Incentives Under Verification: Theory and Evidence on the Real Effects of Bottom-Up Climate Disclosure*

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Abstract

I develop and test a model in which regulator-verified, facility-level greenhouse gas disclosure realigns corporate incentives by altering the trade-off between greenwashing and genuine emissions abatement. Verification activates three mechanisms: external stakeholder discipline, imposing relational costs when voluntary and verified emissions diverge; internal managerial learning, as salient verification increases managerial attention to climate risk; and valuation effects, as verified emissions reductions enter long-run firm value. Using staggered firm-level exposure to the U.S. EPA's Greenhouse Gas Reporting Program, I find that treated firms significantly reduce total organizational emissions and that verified emissions reductions correlate with increased low-carbon patenting. Underreporters experience negative abnormal returns and environmental-rating downgrades, consistent with discipline, while treated firms expand climate-related discussions in earnings calls, consistent with learning. Verified emissions reductions are associated with higher future market valuations, consistent with value effects. Overall, I show how verified, bottom-up transparency generates substantive firm-level environmental improvements beyond the regulated facilities.

Keywords: Environmental disclosure; Greenwashing; Verification; Managerial attention; Stakeholder discipline; Climate risk; Market valuation.

JEL Codes: M14; Q56; G14; D83; L51

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

1 Introduction

How does verifiable environmental transparency reshape corporate behavior? As climate disclosure regimes become more granular, standardized, and regulator-enforced, firms face intensifying scrutiny—not only from external stakeholders but also from internal decision-makers whose priorities shift when credible information becomes available. A prominent example is the U.S. Environmental Protection Agency's (EPA) Greenhouse Gas Reporting Program (GHGRP), which mandates annual disclosure of greenhouse gas (GHG) emissions at the facility level. Unlike traditional top-down, firm-level reporting—where managers retain discretion over aggregation, estimation methods, and organizational boundaries—the GHGRP requires emissions to be reported separately for each physical site a firm owns or operates, such as factories, refineries, and power plants. This bottom-up, regulator-verified format delivers a detailed, credible, and traceable account of environmental performance. Prior work shows that facility-level transparency can reduce emissions at directly regulated sites (Tomar (2022), Yang et al. (2021)). Yet whether these localized improvements translate into broader organizational change remains an open question. For large, multi-facility firms, total corporate emissions need not decline even if GHGRP-regulated facilities improve: firms may offset local gains by shifting emissions-intensive activities to unregulated jurisdictions or redefining reporting boundaries. Consistent with this concern, Bartram et al. (2022) show that financially constrained firms subject to California's cap-and-trade program increased emissions outside the regulated domain by 14 percent. These offsetting strategies motivate the central question of this paper: does bottom-up, regulator-verified disclosure reshape firm-wide incentives and decision-making—and through what mechanisms?

To address this question, I develop a stylized Bayesian model of emissions disclosure, misreporting, and verification and test its predictions using quasi-experimental evidence

from facility-level disclosure mandates. Building on Kanodia & Sapra (2016) and Goldstein et al. (2013), the model features a firm that allocates managerial effort between two activities: costly real abatement, which reduces true emissions, and strategic misreporting in voluntary disclosures, which can temporarily improve market perceptions. The timing unfolds in three stages. First, the firm chooses abatement effort. Second, it issues a voluntary firm-level disclosure; investors observe this soft signal, update beliefs, and set an interim price based on perceived—rather than verified—emissions. Consistent with prior evidence that lower reported emissions are associated with higher valuations (Matsumura et al. (2014), Griffin et al. (2017), Choi & Luo (2021)), this interim pricing channel can incentivize underreporting. Third, regulator-verified facility-level disclosure—such as under the GHGRP—produces a high-precision measure of the firm's emissions footprint by combining facility-level and firm-level information, thereby exposing any prior misreporting. Verification activates three mechanisms. First, external stakeholder discipline arises when discrepancies between voluntary and verified emissions trigger relational costs, including negative market reactions and ESG rating downgrades. Second, internal managerial learning occurs as the salient and diagnostically rich verified signal reallocates managerial attention toward climate risk and emissions performance. Third, valuation effects emerge because verified emissions—rather than voluntary claims—enter long-run firm value once verification occurs. A central prediction of the model is that external discipline and managerial attention are complementary in deterring misreporting, while the valuation relevance of verified emissions independently strengthens incentives for real abatement. When all three channels operate—as under salient, regulator-verified facility-level disclosure—managerial incentives shift away from symbolic compliance and toward substantive, organization-wide emissions reductions, even when the mandate covers only part of a firm's operations.

I test these predictions using comprehensive firm-level data from 2007 to 2022, exploiting staggered firm entry into the GHGRP. Firm-level exposure is defined in two steps. First, the sample is restricted to firms that voluntarily disclose firm-level GHG emissions, which

is necessary to construct verified emissions measures and observe firm-wide outcomes. For example, Exxon Mobil begins disclosing firm-level emissions in 2007, whereas Phillips 66 begins disclosure in 2014. Second, within this sample, treatment timing is determined by when a firm first owns or operates a facility exceeding the EPA's reporting threshold. Although the commonly cited threshold is 25,000 tons of CO_2e, many sub-threshold facilities are required to report under source-category-specific rules, and coverage hinges on technical emissions processes rather than managerial discretion. As a result, GHGRP entry provides plausibly exogenous variation in the onset of verified disclosure. For instance, both Exxon Mobil and Phillips 66 enter GHGRP coverage in 2010, while Analog Devices Inc. enters in 2011. I exploit this staggered adoption using a generalized difference-in-differences design with firm fixed effects and industry-by-year fixed effects. Consistent with the model, firms reduce verified firm-wide emissions by approximately 14 percent within two years of entering GHGRP coverage. This delayed but economically meaningful response reflects the dynamics of verified disclosure: once facility-level emissions become public and salient, stakeholders can discipline inconsistencies, and managers gain granular information that reallocates attention toward abatement. Even localized, bottom-up transparency can therefore induce substantive, organization-wide emissions reductions.

To establish that these effects reflect genuine adaptation rather than narrow or mechanical compliance, I rule out two leading alternative explanations. First, the decline in verified firm-wide emissions cannot be explained solely by abatement at GHGRP-reporting facilities (Tomar (2022), Yang et al. (2021)). Conditioning on regulator-verified facility emissions leaves the treatment effect large and highly statistically significant, rejecting a pure localization interpretation and implying that emissions reductions extend beyond the regulated footprint. Second, the reductions are not mechanically driven by reporting-boundary effects. GHGRP entry significantly compresses noncovered emissions—the portion of verified firm-wide emissions not accounted for by facility-level reports—indicating that firms reduce emissions outside regulated facilities rather than merely reallocating or reclassifying emissions

within the reporting perimeter. Consistent with real organizational adaptation, I further link verified abatement to forward-looking investment. Using USPTO patent data (Kogan et al. (2017)), I show that firms achieving verified emissions reductions under the GHGRP subsequently increase low-carbon innovation, as measured by CPC Y02 patents (CCohen et al. (2024), Chen et al. (2023)). The interaction between GHGRP exposure and verified emissions reductions is positive and statistically significant, whereas verified emissions increases exhibit no comparable relationship with innovation. This asymmetry rules out scale effects or coincident production shocks and indicates that GHGRP-induced transparency triggers substantive capability-building rather than symbolic reporting adjustments.

Beyond real abatement, I provide empirical evidence that GHGRP verification activates the three mechanisms emphasized in the model. First, external stakeholder discipline emerges when regulator-verified emissions contradict prior voluntary disclosures. Firms identified as underreporters experience sharp and persistent stock price declines around the initial public release of GHGRP data and face systematic downgrades in MSCI environmental ratings. These responses indicate that investors and ESG evaluators penalize credibility shocks—instances in which verified information reveals previously hidden emissions—rather than emissions levels per se. Second, internal managerial learning is triggered by the arrival of credible and granular facility-level emissions data. Following GHGRP verification, firms significantly increase climate-related discussion in earnings calls (Sautner et al. (2023)), consistent with a reallocation of managerial attention toward climate risk and emissions performance. Finally, I document a long-run valuation channel: firms that achieve verified emissions reductions experience economically meaningful increases in firm value, whereas firms whose verified emissions increase receive no comparable valuation premium. This asymmetric pricing response confirms that markets treat GHGRP-certified abatement as value-relevant while disregarding deteriorations in verified emissions performance.

This paper makes three contributions to the literature on environmental disclosure and firm behavior. First, it advances research on disclosure policies and real effects (e.g., Kanodia

& Sapra (2016), Roychowdhury et al. (2019)) by developing a theory of how and why facility-level GHG transparency can induce organization-wide behavioral change. The model shows that when disclosure is regulator-verified and salient, it reshapes managerial incentives well beyond the boundaries of directly regulated operations. To my knowledge, this is the first paper to demonstrate that disclosure policies implemented at a disaggregated, site-specific level can scale upward to affect firm-level resource allocation and strategic orientation. Existing empirical work documents localized responses to granular transparency—such as abatement at covered units through benchmarking, cross-jurisdiction comparisons (e.g., Tomar (2022) on Canadian versus U.S. facilities), or within-plant adjustments at power stations (Yang et al. (2021))—but stops short of showing that regulator-enforced facility-level disclosure systematically alters corporate behavior more broadly. At the firm level, effects often appear muted when researchers rely on vendor-estimated emissions: GHGRP-regulated firms show no greater total emissions reductions than controls (BBauckloh et al. (2023)) and reallocate emissions to unregulated sites (Bartram et al. (2022)). This paper fills that gap. I show that facility-level transparency can generate substantive, organization-wide responses when regulator verification activates three reinforcing mechanisms: (i) external stakeholder discipline, (ii) internal managerial learning, and (iii) valuation effects. In doing so, the paper bridges the environmental disclosure literature with research on CSR reporting (e.g., Christensen et al. (2017), Johnson (2020)) and with work on feedback effects in financial markets (e.g., Subrahmanyam & Titman (2001), Goldstein et al. (2013), Bond et al. (2012))), demonstrating how verified environmental information simultaneously shapes external perceptions and internal strategic realignment.

Second, the paper reframes the literature on the real effects of mandatory GHG disclosure by shifting the analytical focus from firm-level mandates to the organizational implications of bottom-up, facility-level transparency. Prior studies—largely examining top-down firm-level disclosure regimes, particularly in the United Kingdom—show that mandatory reporting can induce meaningful emissions reductions. For example, Downar et al. (2021)

find that UK firms cut EU ETS emissions more than firms in other EU countries; Jouvenot & Krueger (2019) document larger reductions using vendor-estimated emissions; and Grewal (2024), using CDP data, identifies both absolute and intensity-based declines. These studies emphasize how firm-level rules can drive real improvements by targeting high-emitting units or prompting firm-wide strategic shifts. This paper reverses the causal lens. Rather than asking whether firm-level mandates affect facility-level outcomes, it examines whether regulator-verified, facility-level disclosure can scale upward to reshape firm-wide incentives, learning, and decision-making. This perspective highlights the strategic role of granular operational transparency in inducing organization-level change.

Third, the paper offers policy implications for the design of effective climate-disclosure regulation, particularly for regulators seeking to sustain market discipline within firms (Leuz & Wysocki (2016)). While the US SEC (2024) proposed firm-level Scope 1 and Scope 2 disclosure rules[1] represent progress toward standardization, their reliance on firm-selected estimation methods introduces discretion that weakens cross-firm and intertemporal comparability, undermining credibility and verifiability. In contrast, the EPA's GHGRP mandates facility-level reporting using regulator-verified methodologies, producing disclosures that are standardized, credible, and easily interpretable. The central insight of this paper is that transparency influences behavior only when information is both comparable and verifiable. As Justice Louis Brandeis famously observed, "sunlight is the best disinfectant"—but only when the light is clear and consistent. Effective climate transparency requires what I term heterogeneous comparability: information that allows stakeholders to compare firms reliably while still reflecting meaningful differences in environmental performance and strategic response. When disclosure meets these criteria, stakeholders act on it—exerting external pressure and triggering internal managerial reassessment—transforming transparency from a reporting obligation into a catalyst for real organizational change.

The remainder of the paper is structured as follows. Section 2 develops the theoretical

[1]Implementation, however, has stalled amid political turnover and litigation.

framework, formalizing how facility-level GHG transparency can generate real effects on firm behavior. Section 3 derives empirically testable predictions from the model. Section 4 provides institutional background and describes the data sources. Section 5 outlines the empirical strategy and presents the testing results. Finally, Section 6 concludes and discusses policy implications.

2 A Stylized Model of Incentives Under Verification

2.1 Bayesian Model of Emissions Disclosure, Misreporting, and Verification

This section develops a stylized three-period model in which a firm allocates managerial resources between real emissions abatement and strategic misreporting in voluntary disclosures. The framework formalizes the trade-off between undertaking costly real actions that reduce true emissions and manipulating the sustainability narrative to influence investor perceptions. The introduction of granular, regulator-verified disclosure—such as facility-level reporting under the U.S. Environmental Protection Agency's Greenhouse Gas Reporting Program (GHGRP)—generates three incentive-relevant forces: (i) external stakeholder discipline, (ii) internal managerial attention and learning, and (iii) long-run valuation effects operating through verified emissions.

Voluntary firm-level disclosures are treated as unverifiable soft information that affects the interim stock price through Bayesian belief updating, following Kanodia & Sapra (2016). In contrast, the combination of GHGRP facility-level data and firm-level totals produces a high-precision, effectively verifiable measure of the firm's environmental footprint that enters long-run price determination, consistent with Goldstein et al. (2013). The framework integrates narrative manipulation, information precision, rational inattention, and verification into a unified Bayesian model.

Timing and Information Structure

The economy unfolds over three periods:

- **Period 0 — Real Actions:** The manager chooses abatement effort $e \in [0, 1]$, incurring a real cost but reducing true emissions.
- **Period 1 — Voluntary Disclosure:** The manager chooses misreporting $m \geq 0$ and releases a voluntary disclosure signal s. Bayesian investors observe s, update beliefs about emissions, and set the interim stock price $P_1(s)$.
- **Period 2 — Verification, Internal Learning, and Long-Run Valuation:** Regulator-verified facility-level emissions become observable under the GHGRP. Combined with firm-level reported totals, these data produce a high-precision verified emissions measure $E^{\text{ver}} \equiv \max\{\text{FirmE}, \text{FacilityE}\}$, which serves as a corrected estimate of the firm's environmental footprint. Misreporting is revealed, external discipline is imposed, managerial attention to climate performance is intensified, and the long-run price P_2 is determined from verified emissions.

Period 0 captures real emissions-management decisions; Period 1 captures narrative management through unverifiable voluntary disclosures; and Period 2 captures the arrival of GHGRP verification, which eliminates downward bias by merging facility-level verified data with firm-level totals and increases the salience and diagnostic value of emissions information for both external stakeholders and internal decision makers.

True Emissions, Abatement, and Cost

True emissions after abatement are given by:

$$E(e) = E_0 - \kappa e, \quad \kappa > 0 \tag{1}$$

Here, E_0 is baseline emissions in the absence of abatement, and κ measures abatement effectiveness: a higher κ means a given unit of effort yields a larger reduction in emissions.

Abatement incurs a convex cost:

$$c(e) = \frac{1}{2}\gamma e^2, \quad \gamma > 0 \tag{2}$$

The parameter γ governs the marginal cost of abatement. The quadratic form implies increasing marginal cost of emissions reductions, consistent with standard abatement cost functions.

Prior Beliefs and the Voluntary Disclosure Signal

Investors begin with a Normal prior over true emissions:

$$E \sim N(\mu_0, \tau_0^{-1}), \quad \tau_0 > 0 \tag{3}$$

Here, μ_0 is the prior expected level of emissions (based on history, industry peers, ESG ratings, etc.), and τ_0 is the prior precision (inverse variance).

After choosing (e, m), the manager releases a voluntary disclosure signal:

$$s = E - m + \eta, \quad \eta \sim N(0, \tau_m^{-1}) \tag{4}$$

where $\tau_m > 0$ is the precision of the voluntary disclosure. The term $m \geq 0$ represents downward bias (greenwashing): larger m mechanically reduces the reported emissions. The shock η captures noise, ambiguity, or unverifiability in the voluntary disclosure. Investors observe s but do not observe e or m.

Bayesian Posterior Updating

Because investors treat the voluntary signal as if it were unbiased (they do not explicitly correct for misreporting), the posterior precision after observing s is:

$$\tau_1 = \tau_0 + \tau_m \tag{5}$$

The corresponding posterior mean is:

$$\mu_1(s) = \frac{\tau_0}{\tau_1}\mu_0 + \frac{\tau_m}{\tau_1}s \tag{6}$$

Substituting $s = E - m + \eta$, the expected posterior mean given true emissions and misreporting is:

$$E[\mu_1(s) \mid E, m] = \frac{\tau_0}{\tau_1}\mu_0 + \frac{\tau_m}{\tau_1}(E - m) \tag{7}$$

This shows that, holding true emissions E fixed, greater misreporting m reduces the expected posterior mean μ_1 of emissions: voluntary greenwashing lowers perceived emissions on average.

Interim Stock Price

Consistent with the literature on the valuation implications of emissions performance (e.g., Matsumura et al. (2014), Griffin et al. (2017), Choi & Luo (2021)), lower emissions improve firm value by reducing regulatory exposure, lowering transition risk, and increasing operational efficiency. These channels create incentives for managers to shape investor perceptions of emissions performance in the short run.

The interim stock price responds to perceived emissions:

$$P_1(s) = A_1 - \theta_S \mu_1(s), \quad \theta_S > 0 \tag{8}$$

where A_1 is the component of interim value unrelated to emissions, and θ_S captures how strongly markets respond to perceived emissions in the short run.

Lemma 1 (Marginal Effect of Misreporting on Interim Price)**.** *The marginal benefit of misreporting on the interim price is positive and increasing in the precision of the voluntary signal:*

$$\frac{\partial P_1(s)}{\partial m} = \theta_S \frac{\tau_m}{\tau_1} > 0.$$

Proof. From the posterior mean expression (6), $\frac{\partial \mu_1}{\partial s} = \frac{\tau_m}{\tau_1}$. From (4), $\frac{\partial s}{\partial m} = -1$. By the chain rule, $\frac{\partial P_1}{\partial m} = -\theta_S \left(-\frac{\tau_m}{\tau_1}\right) = \theta_S \frac{\tau_m}{\tau_1}$. □

Verification, External Discipline, Managerial Attention, and Long-Run Price

In Period 2, facility-level GHGRP data provide a regulator-verified lower bound on emissions. We define a hybrid verified emissions measure:

$$E^{\text{ver}} \equiv \max\{\text{FirmE}, \text{FacilityE}\} \tag{9}$$

This measure serves as a high-precision, downward-bias-corrected proxy for the firm's true environmental footprint and exposes the extent of earlier greenwashing.

Let $\lambda > 0$ denote external stakeholder discipline (e.g., market backlash or ESG rating downgrades), and let $\psi \geq 0$ denote internal managerial attention to climate risk. Following rational inattention theory (Sims (2003)), attention responds to the salience of information. Standardized, regulator-verified facility-level disclosure increases the informational salience of emissions performance:

$$\psi = \begin{cases} \psi_0 & \text{no verification} \\ \psi_0 + \delta\psi_{\text{GHGRP}} & \text{under GHGRP}, \quad \delta\psi_{\text{GHGRP}} > 0 \end{cases} \tag{10}$$

The penalty intensity for misreporting increases convexly in both discipline and attention:

$$\Phi(\lambda, \psi) = \exp(\rho\lambda\psi), \quad \rho > 0 \tag{11}$$

The parameter ρ governs the curvature of the penalty function. The long-run stock price is given by:

$$P_2(E^{\text{ver}}, m) = A_2 - \theta_L E^{\text{ver}} - \Phi(\lambda, \psi)m^2, \quad \theta_L > 0 \tag{12}$$

where θ_L reflects the valuation relevance of verified emissions, and $\Phi(\lambda, \psi)m^2$ captures the relational costs of detected greenwashing.

2.2 Optimal Managerial Behavior

The manager maximizes a weighted average of interim and long-run prices, net of abatement costs:

$$\max_{e,m} \quad \alpha_1 P_1(s) + \alpha_2 P_2(E^{\text{ver}}, m) - \frac{1}{2}\gamma e^2, \quad \alpha_1 + \alpha_2 = 1 \tag{13}$$

Optimal Misreporting

The manager chooses m to balance the short-run benefits of voluntary greenwashing against the long-run penalties.

Proposition 1 (Optimal Misreporting)**.** *The optimal level of misreporting m^* is given by:*

$$m^* = \frac{\alpha_1 \theta_S \tau_m}{2\alpha_2 \Phi(\lambda, \psi)\tau_1} \tag{14}$$

Proof. The first-order condition (FOC) with respect to m is $\alpha_1 \frac{\partial P_1}{\partial m} + \alpha_2 \frac{\partial P_2}{\partial m} = 0$. Substituting Lemma 1 and differentiating (12), we get $\alpha_1(\theta_S \frac{\tau_m}{\tau_1}) + \alpha_2(-2\Phi(\lambda, \psi)m) = 0$. Solving for m yields (14). □

Comparative Statics: Optimal misreporting m^* decreases in external discipline λ and managerial attention ψ. Thus, GHGRP verification—which increases ψ by raising the salience

of emissions information and may raise λ as markets learn to price verified data—makes greenwashing less attractive.

Optimal Abatement

The manager chooses e to minimize E^{ver} and improve long-run value.

Proposition 2 (Optimal Abatement)**.** *Assuming the firm's emissions exceed the facility-level lower bound (so E^{ver} responds to abatement), the optimal abatement level is:*

$$e^* = \min\left\{1, \frac{\alpha_2 \theta_L \kappa}{\gamma}\right\} \tag{15}$$

Proof. The FOC with respect to e for the term $\alpha_2 P_2 - c(e)$ is $\alpha_2 \frac{\partial P_2}{\partial E^{\text{ver}}} \frac{\partial E^{\text{ver}}}{\partial e} - \gamma e = 0$. This yields $\alpha_2(-\theta_L)(-\kappa) - \gamma e = 0 \implies \alpha_2 \theta_L \kappa = \gamma e$. □

Comparative Statics: Abatement e^* increases with the long-run valuation sensitivity θ_L and the manager's long-run weight α_2. By making verified emissions more central to long-run pricing (higher effective θ_L), GHGRP verification increases the perceived benefit of abatement.

Incentive Reallocation Under Verification

I now derive the central insight of the model regarding the shift in behavior under the GHGRP.

Corollary 1 (Incentive Reallocation Under Verification)**.** *The introduction of the GHGRP systematically shifts managerial behavior by strictly reducing optimal misreporting ($m^* \downarrow$) and increasing real abatement ($e^* \uparrow$).*

1. **Reduction in Greenwashing ($m^* \downarrow$):** Differentiating (14) with respect to the penalty term Φ: $\frac{\partial m^*}{\partial \Phi} < 0$. Since Φ is strictly increasing in both λ and ψ (given $\rho > 0$), the increase in salience and discipline under the GHGRP strictly increases Φ, thereby decreasing m^*.

(a) **Increase in Real Abatement ($e^* \uparrow$):** Differentiating (15) with respect to θ_L: $\frac{\partial e^*}{\partial \theta_L} = \frac{\alpha_2 \kappa}{\gamma} > 0$. As the market learns to price the high-precision measure E^{ver}, θ_L effectively rises, increasing the marginal benefit of abatement.

Conclusion: By making emissions performance more precise, credible, and salient, verification reallocates managerial effort away from narrative manipulation and toward real environmental improvement, while simultaneously strengthening both external discipline and internal managerial learning.

3 Empirical Predictions from the Model

The theoretical framework implies that the introduction of regulator-verified, facility-level emissions disclosures systematically alters beliefs, incentives, and managerial behavior. Prior to verification, investors rely on noisy voluntary disclosures (s) that affect interim prices (P_1) through Bayesian belief updating. After verification, the GHGRP provides a high-precision measure (E^{ver}) that reveals misreporting (m), imposes relational penalties (Φ), and heightens managerial attention (ψ). These forces generate a set of distinct, testable empirical implications. I organize them into five categories corresponding to the model's logical progression: (i) firm-level real effects, (ii) distinguishing adaptation from mechanical alternatives, (iii) external stakeholder discipline, (iv) internal managerial learning, and (v) long-run valuation effects.

3.1 Firm-Level Real Effects

In the model, the anticipation of credible verification raises the relational stakes for managers. Because the verified measure E^{ver} ultimately reveals the extent of misreporting, managers understand *ex ante* that greenwashing increases future penalties through the discipline term $\Phi(\lambda, \psi)m^2$. As derived in **Corollary 1**, this leads to a substitution effect: optimal misreporting (m^*) declines, while real abatement effort (e^*) increases. Consequently, emissions

reductions arise from real operational changes rather than improved disclosure optics. This aligns with stakeholder theory (Freeman 1984), where public visibility triggers responses from key constituents, and political cost theory (Watts & Zimmerman 1978), where firms act strategically to avoid regulatory scrutiny.

> **P1 (Firm-Level Real Effects):** Firms subject to the GHGRP reduce total firm-level emissions more than comparable firms without regulated facilities.

This baseline prediction captures the central implication of the model: credible, verifiable transparency reallocates managerial effort away from narrative manipulation and toward real environmental improvement.

3.2 Ruling out Alternative Explanations

While the model posits that the GHGRP induces organization-wide adaptation, observed reductions in firm-level emissions could theoretically arise from narrower mechanisms. I develop predictions to distinguish genuine adaptation from two leading alternative explanations: *Pure Localization* and *Mechanical Redistribution*.

Pure Localization vs. Spillovers The first alternative is that firms respond to the mandate solely by abating emissions at the specific facilities subject to reporting (e.g., Tomar 2022), with no spillover to the broader organization. If this "pure localization" hypothesis holds, the firm-wide treatment effect should be entirely explained by changes at regulated sites.

> **P2a (Pure Localization Test):** If firm-wide emissions reductions are driven solely by compliance at regulated facilities, then conditioning on verified facility-level emissions should fully absorb the estimated GHGRP treatment effect. Conversely, a persistent treatment effect suggests emissions reductions extend beyond the regulated footprint.

Mechanical Redistribution A second concern is that the estimated effect reflects a mechanical redistribution or accounting reallocation across reporting boundaries. To test this, I focus on "noncovered emissions"—the gap between firm-wide disclosures and facility-level verifications. If the response is mechanical, GHGRP exposure should have no impact on this residual component. However, if the regulation induces organization-wide management of climate risk, firms should actively compress this gap.

> **P2b (Noncovered Emissions Response):** If GHGRP induces genuine organization-wide adaptation, exposure to the regulation will reduce "noncovered emissions" (the gap between firm-level and facility-level emissions). A significant negative response in noncovered emissions rules out mechanical redistribution as the sole driver.

Low-Carbon Innovation as a Falsification Test A stringent test of genuine adaptation links emissions reductions to costly, forward-looking inputs. The model suggests that real abatement (e^*) involves learning and capability building, which should manifest in low-carbon innovation.

> **P2c (Innovation-Abatement Linkage):** Firms that achieve verified emissions reductions following GHGRP entry will exhibit increased low-carbon patenting intensity.

> **P2d (Innovation Falsification):** Firms that experience verified emissions *increases* will not exhibit increased innovation, ruling out scale effects or coincident production shocks.

3.3 External Stakeholder Discipline

The model predicts that external stakeholders utilize regulator-verified data to update beliefs about firm credibility. This discipline manifests through two distinct channels: immediate market reactions and institutional rating adjustments.

Market Discipline via Credibility Shocks In Period 2, verification reveals the true state E^{ver}. If E^{ver} significantly exceeds prior voluntary disclosures (s), investors perceive a "credibility shock."

> **P3a (Market Reaction to Underreporting):** Firms identified as "underreporters"—where verified emissions exceed prior voluntary disclosures—will experience negative cumulative abnormal returns (CARs) around the public release of verified data. Conversely, "overreporters" (who conservatively over-disclosed) will experience no such penalty.

Reputational Discipline via ESG Ratings Non-investor stakeholders, such as ESG rating agencies, also process verified information. The model predicts that penalties differ based on the revealed information gap.

> **P3b (ESG Ratings):** GHGRP regulation leads to ESG rating downgrades specifically for firms where verified emissions reveal underreporting. The magnitude of the downgrade increases with the extent of the underreporting discrepancy.

3.4 Internal Managerial Learning

Beyond external discipline, the model proposes an internal learning channel. Regulator-verified disclosure increases the salience (ψ) and granularity of emissions data for managers, leading to an immediate reallocation of attention toward climate risks.

> **P4 (Managerial Attention):** Upon entry into the GHGRP, firms will increase the frequency and intensity of climate-related discussion in earnings calls. This shift reflects an internal cognitive adjustment to the increased credibility and salience of verified emissions information.

3.5 Long-Term Firm Valuation Channel

Finally, the model describes how capital markets price verified environmental performance in the long run (P_2). While voluntary disclosures influence interim prices, long-run valuation depends on verified outcomes. The model implies an asymmetry: markets reward genuine risk reduction but do not reward (and may penalize) worsening performance.

Because the long-run price is decreasing in verified emissions E^{ver}, the valuation channel generates two testable predictions:

> **P5a (Valuation of Abatement):** Firms that achieve verified emissions reductions under the GHGRP regime will experience higher long-run market valuations, reflecting lower transition risk and improved operational efficiency.
>
> **P5b (Valuation Falsification):** Firms whose verified emissions increase will typically experience no comparable valuation gains. This falsification test ensures that observed value creation is driven by improved environmental performance rather than mechanically by regulatory coverage.

4 Institutional Background and Data

4.1 Greenhouse Gas Reporting Program by the EPA

In response to growing concerns about GHG emissions, the Consolidated Appropriations Act of 2008[2] provided funding for the U.S. Environmental Protection Agency (EPA) to develop a rule mandating GHG emissions reporting across all sectors of the U.S. economy under the Clean Air Act.[3] This initiative led to the creation of the Greenhouse Gas Reporting Program (GHGRP), which went into effect on January 1, 2010. Under the GHGRP, facilities emitting above specified thresholds—typically 25,000 metric tons of CO_2e annually—are required to measure and report their emissions using a standardized methodology outlined in Part 98

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

of Title 40 of the Code of Federal Regulations. Although the EPA's threshold is 25,000 tons of CO2e, many sub-threshold facilities must report based on source-category rules. Because reporting hinges on technical emissions processes rather than managerial discretion, GHGRP entry is plausibly orthogonal to firm-level strategy. To ensure the accuracy and integrity of reported data, the EPA enforces robust monitoring,[4] verification,[5] and enforcement.[6] A key feature of the GHGRP is that it standardizes how to calculate GHG emissions at the facility level[7] and enhances the credibility and verifiability of disclosures, since reporting is mandated and overseen by a regulator. This stands in sharp contrast to voluntary firm-level disclosures, which often differ in their methodological rigor, scope definitions, and organizational boundaries. By delivering consistent, high-quality emissions data, the GHGRP reduces information asymmetry and mitigates the risk of greenwashing. Since 2012, the EPA has made annual emissions data for more than 8,000 facilities publicly available through the Facility Level Information on Greenhouse Gases Tool (FLIGHT).[8] This interactive platform includes total emissions and ownership information, promoting transparency and enabling better-informed decisions by investors, regulators, researchers, and the general public. Although the GHGRP does not directly require firms to reduce emissions, it imposes binding disclosure obligations on publicly traded firms with regulated facilities. These firms face scrutiny that is not applicable to peers without such facilities. This contrast introduces a quasi-experimental setting for evaluating how credible, regulator-verified transparency affects firm behavior. For a summary of key regulatory milestones during the sample period, see Table 1.

[4] https://www.epa.gov/sites/default/files/2017-12/documents/ghgrp_bamm_factsheet.pdf
[5] https://www.epa.gov/sites/default/files/2017-12/documents/ghgrp_verification_factsheet.pdf
[6] https://www.epa.gov/enforcement/enforcement-greenhouse-gas-reporting-program-hfc-importers
[7] https://www.ecfr.gov/current/title-40/chapter-I/subchapter-C/part-98?toc=1
[8] https://ghgdata.epa.gov/ghgp/main.do?site_preference=normal

Table 1: Timeline of important Greenhouse Gas Reporting Program events

Calendar Time	Event
2010-01-01	EPA launches the Greenhouse Gas Reporting Program (GHGRP), requiring large facilities to measure and report annual facility-level GHG emissions.
2012-01-11	Facility-level GHG data for calendar year 2010 released to the public for the first time.
2012-02-22	Revised facility-level GHG data for calendar year 2010 released following EPA verification adjustments.
2013-02-05	Facility-level GHG data for calendar year 2011 released to the public.
2013-10-23	Facility-level GHG data for calendar year 2012 released.
2014-09-30	Facility-level GHG data for calendar year 2013 released.
2015-10-05	Facility-level GHG data for calendar year 2014 released.
2016-10-03	Facility-level GHG data for calendar year 2015 released.
2017-10-04	Facility-level GHG data for calendar year 2016 released.
2018-10-17	Facility-level GHG data for calendar year 2017 released.
2019-10-03	Facility-level GHG data for calendar year 2018 released.
2020-11-09	Facility-level GHG data for calendar year 2019 released.
2021-10-06	Facility-level GHG data for calendar year 2020 released.
2022-10-17	Facility-level GHG data for calendar year 2021 released.
2023-10–05	Facility-level GHG data for calendar year 2022 released.

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

Before the implementation of the GHGRP, many U.S. firms voluntarily disclosed their firm-level GHG emissions in response to growing pressure from shareholders, institutional investors, regulators, consumers, and the broader public. These disclosures served as a means of signaling environmental accountability and responding to rising expectations for climate transparency. A central catalyst for voluntary reporting was the Carbon Disclosure Project (CDP), a global non-profit initiative that collects detailed emissions information through annual surveys.[9] As of 2021, more than 80% of S&P 500 firms—representing over $28 trillion in market capitalization—voluntarily disclosed GHG emissions through CDP or corporate sustainability channels such as annual reports, ESG data sheets, and standalone sustainability reports.[10]

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

[10] https://www.cdp.net/en/articles/investor/the-future-of-corporate-climate-action-sp-500-firms-assessing-risks-and-financial-benefits-of-transition

To isolate the effects of GHGRP regulation, this study focuses on firms that voluntarily disclosed firm-level GHG emissions around GHGRP adoption. Although this restriction narrows the sample and may limit external generalizability, it is essential for credible identification: only firms with consistent voluntary reporting histories provide valid, comparable, and behaviorally meaningful measures of firm-level emissions over time. These firms constitute the only sample in which GHGRP-induced changes in emissions can be causally inferred.

Importantly, I exclude vendor-estimated emissions data for several reasons. First, third-party vendor estimates frequently diverge from firm-reported figures and introduce measurement error due to proprietary, "black-box" modeling techniques that often impute emissions based on firm fundamentals (Aswani et al. (2023)). Second, vendor data are commercial products subject to reporting lags, reducing their usefulness for analyzing real-time market responses (Zhang (2024)). Third, Zhang documents an almost one-to-one correlation between log-transformed vendor-estimated emissions and firm sales, suggesting that such estimates primarily proxy for firm size rather than operational emissions performance. By contrast, Aswani et al. show that this correlation does not appear in voluntarily disclosed emissions data, indicating systematic differences between vendor-based and firm-reported measures. Supporting this concern, Bauckloh et al. (2023) find that, when using vendor data, GHGRP-regulated firms do not exhibit larger absolute emissions reductions than unregulated peers, but do show greater declines in emissions intensity (emissions-to-sales ratios), complicating interpretation.

Taken together, these considerations highlight the advantages of focusing on self-reported emissions from firms with consistent disclosure behavior around GHGRP implementation. This empirical design leverages longitudinal voluntary reporting while avoiding the measurement distortions inherent in estimated or proprietary datasets, thereby strengthening the credibility of the causal inference.

4.3 Data

The data used in this study are drawn from multiple sources. The sample consists of U.S. publicly listed firms from 2007 to 2022 that voluntarily disclosed greenhouse gas (GHG) emissions around the implementation of the Greenhouse Gas Reporting Program (GHGRP). Firm-level GHG emissions, measured in metric tons of CO_2-equivalent (tCO_2e), are obtained from Refinitiv Eikon, which compiles emissions data using a hierarchical sourcing protocol. Refinitiv prioritizes companies' self-reported ("Reported") emissions; when these are unavailable, emissions are estimated using CO_2-specific models, energy-consumption metrics, or median-based imputation. To ensure accuracy and consistency, this study exclusively uses observations classified as "Reported." In cases where multiple reported values are available for the same firm-year, I compute their average. The emissions data were collected in April 2022. To focus on economically meaningful emitters and reduce noise from small or sporadic reporters, I exclude firm–year observations with total emissions below 10,000 tCO_2e. Firm financial and accounting characteristics are obtained from Compustat and matched by aligning fiscal years with the corresponding calendar years of the firm-level emissions data.

Annual facility-level emissions data—including production quantities, subpart classifications, geographic location, and ownership information—are sourced from the U.S. Environmental Protection Agency's FLIGHT database.[11] Each FLIGHT record corresponds to a unique facility–year observation, covering calendar years 2010–2022. To construct an economically meaningful dataset, I retain only facility–year observations with strictly positive emissions and non-missing parent-entity identifiers, thereby excluding inactive or negligible reporters. Because a nontrivial share of facilities is jointly owned by multiple parent firms, allocating facility-level emissions to firms requires a consistent attribution rule. Following the Greenhouse Gas Protocol Corporate Standard (World Resources Institute and World Business Council for Sustainable Development (2004)), I adopt the equity-share approach, which attributes emissions to parent firms proportionally to their ownership shares. This method

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

aligns with the GHGRP's reporting structure, which provides verified ownership percentages but does not disclose operational-control arrangements. Although the Greenhouse Gas Protocol permits an operational-control approach, it cannot be implemented here due to the absence of information on control rights or governance responsibilities in the GHGRP data. The equity-share method therefore ensures transparency, reproducibility, and consistency with the economic-exposure concept most relevant for market-valuation analyses. In practice, the distinction between the equity-share and operational-control approaches has little quantitative impact in this setting. Among large publicly listed firms (e.g., Exxon Mobil[12]), firms frequently report emissions under both attribution frameworks, and the reported values are generally very close. This similarity suggests that ownership-based allocation closely approximates operational control for the types of facilities covered by the GHGRP. In the raw FLIGHT data, there are 105,627 facility–year observations, of which 6,191 (5.86 percent) are jointly owned and 82,926 (93.99 percent) are solely owned. These facilities collectively emit 32.94 billion tCO_2e. Applying equity-share allocation yields 90,924 ownership-weighted facility–year observations with total emissions of 32.99 billion tCO_2e—only 0.16 percent higher than the raw total—demonstrating internal consistency in EPA ownership reporting and validating the proportional-allocation procedure. To prevent misallocation, I exclude 195 facility–year groups in which reported ownership shares exceed 120 percent. The final facility-level dataset contains 90,729 ownership-weighted facility–year observations. Facility-level emissions are then aggregated to the parent-company level. Parent-entity names are standardized and manually verified to ensure consistency across years and facility identifiers. A parent–year observation represents the sum of equity-weighted emissions across all facilities in which the parent holds an ownership stake. Consistent with the firm-level exclusion rule, I also exclude parent–year observations with total aggregated facility-level emissions below 10,000 tCO_2e. These procedures yield a firm-level panel of 3,715 firm–year observations containing total verified facility-level emissions and the number of regulated facilities

[12] https://corporate.exxonmobil.com/sustainability-and-reports/metrics-and-data#Greenhousegasemissionsperformancedata1

owned.

The main analysis dataset is constructed by merging fiscal-year firm characteristics for firms that voluntarily disclose GHG emissions with calendar-year facility-level GHG disclosures. Restricting the sample to voluntary disclosers ensures the availability of firm-level emissions data and allows construction of verified firm-wide emissions measures. This merge generates the policy variable of interest, GHGRP, defined as an indicator equal to one beginning in the year a firm first becomes subject to GHGRP reporting requirements and zero otherwise. While the analysis sample is limited to voluntary disclosing firms, the timing of GHGRP exposure within this sample is driven by facility-level regulatory eligibility—specifically, when a firm first owns or operates a facility exceeding the reporting threshold—rather than by firms' disclosure decisions. As a result, treatment timing varies across firms in a staggered manner that is plausibly exogenous to firm-level emissions outcomes, conditional on sample inclusion. Firms are matched to CRSP identifiers (PERMNO) via the CRSP/Compustat Merged Database (CCM), enabling integration with stock-return data from CRSP. Analyst coverage data are obtained from I/B/E/S, and institutional ownership data are sourced from Thomson Reuters 13F filings.

To measure firm-level climate concerns, I use the publicly available dataset developed by Sautner et al. (2023), which employs machine learning to quantify climate-related exposure based on earnings-call transcripts. The dataset identifies climate-related keywords and measures their frequency, producing firm-year climate-salience measures that I aggregate by PERMNO and calendar year.

To analyze firm-level green innovation, I use U.S. patent data from the United States Patent and Trademark Office (USPTO), linked to public firms via the concordance developed by Kogan et al. (2017). Following prior research (e.g., Cohen et al. (2024), Chen et al. (2023)), I identify low-carbon innovation using the Cooperative Patent Classification (CPC) Y02 class, which captures technologies related to environmental sustainability and climate change mitigation. Patent applications are aggregated by PERMNO and year to align them

with financial and regulatory data.

For the event-study analysis, daily stock returns are sourced from CRSP, and factor returns are obtained from Kenneth French's data library. Environmental ratings data are drawn from MSCI ESG ratings, specifically the Environment Pillar, which assesses metrics related to carbon emissions, climate change exposure, and raw-materials sourcing.

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, and raw material sourcing. The MSCI dataset provides an independent assessment of firms' environmental performance.

In total, the final merged dataset comprises 5,224 firm–year observations for 767 unique firms (GVKEY) over the period 2007–2022.

4.4 Descriptive Statistics

Table 2 reports descriptive patterns for the main variables used in the analysis. Verified firm-wide emissions, $\ln(E^{ver})$, have a mean of 12.93 (STD = 2.16) and a median of 12.63, indicating substantial cross-sectional dispersion in emissions intensity across firms. The policy indicator GHGRP has a mean of 0.26 and a median of 0, reflecting staggered exposure to facility-level disclosure regulation. Regulator-verified facility emissions, ln(FacilityE), exhibit pronounced heterogeneity (mean = 3.50, STD = 6.07), with a median of 0 because many firms do not operate GHGRP-covered facilities. Climate-related communication (ClimateConcerns) varies widely across firms (mean = 1.92, STD = 4.03), while low-carbon innovation remains limited: ln(LowCarbonPatents) has a mean of 0.40 and a median of 0, indicating that most firms do not engage in patenting related to low-carbon technologies. Environmental performance, measured by EnvironmentScore, averages 5.18 (STD = 2.15), suggesting meaningful dispersion in environmental ratings. Firm fundamentals display expected patterns. Size has a mean of 9.33, while BM averages 0.53. Intangible intensity (AI) has a mean of 0.62, leverage averages 0.31, cash holdings 0.12, and profitability (ROA) 0.12.

Dividend payouts are modest (mean = 0.02), institutional ownership is high on average (IO = 0.80), and analyst coverage shows moderate variation (mean = 2.58). Overall, the summary statistics reveal substantial heterogeneity in emissions, climate-related communication, innovation activity, and firm characteristics, consistent with the empirical setting studied in the paper.

Table 3 reports pairwise correlations among the main variables. Verified emissions, $\ln(E^{ver})$, are strongly positively correlated with GHGRP (0.53), ln(FacilityE) (0.58), Size (0.42), and AI (0.47), consistent with scale effects and operational intensity. $\ln(E^{ver})$ is also moderately correlated with ClimateConcerns (0.33) and analyst coverage (0.18), suggesting greater disclosure and market attention for high-emission firms. Correlations with profitability, cash holdings, dividends, and institutional ownership are small in magnitude. EnvironmentScore exhibits weak correlations with emissions measures, indicating that ESG ratings capture dimensions beyond raw emissions levels. Overall, most correlations are below $|0.30|$, suggesting limited multicollinearity in the multivariate analysis.

Table 2: Summary Statistics

	Obs	Mean	STD	Median
$\ln(E^{ver})$	5224	12.93	2.16	12.63
GHGRP	5224	0.26	0.44	0.00
ln(FacilityE)	5224	3.50	6.07	0.00
ClimateConcerns	5224	1.92	4.03	0.50
ln(1+LowCarbonPatents)	5224	0.40	0.99	0.00
EnvironmentScore	4726	5.18	2.15	5.00
Size	5223	9.33	1.49	9.16
BM	5047	0.53	0.50	0.42
AI	4770	0.62	0.53	0.50
Leverage	5223	0.31	0.18	0.30
Cash	5223	0.12	0.12	0.07
ROA	4969	0.12	0.10	0.12
Dividend	5206	0.02	0.04	0.01
IO	4885	0.80	0.19	0.83
Analysts	5185	2.58	0.65	2.71

This table reports descriptive statistics for the key variables used in the analysis. The dependent variable, $ln(E^{ver})$, is the natural logarithm of verified firm-wide greenhouse gas emissions, defined as $E^{\text{ver}} = \max\{\text{FirmE, FacilityE}\}$, where FirmE denotes voluntarily disclosed firm-level emissions and FacilityE denotes the aggregate of facility-level emissions reported under the GHGRP, measured in metric tons of CO_2-equivalent (CO_2e). The main policy variable, GHGRP, is an indicator equal to one beginning in the year a firm becomes subject to the GHGRP reporting mandate and zero otherwise. ln(FacilityE) is the natural logarithm of a firm's total regulator-verified facility-level emissions, providing a granular measure of emissions exposure derived from the GHGRP database. ClimateConcerns captures climate-related attention based on the machine-learning measure of Sautner et al. (2023), constructed from the frequency of climate-related terms in earnings-call transcripts (scaled by 1,000). ln(1+LowCarbonPatents) is the natural logarithm of one plus the number of firm-level low-carbon patents, identified using the CPC Y02 classification for climate-mitigation technologies (Cohen et al. (2024), Chen et al. (2023)). EnvironmentScore is the MSCI Environment Pillar Score, reflecting firms' environmental performance, including emissions management and climate-related risks. SIZE is firm size measured as the natural logarithm of total assets. BM is the book-to-market ratio. AI (asset intensity) is property, plant, and equipment divided by total assets. Leverage is total debt divided by total assets, Cash is cash holdings divided by total assets, and ROA is return on assets. Dividend is total dividends divided by total assets. IO denotes institutional ownership, measured as the fraction of shares held by institutional investors, and Analysts is the natural logarithm of one plus the number of analysts issuing earnings forecasts during the year.

Table 3: Pearson Correlation

#	Variables	$\ln(E^{ver})$	2	3	4	5	6	7	8	9	10	11	12	13	14	15
2	GHGRP	**0.53**	1	**0.98**	**0.27**	**0.16**	**-0.21**	**0.14**	**0.11**	**0.32**	**0.09**	**-0.18**	**-0.05**	0.00	**-0.10**	**0.04**
3	ln(FacilityE)	**0.58**	**0.98**	1	**0.33**	**0.15**	**-0.22**	**0.16**	**0.13**	**0.35**	**0.10**	**-0.20**	**-0.06**	-0.00	**-0.11**	**0.04**
4	ClimateConcerns	**0.33**	**0.27**	**0.33**	1	**-0.03**	-0.02	0.01	**0.12**	**0.18**	**0.08**	**-0.18**	**-0.13**	**-0.05**	**-0.13**	**-0.14**
5	ln(LowCarbonPatents)	**0.17**	**0.16**	**0.15**	**-0.03**	1	**0.09**	**0.28**	**-0.11**	**-0.12**	**-0.11**	**0.23**	**0.10**	**0.05**	**-0.17**	**0.26**
6	EnvironmentScore	**-0.15**	**-0.21**	**-0.22**	-0.02	**0.09**	1	**0.21**	**-0.16**	**-0.29**	-0.01	**0.12**	**0.08**	**0.07**	-0.03	**0.14**
7	Size	**0.42**	**0.14**	**0.16**	0.01	**0.28**	**0.21**	1	**0.11**	**-0.07**	**-0.07**	**-0.03**	**-0.10**	**-0.05**	**-0.21**	**0.52**
8	BM	**0.14**	**0.11**	**0.13**	**0.12**	**-0.11**	**-0.16**	**0.11**	1	**0.24**	**-0.08**	**-0.23**	**-0.31**	**-0.19**	**-0.05**	**-0.18**
9	AI	**0.47**	**0.32**	**0.35**	**0.18**	**-0.12**	**-0.29**	**-0.07**	**0.24**	1	**0.18**	**-0.29**	**-0.10**	**-0.06**	**-0.11**	**-0.11**
10	Leverage	**0.14**	**0.09**	**0.10**	**0.08**	**-0.11**	-0.01	**-0.07**	**-0.08**	**0.18**	1	**-0.24**	**-0.06**	**0.04**	-0.00	**-0.16**
11	Cash	**-0.29**	**-0.18**	**-0.20**	**-0.18**	**0.23**	**0.12**	**-0.03**	**-0.23**	**-0.29**	**-0.24**	1	**0.13**	**0.03**	**0.05**	**0.25**
12	ROA	-0.03	**-0.05**	**-0.06**	**-0.13**	**0.10**	**0.08**	**-0.10**	**-0.31**	**-0.10**	**-0.06**	**0.13**	1	**0.07**	-0.02	**0.14**
13	Dividend	0.02	0.00	-0.00	**-0.05**	**0.05**	**0.07**	**-0.05**	**-0.19**	**-0.06**	**0.04**	**0.03**	**0.07**	1	**-0.16**	**0.04**
14	IO	**-0.24**	**-0.10**	**-0.11**	**-0.13**	**-0.17**	-0.03	**-0.21**	**-0.05**	**-0.11**	-0.00	**0.05**	-0.02	**-0.16**	1	**-0.08**
15	Analysts	**0.18**	**0.04**	**0.04**	**-0.14**	**0.26**	**0.14**	**0.52**	**-0.18**	**-0.11**	**-0.16**	**0.25**	**0.14**	**0.04**	**-0.08**	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.

5 Empirical Analysis

5.1 Firm-Level Real Effects

Empirical Design To estimate the firm-wide consequences of verified emissions disclosure, I employ a generalized difference-in-differences (DiD) design following Bertrand & Mullainathan (2003). Although the GHGRP formally took effect on January 1, 2010, firm-level exposure in my analysis is defined in two steps. First, the analysis sample is restricted to firms that voluntarily disclose firm-level GHG emissions. This restriction is necessary to observe firm-wide emissions outcomes and to construct verified emissions measures, which in turn allows causal inference on how facility-level disclosure regulation translates into firm-wide emissions behavior. For example, Exxon Mobil starts disclosing firm-level emissions in 2007, whereas Phillips 66 begins disclosure in 2014. Second, within this sample of voluntary disclosers, treatment timing is determined by when a firm first owns or operates a facility that exceeds the GHGRP reporting threshold. This timing is driven by the evolution of firms' facility portfolios rather than by their disclosure choices. For instance, both Exxon Mobil and Phillips 66 become subject to GHGRP reporting in 2010, while Analog Devices Inc. first enters GHGRP coverage in 2011. Because firms begin voluntarily disclosing firm-level emissions at different points in time and subsequently cross the GHGRP reporting threshold as their facility portfolios evolve, entry into GHGRP coverage occurs in a staggered manner across firms. This staggered adoption structure generates quasi-exogenous variation in regulatory entry, enabling identification of dynamic behavioral responses as firms transition into the disclosure regime at different points in time. This firm-level variation in regulatory timing contrasts with prior studies (e.g., Yang et al. (2021), Tomar (2022), Bartram et al. (2022), Bauckloh et al. (2023)), which primarily focus on facility-level outcomes or treat the GHGRP as a uniform policy shock.

The main estimating equation is:

$$ln(E_{ft}^{ver}) = \alpha_f + \alpha_{it} + \boldsymbol{\gamma}' X_{ft} + \beta\, GHGRP_{ft} + \epsilon_{ft} \tag{16}$$

where f indexes firms, i denotes the GICS-6 industry classification, and t represents fiscal years. The dependent variable, $ln(E_{ft}^{ver})$, is the natural logarithm of verified firm-wide GHG emissions, defined as $E^{\text{ver}} = \max\{\text{FirmE, FacilityE}\}$, where FirmE denotes voluntarily disclosed firm-level emissions and FacilityE denotes the aggregate of facility-level emissions reported under the GHGRP. This construction reflects the role of granular transparency regulation in setting a binding lower bound on firms' reported emissions, thereby revealing the firm's true corporate climate impact even when voluntary firm-level disclosures understate emissions at regulated facilities. The logarithmic transformation facilitates interpretation in percentage terms and mitigates the influence of outliers. The key explanatory variable, $GHGRP_{ft}$, equals one in the first year the firm becomes subject to GHGRP reporting and remains one thereafter. To examine dynamic adjustments, I also estimate specifications including two-year lags of the treatment indicator.

Control variables include firm size, book-to-market ratio, asset intensity, leverage, institutional ownership, analyst coverage, cash holdings, and profitability. Firm fixed effects absorb time-invariant heterogeneity, while industry-by-year fixed effects control for sector-specific shocks, evolving regulatory expectations, and macroeconomic trends. Standard errors are clustered at the firm level.

Main Results The empirical results provide strong support for Prediction P1: credible, regulator-verified disclosure leads to meaningful reductions in firm-wide GHG emissions. Table X reports baseline difference-in-differences estimates of changes in verified firm-level emissions around GHGRP entry. In Column (1), the contemporaneous GHGRP indicator is small and statistically insignificant (–0.03, t = –0.42), indicating that firms do not immediately adjust their verified emissions upon entering GHGRP coverage. This muted short-run

response is consistent with the institutional features of the program: facility-level emissions become publicly observable only after EPA verification and release, delaying both stakeholder scrutiny and managerial responses. Column (2) reveals a clear delayed adjustment. When allowing for dynamic effects, the contemporaneous GHGRP coefficient becomes negative and statistically significant (–0.14, t = –3.93), implying that firms reduce voluntarily disclosed firm-level emissions by roughly 14 percent following entry into GHGRP coverage. This effect is economically meaningful and consistent with the model's mechanisms. Under the external stakeholder discipline channel, verified facility-level disclosures expose inconsistencies between firm-level claims and underlying emissions, increasing the costs of greenwashing. Under the internal managerial learning channel, granular facility-level data redirect managerial attention toward emissions abatement. Taken together, the results indicate that verified, bottom-up transparency induces substantive firm-wide emissions reductions, but only after disclosure becomes salient and actionable—highlighting the dynamic nature of firms' responses to credible environmental regulation.

Dynamic Effects A central identification assumption in the difference-in-differences framework is the parallel trends assumption—that, absent treatment, emissions trajectories of treated and control firms would have evolved similarly. To assess this assumption and to examine the temporal pattern of the treatment effect, I estimate an event-study specification that traces firm-level emissions dynamics around the timing of GHGRP entry:

$$ln(E_{ft}^{ver}) = \alpha_f + \alpha_{it} + \boldsymbol{\gamma}' X_{ft} + \sum_{T=-2}^{T=+7} \beta_T \, GHGRP_{ft}(T) + \epsilon_{ft} \tag{17}$$

where $GHGRP_{ft}(T)$ is a set of mutually exclusive event-time indicators equal to one if firm f is T years away from its first year of GHGRP coverage.

Figure 1 plots the estimated event-time coefficients. The pre-treatment coefficients at T=−2 and T=−1 are small and statistically indistinguishable from zero, providing no evidence of differential pre-trends between treated and control firms and supporting the parallel

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

	$ln(E_{ft}^{ver})$	
	(1)	(2)
GHGRP(0)	-0.03	
	(-0.42)	
GHGRP(+2)		-0.14***
		(-3.93)
Size	0.24***	0.27***
	(3.44)	(3.86)
BM	0.10***	0.09***
	(3.28)	(3.23)
AI	0.09	0.14
	(0.59)	(0.89)
Leverage	-0.35**	-0.33**
	(-2.22)	(-2.16)
Cash	-0.29**	-0.28*
	(-1.97)	(-1.93)
ROA	0.37***	0.37**
	(2.65)	(2.56)
Dividend	0.10	0.15
	(0.47)	(0.73)
IO	-0.05	-0.00
	(-0.33)	(-0.03)
Analysts	-0.09	-0.08
	(-1.36)	(-1.31)
Observations	4,443	4,443
Adjusted R-squared	0.978	0.978
Firm FE	Yes	Yes
Industry-Year FE	Yes	Yes

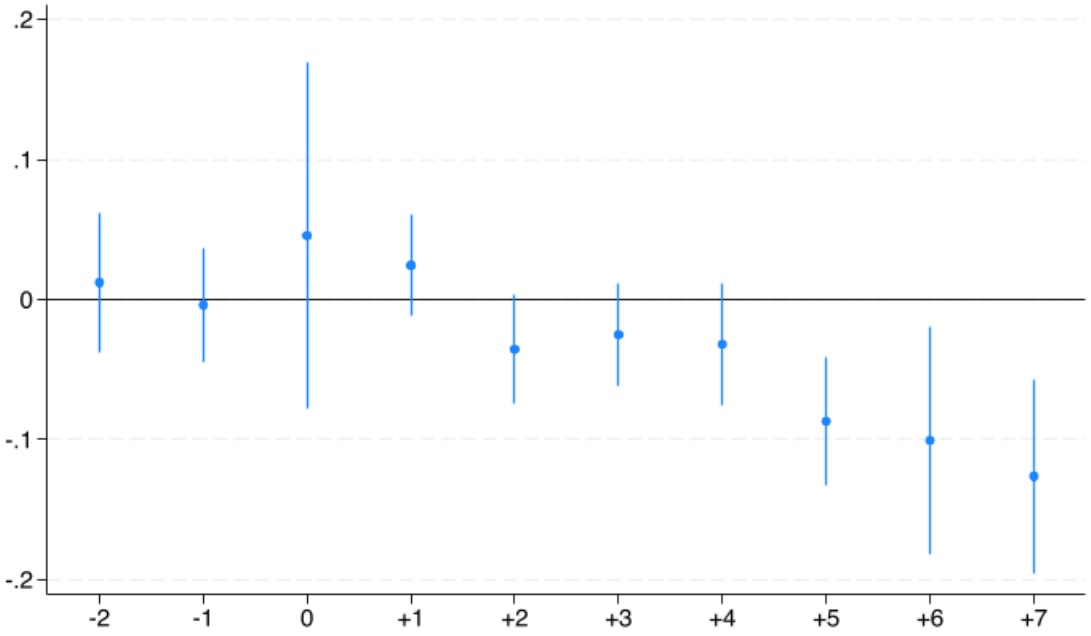
This table reports the estimated impact of the GHGRP on firm-level GHG emissions using a staggered difference-in-differences design. The dependent variable is the natural logarithm of verified firm-wide emissions. GHGRP equals 1 beginning in the first year a firm becomes subject to the reporting mandate—based on when it first owns or operates a facility exceeding the regulatory threshold—and remains 1 thereafter. This staggered structure allows identification from firm-specific timing of entry. To assess dynamic adjustments, specifications also include lagged treatment indicators. Control variables include size, book-to-market, asset intensity, leverage, cash, profitability, institutional ownership, and analyst coverage. All regressions include firm fixed effects and industry-year fixed effects. Standard errors are clustered at the firm level. ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

trends assumption. Around the time of regulatory entry (T=0 and T=+1), the coefficients remain close to zero, indicating little immediate adjustment in firm-level emissions. Beginning at T=+2, the coefficients turn negative and remain consistently below zero through T=+7, with the magnitude of the decline increasing over time. By five to seven years after entry, the estimated reductions are economically meaningful, approaching 10–13 percent relative to baseline emissions. This pattern indicates that firms respond gradually to GHGRP exposure, rather than through anticipatory behavior or a one-time adjustment at entry. Overall, the dynamic profile is consistent with a delayed firm-wide response to verified, facility-level disclosure. Once regulator-verified emissions data become public and salient, stakeholders can discipline inconsistencies between firm-level claims and facility-level outcomes, and managers gain granular information that redirects attention toward emissions abatement. The results therefore support a gradual adjustment mechanism driven by verification and learning, rather than immediate compliance or signaling effects.

Validation Using Goodman-Bacon Decomposition Recent methodological advances (e.g., Baker et al. (2022)) highlight that two-way fixed effects (TWFE) estimators may be biased in settings with staggered treatment timing—such as the GHGRP—when treatment effects are heterogeneous across cohorts. In such cases, already-treated units may serve as controls for not-yet-treated units, generating contaminated comparisons and potentially distorting the estimated average treatment effect. To assess whether this concern affects the baseline DiD results, I implement the Goodman-Bacon (2021) decomposition, which expresses the TWFE estimate as a weighted average of all underlying 2×2 DiD comparisons between treatment-timing cohorts.

Table 5 reports the results. The decomposition reveals that 98.4% of the total weight is placed on comparisons between treated firms and never-treated firms, which represent the cleanest and least contaminated identification source in a staggered adoption setting. These "never vs. timing" comparisons yield an average effect of –0.104, closely matching the overall

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



This figure presents event-study estimates tracing the dynamics of firm-level GHG emissions around the timing of GHGRP exposure. The dependent variable is the natural logarithm of firm-level emissions. Event-time indicators $GHGRP_{ft}(T)$ capture years relative to a firm's first year of GHGRP coverage, with T=−2 and T=−1 serving as pre-treatment periods, T = 0 T=0 as the treatment year, and T=+1 through T=+6 as post-treatment years. The plotted coefficients show how emissions evolve before and after regulatory entry, relative to the pre-treatment baseline, with 95% confidence intervals illustrating statistical precision.

Table 5: Goodman-Bacon Decomposition of TWFE Estimate

Overall TWFE Estimate		
Variable	**Coefficient**	**Std. Error**
GHGRP(+2)	–0.097***	0.036
Comparison Type	β	**Weight**
Early vs. Late	–0.019	0.003
Late vs. Early	0.264	0.004
Early vs. Late	0.673	0.005
Late vs. Early	0.179	0.005
Early vs. Late	0.110	0.000
Late vs. Early	–0.438	0.000
Never vs. Timing	–0.104	0.984

This table reports the Goodman-Bacon (2021) decomposition of the two-way fixed effects estimate for the impact of GHGRP (+2) on the natural logarithm of firm-level emissions. The decomposition expresses the TWFE estimate as a weighted average of all possible 2X2 DiD comparisons across treatment cohorts and the never-treated group.

TWFE estimate. By contrast, comparisons among early- and late-treated cohorts receive negligible weights—each below 0.5%—despite exhibiting more variable coefficient estimates. Because these early–late and late–early comparisons contribute virtually no weight to the aggregate estimator, they do not materially influence the overall result. Taken together, the decomposition indicates that the estimated treatment effect is overwhelmingly driven by comparisons to never-treated firms and is therefore unlikely to suffer from the negative weighting or contamination problems that can arise in staggered TWFE designs. The Goodman–Bacon decomposition thus reinforces the validity of the identification strategy and supports the reliability of the main DiD findings.

5.2 Ruling Out Alternative Explanations

A central question is whether the observed decline in firm-wide emissions following GHGRP adoption reflects genuine organization-wide abatement or instead arises from narrower, mechanical mechanisms confined to GHGRP-reporting facilities. I evaluate two leading alternative explanations—pure localization and mechanical redistribution across reporting boundaries—which correspond directly to Predictions P2a and P2b.

Pure Localization Under pure localization, firms respond to GHGRP solely by abating emissions at facilities directly subject to the reporting mandate, with no adjustments occurring elsewhere in the organization. If this hypothesis holds, then conditioning on emissions from GHGRP-covered facilities should absorb the entire treatment effect on verified firm-wide emissions.

$$ln(E_{ft}^{ver}) = \alpha_f + \alpha_{it} + \boldsymbol{\gamma}' X_{ft} + \beta_1 \, GHGRP_{ft}(+2) + \beta_2 \, ln(facilityE_{ft}) + \epsilon_{ft} \tag{18}$$

where ln(FacilityE) captures regulator-verified emissions from GHGRP-covered facilities. If abatement occurs only at regulated sites, the inclusion of ln(FacilityE) should eliminate the estimated treatment effect, causing β_1 to collapse toward zero.

Residual (Noncovered) Emissions Response A second concern is that the estimated treatment effect reflects a mechanical redistribution of emissions across reporting boundaries, rather than meaningful changes in emissions behavior. To examine this possibility, I study the response of noncovered emissions, defined as the positive difference between verified firm-wide emissions and facility-level emissions and mechanically zero when facility-level emissions exceed firm-level disclosures. This measure captures the residual component of firm-wide emissions not accounted for by GHGRP-covered facilities.

Formally, noncovered emissions are defined as:

$$E_{ft}^{\text{NonCovered}} \equiv \max\left\{E_{ft}^{\text{ver}} - \text{FacilityE}_{ft},\, 0\right\}, \tag{19}$$

and the dependent variable is the logarithmic transformation and I estimate:

$$ln(1 + E_{ft}^{\text{NonCovered}}) = \alpha_f + \alpha_{it} + \boldsymbol{\gamma}' X_{ft} + \beta_1 \, GHGRP_{ft}(+2) + \varepsilon_{ft} \tag{20}$$

If the decline in firm-wide emissions were driven purely by mechanical coverage effects or accounting reallocation at regulated facilities, GHGRP exposure would have no effect on

noncovered emissions. Instead, the estimated coefficient on $\text{GHGRP}_{ft}(+2)$ is negative and statistically significant, indicating that GHGRP entry reduces the extent to which verified firm-wide emissions exceed facility-level emissions.

Column (1) of Table 6 evaluates whether the decline in firm-wide emissions following GHGRP adoption can be explained solely by abatement at facilities directly subject to the reporting mandate. Conditioning explicitly on regulator-verified facility-level emissions, ln(FacilityE), the coefficient on GHGRP(+2) remains negative and highly statistically significant (–0.17, t = –4.26), while the coefficient on ln(FacilityE) is small and statistically insignificant. In economic terms, this estimate implies that firms reduce verified firm-wide emissions by approximately 16–17 percent within two years of entering GHGRP coverage, even after holding constant emissions from regulated facilities. The persistence of a large and significant treatment effect after conditioning on facility-level emissions rules out pure localization as the sole explanation and indicates that emissions reductions are not mechanically driven by compliance at GHGRP-covered sites alone.

Column (2) examines the response of noncovered emissions, defined as the positive difference between verified firm-wide emissions and facility-level emissions. The estimated coefficient on GHGRP(+2) is –0.60 (t = –2.35), implying a roughly 45 percent reduction in the positive firm–facility emissions gap following GHGRP entry ($e^{-0.60} - 1 \approx -0.45$). This effect is economically large, indicating that GHGRP exposure substantially compresses the portion of firm-wide emissions that previously lay outside the scope of facility-level reporting. Because noncovered emissions are mechanically zero for underreporting firms, the estimate reflects both extensive-margin adjustments, in which firms eliminate the firm–facility gap entirely, and intensive-margin reductions among firms with remaining positive gaps. Although the percentage reduction in noncovered emissions is larger than the corresponding reduction in total emissions, noncovered emissions constitute only a subset of firm-wide emissions. As a result, a sharp contraction of the firm–facility emissions gap translates into a more moderate—but still economically meaningful—14–17 percent decline in total verified

emissions. Taken together, these findings indicate that GHGRP induces organization-wide emissions adjustments rather than narrow compliance or accounting-driven redistribution confined to regulated facilities.

Low-Carbon Innovation Linked to Verified Emission Abatement The model predicts that genuine, verified emissions abatement should be systematically linked to low-carbon innovation, and that this linkage should strengthen following firms's entry into the GHGRP. To evaluate this prediction, I examine whether reductions in verified firm-wide emissions are associated with increases in low-carbon innovation. Innovation is measured using USPTO patent data linked via Kogan et al. (2017), with low-carbon technologies identified through the CPC Y02 climate-mitigation classification (Cohen et al. (2024), Chen et al. (2023)). Because CPC Y02 patents require substantial capital investment, technical expertise, and sustained managerial attention, they provide a stringent test of substantive organizational adaptation rather than symbolic or purely localized compliance.

I estimate the following contemporaneous specification:

$$\ln\big(1+\text{LowCarbonPatents}_{ft}\big) = \alpha_f + \alpha_{it} + \boldsymbol{\gamma}' X_{ft} + \beta_1 \, GHGRP_{ft} + \beta_2^{-} \, \Delta^{-} E_{ft}^{\text{ver}} + \beta_3^{-} \, \big(GHGRP_{ft} \times \Delta^{-} E_{ft}^{\text{ver}}\big) + \varepsilon_{ft}, \tag{21}$$

where $\Delta^{-} E_{ft}^{\text{ver}}$ captures the negative (abatement) component of changes in verified firm-wide emissions. Verified emissions changes are measured as the year-over-year percentage change,

$$\Delta E_{ft}^{\text{ver}} \equiv \frac{E_{f,t}^{\text{ver}} - E_{f,t-1}^{\text{ver}}}{E_{f,t-1}^{\text{ver}}}, \tag{22}$$

and decomposed into negative (abatement) and positive components:

$$\Delta^{-} E_{ft}^{\text{ver}} = \begin{cases} \Delta E_{ft}^{\text{ver}}, & \text{if } \Delta E_{ft}^{\text{ver}} < 0, \\ 0, & \text{otherwise,} \end{cases} \qquad \Delta^{+} E_{ft}^{\text{ver}} = \begin{cases} \Delta E_{ft}^{\text{ver}}, & \text{if } \Delta E_{ft}^{\text{ver}} > 0, \\ 0, & \text{otherwise.} \end{cases} \tag{23}$$

Table 6: Ruling Out Facility-Level Compliance as Sole Explanation for Verified Firm-Level Emissions Reductions

	(1) $\ln(E^{ver})$	(2) $ln(1 + E_{ft}^{\text{NonCovered}})$
GHGRP(+2)	-0.17***	-0.60**
	(-4.26)	(-2.35)
ln(facilityE)	0.01	
	(1.09)	
Size	0.26***	0.31
	(3.76)	(1.63)
BM	0.09***	0.16
	(3.27)	(0.89)
AI	0.13	0.22
	(0.90)	(0.48)
Leverage	-0.33**	-0.82*
	(-2.15)	(-1.85)
Cash	-0.29*	-0.20
	(-1.96)	(-0.46)
ROA	0.38**	0.86
	(2.57)	(0.95)
Dividend	0.15	0.94
	(0.75)	(1.58)
IO	-0.01	-0.67
	(-0.05)	(-1.40)
Analysts	-0.09	-0.05
	(-1.38)	(-0.35)
Observations	4,443	4,443
Adjusted R-squared	0.978	0.670
Firm FE	Yes	Yes
Industry-Year FE	Yes	Yes

This table examines whether the firm-wide emissions reductions attributed to the GHGRP can be explained by alternative mechanical mechanisms. Column (1) tests the *pure localization* hypothesis by conditioning on regulator-verified facility-level emissions, ln(FacilityE); if abatement were confined to GHGRP-covered facilities, the coefficient on GHGRP(+2) would collapse toward zero once ln(FacilityE) is included. Column (2) examines the response of *noncovered emissions* ($ln(1 + E_{ft}^{\text{NonCovered}})$), which captures the positive firm–facility emissions gap and is mechanically zero when facility-level emissions exceed firm-level disclosures. Firm and industry-year fixed effects are included in all specifications, and standard errors are clustered at the firm level. ***, **, and * denote significance at the 1%, 5%, and 10% levels.

Thus, $\Delta^{-}E_{ft}^{\text{ver}}$ isolates verified emissions reductions (abatement), while $\Delta^{+}E_{ft}^{\text{ver}}$ captures emissions increases and serves as a natural falsification benchmark.

Table 7 reports the results. Column (1) shows that the interaction between GHGRP exposure and verified emissions abatement is positive and statistically significant (0.35, $t = 2.36$). Because the dependent variable is $\ln(1 + \text{LowCarbonPatents}_{ft})$, this coefficient is interpreted as a semi-elasticity: conditional on GHGRP exposure, a one-unit larger verified emissions reduction is associated with an approximately 35–42% increase in expected low-carbon patenting intensity ($e^{0.35} - 1 \approx 0.42$) relative to the pre-GHGRP period. This economically meaningful effect indicates that verified disclosure strengthens the alignment between emissions abatement and forward-looking innovation. Importantly, neither the main effect of GHGRP nor the standalone effect of emissions abatement is statistically significant. This pattern suggests that innovation does not mechanically increase upon regulatory entry or during generic emissions reductions. Instead, innovation responds specifically when abatement occurs under a verified disclosure regime, consistent with managerial learning and coordinated firm-wide responses rather than isolated compliance actions. As a falsification exercise, Column (2) replaces emissions reductions with the positive component of verified emissions changes, $\Delta^{+}E_{ft}^{\text{ver}}$. Neither the main effect of emissions increases nor its interaction with GHGRP is statistically significant. This absence of a relationship indicates that low-carbon innovation does not generally comove with emissions fluctuations, ruling out scale effects or coincident changes in production activity as alternative explanations. Taken together, the results show that verified disclosure links emissions abatement to forward-looking innovation, indicating that the GHGRP induces real organizational responses rather than symbolic or purely mechanical adjustments.

5.3 External Stakeholder Discipline

This section empirically evaluates Predictions P3a and P3b, which test the model's external stakeholder discipline mechanism. When regulator-verified GHGRP emissions exceed firms'

Table 7: Verified Firm-level Emissions Reductions and Low-Carbon Innovations

	(1)	(2)
	ln(1+LowCarbonPatents)	
GHGRP×$\Delta^- E_{ft}^{ver}$	0.35**	
	(2.36)	
GHGRP×$\Delta^+ E_{ft}^{ver}$		0.04
		(1.10)
GHGRP	-0.02	-0.04
	(-0.34)	(-0.80)
$\Delta^- E_{ft}^{ver}$	-0.03	
	(-0.62)	
$\Delta^+ E_{ft}^{ver}$		-0.01
		(-0.83)
Size	-0.15***	-0.14***
	(-3.10)	(-3.06)
BM	0.02	0.02
	(0.98)	(1.08)
AI	-0.16*	-0.16*
	(-1.92)	(-1.93)
Leverage	-0.25	-0.24
	(-1.28)	(-1.26)
Cash	0.28	0.28
	(1.07)	(1.08)
ROA	-0.19	-0.15
	(-1.23)	(-1.00)
Dividend	-0.65	-0.66
	(-1.30)	(-1.31)
IO	-0.19	-0.18
	(-1.64)	(-1.60)
Analysts	0.04	0.04
	(1.06)	(1.03)
Observations	4,443	4,443
Adjusted R-squared	0.824	0.824
Firm FE	Yes	Yes
Industry-Year FE	Yes	Yes

This table examines whether verified emissions changes following GHGRP exposure are associated with low-carbon innovation. The dependent variable is $\ln(1 + \text{LowCarbonPatents})$, the natural logarithm of one plus the number of firm-level low-carbon patents, constructed from USPTO patent data using Kogan et al. (2017) concordance and the CPC Y02 climate-mitigation classification (Cohen et al. (2024), Chen et al. (2023)). Year-over-year changes in verified firm-wide emissions are decomposed into reductions and increases, $\Delta^- E^{\text{ver}}$ and $\Delta^+ E^{\text{ver}}$. The interaction term $GHGRP \times \Delta^- E^{\text{ver}}$ tests whether emissions reductions are more strongly associated with low-carbon patenting following entry into the GHGRP. The interaction with emissions increases, $GHGRP \times \Delta^+ E^{\text{ver}}$, serves as a falsification test, as emissions increases should not be associated with innovation if the mechanism reflects abatement-driven capability building. All regressions include firm and industry-year fixed effects, with standard errors clustered at the firm level. ***, **, and * denote significance at the 1%, 5%, and 10% levels.

previously disclosed voluntary emissions, the resulting discrepancy constitutes a credibility shock. Because GHGRP emissions are regulator-verified and effectively noise-free, they provide a reliable benchmark for firms' true environmental footprints and the accuracy of prior disclosures. Upon disclosure, external stakeholders—including investors, ESG rating agencies, creditors, and regulators—update their beliefs about firms' environmental risk exposure and disclosure credibility. These belief revisions generate relational and reputational costs for firms revealed to have underreported emissions. The model predicts that such costs manifest along two observable dimensions. First, investors impose immediate market discipline through negative stock price reactions when verified emissions reveal prior underreporting (Prediction P3a). Second, non-investor stakeholders—most notably ESG rating agencies—impose reputational discipline through rating downgrades following GHGRP entry, with penalties that scale in the severity of revealed underreporting (Prediction P3b).

Market Discipline: Stock Price Responses to Verified Emissions Disclosure Prediction P3a states that firms identified as underreporters—those whose GHGRP-verified emissions exceed their prior voluntary disclosures—experience negative abnormal stock returns when verified emissions become public. I test this prediction using an event-study design centered on the EPA's annual GHGRP disclosure date.

Standard Event Study Following Campbell et al. (1998), expected returns for firm i on day t are estimated using the Fama–French three factors (Fama & French (1996)) and the momentum factor (Jegadeesh & Titman (1993), Carhart (1997):

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

where K_{it} is the benchmark return for firm i on day t.

Abnormal returns are then computed as:

$$e_{it} = R_{it} - K_{it}$$

and daily average abnormal returns are:

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

Cumulative abnormal returns over window (t_1,t_2) are:

$$CAR(t_1, t_2) = \sum_{\tau=t_1}^{t_2} AR_t$$

with test statistic:

$$T - statistics = \frac{CAR(t_1, t_2)}{[D * \sigma^2(AR_t)]^{1/2}}$$

where D is the number of days in the window and $\sigma^2(AR_t)$ is the variance of daily average abnormal returns.

Figure in Table 8 reveal a sharp divergence in stock market reactions between underreporting and overreporting firms. Underreporters experience economically large and statistically meaningful price declines across all event windows. The CAR for underreporters is –1.67% (t=−1.85) in the [–1,+1] window and grows monotonically as the window widens, reaching –2.13% (t=−2.76) in the [–4,+4] window. Although the number of underreporters is modest (N = 127), the effect is consistent across windows and increases in magnitude as additional post-disclosure days are included, indicating a persistent market penalty. In contrast, overreporters—firms whose voluntary emissions exceed GHGRP-verified emissions—exhibit CARs that are close to zero across all windows (–0.39% to –0.44%). While these estimates are statistically significant due to the much larger sample size (N = 1,211), their economic

magnitude is negligible. The price paths of overreporters remain essentially flat around the disclosure date. Taken together, these results provide strong support for Prediction P3a: investors respond sharply to credibility shocks—instances where verified information contradicts prior voluntary disclosures—rather than to emissions levels per se.

ESG Rating Responses to Regulation and Underreporters Prediction P3b examines whether ESG evaluators—specifically MSCI—incorporate GHGRP-verified emissions information into firms' environmental ratings. If external stakeholder discipline operates beyond financial markets, ESG penalties should be more severe when regulator-verified facility-level emissions reveal larger discrepancies relative to firms' prior voluntary disclosures.

To test this prediction, I estimate the following panel regression:

$$\text{EnvironmentScore}_{ft} = \alpha_f + \alpha_t + \boldsymbol{\gamma}' X_{ft} + \beta_1 \, GHGRP_{ft} + \beta_2 \left(GHGRP_{ft} \times \text{Underreporting}_{ft} \right) + \varepsilon_{ft} \tag{24}$$

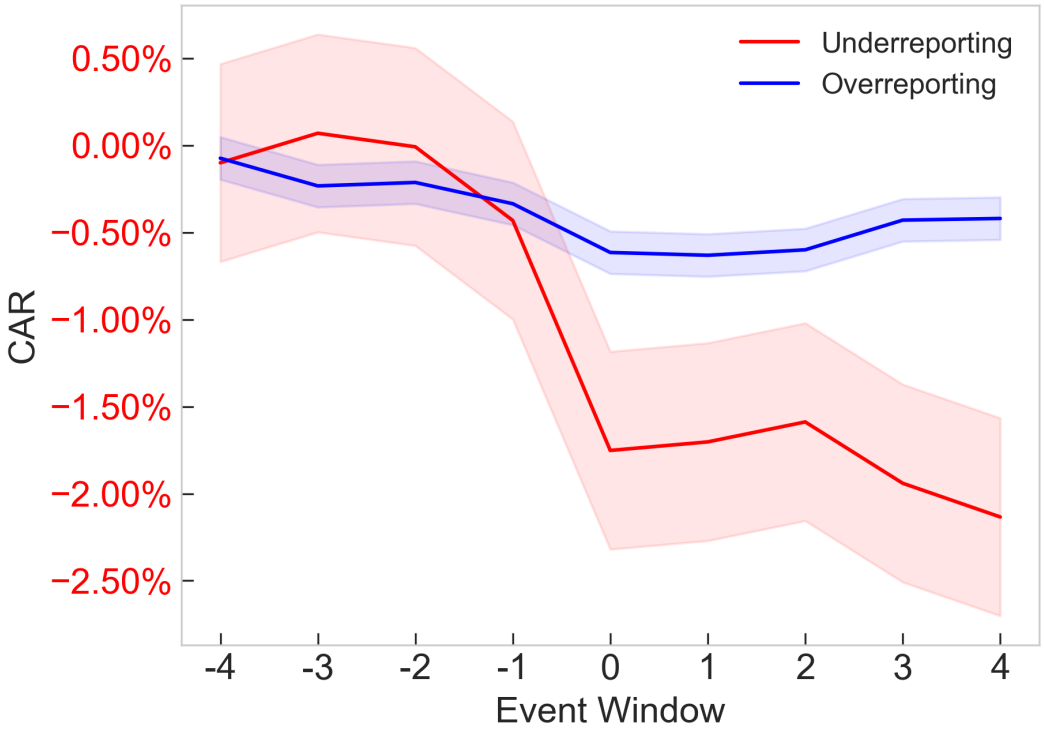
where $\text{EnvironmentScore}_{ft}$ is MSCI's environmental pillar score for firm f in year t, $GHGRP_{ft}$ is an indicator equal to one beginning in the year the firm enters GHGRP coverage, and $\text{Underreporting}_{ft}$ measures the extent to which voluntarily disclosed firm-level emissions fall short of regulator-verified facility-level emissions:

$$\text{Underreporting}_{ft} = \max \left\{ \frac{\text{FacilityE}_{ft} - \text{FirmE}_{ft}}{\text{FirmE}_{ft}}, \, 0 \right\}. \tag{25}$$

Table 9 reports results from two specifications that differ in their fixed-effects structure. Column (1) includes industry and year fixed effects, consistent with prior ESG ratings literature, which typically does not incorporate firm fixed effects. Column (2) includes firm fixed effects and industry-by-year fixed effects, identifying effects from within-firm variation over time. Across both specifications, the interaction term $GHGRP \times Underreporting$ is negative and statistically significant. In Column (1), the coefficient is -0.37 ($t = -2.92$), and in the more demanding specification in Column (2), it remains economically large and

Table 8: Market Reactions for Emissions Discrepancies

Underreporting				Overreporting			
Window	CAR	t-stat	N	Window	CAR	t-stat	N
[-1,1]	-1.67	-1.85	127	[-1,1]	-0.44	-3.84	1211
[-2,2]	-1.68	-1.87	127	[-2,2]	-0.40	-3.29	1211
[-3,3]	-1.87	-2.28	127	[-3,3]	-0.39	-2.85	1211
[-4,4]	-2.13	-2.76	127	[-4,4]	-0.42	-2.58	1211



This table reports event-study CARs around the initial release of GHGRP-verified facility-level emissions. Underreporting firms experience economically meaningful and statistically significant stock price declines across all event windows, while overreporting firms show CARs near zero.

statistically significant at -0.34 ($t = -2.15$). These estimates indicate that firms whose regulator-verified facility-level emissions exceed their prior voluntary disclosures experience additional ESG rating downgrades upon GHGRP entry. Economically, a one-unit increase in the underreporting measure is associated with a decline of approximately 0.34–0.37 points in MSCI's environmental pillar score following verified disclosure, representing a meaningful reputational penalty given the scale of MSCI ratings. By contrast, the main effect of $GHGRP$ differs across specifications. In Column (1), $GHGRP$ is negative and statistically significant (-0.54, $t = -3.33$), suggesting an average ESG downgrade upon entry into the verified disclosure regime. However, once firm fixed effects and industry-year fixed effects are included in Column (2), the $GHGRP$ coefficient becomes smaller in magnitude and statistically insignificant (-0.17, $t = -0.96$). This attenuation indicates that regulatory entry alone does not uniformly trigger ESG penalties; instead, ESG downgrades arise primarily when verified disclosure reveals inconsistencies between voluntary reporting and true emissions. Taken together, these findings provide strong support for Prediction P3b and the model's external stakeholder discipline mechanism. ESG rating agencies respond not merely to GHGRP coverage per se, but to the informational content of verified disclosure, imposing reputational costs that scale with the severity of revealed underreporting. Combined with the stock-market evidence in Prediction P3a, the results demonstrate that credible, regulator-verified transparency disciplines firms through both investor and non-investor stakeholder channels.

5.4 Internal Managerial Learning: Climate-Related Discussion and the Salience of Verified Information

This section evaluates Prediction P4, which tests the model's internal managerial learning mechanism. The central idea is that GHGRP verification affects firms not only through external stakeholder discipline, but also by reshaping internal information processing and managerial attention. In the model, regulator-verified emissions disclosure increases the at-

Table 9: Stakeholder Reactions Beyond Stock Market: Environmental Ratings

	(1)	(2)
	EnvironmentScore	
GHGRP×Underreporting	-0.37***	-0.34**
	(-2.92)	(-2.15)
GHGRP	-0.54***	-0.17
	(-3.33)	(-0.96)
Size	0.42***	0.64***
	(7.39)	(3.70)
BM	-0.35***	-0.31***
	(-3.26)	(-2.70)
AI	-0.41***	-0.40
	(-2.66)	(-1.56)
Leverage	-0.47	0.72
	(-1.35)	(1.52)
Cash	0.61	0.91**
	(1.49)	(2.03)
ROA	0.72	0.78
	(1.47)	(1.62)
Dividend	2.70*	1.33
	(1.96)	(1.11)
IO	-0.00	1.36***
	(-0.00)	(2.62)
Analysts	0.03	-0.09
	(0.25)	(-0.65)
Observations	4,084	4,060
Adjusted R-squared	0.461	0.690
Industry FE	Yes	No
Year FE	Yes	No
Firm FE	No	Yes
Industry-Year FE	No	Yes

This table examines ESG rating responses to regulator-verified emissions disclosure under the GHGRP. The dependent variable is MSCI's environmental pillar score. GHGRP is an indicator equal to one beginning in the year a firm enters GHGRP coverage. Underreporting measures the extent to which voluntarily disclosed firm-level emissions fall short of regulator-verified facility-level emissions and is defined as $\max\{(\text{FacilityE} - \text{FirmE})/\text{FirmE}, 0\}$. Column (1) includes industry and year fixed effects, while Column (2) includes firm fixed effects and industry-year fixed effects, identifying effects from within-firm variation over time. Standard errors are clustered at the firm level. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively

tention parameter ψ by making emissions information more credible, granular, and salient within the organization. Because the GHGRP generates facility-level, regulator-certified emissions data during the fiscal year—well before public dissemination—managers internalize this information when forming expectations and preparing contemporaneous communications, including earnings calls. A key implication of the internal learning mechanism concerns *timing*. Unlike market reactions, which occur only after verified emissions become publicly available, managerial learning operates within the same reporting cycle. Managers observe verified emissions internally and adjust their attention immediately, even before external stakeholders fully process the information. As a result, climate-related discussion should increase contemporaneously with GHGRP verification.

To test Prediction P4a, I estimate the following specification:

$$\text{ClimateConcerns}_{ft} = \alpha_f + \alpha_{it} + \boldsymbol{\gamma}' X_{ft} + \beta\, \text{GHGRP}_{ft} + \varepsilon_{ft} \tag{26}$$

where ClimateConcerns measures the intensity of climate-related language in earnings-call transcripts by Sautner et al. (2023). The coefficient β captures the shift in managerial attention induced by GHGRP verification.

Table 10 reports the results. The coefficient on GHGRP_{ft} is positive and highly statistically significant (0.68, $t = 3.25$), indicating that firms substantially increase climate-related discussion in earnings calls upon entering the GHGRP. Economically, because the dependent variable is a standardized intensity measure of climate language, this estimate implies a sizable contemporaneous increase in managerial attention to climate issues following internal exposure to regulator-verified emissions information. Importantly, this effect is identified using within-firm variation and remains robust after absorbing firm fixed effects and industry-year fixed effects, ruling out time-invariant firm characteristics and sector-wide shocks as alternative explanations. The result therefore reflects a genuine shift in internal focus rather than changes in firm composition or broader trends in climate discourse. Taken together,

these findings provide direct evidence for the internal managerial learning channel. GHGRP verification increases the salience and credibility of emissions information inside the firm, leading managers to reallocate attention toward climate issues in real time. This contemporaneous adjustment in earnings-call communication supports the model's prediction that verified disclosure reshapes internal cognition and information processing, complementing the external stakeholder discipline documented in earlier sections.

5.5 Firm Valuation Channel: Long-Run Pricing of Verified Emissions Reductions and Increases

This section evaluates Predictions P5a and P5b, which examine how capital markets price verified emissions information in the long run. In the theoretical framework, voluntary emissions disclosures affect only the interim price, while long-run valuation depends exclusively on verified emissions performance. Once GHGRP verification reveals a high-precision, regulator-certified measure of a firm's emissions footprint, investors update beliefs about long-run climate risk exposure, operational efficiency, and environmental positioning. As a result, firms that achieve verified emissions reductions should experience valuation gains (P5a), whereas firms whose verified emissions increase should receive no comparable valuation benefits (P5b). This contrast provides a falsification-style test that isolates the valuation channel from confounding regulatory or correlated shocks.

To examine how markets price verified changes in firm-level emissions, I estimate the following specification:

$$\begin{aligned} ln(\text{MVE})_{ft} = \alpha_f + \alpha_{it} + \boldsymbol{\gamma}' X_{ft} + \beta_1 \, GHGRP_{ft}(+2) \\ + \beta_2 \, \Delta^- E^{\text{ver}}_{ft} + \beta_3 \big(GHGRP_{ft}(+2) \times \Delta^- E^{\text{ver}}_{ft} \big) + \varepsilon_{ft}, \end{aligned} \tag{27}$$

where $\log(\text{MVE})_{ft}$ is the natural logarithm of firm f's market value of equity. The indicator $GHGRP_{ft}(+2)$ equals one beginning two years after the firm becomes subject to GHGRP

Table 10: Impact of Facility-Level GHG Transparency Regulation on Firm-Level Climate Change Exposures

	ClimateConcerns
GHGRP	0.68***
	(3.25)
Size	0.72***
	(4.56)
BM	-0.39***
	(-2.61)
AI	0.96***
	(3.87)
Leverage	-0.11
	(-0.25)
Cash	0.15
	(0.32)
ROA	0.46
	(1.10)
Dividend	-0.53
	(-0.64)
IO	0.20
	(0.48)
Analysts	-0.14
	(-0.72)
Observations	4,443
Adjusted R-squared	0.844
Firm FE	Yes
Industry-Year FE	Yes

This table examines the effect of facility-level GHG transparency regulation on managerial attention to climate issues. The dependent variable, ClimateConcerns, measures the intensity of climate-related language in firms' earnings-call transcripts by Sautner et al. (2023). GHGRP is an indicator equal to one beginning in the year a firm enters the EPA's Greenhouse Gas Reporting Program. The regression includes firm fixed effects and industry-year fixed effects. Standard errors are clustered at the firm level. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

reporting. This lag reflects the theoretical timing: firms adjust emissions only after verification, and markets price these adjustments once verified data become salient and widely processed. The interaction term $GHGRP_{ft}(+2) \times \Delta^{-} E_{ft}^{\text{ver}}$ tests Prediction P5a—whether verified emissions reductions earn a valuation premium under regulator-certified disclosure. A positive and statistically significant coefficient on this interaction is the key prediction. In parallel, I estimate an analogous specification interacting $GHGRP_{ft}(+2)$ with emissions increases, $\Delta^{+} E_{ft}^{\text{ver}}$, which serves as a falsification benchmark to test Prediction P5b.

Table 11 provides strong evidence in support of the valuation channel predicted by the model. The coefficient on $GHGRP(+2) \times \Delta^{-} E_{ft}^{\text{ver}}$ is 0.55 ($t = 4.32$), indicating that firms subject to GHGRP reporting experience significantly higher market valuations when they achieve verified emissions reductions. Economically, this estimate implies that a 10% verified reduction in emissions following GHGRP coverage ($-\Delta^{-} E_{ft}^{\text{ver}} = 0.10$) is associated with an increase in market value of approximately

$$100\big(\exp(0.55 \times 0.10) - 1\big) \approx 5.7\%.$$

This magnitude is economically large and suggests that verified abatement—once credibly revealed through regulator-certified disclosure—is associated with substantial long-run valuation gains. These gains are consistent with lower perceived transition risk, improved operational efficiency, and stronger environmental positioning. In contrast, the interaction $GHGRP(+2) \times \Delta^{+} E_{ft}^{\text{ver}}$ is small and statistically insignificant (0.09, $t = 1.44$), confirming Prediction P5b: firms whose verified emissions increase do not receive valuation benefits. This falsification-style contrast rules out the possibility that GHGRP coverage alone mechanically drives valuation improvements. The main effects also behave as expected: verified emissions changes load negatively in levels, reflecting the well-established negative association between emissions intensity and firm value, while GHGRP entry captures average valuation adjustments unrelated to emissions performance. Taken together, these results

show that markets price verified emissions performance asymmetrically in the long run, rewarding firms that genuinely reduce their verified emissions footprint while not extending comparable valuation benefits to firms whose verified emissions increase. This pattern aligns precisely with the theoretical model and underscores the distinct role of regulator-verified disclosure in shaping long-term firm valuation.

6 Conclusion and Policy Implications

This study investigates whether and how regulator-verified, facility-level transparency alters corporate environmental behavior. By exploiting the staggered implementation of the U.S. EPA's Greenhouse Gas Reporting Program (GHGRP), I isolate the causal effect of mandatory, granular verification on firms that previously engaged in voluntary, unverifiable disclosure. The results provide robust evidence that credible verification forces a substitution from narrative manipulation toward real emissions abatement.

My theoretical framework formalizes the mechanism: voluntary disclosures are treated as "soft" information, allowing managers to strategically misreport (m) to influence interim stock prices. The introduction of a verified, high-precision signal (E^{ver}) imposes disciplinary costs on greenwashing (Φ) and heightens internal managerial attention (ψ). Consistent with the model's predictions, I find that firms reduce verified firm-wide emissions by approximately 14 percent within two years of GHGRP entry. Crucially, these reductions are not driven by mechanical compliance at regulated facilities or accounting reallocation. The persistence of the treatment effect after controlling for regulated facility emissions, combined with the significant compression of "noncovered" emissions and the rise in low-carbon patenting, points to substantive organization-wide capability building.

The analysis elucidates two distinct channels through which verified transparency disciplines firms. First, an external stakeholder channel operates through credibility shocks. When verified data reveal "underreporting"—where verified emissions exceed prior voluntary

Table 11: Long-Run Pricing of Verified Emissions Reductions and Increases

	(1)	(2)
	Log(MVE)	
GHGRP(+2)×$\Delta^{-}E_{ft}^{\text{ver}}$	0.55***	
	(4.32)	
GHGRP(+2)×$\Delta^{+}E_{ft}^{\text{ver}}$		0.09
		(1.44)
GHGRP(+2)	0.29***	0.26***
	(9.01)	(8.14)
$\Delta^{-}E_{ft}^{\text{ver}}$	-0.24***	
	(-3.33)	
$\Delta^{+}E_{ft}^{\text{ver}}$		0.00***
		(10.53)
BM	-0.71***	-0.71***
	(-8.79)	(-8.65)
AI	-0.68***	-0.68***
	(-5.71)	(-5.84)
Leverage	0.40*	0.43**
	(1.87)	(2.01)
Cash	-0.70***	-0.67***
	(-3.49)	(-3.32)
ROA	0.91***	0.91***
	(4.35)	(4.28)
Dividend	0.80	0.80
	(1.40)	(1.38)
IO	0.21	0.21
	(1.27)	(1.25)
Analysts	0.35***	0.35***
	(8.16)	(8.08)
Observations	4,800	4,800
Adjusted R-squared	0.933	0.933
Firm FE	Yes	Yes
Industry-Year FE	Yes	Yes

This table examines the long-run valuation effects of verified emissions reductions and increases following entry into the GHGRP. The dependent variable is the natural logarithm of firm market value of equity (log(MVE)). Verified emissions are defined as the maximum of voluntarily disclosed firm-level emissions and regulator-verified facility-level emissions. Emissions changes are measured as year-over-year percentage changes in verified emissions and decomposed into reductions ($\Delta^{-}E_{ft}^{\text{ver}}$) and increases ($\Delta^{+}E_{ft}^{\text{ver}}$). The indicator $GHGRP(+2)$ equals one beginning two years after a firm first becomes subject to GHGRP reporting, reflecting the timing at which verified emissions adjustments are expected to be priced by the market. The interaction $GHGRP(+2) \times \Delta^{-}E_{ft}^{\text{ver}}$ tests whether verified emissions reductions earn a valuation premium under regulator-certified disclosure, while the interaction with $\Delta^{+}E_{ft}^{\text{ver}}$ serves as a falsification benchmark. All regressions include firm and industry-year fixed effects, and standard errors are clustered at the firm level. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

claims—investors impose immediate market penalties, and ESG rating agencies downgrade environmental scores. Second, an internal learning channel operates through salience. I document a sharp, contemporaneous increase in climate-related discussion in earnings calls upon regulatory entry, indicating that granular, verified data reshapes managerial cognition and resource allocation even before market penalties materialize. Finally, I provide evidence of a long-run valuation channel. Consistent with the theoretical prediction that verified emissions determine long-run value, capital markets asymmetrically reward firms that achieve verified abatement with higher equity valuations, while offering no such premium to firms with rising emissions.

These findings yield several policy implications for the design of effective climate-disclosure regimes. First, verifiability is essential. The GHGRP's regulator-certified methodologies generate emissions data that stakeholders trust and managers internalize. In contrast, disclosure systems that allow firms to choose their own estimation techniques—as under the US SEC (2024)'s evolving firm-level Scope 1 and Scope 2 rules—risk undermining credibility through discretionary assumptions and limited comparability. Verifiable information is the foundation on which both market discipline and internal learning depend.

Second, facility-level granularity strengthens organizational impact. While firm-level reporting enables cross-firm comparisons, facility-level transparency provides the diagnostic detail necessary for internal managerial learning. GHGRP data allow managers to benchmark units, identify inefficiencies, and reallocate resources. Effective disclosure policy may therefore require a hybrid architecture: firm-level aggregation for investors and facility-level detail for managerial oversight and stakeholder monitoring. However, recent policy developments threaten to dismantle this architecture. In September 2025, the EPA proposed a rule to effectively terminate the GHGRP, eliminating reporting obligations for the vast majority of industrial facilities.[13] My findings suggest this reversal would be socially detrimental because, absent verified transparency, firms will no longer internalize the negative externalities

[13] https://www.epa.gov/system/files/documents/2025-09/reconsideration-of-ghgrp-proposal-fact-sheet.pdf

of their corporate emissions. By removing the regulator-verified benchmark that underpins both internal learning and market discipline, the proposal risks eroding the incentives for genuine abatement and stalling the capital investments needed for decarbonization.

Third, verified transparency can complement—or partially substitute for—more intrusive regulation. The GHGRP induces substantial abatement even without explicit penalties or emissions caps, suggesting that credible, standardized disclosure can motivate improvement through market-based and internal channels. Policymakers seeking cost-effective climate tools should recognize verification as a powerful governance mechanism. This insight informs ongoing international debates about climate-disclosure architecture, such as the European CSRD, the UK SDR, and ISSB standards. The evidence underscores that effective transparency requires information that is credible, comparable, and diagnostically rich. When these conditions are met, disclosure becomes more than a reporting requirement: it becomes a catalyst for organizational and environmental change. In short, sunlight is the best disinfectant only when it is bright, consistent, and trustworthy.

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