18	-0.18	-0.17
	(-0.89)	(-0.87)	(-0.86)
Cash	0.37*	0.34	0.35
	(1.73)	(1.58)	(1.63)
ROA	0.34	0.33	0.33
	(0.77)	(0.76)	(0.76)
Dividend	0.26	0.15	0.09
	(0.28)	(0.16)	(0.10)
IO	-0.08	-0.08	-0.08
	(-0.47)	(-0.49)	(-0.46)
Analysts	-0.02	-0.02	-0.02
	(-0.51)	(-0.53)	(-0.58)
Observations	1,890	1,890	1,890
Adj R2	0.984	0.984	0.984
Firm FE	Yes	Yes	Yes
FF12-Year FE	Yes	Yes	Yes

This table presents the main results of the GHGRP's impact on firm-level GHG emissions. The dependent variable is the natural logarithm of firm-level emissions voluntarily disclosed by firms before and after the implementation of the facility-level transparency regulation. The primary policy variable of interest, GHGRP, is a binary indicator equal to 1 starting in the year a firm first becomes subject to the GHGRP and continuing in all subsequent years, and 0 otherwise. This variable captures contemporaneous changes in firm-level emissions in response to the program. To evaluate behavioral changes that may occur in the years following the program's implementation, lagged values of the GHGRP variable are included in the analysis. Firm and industry-year fixed effects are included to control for unobserved heterogeneity across firms and industries over time. Standard errors are clustered at the firm level to ensure robust statistical inference. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

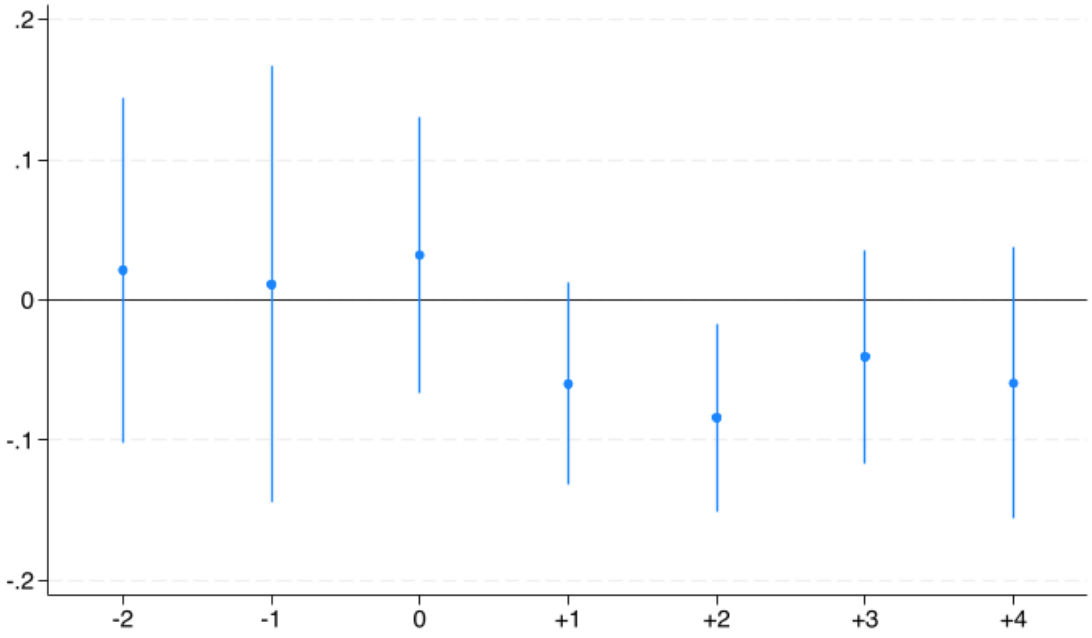
and subsequent years (T = 1 through T = 4+, where T = 4+ aggregates year 4 and all later years).

$$ln(firmE)_{fit} = \alpha_f + \alpha_{it} + \sum_{T=-2}^{T=+4} \beta_T * GHGRP_{ft}(T) + \epsilon_{it} \tag{2}$$

The coefficients for the pre-treatment periods (T = −2 and T = −1) are close to zero and statistically insignificant, as indicated by the wide confidence intervals overlapping zero. This result supports the parallel-trend assumption, confirming that treated and control firms exhibited similar trends in firm-level emissions before the regulation's implementation. Similarly, the coefficient for T = 0 (the year of initial disclosure) is also statistically insignificant, suggesting no immediate effect of the facility-level transparency regulation on firm-level emissions. Post-treatment, the results show a significant decline in emissions starting at T = +1, with the coefficient becoming more negative by T = +2. This pattern indicates that firms begin to meaningfully reduce their emissions one year after their initial disclosure, with these reductions becoming more pronounced two years after the regulation's implementation. The coefficients for T = +3 and T = +4 remain negative, suggesting that the emissions reductions persist over time, though the magnitude stabilizes rather than intensifies further. Overall, the figure provides compelling evidence that the facility-level GHG transparency regulation effectively drives significant reductions in firm-level emissions, with the effects materializing one year after the initial disclosure. This delayed response underscores the time required for firms to adapt their operations and strategies to meet the demands of transparency-driven pressures.

The generalized DID estimator essentially represents a weighted average of all conceivable standard DID estimates between treated and control observations. Recent studies (Goodman-Bacon (2021), Baker et al. (2022)) highlight the potential bias that can arise when already-treated firms are included in the control group, as the treatment effect may

Figure 1: Dynamics of GHGRP Impact on Firm-Level Emissions Changes



e

This figure illustrates the dynamic effects of the GHGRP's facility-level transparency regulation on firm-level GHG emissions. The dependent variable is the natural logarithm of firm-level emissions, observed across two years prior to the mandate (T = −2 and T = −1), the year of implementation (T = 0), and subsequent years (T = +1 through T = +4). The primary policy variable consists of policy dummies that measure the temporal impact of the regulation on emissions relative to the pre-treatment baseline. The figure presents the estimated coefficients for these policy dummies, accompanied by 90% confidence intervals, providing a clear depiction of both the magnitude and statistical significance of the regulation's effects over time. This visualization highlights the delayed but sustained reductions in emissions following the regulation's implementation, offering insights into the evolving impact of transparency-driven policies on corporate environmental behavior.

Table 5: Goodman-Bacon Decomposition

	ln(FirmE)	
	Beta	std. err
Overall Estimate	-0.10	0.03
Control Group Type	Beta	Total weight
Early vs Late	-0.08	0.05
Late vs Early	-0.07	0.025
Never vs Timing	-0.10	0.923

This table presents the Goodman-Bacon decomposition of the generalized DID estimator, which breaks down the overall treatment effect of the GHGRP(+1) into components based on comparisons across distinct timing groups. The analysis ensures robustness by limiting the sample to a balanced panel from 2009–2012, as required for accurate decomposition.

vary over time. To address this issue, I apply the methodology proposed by Goodman-Bacon (2021) to decompose the generalized DID estimate into components based on distinct sets of control firms. For the decomposition analysis, a balanced panel without control variables is required. Therefore, I limit the sample period to 2009–2012 to ensure a robustly balanced panel. Table 5 presents the Bacon decomposition results, illustrating how the overall treatment effect (GHGRP(+1)) is constructed from comparisons across different timing groups under the facility-level GHG transparency regulation. The most substantial contribution comes from the "Never vs Timing" group, which has a Beta coefficient of -0.10 and a total weight of 92.3%. This indicates that the generalized DID estimates are primarily driven by comparisons between the treatment group and firms that were either treated later or never treated, highlighting their importance for deriving robust insights into the impact of the facility-level GHG transparency regulation on firm-level GHG emissions reductions.

4.2 H2: Managerial Learning—The Impact of Facility-Level GHG Transparency Regulation on Firm-Level Climate Concerns

The findings for H1 indicate that firms subject to the GHGRP reduce their firm-level GHG emissions by an average of 8 to 11% more than firms without regulated facilities in the years following the program's implementation. However, it remains essential to deter-

mine whether these reductions reflect substantive firm-wide environmental improvements or merely compliance-driven facility-level adjustments. Declines in reported emissions may stem from methodological shifts, selective measurement techniques, or localized reductions at regulated facilities rather than a broader shift in corporate sustainability strategy. For facility-level transparency regulation to drive meaningful firm-wide change, it must extend beyond compliance and foster managerial learning—the internalization of regulatory scrutiny that reshapes corporate decision-making and strategic priorities. Managerial learning occurs when heightened transparency increases firms' awareness of climate risks, prompting a reassessment of regulatory exposure and long-term environmental commitments. This process facilitates the firm-wide integration of sustainability considerations rather than limiting responses to regulatory compliance at the facility level.

One way to assess whether facility-level regulation drives broader behavioral change is by examining its impact on organizational priorities and public messaging, particularly in forums where management interacts with key stakeholders. Earnings conference calls provide real-time insights into how management frames climate-related risks and opportunities, serving as a key platform for firms to articulate strategic responses to external pressures. If facility-level transparency fosters managerial learning, firms should engage more in climate-related discussions, acknowledge regulatory risks, and signal stronger commitments to addressing them. Increased climate discourse in earnings calls would suggest that transparency influences firm-wide strategy and stakeholder communication rather than being confined to facility-level compliance. To test H2, I examine whether firms subject to facility-level GHG transparency regulation exhibit a simultaneous increase in climate change concerns and negative regulatory sentiment in earnings conference calls compared to firms without regulated facilities. The empirical model is specified as follows:

$$\begin{cases} ClimateConcerns_{fit} \\ NegRegSenti_{fit} \end{cases} = \alpha_f + \alpha_{it} + \gamma * X_{ft} + \beta * GHGRP_{ft} + \epsilon_{it} \quad (3)$$

The empirical setup mirrors the main difference-in-differences equation used in H1, with the dependent variables adapted to climate change exposure measures introduced by Sautner et al. (2023). ClimateConcerns measures the relative frequency of bigrams related to climate change appearing in earnings call transcripts, capturing the extent to which management and analysts discuss climate-related issues. NegRegSenti identifies bigrams associated with regulatory discussions on climate change, conditioned on the presence of negative tone words, following the Loughran & Mcdonald (2011) sentiment classification. This metric reflects firms' perceptions of regulatory risks related to climate policies, providing insights into the negative sentiment surrounding regulatory exposure. The key policy variable, GHGRP, is a binary indicator set to 1 starting in the year a firm first becomes subject to GHGRP and all subsequent years, and 0 otherwise. By analyzing these measures, this study evaluates whether facility-level transparency regulation influences firm-wide climate concerns and how firms frame regulatory risks in public discourse.

The results in Table 6 provide strong support for H2. Firms subject to GHGRP regulation exhibit a significant increase in climate change concerns and negative regulatory sentiment in earnings conference calls. In Column (1), the coefficient for GHGRP on ClimateConcerns is 0.20 (t = 2.10), statistically significant at the 5% level, indicating that facility-level transparency raises the prominence of climate-related issues in strategic discussions. In Column (2), the coefficient for GHGRP on NegRegSenti is 0.11 (t = 1.98), also significant at the 5% level, suggesting that firms perceive heightened regulatory risks and express these concerns more negatively in earnings calls. These findings indicate that although GHGRP applies at the facility level, it fosters firm-wide managerial learning, prompting firms to reassess their exposure to climate risks and adjust strategic priorities accordingly. By increasing

stakeholder scrutiny and regulatory visibility, GHGRP compels firms to integrate climate concerns into broader decision-making rather than treating them as isolated compliance issues. This learning process encourages management to acknowledge and address climate challenges more explicitly in public communications, signaling a shift toward proactive climate engagement rather than reactive compliance. Moreover, the rise in negative regulatory sentiment suggests that firms anticipate stricter climate policies, carbon pricing mechanisms, and heightened compliance requirements, reinforcing the idea that granular transparency mandates can accelerate corporate adaptation to an evolving regulatory landscape.

4.3 The Effect of Facility-Level GHG Transparency Regulation on Firm-Level Green Innovation

While H2 establishes that, despite being a facility-level policy, GHGRP heightens firm-level climate change concerns, a critical question remains: Does this managerial learning lead to tangible emissions-reduction efforts through innovation, or does it remain rhetorical? A key indicator of a substantive strategic shift is a greater emphasis on low-carbon innovation, particularly through the development of low-carbon patents. To evaluate this, H3 examines whether firms subject to facility-level GHG transparency regulation engage in greater green innovation—specifically, the development of low-carbon patents—compared to non-GHGRP firms in the years following the program's implementation. This relationship is modeled as follows:

$$LowCarbonPatents_{fit} = \alpha_f + \alpha_{it} + \gamma * X_{ft} + \beta * \begin{cases} GHGRP_{ft}(+1) \\ GHGRP_{ft}(+2) \end{cases} + \epsilon_{it} \qquad (4)$$

The empirical framework follows the difference-in-differences approach used in H1 and H2, adapting the dependent variable to measure a firm's low-carbon patent output. Low-

Table 6: Impact of Facility-Level GHG Transparency Regulation on Firm-Level Climate Change Concerns

	(1) ClimateConcerns	(2) NegRegSenti
GHGRP	0.20**	0.11**
	(2.10)	(1.98)
Size	-0.02	-0.01
	(-0.13)	(-0.10)
BM	-0.12	0.01
	(-0.57)	(0.08)
AI	0.22	-0.04
	(0.42)	(-0.07)
Leverage	0.30	-0.08
	(0.56)	(-0.10)
Cash	-0.46	-0.37
	(-0.88)	(-1.36)
ROA	0.36	-0.87
	(0.63)	(-1.00)
Dividend	-2.25	1.95
	(-1.20)	(1.51)
IO	-1.54*	1.17*
	(-1.82)	(1.92)
Analysts	0.15	-0.08
	(0.80)	(-0.77)
Observations	1,890	1,890
Adj R2	0.888	0.250
Firm FE	Yes	Yes
Industry-Year FE	Yes	Yes

This table presents the results of the impact of the GHGRP on firm-level climate change concerns and regulatory sentiment as discussed during earnings conference calls. The dependent variables are ClimateConcerns and NegRegSenti, which capture the frequency of climate-related discussions and the negative sentiment associated with regulatory risks, respectively, in the transcripts of these calls (Sautner et al. (2023)). The primary policy variable of interest, GHGRP, is a binary indicator equal to 1 starting in the year a firm first becomes subject to the GHGRP and continuing in all subsequent years, and 0 otherwise. This measures the contemporaneous impact of facility-level GHG transparency regulation on firm-wide climate change concerns and regulatory sentiment. Firm and industry-year fixed effects are included to control for unobserved heterogeneity across firms and industries over time. Standard errors are clustered at the firm level to ensure robust statistical inference. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

carbon patents are classified under the Cooperative Patent Classification (CPC) Y02 class, which identifies technologies with environmental benefits (Sautner et al. (2023), Cohen et al. (2024)). Patent data are sourced from the United States Patent and Trademark Office (USPTO) and linked to publicly traded firms' patent records (Kogan et al. (2017)). To isolate the impact of facility-level transparency regulation on green innovation post-implementation, I incorporate lagged values of the GHGRP indicator (GHGRP(+1) and GHGRP(+2)). This accounts for the time required for firms to internalize climate awareness through managerial learning and translate it into R&D investments and technological advancements.

The results in Table 7 provide strong empirical support for H3, demonstrating that facility-level GHG transparency regulations drive firm-level green innovation. In Column (1), the coefficient for GHGRP(+1) is 11.65 (t = 2.10), statistically significant at the 5% level, indicating that facility-level transparency has a delayed but substantial effect on low-carbon patent development, emerging one year after implementation. In Column (2), the coefficient for GHGRP(+2) remains positive (11.12, t = 1.94) and statistically significant at the 10% level, reinforcing that the effect persists over time. These findings confirm that while GHGRP operates at the facility level, its influence extends beyond emissions reductions to stimulate firm-wide innovation in green technologies. By fostering managerial learning, GHGRP prompts firms to internalize climate risks, realign R&D priorities, and embed sustainability into corporate strategy. This transformation moves firms beyond compliance, positioning them as leaders in sustainable innovation and enhancing their competitive advantage in the low-carbon economy.

While H3 establishes a general link between facility-level transparency regulation and increased low-carbon innovation, it remains uncertain whether this innovation stems from actual firm-level emissions reductions or simply reflects broader environmental initiatives or regulatory compliance. If transparency regulation truly drives substantive technological progress, firms that successfully reduce emissions should also exhibit higher levels of low-carbon patenting. To test this, H3a examines whether GHGRP firms that achieve greater

Table 7: Impact of Facility-Level GHG Transparency Regulation on Firm-Level Green Innovations

	(1)	(2)
	LowCarbonPatents	
GHGRP(+1)	11.65**	
	(2.10)	
GHGRP(+2)		11.12*
		(1.94)
Size	7.98	7.72
	(1.58)	(1.56)
BM	0.88	0.84
	(0.46)	(0.44)
AI	-4.84	-4.76
	(-0.50)	(-0.49)
Leverage	-4.72	-4.96
	(-0.35)	(-0.37)
Cash	-13.46	-15.87
	(-1.05)	(-1.19)
ROA	15.65	15.71
	(1.33)	(1.32)
Dividend	71.25	69.62
	(1.23)	(1.16)
IO	-32.52**	-33.16**
	(-2.05)	(-2.05)
Analysts	1.37	1.48
	(0.81)	(0.86)
Observations	1,890	1,890
Adj R2	0.854	0.854
Firm FE	Yes	Yes
Industry-Year FE	Yes	Yes

This table presents the results of the impact of the GHGRP on firm-level green innovation. The dependent variable is the number of low-carbon patents developed by a firm, classified according to the Cooperative Patent Classification (CPC) Y02 class, which identifies technologies with environmental benefits (Sautner et al. (2023), Cohen et al. (2024)). Firm-level patent data are sourced from the United States Patent and Trademark Office (USPTO) and linked to public firms' patent records (Kogan et al. (2017)). The primary policy variables of interest, GHGRP(+1) and GHGRP(+2), are lagged indicators equal to 1 in the first and second years, respectively, after a firm becomes subject to the GHGRP and 0 otherwise. These variables measure the delayed impact of facility-level GHG transparency regulation on green innovation, capturing the time it may take for firms to develop and file environmentally beneficial patents in response to the program. The empirical setup includes firm and industry-year fixed effects to control for unobserved heterogeneity across firms and industries over time. Standard errors are clustered at the firm level to ensure robust statistical inference. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

firm-level emissions reductions develop more low-carbon patents than firms without regulated facilities following program implementation. The relationship is estimated using the following specification:

$$\begin{aligned} LowCarbonPatents_{fit} = \alpha_f + \alpha_{it} + \gamma * X_{ft} + \beta_1 GHGRP_{ft}(+1) \\ + \beta_2 \triangle^{Negative} firmE_{ft} + \beta_3 (GHGRP_{ft} * \triangle^{Negative} firmE_{ft})(+1) \\ + \epsilon_{it} \end{aligned} \tag{5}$$

$\triangle firmE_{ft}^{Negative}$ captures firm-level emissions reductions, define as:

$$\begin{cases} \frac{firmE_{ft} - firmE_{ft-1}}{firmE_{ft-1}}, & \text{if } firm_{ft} - firm_{ft-1} < 0 \\ 0, & otherwise \end{cases}.$$

This term ensures that only firms with actual emissions reductions are considered, excluding firms with stable or increasing emissions. The main variable of interest ($GHGRP_{ft} * \triangle^{Negative} firmE_{ft})(+1)$ is the interaction term testing whether the effect of granular transparency regulation on low-carbon innovation is strongest among firms that reduce emissions. A positive and significant β_3 would indicate that emissions reductions—not merely regulatory compliance—drive low-carbon patenting activity.

The results, presented in Table 8 provide strong empirical support for H3a. The interaction term ($GHGRP_{ft} * \triangle^{Negative} firmE_{ft})(+1)$ is positive and significant (8.37, t = 2.14), offering direct evidence that firms experiencing greater emissions reductions following GHGRP implementation are significantly more likely to innovate in low-carbon technologies. From an economic perspective, a 1-unit decrease in fractional firm-level emissions is associated with the development of eight additional low-carbon patents, further reinforcing the strong link between emissions reduction and innovation in low-carbon technologies.

To further validate the relationship between firm-level emissions reductions and low-

Table 8: Firm-level Emissions Reductions on Low-Carbon Innovations

	(1) LowCarbonPatents
GHGRP(+1)	12.16**
	(2.17)
$\triangle^{Negative} firmE_{ft}$	2.98
	(1.30)
$(GHGRP * \triangle^{Negative} firmE)(+1)$	8.37**
	(2.14)
Size	7.68
	(1.54)
BM	0.88
	(0.46)
AI	-5.36
	(-0.56)
Leverage	-4.61
	(-0.34)
Cash	-13.35
	(-1.03)
ROA	16.32
	(1.38)
Dividend	69.70
	(1.20)
IO	-32.70**
	(-2.05)
Analysts	1.39
	(0.82)
Observations	1,845
Adjusted R-squared	0.857
Firm FE	Yes
Industry-Year FE	Yes

This table presents the results of the firm-level emissions Reductions on low-carbon innovations The dependent variable is the number of low-carbon patents developed by a firm, classified according to the Cooperative Patent Classification (CPC) Y02 class, which identifies technologies with environmental benefits (Sautner et al. (2023), Cohen et al. (2024)). Firm-level patent data are sourced from the United States Patent and Trademark Office (USPTO) and linked to public firms' patent records (Kogan et al. (2017)). $\triangle firmE_{ft}^{Negative}$ captures firm-level emissions reductions, define as: $\begin{cases} \frac{firmE_{ft} - firmE_{ft-1}}{firmE_{ft-1}}, & \text{if } firm_{ft} - firm_{ft-1} < 0 \\ 0, & otherwise \end{cases}$. The main variable of interest $(GHGRP_{ft} * \triangle^{Negative} firmE_{ft})(+1)$ is the interaction term testing whether the effect of transparency regulation on low-carbon innovation is strongest among firms that reduce emissions. A positive and significant β_3 would indicate that emissions reductions—not merely regulatory compliance—drive low-carbon patenting activity. Standard errors are clustered at the firm level to ensure robust statistical inference. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

carbon innovation, I conduct a robustness check by examining the reverse scenario: Does an increase in emissions also lead to greater patenting activity? If firms that continue to emit more do not exhibit a corresponding rise in low-carbon innovation, it would indicate that emissions reductions—not broader environmental policies, compliance mandates, or industry trends—are the primary driver of low-carbon patenting. To test this, H3b evaluates whether GHGRP firms that experience greater firm-level emissions increases fail to develop more low-carbon patents compared to firms without regulated facilities in the years following program implementation. The relationship is estimated using the following specification:

$$\begin{aligned} LowCarbonPatents_{fit} = \alpha_f + \alpha_{it} + \gamma * X_{ft} + \beta_1 GHGRP_{ft}(+1) \\ + \beta_2 \triangle^{Positive} firmE_{ft} + \beta_3 (GHGRP_{ft} * \triangle^{Positive} firmE_{ft})(+1) \\ + \epsilon_{it} \end{aligned} \tag{6}$$

$\triangle firmE_{ft}^{Positive}$ captures firm-level emissions increases, define as:

$$\begin{cases} \frac{firmE_{ft} - firmE_{ft-1}}{firmE_{ft-1}}, & \text{if } firm_{ft} - firm_{ft-1} > 0 \\ 0, & otherwise \end{cases}.$$

This term ensures that only firms with actual emissions increases are considered, excluding those with stable or declining emissions. The main variable of interest, $(GHGRP_{ft} * \triangle^{Positive} firmE_{ft})(+1)$, is an interaction term testing whether facility-level transparency regulation has little or no effect on low-carbon innovation among firms that increase emissions. A statistically insignificant or negative β_3 would indicate that emissions increases do not drive green patenting activity, reinforcing the argument that low-carbon innovation is directly tied to emissions reductions rather than regulatory compliance alone.

The results in Table 9 provide strong empirical support for H3b. The findings indicate that increases in firm-level emissions do not lead to greater low-carbon innovation, reinforcing the conclusion that green patenting is driven by emissions reductions rather than general

regulatory compliance. The interaction term $(GHGRP_{ft} * \triangle^{Positive} firmE_{ft})(+1)$ is negative and statistically insignificant (-0.21, t = -0.71), providing direct evidence that firms with rising emissions do not contribute to low-carbon patenting.

Taken together, the findings from H3a and H3b suggest a strong and meaningful link between actual emissions reductions and low-carbon innovation. Rather than a symbolic response to regulatory pressure, the development of low-carbon patents appears to be a deliberate, strategic effort tied to emissions management. These results underscore the role of granular transparency regulation in incentivizing substantive technological advancements, reinforcing its impact on corporate sustainability practices.

4.4 H4: The Sunshine Mechanism and Market Penalties for Emission Discrepancies

4.4.1 Firm-Level Emission Discrepancies: Underreporting and the Notion of "Bad News"

The "sunshine mechanism" of facility-level GHG transparency regulation plays a crucial role in uncovering discrepancies in voluntary firm-level emissions disclosures. Unlike self-reported, subjective, and strategically framed voluntary disclosures, EPA-mandated facility-level GHG data follows standardized methodologies, undergoes independent verification, and provides an objective measure of emissions. This regulatory oversight allows stakeholders to benchmark firm-level disclosures against facility-level data, exposing potential underreporting or misrepresentation.When mandatory facility-level disclosures reveal higher emissions than prior firm-level reports, it signals strategic underestimation or misrepresentation in voluntary disclosures. This credibility shock alerts investors and stakeholders that the firm's true climate impact is worse than initially perceived, prompting negative reassessments of corporate credibility and environmental integrity. As a result, these revelations serve as "bad news" in financial markets, leading to declining investor confidence, heightened regulatory

Table 9: Firm-level Emissions Increases on Low-Carbon Innovations

	(1) LowCarbonPatents
GHGRP(+1)	11.66**
	(2.10)
$\triangle^{Posotive} firmE$	0.03
	(0.16)
$(GHGRP * \triangle^{Positive} firmE)(+1)$	-0.21
	(-0.71)
Size	7.98
	(1.58)
BM	0.88
	(0.46)
AI	-4.87
	(-0.50)
Leverage	-4.73
	(-0.35)
Cash	-13.43
	(-1.05)
ROA	15.73
	(1.34)
Dividend	71.22
	(1.23)
IO	-32.51**
	(-2.05)
Analysts	1.37
	(0.81)
Observations	1,845
Adjusted R-squared	0.857
Firm FE	Yes
Industry-Year FE	Yes

This table presents the results of the firm-level emissions Reductions on low-carbon innovations The dependent variable is the number of low-carbon patents developed by a firm, classified according to the Cooperative Patent Classification (CPC) Y02 class, which identifies technologies with environmental benefits (Sautner et al. (2023), Cohen et al. (2024)). Firm-level patent data are sourced from the United States Patent and Trademark Office (USPTO) and linked to public firms' patent records (Kogan et al. (2017)). $\triangle firmE_{ft}^{Positive}$ captures firm-level emissions increases, define as: $\begin{cases} \frac{firmE_{ft} - firmE_{ft-1}}{firmE_{ft-1}}, & \text{if } firm_{ft} - firm_{ft-1} > 0 \\ 0, & otherwise \end{cases}$. The main variable of interest $(GHGRP_{ft} * \triangle^{Positive} firmE_{ft})(+1)$ is the interaction term testing whether the effect of transparency regulation on low-carbon innovation is weaker or absent among firms that increase emissions. A statistically insignificant or negative β_3 would indicate that emissions increases do not drive green patenting activity, reinforcing the argument that low-carbon innovation is tied to actual emissions reduction efforts rather than regulatory compliance alone. Standard errors are clustered at the firm level to ensure robust statistical inference. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

Table 10: Comparing Firm-disclosed Emissions to Aggregated Facility Emissions: Underreporting

Underreporting cases	Firm-disclosed Emissions	Aggregated Facility Emissions
N	175	175
mean	31,846,553	188,164,285
std	36,174,807	386,424,891
min	33,164	131,527
25%	5,259,330	8,529,088
median	19,974,600	35,760,559
75%	39,790,150	90,679,353
max	143,000,000	1,288,226,838

This table compares firm-disclosed emissions with aggregated facility-level emissions for cases of underreporting within the same reporting year. Firm-disclosed emissions refer to voluntary GHG emissions reported at the organizational level, while aggregated facility-level emissions represent the total emissions from individual facilities owned by these firms, as reported under the Greenhouse Gas Reporting Program (GHGRP). Emissions are measured in tons of CO2E.

scrutiny, and increased legal or reputational risks.

Table 10 highlights the extent of these discrepancies. On average, firms voluntarily report 31.8 million metric tons of GHG emissions at the firm level, with a median of 20.0 million metric tons. However, these disclosures vary widely, reflecting inconsistent reporting methodologies. In contrast, standardized facility-level data reveals significantly higher emissions, averaging 188.2 million metric tons with a median of 35.8 million metric tons. These stark differences underscore how facility-level transparency enhances corporate accountability by exposing misreporting in voluntary firm-level disclosures. By providing stakeholders—including investors, regulators, and environmental advocacy groups—with reliable emissions data, facility-level disclosures discourage underreporting, foster greater accountability, and enable more informed investment and regulatory decisions. This transparency mechanism plays a critical role in strengthening environmental governance and aligning corporate practices with societal and regulatory expectations. Appendix A presents 20 specific cases, detailing company names, reporting year, firm-level and facility-level emissions, total number of facilities owned, and the extent of underreporting.

4.4.2 Standard Event Study Methodology

To assess how financial markets react when firm-level underreporting is revealed through facility-level GHG disclosures, I employ a standard event study methodology. Additionally, to provide a more comprehensive analysis, I examine overreporting cases, where firms report higher firm-level emissions compared to aggregated facility-level emissions. Overreporting is a natural occurrence, as firm-level disclosures often include emissions from non-U.S. facilities, upstream and downstream activities, and indirect emissions sources that facility-level data does not capture.

To assess the stock market response when prior firm-level underreporting is revealed through the mandated public disclosure of facility-level GHG emissions by the EPA, I employ a standard event study methodology. To provide a comprehensive perspective, I also analyze the opposite cases of overreporting, where firms report higher firm-level emissions compared to aggregated facility-level emissions. This overreporting is a natural occurrence since firm-level emissions are a superset of facility-level emissions. The cumulative abnormal return (CAR) is calculated over the event window [0,+4], corresponding to the disclosure events detailed in Table 1. The methodology can be summarized by the following equations:

$$K_{it} = b_i[E(R_m) - R_f] + s_i E(SMB) + h_i E(HML) + m_i E(MOM) \tag{7}$$

$$e_{it} = R_{it} - K_{it} \tag{8}$$

$$AR_t = \frac{1}{N}\sum_{i=1}^{N} e_{it} \tag{9}$$

$$CAR(0,+4) = \sum_{t=0}^{+4} AR_t \tag{10}$$

In the given equations, i represents firm (security) and t corresponds to the announcement dates of facility-level GHG information. To isolate market effects linked to mandatorily disclosed GHG information, the benchmark return (K_{it}) incorporates the Fama-French three

factors (Fama & French (1996)) and the momentum factor (e.g., Jegadeesh & Titman (1993), Carhart (1997)). Abnormal return(e_{it}) is the difference between the return conditional on the event and the expected return unconditional on the event. The average abnormal return (AR_t) indicates a sample of the cross-sectional mean abnormal return of N securities for any period t. The cumulative abnormal return ($CAR(0, +4)$) represents the abnormal performance measure the sum of each date's average abnormal performance with an event window from 0 to +4. Following Campbell et al. (1998), the test statistic is calculated as follows:

$$T - statistics = \frac{CAR(0, +5)}{[D * \sigma^2(AR_t)]^{1/2}}$$

where $\sigma^2(AR_t)$ is the variance of the one-period mean abnormal return and D indicates the total number of dates in the event window.

4.4.3 H4: Event Study Results

The event study results reveal distinct stock market reactions to facility-level GHG disclosures, depending on whether a firm underreported or overreported emissions. For underreporting firms, the cumulative abnormal return (CAR) is -0.49% with a statistically significant t-statistic of -2.37, indicating a negative market reaction. Investors perceive underreporting as a credibility shock, raising concerns about corporate transparency, regulatory risk, and potential financial penalties. The revelation that actual emissions exceed prior voluntary disclosures signals possible misrepresentation, regulatory non-compliance, or reputational damage, prompting investors to reassess the firm's risk profile and market valuation. In contrast, for overreporting firms, the CAR is effectively zero (0.00%) with a t-statistic of 0.01, indicating no significant market reaction. Investors do not penalize firms for reporting higher firm-level emissions than facility-level figures, likely because firm-level disclosures often include additional emissions sources beyond U.S. facilities. As a result, higher firm-level emissions relative to facility-level data are not viewed as misleading or unexpected.

The accompanying figure further illustrates these dynamics over the event window. For underreporting firms (red line), CARs exhibit a persistent downward trend, reflecting sustained negative investor sentiment following the disclosure of discrepancies. In contrast, for overreporting firms (blue line), CARs remain flat, indicating no discernible market response and reinforcing that higher firm-level emissions do not concern investors in the absence of perceived misrepresentation.

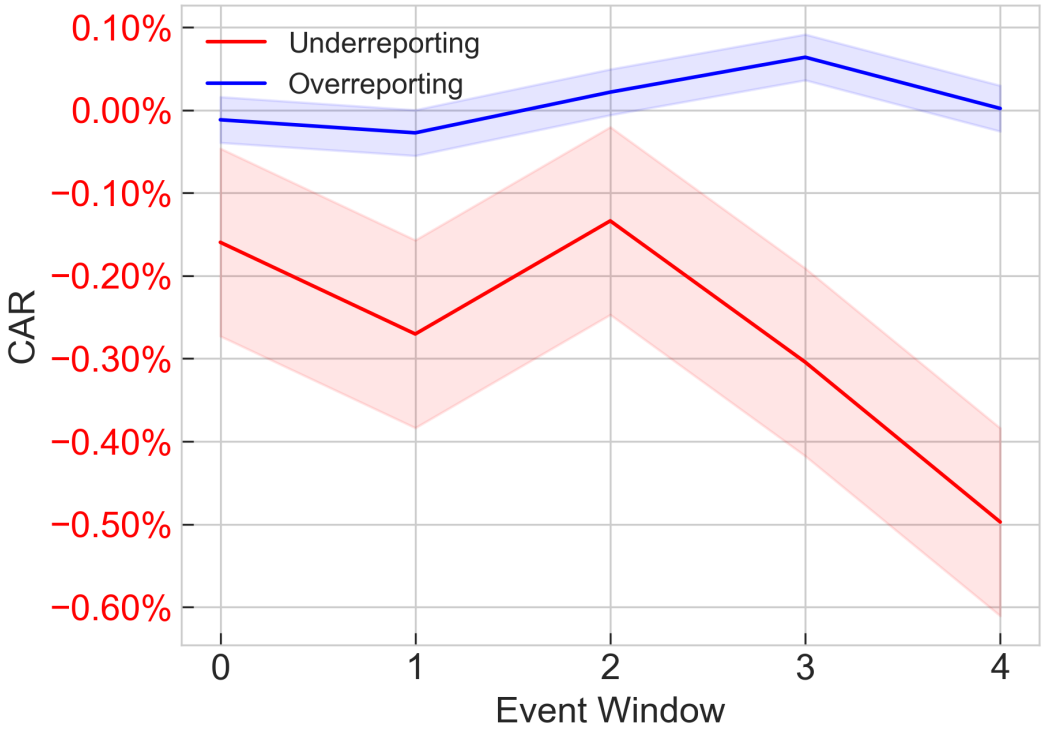
These findings highlight the power of the "sunshine mechanism" in facility-level GHG disclosures to expose corporate misreporting and elicit negative financial consequences for firms that misrepresent their emissions. By revealing discrepancies in voluntary disclosures, transparency regulation enhances corporate accountability and strengthens investor trust in environmental reporting. Overall, the results confirm that market participants react negatively when transparency exposes emissions underreporting, reinforcing the importance of accurate and verifiable emissions disclosures in maintaining credibility, reducing regulatory risk, and preserving investor confidence.

4.5 H5: The Sunshine Mechanism in Stakeholder Reactions and Environmental Ratings

Beyond market reactions, this section examines broader stakeholder responses to facility-level GHG disclosure regulation, focusing on third-party environmental ratings. These ratings capture the perceptions of investors, consumers, and environmental advocacy groups regarding a firm's sustainability practices and play a crucial role in assessing environmental performance, long-term risk exposure, and alignment with climate-related regulations.A key question is whether facility-level reporting materially impacts ESG ratings for firms that had already voluntarily disclosed firm-level emissions. One might expect little effect, given that these firms were already providing emissions data to the market. Prior research suggests that voluntary firm-level GHG disclosures provide value-relevant information to investors and stakeholders (Matsumura et al. (2014), Griffin et al. (2017), Choi & Luo (2021)), im-

Table 11: Market Reactions for Emissions Discrepancies

	CAR	T-statistics	N
Underreporting	-0.49%	-2.37	175
Overreporting	0.00%	0.01	472



This table and figure present the results of the impact of facility-level GHG disclosures on cumulative abnormal returns (CAR) for underreporting and overreporting cases. The dependent variable is the CAR, which measures the abnormal stock performance over the event window [0,+4] surrounding the disclosure dates. The primary focus is on the underreporting and overreporting of emissions, where underreporting occurs when facility-level GHG disclosures reveal lower firm-level emissions than expected, and overreporting occurs when firm-level emissions exceed facility-level totals, a natural result since firm-level emissions are a superset of facility-level data.

plying that firms were already being evaluated based on self-reported emissions. However, facility-level GHG disclosures differ from voluntary disclosures by providing standardized, independently verified data, which enhances transparency and external scrutiny. Unlike voluntary disclosures—often shaped by strategic reporting choices—facility-level data presents a more objective, detailed, and disaggregated view of a firm's actual carbon footprint. This additional granularity enables third-party evaluators to detect inconsistencies, selective reporting, or misrepresentations, triggering the sunshine mechanism—a process that exposes a firm's true climate impact more accurately than self-reported emissions. If facility-level disclosures reveal previously understated emissions, third-party evaluators may downgrade environmental ratings, reinforcing the importance of independent, verifiable emissions data in corporate sustainability assessments. This adjustment ensures that stakeholders rely on more credible information when evaluating a firm's environmental performance, strengthening corporate accountability and aligning ratings with actual climate impact.

To empirically assess the sunshine mechanism in stakeholder reactions, H5 tests whether facility-level GHG disclosures impact the MSCI Environment Pillar Score, a widely used measure of stakeholder perceptions of environmental performance. The model specification is as follows, incorporating industry and year fixed effects, with standard errors clustered at the firm level:

$$EnvironmentScore_{fit} = \alpha_f + \alpha_i + \gamma * X_{ft} + \beta * GHGRP_{ft} + \epsilon_{it} \tag{11}$$

Here, the dependent variable is the MSCI Environment Pillar Score, and the key policy variable, GHGRP, is a binary indicator set to 1 from the year a firm becomes subject to GHGRP onward. This captures the impact of facility-level GHG transparency regulation on environmental ratings. A negative and statistically significant β would indicate that facility-level transparency regulation leads to lower environmental ratings, supporting the hypothesis that enhanced transparency exposes discrepancies in prior firm-level disclosures. This would confirm that third-party evaluators adjust their assessments based on more reliable facility-

level data, rather than continuing to rely on voluntary firm-level reports.

The results in Table 12 provide strong empirical support for H5. Firms subject to GHGRP experience a significant decline in their MSCI Environment Pillar Scores, with a coefficient of -0.45 ($t = -2.65$), statistically significant at the 1% level. This confirms that facility-level transparency regulation lowers environmental ratings compared to unregulated firms, reinforcing the idea that heightened scrutiny exposes gaps in environmental practices and prompts negative stakeholder reactions. As facility-level data reveal previously understated or misrepresented emissions, third-party rating agencies adjust their assessments, applying greater scrutiny to firms whose voluntary disclosures failed to align with verified facility-level data. Companies that previously maintained favorable ESG ratings through selective reporting now face downgrades, as their true environmental impact becomes clearer. The decline in ESG ratings highlights the critical role of facility-level GHG disclosures in reinforcing corporate accountability. By providing standardized, verifiable emissions data, GHGRP enables stakeholders to identify environmental performance gaps, prompting firms to reassess and improve their sustainability strategies. This adjustment aligns with the broader sunshine mechanism effect, where greater transparency corrects prior misperceptions and reshapes firms' reputational standing based on verified data rather than self-reported estimates. Overall, these results demonstrate that facility-level transparency not only affects financial markets but also influences broader stakeholder perceptions, strengthening corporate environmental accountability and aligning firms with societal expectations for sustainability.

To assess whether the decline in environmental ratings reflects a genuine reassessment of corporate environmental impact rather than a mechanical response to increased transparency, H5a tests whether firms that underreport their firm-level GHG emissions relative to verified facility-level data experience larger rating downgrades. If environmental ratings accurately capture firms' true climate impact, then the revelation of underreporting through facility-level disclosures should lead to more severe rating penalties for firms that previously understated their emissions. This would suggest that rating agencies and stakeholders ad-

Table 12: The Sunshine Mechanism of Stakeholder Reactions and Environmental Ratings

	(1) EnvironmentScore
GHGRP	-0.45***
	(-2.65)
Size	0.41***
	(6.49)
BM	-0.64***
	(-2.93)
AI	-0.22
	(-0.82)
Leverage	0.38
	(0.76)
Cash	0.42
	(0.72)
ROA	0.88
	(0.79)
Dividend	0.55
	(0.16)
IO	-0.44
	(-0.98)
Analysts	-0.03
	(-0.17)
Observations	1,730
Adjusted R-squared	0.208
Industry FE	Yes
Year FE	Yes

This table presents the results of the impact of the GHGRP on firms' environmental performance as measured by their MSCI Environment Pillar Scores. The dependent variable, Environment Pillar Score, offers an independent evaluation of a firm's environmental practices, covering key areas such as carbon emissions, climate change vulnerability, and natural resource management. The primary policy variable of interest, GHGRP, is a binary indicator set to 1 starting in the year a firm becomes subject to the GHGRP's implementation and remains 1 in all subsequent years. This variable captures the contemporaneous effect of facility-level GHG transparency regulation on third-party assessments of a firm's environmental performance. The empirical model incorporates industry and year fixed effects to control for unobserved heterogeneity across industries and time-specific shocks. Standard errors are clustered at the firm level to ensure robust statistical inference. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

just their assessments based on enhanced transparency, rather than merely reacting to the disclosure mandate itself. The relationship is modeled as follows:

$$EnvironmentScore_{fit} = \alpha_f + \alpha_i + \gamma * X_{ft} + \beta_1 * GHGRP_{ft} + \beta_2 * GHGRP_{ft} * UnderPct_{ft} + \epsilon_{it}$$

where $UnderPct_{ft}$ quantifies the degree of underreporting in a firm's voluntary firm-level emissions relative to its facility-level reported emissions for the same reporting year:

$$\begin{cases} \frac{firmE_{ft} - facilityE_{ft}}{firmE_{ft}}, & \text{if } firmE_{ft} - facilityE_{ft} < 0 \\ 0, & otherwise \end{cases}.$$

The main variable of interest, $GHGRP_{ft} * UnderPct_{ft}$, tests whether the negative effect of transparency regulation on environmental ratings intensifies as firms underreport emissions to a greater extent. A negative and statistically significant β_2 would indicate that firms with greater underreporting experience sharper declines in environmental ratings, reinforcing the role of facility-level transparency in strengthening corporate accountability.

The results in Table [Direct Effect of Underreporting on Environmental Ratings] provide strong empirical support for H5a, confirming that facility-level GHG disclosures lead to a significant reassessment of corporate environmental performance, particularly for firms that previously underreported emissions. The negative and statistically significant interaction term (UnderPct × GHGRP) indicates that firms with greater discrepancies between voluntary and facility-level emissions disclosures experience more substantial declines in environmental ratings. This finding reinforces the role of mandatory transparency in corporate accountability, demonstrating that stakeholders actively incorporate independently verified emissions data into their assessments rather than relying solely on self-reported firm-level disclosures.

Economically, a one-unit increase in the underreporting fraction is associated with a

0.0015-point decrease in environmental ratings. While seemingly small in absolute terms, this effect becomes substantial for firms with extreme underreporting. For instance, some firms significantly understate emissions, with the minimum UnderPct value at -1024. The estimated impact is:

$$-1024 \times 0.0015 = -1.536$$

This suggests that firms with severe underreporting can experience a 1.5-point decline in their MSCI Environment Pillar Score, a meaningful reduction given the typical range of ESG ratings. Such a decline may negatively influence investor sentiment, capital allocation, and stakeholder trust, reinforcing the broader consequences of misaligned emissions disclosures.

Overall, these findings confirm that ESG ratings do not merely react to new regulatory mandates but actively adjust based on independently verified emissions data. Facility-level disclosures reshape stakeholder perceptions, reinforce corporate environmental accountability, and provide a more accurate assessment of firms' sustainability performance. By exposing inconsistencies in voluntary disclosures, transparency regulations enhance the credibility of sustainability assessments in capital markets, ensuring that ESG ratings more accurately reflect a firm's true environmental impact.

5 Conclusion and Policy Implications

This study examines the broader organizational impacts of facility-level GHG transparency regulation, focusing on the U.S. Environmental Protection Agency's (EPA) Greenhouse Gas Reporting Program (GHGRP). By analyzing firms that voluntarily disclosed emissions before and after GHGRP implementation, this study provides empirical evidence on how granular transparency mandates influence firm-wide strategic behavior and environmental decision-making. The findings reveal significant organizational real effects, demonstrating that mandatory facility-level disclosures drive managerial learning, enhance climate awareness across organizations, and catalyze strategic shifts toward sustainable innovation and

Table 13: Direct effect of Underreporting on Environmental Ratings

	(1) EnvironmentScore
UnderPct*GHGRP	-0.0015***
	(-3.59)
GHGRP	-0.46***
	(-2.67)
Size	0.41***
	(6.53)
BM	-0.64***
	(-2.93)
AI	-0.23
	(-0.87)
Leverage	0.39
	(0.77)
Cash	0.42
	(0.73)
ROA	0.88
	(0.79)
Dividend	0.57
	(0.17)
IO	-0.45
	(-1.00)
Analysts	-0.03
	(-0.18)
Observations	1,730
Adjusted R-squared	0.208
Industry FE	Yes
Year FE	Yes

This table presents the results of the impact of the GHGRP on firms' environmental performance as measured by their MSCI Environment Pillar Scores. The dependent variable, Environment Pillar Score, offers an independent evaluation of a firm's environmental practices, covering key areas such as carbon emissions, climate change vulnerability, and natural resource management. $UnderPct_{ft}$ quantifies the degree of underreporting in a firm's voluntary firm-level emissions relative to its objective facility-level reported emissions for the same reporting year,define as: $\begin{cases} \frac{firmE_{ft}-facilityE_{ft}}{firmE_{ft}}, & \text{if } firmE_{ft} - facilityE_{ft} < 0 \\ 0, & otherwise \end{cases}$. The main variable of interest $GHGRP_{ft} * UnderPct_{ft}$ tests whether the negative effect of transparency regulation on environmental ratings intensifies as firms underreport emissions to a greater extent. A negative and statistically significant β_2 would indicate that firms with greater underreporting experience sharper declines in environmental ratings, reinforcing the role of facility-level transparency in strengthening corporate accountability. Standard errors are clustered at the firm level to ensure robust statistical inference. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

accountability.

The results show that facility-level transparency regulation reduces emissions beyond compliance-focused facility-level actions, leading to firm-wide reductions among GHGRP-regulated firms compared to non-regulated counterparts. These reductions reflect strategic shifts in corporate priorities, driven by increased external scrutiny. A key mechanism behind these changes is managerial learning, where transparency-driven stakeholder pressure and regulatory scrutiny prompt firms to internalize climate-related risks and reassess strategic priorities. This heightened awareness is evident in the increase in climate-related discussions during corporate earnings conference calls, signaling greater recognition of climate risk and the integration of sustainability into corporate decision-making. Additionally, facility-level transparency stimulates innovation in clean technology. GHGRP-regulated firms develop significantly more low-carbon patents than non-regulated firms, demonstrating that granular transparency regulation incentivizes proactive investments in sustainable technologies. This innovation suggests that firms are making substantive progress in emissions management rather than engaging in symbolic compliance. Moreover, the findings highlight that effective disclosure policies not only heighten managerial climate awareness but also drive long-term investments in sustainability innovation, reinforcing the broader strategic benefits of transparency regulations.

A concrete example of facility-level transparency regulation as a sunshine mechanism is its ability to expose discrepancies between voluntary firm-level emissions disclosures and objective facility-level data. This study finds that firms that previously underreported emissions face significant reputational and financial penalties when mandatory disclosures reveal their true environmental impact. Specifically, the market reacts negatively to such revelations, imposing substantial financial costs on firms whose mandatory disclosures contradict prior voluntary reports. Investors perceive these discrepancies as credibility shocks, raising concerns about corporate transparency and regulatory risk. As a result, market participants adjust expectations downward, enforcing financial discipline based on independently verified

emissions data. Empirically, firms exposed by the GHGRP for underreporting emissions experience significant stock price declines and reductions in market valuations. These firms also face pronounced downgrades in third-party environmental ratings, reflecting diminished stakeholder trust. The decline in environmental ratings underscores transparency's critical role in enabling third-party evaluators to provide more accurate assessments of corporate environmental performance. These findings highlight the effectiveness of transparency-driven accountability mechanisms, as third-party evaluators increasingly rely on objective, verifiable emissions data rather than voluntary, potentially manipulated disclosures to assess firms' environmental commitments.

These findings provide critical policy insights for regulators. A key takeaway is the importance of standardized and independently verifiable disclosures. While the US SEC (2024)'s firm-level GHG disclosure mandate marks progress in corporate transparency, its reliance on firm-specific methodologies reduces comparability and limits its ability to enforce accountability. In contrast, the EPA's GHGRP, with its standardized and rigorously verified facility-level reporting, provides more credible, consistent, and comparable emissions data. This granular transparency allows stakeholders to accurately assess corporate environmental performance and hold firms accountable. The results emphasize that transparency regulations drive meaningful change most effectively when disclosures are structured to facilitate stakeholder interpretation and action. Specifically, transparency must be complemented by robust feedback mechanisms—such as negative market reactions or third-party environmental rating downgrades—to enable stakeholders to enforce market discipline based on objective emissions data. Without such mechanisms, transparency alone may fail to drive substantial environmental improvements. Thus, policymakers should design disclosure frameworks that not only enhance transparency but also empower stakeholders to act on the disclosed information, ensuring firms are effectively incentivized toward genuine sustainability commitments.

Overall, this study provides key insights for regulators, investors, and corporate decision-

makers by offering the first empirical evidence of the organizational real effects of facility-level GHG transparency mandates in the U.S. It bridges the previously unexplored gap between localized facility-level compliance and broader firm-wide sustainability strategies, highlighting managerial learning as a key driver of transparency effectiveness. The findings emphasize that transparency regulations are most impactful when they trigger meaningful managerial responses to heightened stakeholder scrutiny and internalized climate risks. This managerial learning process fosters strategic shifts toward firm-wide sustainability, advancing beyond mere compliance to the integration of environmental considerations into corporate decision-making and innovation strategies. A core insight is that transparency alone is insufficient; it must empower stakeholders—including investors, policymakers, and the public—to hold firms accountable through standardized, objective, and verifiable emissions disclosures. By providing actionable information for assessing corporate environmental performance, facility-level transparency regulations play a critical role in reshaping corporate behavior, aligning firms with societal climate goals, and ultimately fostering sustainable economic growth.

References

Aswani, J., Raghunandan, A. & Rajgopal, S. (2023), 'Are carbon emissions associated with stock returns?', *Review of Finance* . 1

Baker, A. C., Larcker, D. F. & Wang, C. C. (2022), 'How much should we trust staggered difference-in-differences estimates?', *Journal of Financial Economics* **144**(2), 370–395. 4.1.3

Bartram, S. M., Hou, K. & Kim, S. (2022), 'Real effects of climate policy: Financial constraints and spillovers', *Journal of Financial Economics* **143**(2), 668–696. 1

Bauckloh, T., Klein, C., Pioch, T. & Schiemann, F. (2023), 'Under Pressure? The Link Between Mandatory Climate Reporting and Firms' Carbon Performance', *Organization & Environment* **36**(1), 126–149. 1

Bertrand, M. & Mullainathan, S. (2003), 'Enjoying the quiet life? Corporate governance and managerial preferences', *Journal of political Economy* **111**(5), 1043–1075. 4.1.1

Bond, P., Edmans, A. & Goldstein, I. (2012), 'The real effects of financial markets', *Annu. Rev. Financ. Econ.* **4**(1), 339–360. 1

Campbell, J. Y., Lo, A. W., MacKinlay, A. C. & Whitelaw, R. F. (1998), 'The econometrics of financial markets', *Macroeconomic Dynamics* **2**(4), 559–562. 4.4.2

Carhart, M. M. (1997), 'On Persistence in Mutual Fund Performance', *The Journal of Finance* **52**(1), 57–82. 4.4.2

Chen, Y.-C., Hung, M. & Wang, Y. (2018), 'The effect of mandatory CSR disclosure on firm profitability and social externalities: Evidence from China', *Journal of Accounting and Economics* **65**(1), 169–190. 1

Choi, B. & Luo, L. (2021), 'Does the market value greenhouse gas emissions? Evidence from multi-country firm data', *The British Accounting Review* **53**(1), 100909. 1, 2.3, 4.5

Christensen, H. B., Floyd, E., Liu, L. Y. & Maffett, M. (2017), 'The real effects of mandated information on social responsibility in financial reports: Evidence from mine-safety records', *Journal of Accounting and Economics* **64**(2-3), 284–304. 1, 2.3

Cohen, L., Gurun, U. G. & Nguyen, Q. H. (2024), The ESG-innovation disconnect: Evidence from green patenting, Technical report, National Bureau of Economic Research. 1, 3.1, 2, 4.3, 7, 8, 9

Downar, B., Ernstberger, J., Reichelstein, S., Schwenen, S. & Zaklan, A. (2021), 'The impact of carbon disclosure mandates on emissions and financial operating performance', *Review of Accounting Studies* **26**(3), 1137–1175. 1, 4.1.1

Fama, E. F. & French, K. R. (1996), 'Multifactor Explanations of Asset Pricing Anomalies', *The Journal of Finance* **51**(1), 55–84. 4.4.2

Freeman, R. E. (1984), *Strategic Management: A Stakeholder Approach*, Cambridge University Press. 1, 2.3

Goldstein, I., Ozdenoren, E. & Yuan, K. (2013), 'Trading frenzies and their impact on real investment', *Journal of Financial Economics* **109**(2), 566–582. 1

Goodman-Bacon, A. (2021), 'Difference-in-differences with variation in treatment timing', *Journal of Econometrics* **225**(2), 254–277. 4.1.3

Grewal, J. (2024), 'How Voluntary Disclosers Respond to Mandatory Reporting: Evidence from Greenhouse Gas Emissions'. 1

Griffin, P. A., Lont, D. H. & Sun, E. Y. (2017), 'The relevance to investors of greenhouse gas emission disclosures', *Contemporary Accounting Research* **34**(2), 1265–1297. 1, 2.2, 2.3, 4.5

Jegadeesh, N. & Titman, S. (1993), 'Returns to buying winners and selling losers: Implications for stock market efficiency', *The Journal of finance* **48**(1), 65–91. 4.4.2

Johnson, M. S. (2020), 'Regulation by shaming: Deterrence effects of publicizing violations of workplace safety and health laws', *American economic review* **110**(6), 1866–1904. 1

Jouvenot, V. & Krueger, P. (2019), 'Mandatory corporate carbon disclosure: Evidence from

a natural experiment', *Available at SSRN 3434490* . 1

Kanodia, C. & Sapra, H. (2016), 'A real effects perspective to accounting measurement and disclosure: Implications and insights for future research', *Journal of Accounting Research* **54**(2), 623–676. 1

Kogan, L., Papanikolaou, D., Seru, A. & Stoffman, N. (2017), 'Technological innovation, resource allocation, and growth', *The quarterly journal of economics* **132**(2), 665–712. 1, 3.1, 4.3, 7, 8, 9

Leuz, C. & Wysocki, P. D. (2016), 'The economics of disclosure and financial reporting regulation: Evidence and suggestions for future research', *Journal of accounting research* **54**(2), 525–622. 1, 2.2

Levenshtein, V. I. (1966), Binary codes capable of correcting deletions, insertions, and reversals, *in* 'Soviet Physics Doklady', Vol. 10, Soviet Union, pp. 707–710. 3.1

Loughran, T. & Mcdonald, B. (2011), 'When Is a Liability Not a Liability? Textual Analysis, Dictionaries, and 10-Ks', *Journal of Finance* **66**(1), 35–65. 4.2

Matsumura, E. M., Prakash, R. & Vera-Muñoz, S. C. (2014), 'Firm-Value Effects of Carbon Emissions and Carbon Disclosures', *The Accounting Review* **89**(2), 695–724. 1, 2.2, 2.3, 4.5

Rauter, T. (2020), 'The Effect of Mandatory Extraction Payment Disclosures on Corporate Payment and Investment Policies Abroad', *Journal of Accounting Research* **58**(5), 1075–1116. 1

Roychowdhury, S., Shroff, N. & Verdi, R. S. (2019), 'The effects of financial reporting and disclosure on corporate investment: A review', *Journal of Accounting and Economics* **68**(2-3), 101246. 1

Sautner, Z., Van Lent, L., Vilkov, G. & Zhang, R. (2023), 'Firm-Level Climate Change Exposure', *The Journal of Finance* **78**(3), 1449–1498. 1, 2.3, 3.1, 2, 4.2, 6, 4.3, 7, 8, 9

Subrahmanyam, A. & Titman, S. (2001), 'Feedback from stock prices to cash flows', *The Journal of Finance* **56**(6), 2389–2413. 1

the CDP (2010), 'Carbon Disclosure Project 2010 S&P 500 Report'. 2.2

Tomar, S. (2022), 'Greenhouse Gas Disclosure and Emissions Benchmarking', *Journal of Accounting Research* . 1, 2.3, 4.1.1

US SEC (2024), 'The Enhancement and Standardization of Climate-Related Disclosures for Investors'. 1, 5

Watts, R. L. & Zimmerman, J. L. (1978), 'Towards a positive theory of the determination of accounting standards', *Accounting review* pp. 112–134. 1, 2.3

Watts, R. L. & Zimmerman, J. L. (1990), 'Positive accounting theory: A ten year perspective', *Accounting review* pp. 131–156. 1, 2.3

Yang, L., Muller, N. Z. & Liang, P. J. (2021), The Real Effects of Mandatory CSR Disclosure on Emissions: Evidence from the Greenhouse Gas Reporting Program, SSRN Scholarly Paper 3880217, Social Science Research Network, Rochester, NY. 1, 2.3, 4.1.1

Zhang, S. (2024), 'Carbon Returns across the Globe', *The Journal of Finance* . 1

A Appendix Underreporting Examples

Company Name	Year	Firm Emissions	Facility Emissions	Total Facilities	Underreporting Amount
CONOCOPHILLIPS	2012	26,116,829	1,272,812,677	217	1,246,695,848
CIMAREX ENERGY CO	2012	1,088,000	1,231,537,593	17	1,230,449,593
OCCIDENTAL PETROLEUM CORP	2012	15,000,000	1,242,309,850	91	1,227,309,850
DEVON ENERGY CORP	2012	8,684,562	1,235,762,895	77	1,227,078,333
CHEVRON CORP	2012	62,000,000	1,267,350,562	193	1,205,350,562
EXXON MOBIL CORP	2012	141,000,000	1,288,226,838	248	1,147,226,838
DYNEGY INC	2013	32,000,000	116,048,430	51	84,048,430
NRG ENERGY INC	2010	57,182,000	131,717,743	96	74,535,743
DUKE ENERGY CORP	2013	103,922,548	151,176,394	78	47,253,846
AMERICAN ELECTRIC POWER CO	2011	135,671,200	181,519,530	57	45,848,330
EDISON INTERNATIONAL	2014	4,000,000	37,649,018	24	33,649,018
ENTERGY CORP	2011	35,569,940	66,363,311	52	30,793,371
EXELON CORP	2010	9,515,382	34,880,663	46	25,365,281
PINNACLE WEST CAPITAL CORP	2013	14,245,800	39,588,836	32	25,343,036
PPL CORP	2013	33,679,616	58,367,584	26	24,687,968
SOUTHERN CO	2012	99,000,000	121,489,731	54	22,489,731
NEXTERA ENERGY INC	2012	47,608,369	69,829,575	38	22,221,206
XCEL ENERGY INC	2011	55,799,252	75,574,301	54	19,775,049
CONSTELLATION ENERGY GRP INC	2010	17,474,460	35,760,559	21	18,286,099
ALLIANT ENERGY CORP	2011	18,781,755	37,018,531	41	18,236,776