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

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Abstract

This paper draws the causal inference of facility-level GHG transparency on firm-wide emissions by analyzing firms that voluntarily disclosed their 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 facility-level regulation functions as a sunshine mechanism, objectively revealing a firm's true climate impact—such as previous firm-level underreporting—which triggers negative stakeholder feedback and incentivizes 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 change concerns and increases negative regulatory sentiment during earnings conference calls. This managerial learning fosters greater investment in low-carbon patent development. Overall, my findings suggest that facility-level GHG transparency regulation has spillover 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

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"*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 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 significantly impacts 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 achieve greater emissions reductions than control facilities. However, Bartram et al. (2022)

[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

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, complicating 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 fractional decrease in firm-level emissions is associated with the development of eight additional low-carbon patents, reinforcing the connection between emissions reduction 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 theoretical rationale for how and why facility-level GHG transparency regulation generates spillover 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 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 valuable 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 underreporting. 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 GHGRP standardizes the calculation of facility-level GHG emissions[7] and mandates 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
[7]https://www.ecfr.gov/current/title-40/chapter-I/subchapter-C/part-98?toc=1

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.

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.

[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 a growing literature identifying climate change as a critical driver of corporate decision-making (Sautner et al. (2023)). As regulatory pressures and stakeholder expectations intensify, firms increasingly reassess their environmental strategies and risk management practices. Mandatory facility-level GHG disclosures, characterized by standardized calculation, monitoring, verification, and enforcement processes, act as a "sunshine mechanism." This mechanism objectively reveals the true scale of firms' climate impacts, previously concealed by voluntary, firm-level disclosures. By providing accurate, detailed, and publicly accessible facility-level emissions data, mandatory disclosure enhances transparency and comparability, explicitly identifying publicly traded companies owning regulated facilities and heightening their external visibility. Previously, voluntary firm-level emissions reporting lacked regulation, allowing firms considerable discretion over reporting boundaries, methodologies, and emission sources. This discretion often resulted in aggregated disclosures that obscured individual facility emissions, enabling firms to present an artificially favorable environmental profile without rigorous verification.

Facility-level disclosures break through prior opacity by establishing standardized, independently verified emissions reporting, thereby eliminating ambiguities in methodologies and enhancing comparability across firms and industries. This granular transparency increases stakeholder awareness and significantly elevates corporate visibility among investors, regulators, and the broader public. Consequently, firms face heightened expectations of potential negative feedback and political costs (Watts & Zimmerman (1978, 1990)) associated with mandatory disclosure of their true emissions. Unlike voluntary disclosures, which allowed firms considerable control over their emissions narratives, facility-level transparency provides

a standardized and objective representation of corporate environmental impacts. This transparency amplifies reputational risks, regulatory scrutiny, and investor divestment pressures, particularly for high-emission firms. Consistent with stakeholder theory (Freeman (1984)), which emphasizes responsiveness to stakeholder interests as central to corporate success, the anticipation of these negative consequences incentivizes firms to proactively embrace socially responsible practices. By intensifying external pressures from investors, regulators, and the public, facility-level transparency motivates firms to actively enhance environmental performance, integrate sustainability into their strategic decision-making, and pursue meaningful emissions-reduction initiatives.

Despite the potential of facility-level transparency to stimulate firm-wide emissions reductions, the magnitude of its influence remains uncertain due to two primary factors. First, the GHGRP mandates disclosure only at the facility level, whereas many firms operate globally under diverse regulatory environments. This raises questions about whether transparency at selected U.S. facilities can genuinely drive broader, firm-wide sustainability initiatives, or if firms compartmentalize environmental strategies based on regional regulatory contexts. Second, unlike SEC-regulated financial disclosures—which undergo formal auditing and integration into standardized 10-K filings—GHGRP data are released via informal channels, such as the EPA's website. Prior research suggests investors often discount non-financial disclosures from informal channels (Christensen et al. (2017)), perceiving them as less credible due to limited regulatory oversight and weaker integration with financial reporting. These factors collectively introduce uncertainty regarding the effectiveness of facility-level transparency in shaping investor perceptions and influencing broader corporate climate strategy.

Despite the potential of facility-level transparency to stimulate firm-wide emissions reductions, empirical uncertainty remains regarding its broader effectiveness. First, since GHGRP disclosure requirements apply only at the facility level, multinational firms may limit their environmental responses to regulated jurisdictions, raising doubts about whether facility-level transparency prompts comprehensive, firm-wide sustainability efforts. Second, unlike

formal financial disclosures mandated by the SEC—which are integrated into standardized filings and subject to rigorous auditing—GHGRP data are disseminated informally, potentially diminishing investor attention and influence on corporate strategy. These factors create empirical uncertainty about the capacity of facility-level transparency to drive significant environmental improvements across an entire organization. To empirically examine this question, I propose the following hypothesis:

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 evaluated to differentiate substantive reductions from methodological adjustments or localized compliance responses. One concern is that declines in reported emissions may stem from revisions in reporting methodologies rather than genuine operational improvements. Firms have considerable discretion over measurement standards, emission factors, and disclosure boundaries, allowing them to artificially lower reported emissions without materially altering their environmental impact. For example, firms might adopt less stringent measurement criteria, reclassify certain emission sources, or exclude particular facilities or subsidiaries from aggregated totals, thereby presenting a misleadingly favorable emissions profile. Another possibility is that emissions reductions are primarily localized responses to regulatory compliance pressures at specific facilities (Yang et al. (2021), Tomar (2022)), rather than reflecting broader, firm-wide sustainability commitments. Facility-level actions such as efficiency upgrades or process optimization, although beneficial locally, may simply represent reactive compliance efforts without indicating deeper strategic integration of sustainability. Thus, these reductions might fulfill minimum regulatory requirements without fundamentally shifting a firm's overall emissions trajectory or its long-term climate strategy.

I argue that the effectiveness of facility-level transparency regulation in driving firm-wide behavioral change depends critically on its ability to heighten organizational awareness of

climate-related concerns through granular disclosure. An essential indicator of managerial learning regarding climate change is its observable impact on organizational priorities and public communication, especially in forums where management directly engages with stakeholders. Corporate earnings conference calls provide ideal venues for such engagement, offering management opportunities to articulate strategic priorities and respond to stakeholder inquiries about external developments such as regulatory changes and investor concerns. As facility-level transparency brings greater clarity to a firm's climate impact, stakeholders are likely to intensify scrutiny, posing targeted questions about climate strategies, regulatory risks, and the firm's readiness for potential climate policy shifts, including carbon taxes or emissions caps. In response, firms experiencing heightened scrutiny may proactively increase climate-related discussions during earnings calls, signaling deeper internal recognition of climate risks and a stronger strategic commitment to addressing them. Moreover, elevated stakeholder attention can amplify negative regulatory sentiment, particularly as investors, analysts, and policymakers critically evaluate firms' environmental performance and readiness for an evolving regulatory landscape. Firms with significant facility-level emissions face increased skepticism about their capacity to adapt effectively to stricter environmental regulations. Consequently, this heightened regulatory and reputational pressure incentivizes firms to adopt proactive, organization-wide environmental strategies that extend beyond minimal compliance-focused adjustments at regulated facilities.

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 meaningfully drive firm-wide action, managerial learning triggered by heightened climate awareness must lead to tangible, organization-wide adjustments in emissions practices. These strategic shifts should extend beyond mere localized compliance, embedding sustainability into the core of corporate decision-making. A key

indicator of such an organizational transformation is increased investment in low-carbon innovation, particularly reflected through the development of low-carbon patents. Firms facing enhanced regulatory scrutiny develop a deeper understanding of climate-related risks, innovation opportunities, and evolving stakeholder expectations, positioning them to proactively integrate green technologies into their long-term strategies. Such investments signal genuine strategic commitment rather than symbolic compliance, enabling firms to capitalize on emerging market trends and effectively manage competitive pressures. Low-carbon patents represent significant long-term R&D commitments, clearly demonstrating the integration of sustainability within corporate strategy. This aligns with existing research suggesting regulatory pressures can catalyze innovation, especially when transparency mechanisms simultaneously heighten external stakeholder scrutiny and internal managerial awareness of climate risks. Consequently, firms proactively prioritizing low-carbon innovation are well-positioned to achieve enhanced market valuations, improved access to capital, and strengthened stakeholder relationships, as corporate environmental performance continues to gain prominence among investors and policymakers.

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.

While transparency requirements are linked to increased low-carbon innovation, it remains crucial to determine whether this innovation genuinely results from actual firm-level emissions reductions or merely reflects broader environmental initiatives, regulatory pressures, or general industry trends. Specifically, the key question is whether genuine reductions in firm-level emissions directly stimulate increased patenting activity in low-carbon technologies, or if this innovation occurs independently from actual emissions performance. If firms demonstrating meaningful emissions reductions also generate higher levels of low-carbon patents, this would suggest that transparency regulations incentivize authentic technological progress rather than merely symbolic compliance or reactive alignment with external trends.

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 reverse scenario can strengthen the interpretation of this relationship: if low-carbon innovation genuinely reflects a firm's emissions management efforts rather than symbolic compliance or responses to external pressures, firms experiencing increases in emissions should not exhibit a corresponding rise in patenting activity. Such a finding would support the view that patenting activity represents a deliberate strategic response directly tied to successful emissions reductions, rather than mere regulatory compliance, symbolic actions, 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 this occurs primarily through negative stakeholder feedback, triggered when mandatory transparency exposes discrepancies between independently verified facility-level emissions data and earlier voluntary firm-level disclosures. Voluntary disclosures, typically lacking regulatory oversight, allow firms significant discretion to selectively define emissions boundaries and adopt subjective measurement methodologies, incentivizing more favorable emissions reporting. Prior research in accounting valuation (Matsumura et al. (2014), Griffin et al. (2017), Choi & Luo (2021)) supports the notion that lower voluntarily reported emissions can positively influence firm valuation. In contrast, mandatory facility-level emissions disclosures under the EPA's GHGRP offer standardized, credible, and rigorously verified emissions benchmarks. Stakeholders generally anticipate that these mandatory disclosures will align closely with, or be lower than, prior voluntary disclosures. When facility-level data instead reveal higher emissions, it objectively confirms that the firm previously understated its climate impact. This transparency—or "sunshine"—mechanism

prompts investors, regulators, and advocacy groups to negatively reassess the firm's environmental credibility, thereby driving managerial learning and strategic behavioral adjustments across the organization.

Empirically, I assess stakeholder responses by examining short-term stock market reactions to mandatory facility-level GHG disclosures. Investors generally expect facility-level emissions data to align closely with—or fall below—previously disclosed voluntary figures. However, when mandatory disclosures reveal emissions exceeding voluntary reports, investors experience a credibility shock, interpreting the discrepancy as evidence of potential misreporting or prior underestimation of climate impacts. This transparency-induced credibility shock negatively affects market valuations, as investors reassess regulatory risks, potential litigation exposure, and reputational threats. Such negative market reactions exemplify the "sunshine" mechanism, where transparent and objective disclosures expose previously concealed misreporting, intensifying stakeholder scrutiny and prompting managerial learning and strategic adjustments across the firm.

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

Beyond short-term market reactions, I investigate broader stakeholder responses by examining changes in third-party environmental ratings following the implementation of mandatory facility-level GHG disclosures. Independent ESG ratings reflect stakeholder perceptions—including those of investors, consumers, and advocacy groups—regarding corporate sustainability performance, influencing investment decisions, policymaking, and sustainability-oriented funds. A critical question arises: Does mandatory transparency impact ESG ratings even for firms already voluntarily disclosing emissions? One might initially anticipate minimal effects, given prior access to voluntary disclosures, whose informational value is established in existing literature (Matsumura et al. (2014), Griffin et al. (2017), Choi & Luo (2021)). However, mandatory facility-level disclosures provide standardized, independently

verified, and granular data, significantly enhancing transparency compared to voluntary reporting, which typically permits managerial discretion. This increased objectivity allows third-party evaluators to detect discrepancies or deliberate underreporting previously concealed within voluntary disclosures. Thus, the "sunshine" mechanism activated by mandatory transparency objectively exposes a firm's actual climate impact, prompting ESG rating agencies to downgrade environmental ratings when verified emissions exceed earlier voluntary reports. In this way, mandatory disclosures serve as a corrective force, promoting greater accuracy and accountability in 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 determine if reductions 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 transparency drives these rating declines, firms that previously understated emissions relative to verified facility-level data should face more substantial penalties, as stakeholders revise perceptions of their environmental credibility. Historically, third-party evaluators and investors relied on voluntary emissions reports, allowing firms significant discretion over reporting boundaries, methodologies, and included emission sources. This flexibility enabled firms to portray more favorable environmental profiles, often obscuring their actual carbon footprints. Mandatory facility-level disclosures eliminate this discretion by providing standardized, independently verified data, establishing a credible benchmark to evaluate past voluntary disclosures. When facility-level data reveal substantial underreporting, stakeholders identify material discrepancies, undermining trust in the firm's transparency and sustainability commitments. Consequently, the resulting erosion in stakeholder confidence heightens reputational risks and prompts ESG rating agencies to impose greater downgrades. Firms with more significant underreporting thus experience sharper declines in environmental ratings, reinforcing transparency's critical role in enhancing corporate envi-

ronmental accountability.

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

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, 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 obtained from the EPA's FLIGHT database.[13] To match each facility ID with Compustat identifiers (GVKEY), I compare the legal names of facility parent entities with the names of publicly traded companies using a Levenshtein distance algorithm (Levenshtein (1966)) and manually correct mismatches. In rare cases where a single facility is owned by multiple parent firms, emissions are allocated based on each entity's ownership percentage.

The main panel dataset is constructed by merging fiscal year firm characteristics with

[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

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 analyze firm-level green innovations, I use patent data sourced from the United States Patent and Trademark Office (USPTO), linked to public firms' patent records (Kogan et al. (2017)). Following previous literature (Sautner et al. (2023), Cohen et al. (2024)), low-carbon patents are identified using the Cooperative Patent Classification (CPC) Y02 class, which captures technologies with environmental benefits. This dataset allows for an assessment of how facility-level transparency regulations influence innovation in sustainable technologies.

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: Impact 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:

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

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), and

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.

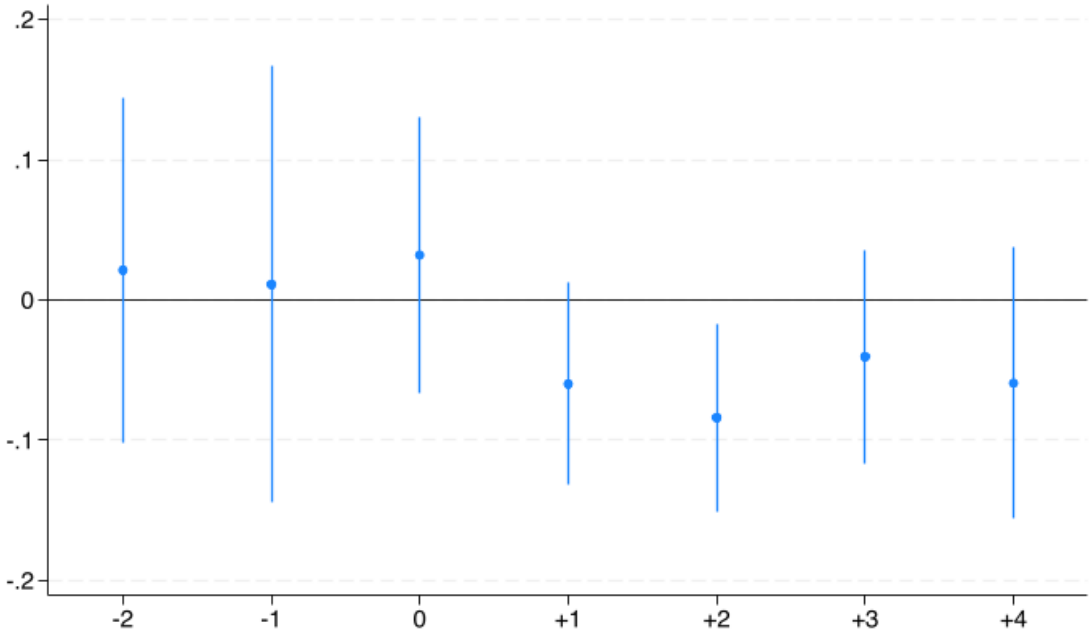
subsequent years (T=1 through T=4+, where T=4+ aggregates year 4 and all later years).

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

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 vary over time. To address this issue, I apply the methodology proposed by Goodman-Bacon

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



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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.

(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: Impact of Facility-Level GHG Transparency Regulation on Firm-Level Climate Change 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, understanding whether these reductions reflect substantive firm-wide environmental improvements—or merely compliance-

driven facility-level adjustments—remains crucial. Declines in reported firm-level emissions may result from methodological shifts in reporting practices, selective measurement techniques, or localized emissions reductions at regulated facilities rather than a fundamental shift in corporate sustainability strategy.

For facility-level transparency regulation to drive meaningful firm-wide change, it must extend beyond compliance and trigger 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 fosters a 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 fosters firm-wide behavioral change is by analyzing its influence 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 crucial venue where firms articulate strategic responses to external developments. If facility-level transparency regulation drives managerial learning, firms should exhibit greater engagement in climate discussions, acknowledging regulatory risks and signaling an increased commitment to addressing them. Increased climate-related discourse in earnings calls would indicate that transparency extends beyond mere facility-level compliance to influence firm-wide strategy and stakeholder communication.To test H2, I examine whether firms subject to facility-level 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. 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 evidence supporting H2. Firms subject to GHGRP regulation exhibit a significant increase in firm-level 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. This indicates that facility-level transparency elevates the attention paid to climate-related issues in earnings calls, reinforcing the idea that firms integrate climate considerations into their strategic discussions. In Column (2), the coefficient for GHGRP on NegRegSenti is 0.11 (t = 1.98), also statistically significant at the 5% level. This suggests that firms under facility-level GHG transparency regulation increasingly perceive regulatory risks and express these concerns in a more negative tone during earnings calls.

These findings suggest that although the 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. By increasing stakeholder scrutiny and regulatory visibility, GHGRP compels firms to integrate climate concerns into broader strategic decision-making rather than treating them as isolated compliance issues. This learning process drives 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 increase in negative regulatory sentiment suggests that firms anticipate stricter climate policies, carbon pricing mechanisms, and heightened compliance requirements, reinforcing the notion that transparency mandates accelerate corporate adaptation to an evolving regulatory landscape.These results align with prior research showing that greater transparency and stakeholder scrutiny heighten firms' awareness of climate risks, leading them to adjust their strategic outlooks and communication strategies accordingly.

4.3 H3: Impact of Facility-Level GHG Transparency Regulation on Firm-Level Green Innovations

While H2 establishes that facility-level transparency regulation heightens climate change concerns within firms, a critical question remains: Does this managerial learning translate into tangible emissions-reduction efforts through innovation, or does it remain rhetorical? A key indicator of a substantive strategic shift is an increased emphasis on low-carbon innovation, particularly 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:

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.

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

The empirical framework mirrors the main difference-in-differences equation used in H1 and H2, with the dependent variable adapted to measure the number of low-carbon patents developed by a firm. Low-carbon patents are classified based on the Cooperative Patent Classification (CPC) Y02 class, which identifies technologies with environmental benefits (Sautner et al. (2023), Cohen et al. (2024)). Patent data is sourced from the United States Patent and Trademark Office (USPTO) and linked to public firms' patent records (Kogan et al. (2017)). To isolate the impact of facility-level transparency regulation on green innovation emerging after program implementation, I incorporate lagged values of the GHGRP indicator (GHGRP(+1) and GHGRP(+2)). This approach 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 foster firm-level green innovation. In Column (1), the coefficient for GHGRP(+1) is 11.65 (t = 2.10), statistically significant at the 5% level. This suggests that facility-level transparency has a delayed but notable impact on the development of low-carbon patents, becoming evident one year after implementation. In Column (2), the coefficient for GHGRP(+2) remains positive (11.12, t = 1.94), statistically significant at the 10% level. These findings reinforce that while transparency regulation applies at the facility level, its impact extends beyond emissions reductions to drive firm-wide innovation in green technologies. By fostering managerial learning, GHGRP compels firms to internalize climate risks, realign R&D priorities, and embed sustainability into corporate strategy. This transformation moves beyond regulatory compliance, positioning firms as leaders in sustainable innovation and strengthening 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 unclear whether this innovation is driven by actual firm-level emissions reductions or merely reflects broader environmental initiatives or regulatory compliance. If transparency regulation serves as a catalyst for substantive technological progress, firms that successfully reduce their emissions should also exhibit higher levels of low-carbon patenting activity. To test this, H3a examines whether firms subject to GHGRP that achieve greater 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 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 =

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.

2.14), providing direct evidence that firms experiencing larger emissions reductions following GHGRP implementation are significantly more likely to innovate in low-carbon technologies. From an economic perspective, a fractional decrease in 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-carbon innovation, it is useful to examine the reverse scenario as a robustness check: 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 examines whether firms subject to GHGRP 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. 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 firms with stable or declining emissions. 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.

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.

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.

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

Taken together, the findings from H3a and H3b suggest a strong and meaningful relationship between actual emissions reductions and low-carbon innovation. Rather than being a symbolic response to regulatory pressure, the development of low-carbon patents appears to be an intentional and strategic effort tied to emissions management, highlighting the role of transparency regulation in incentivizing substantive technological advancements.

4.4 H4: The Sunshine Mechanism and Market Penalties for Emissions 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 voluntary firm-level emissions reports, which are self-reported, subjective, and often strategically framed, facility-level GHG data mandated by the EPA follows standardized methodologies, undergoes independent verification, and provides an objective measure of emissions. This standardization through regulatory oversight enables stakeholders to benchmark firm-level disclosures against facility-level data, exposing potential underreporting. When mandatory

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.

facility-level disclosures reveal higher emissions than previously reported at the firm level, it suggests misrepresentation or strategic underestimation in voluntary disclosures. This credibility shock signals to investors and other stakeholders that the firm's true climate impact is worse than initially perceived, triggering negative reassessments of corporate credibility and environmental integrity. Consequently, these revelations serve as "bad news" in financial markets, leading to declines in investor confidence, increased regulatory scrutiny, and potential legal or reputational risks.

Table 10 highlights the extent of these discrepancies. Firms voluntarily report an average of 31.8 million metric tons of GHG emissions at the firm level, with a median of 20.0 million metric tons. However, the range of these disclosures varies widely, reflecting inconsistent reporting methodologies. In contrast, standardized facility-level data reveals significantly higher emissions, with an average of 188.2 million metric tons and a median of 35.8 million metric tons. These stark differences demonstrate how facility-level transparency enhances corporate accountability by exposing misreporting in voluntary firm-level disclosures. This transparency mechanism provides stakeholders—including investors, regulators, and environmental advocacy groups—with reliable emissions data, fostering greater accountability. By discouraging underreporting and enabling more informed investment and regulatory decisions, facility-level GHG disclosures play a critical role in improving environmental governance and aligning corporate practices with societal and regulatory expectations.

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

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 for the same reporting year. Firm-disclosed emissions refer to the voluntary greenhouse gas (GHG) emissions reported by firms at the organizational level, whereas aggregated facility-level emissions represent the total emissions from individual facilities owned by these firms, as reported under the Greenhouse Gas Reporting Program (GHGRP).

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

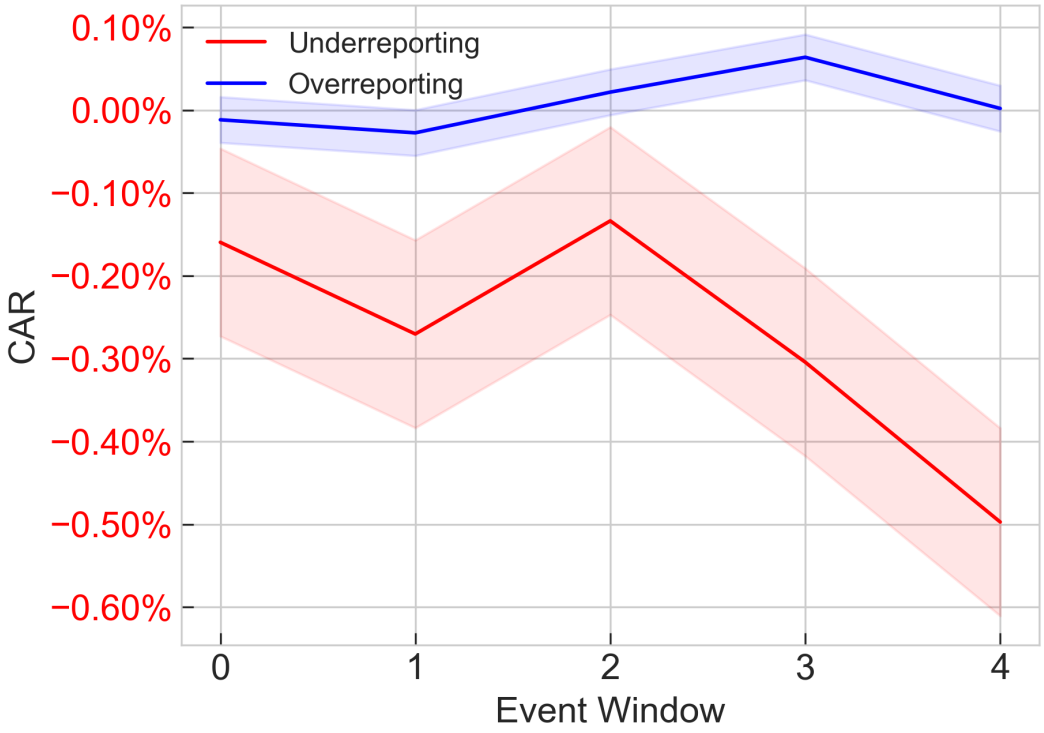
The event study results reveal distinct stock market reactions to facility-level GHG disclosures, depending on whether a firm underreported or overreported emissions. For un-

derreporting firms, the cumulative abnormal return (CAR) is -0.49%, with a statistically significant t-statistic of -2.37. This negative market reaction suggests that investors perceive underreporting as a credibility shock, raising concerns about corporate transparency, regulatory risk, and potential financial penalties. The revelation of higher actual emissions compared to prior voluntary disclosures signals possible misrepresentation, regulatory noncompliance, 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. This suggests that 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 by investors.

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

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.

4.5 H5: The Sunshine Mechanism of 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 reflect 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 affects ESG ratings for firms that had already been voluntarily disclosing firm-level emissions. One might expect little impact, 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)), implying that these firms were already being evaluated based on their self-reported emissions. However, facility-level GHG disclosures differ from voluntary disclosures by providing standardized, independently verified data, which enhances transparency and intensifies external scrutiny. Unlike voluntary disclosures—often shaped by strategic reporting choices—facility-level data presents a more objective, detailed, and disaggregated representation of a firm's actual carbon footprint. This additional granularity enables third-party evaluators to identify inconsistencies, selective reporting, or misrepresentations, thereby triggering the sunshine mechanism—a process that exposes a firm's true climate impact more accurately than self-reported emissions data. If facility-level disclosures reveal that a firm previously understated its emissions, third-party evaluators may downgrade its environmental ratings, reinforcing the role 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 evaluate this 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, capturing 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, presented 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, statistically significant at the 1% level ($t = -2.65$). This indicates that facility-level transparency regulation leads to lower environmental ratings compared to unregulated firms. These findings confirm that heightened scrutiny from facility-level GHG disclosures exposes gaps in environmental practices, prompting 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 more detailed, verified facility-level information. 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 and 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 influences financial market reactions but also shapes broader stakeholder perceptions, strengthening corporate environmental accountability and aligning firms with societal expectations for sustainability.

To determine 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 reflect firms' true climate impact, then the revelation of underreporting through facility-level data should lead to more severe rating penalties for firms that previously understated their emissions. This would suggest that rating agencies and stakeholders adjust their assessments based on enhanced transparency, rather than merely reacting to the disclosure mandate itself. The relationship is modeled as follows:

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

$UnderPct_{ft}$ 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:

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

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.

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, presented in Table 13, 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 their 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 their environmental ratings. This finding reinforces the role of mandatory transparency in corporate accountability, as it demonstrates that stakeholders actively incorporate new, 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 this value may seem small in absolute terms, it becomes substantial when considering firms with extreme levels of underreporting. For example, given that some firms significantly understate their firm-level emissions (e.g., the minimum value of UnderPct is -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, which is economically meaningful given the typical range of ESG ratings. Such a reduction may 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 the introduction of regulatory mandates but actively adjust based on newly available, 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 revealing inconsistencies in prior voluntary disclosures, transparency regulations ensure that ESG ratings reflect a firm's true environmental impact, enhancing the credibility of sustainability assessments in capital markets.

5 Conclusion and Policy Implications

This study investigates the broader organizational impacts of facility-level greenhouse gas (GHG) transparency regulation, with a specific focus on the U.S. Environmental Protection Agency's (EPA) Greenhouse Gas Reporting Program (GHGRP). By analyzing firms previously engaged in voluntary emissions disclosures, both before and after the introduction of GHGRP, this study provides empirical evidence on how granular transparency mandates influence firm-wide strategic behavior and environmental decision-making. The findings highlight significant organizational spillovers, demonstrating that mandatory facility-level disclosures drive broader managerial learning, increase climate awareness across organizations, and catalyze strategic shifts toward sustainable innovation and accountability.

The findings indicate that facility-level transparency regulation generates significant organizational spillover effects, driving emissions reductions beyond compliance-focused facility-level actions. Specifically, firms subject to GHGRP regulation demonstrate substantial firm-wide emissions reductions compared to non-regulated firms, achieving strategic shifts in corporate priorities due to increased external scrutiny. A key mechanism underpinning these broader organizational changes is managerial learning, whereby transparency-driven stakeholder pressure and regulatory scrutiny prompt firms to internalize climate-related risks and reassess their strategic priorities. This heightened awareness is evidenced by a notable in-

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.

crease in climate-related discussions during corporate earnings conference calls, highlighting management's growing recognition of climate risk and signaling an organizational shift toward integrating sustainability into strategic decision-making. Furthermore, transparency-driven accountability stimulates innovation in clean technology: GHGRP-regulated firms develop significantly more low-carbon patents than their non-regulated counterparts. This increased innovation underscores how granular transparency regulation motivates proactive investments in sustainable technologies, with firms achieving tangible progress in emissions management rather than merely symbolic compliance. Additionally, these results suggest that effective disclosure policies not only heighten managerial climate awareness but also incentivize substantial long-term investment in sustainability innovation, reinforcing the broader strategic benefits of transparency policies.

A fundamental feature of facility-level transparency regulation is its capacity to expose discrepancies between voluntary firm-level emissions disclosures and objective facility-level data. This study reveals that firms previously underreporting their emissions incur significant reputational and financial penalties when mandatory disclosures expose their true environmental impact. Specifically, the market reacts negatively to such revelations, imposing substantial financial costs on firms whose mandatory disclosures indicate prior underreporting. Investors perceive these discrepancies as credibility shocks, triggering concerns about corporate transparency and increased regulatory risk. Consequently, market participants adjust expectations downward, imposing financial discipline based on independently verified emissions data. Empirically, firms exposed by the GHGRP to have previously underreported emissions suffer significant declines in stock prices and reductions in market valuations. Additionally, these firms experience pronounced downgrades in third-party environmental ratings, further reflecting diminished stakeholder trust. The decline in environmental ratings highlights transparency's critical role in enabling third-party evaluators to deliver more accurate assessments of corporate environmental performance. These results underscore the effectiveness of transparency-driven accountability mechanisms, as third-party evaluators in-

creasingly rely on objective emissions data rather than voluntary, potentially manipulated disclosures to assess firms' environmental commitments.

These results offer critical policy insights for regulators, investors, and corporate decision-makers. A primary insight is the necessity of standardized and independently verifiable disclosures. While the U.S. Securities and Exchange Commission's recent mandate for firm-level GHG disclosures (US SEC (2024)) represents notable progress toward corporate transparency, its reliance on firm-specific methodologies reduces comparability, limiting the policy's capacity 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 granularity enables stakeholders to accurately evaluate corporate environmental performance and effectively hold firms accountable. The findings 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—allowing stakeholders to enforce market discipline based on objective emissions data. Absent such mechanisms, transparency initiatives may fall short of motivating substantial environmental improvements. Thus, policymakers should design disclosure frameworks that not only enhance transparency but also empower stakeholders to leverage the disclosed information, effectively incentivizing firms toward genuine sustainability commitments.

This study provides important insights for regulators, investors, and corporate decision-makers by contributing the first empirical evidence of the organizational spillover effects arising from 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, emphasizing managerial learning as a key mechanism driving transparency effectiveness. The findings underscore that transparency regulations achieve their greatest impact when combined with meaningful managerial responses to heightened stakeholder

scrutiny and internalized climate risks. This managerial learning process facilitates strategic shifts toward firm-wide sustainability, moving beyond mere compliance to deeper integration of environmental considerations into corporate decision-making and innovation strategies. A core insight is that transparency alone is insufficient; it must enable stakeholders—investors, policymakers, and the public—to hold firms accountable through standardized, objective, and verifiable emissions disclosures. By providing stakeholders with actionable information to assess corporate environmental performance accurately, facility-level transparency regulations play a pivotal role in reshaping corporate behavior, aligning firms with broader 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