The Sunshine Effect: GHG Transparency Regulation on Underreporting*

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Abstract

This paper investigates the impact of the Greenhouse Gas Reporting Program, a granular transparency regulation requiring firms to disclose Greenhouse Gas (GHG) information from their facilities. By analyzing firms that voluntarily disclosed firm-level GHG emissions before and after program implementation, the study draws causal inferences on the effect of increased disaggregated-level transparency on aggregated-level behavior. Using a generalized difference-in-differences methodology, I find a reduction in overall emissions after the public release of facility GHG information. The standardized transparency regulation acts as a "sunshine," exposing specific emission sources of negative externalities and previous underreporting by firms. This exposure prompts stakeholders' engagement with negative feedback to the firms, incentivizing them to reduce emissions.

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

JEL Codes: D72, M40, Q54, Q56

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1 Introduction

Regulators are increasingly turning to disaggregated level transparency regulations to induce market discipline at the facility level (e.g., Yang et al. (2021), Tomar (2022)). A pivotal development in this area is the introduction of the Greenhouse Gas Reporting Program (GHGRP) by the U.S. Environmental Protection Agency (EPA) in 2010. This program mandates GHG information disclosure for facilities emitting above a certain threshold per year and standardizes how to calculate facility-level GHG emissions including both scope 1 (direct) and scope 2 (indirect) emissions. Following a verification process, the EPA began the annual publication of facility-level GHG details, including emissions production quantities and ownership information, on its website starting in 2012. While this form of granular transparency regulation does not mandate reduction measures, it holds implications for publicly traded firms owning regulated facilities, as they are obliged to fulfill annual reporting requirements. This distinctive reporting regulatory framework offers an opportunity to assess the influence of granular transparency regulation on the actual decision-making processes of firms.

The central question of this paper is how and why transparency regulation at the disaggregated level influences behavior at the aggregated level, like how firm-level disclosure regulation affects firm-level behavior (e.g., Kanodia & Sapra (2016), Leuz & Wysocki (2016), Roychowdhury et al. (2019)). Specifically, does mandating the disclosure of GHG emissions at the facility level incentivize firms to proactively reduce their overall GHG emissions? And if so, what potential mechanism drives this effect? To address this question, I examine a sample of firms that voluntarily disclosed their GHG emissions at the firm level both before and after the program’s introduction, considering the differential impacts on firms with and without regulated facilities. An important institutional backdrop is that, at the aggregated level, firms had already made their value-relevant information—namely, firm-level GHG emissions—public both before and after the
program’s implementation (e.g., Matsumura et al. (2014)). Hence, these firms are less inclined
to modify their behavior in “anticipation” of the policy at the facility level. This focused setting
enhances the internal validity of the study, enabling a robust causal inference regarding the impact
of granular transparency regulation on firms’ behavior.

The mandatory disclosure of facility-level GHG information may serve as a “sunshine” mech-
anism. First, the detailed disclosure reveals how firms have contributed to negative externalities in
society, such as air pollution and climate change, through specific emission sources from their fa-
cilities. Stakeholders—regulators, investors, and consumers—become aware of the negative exter-
nalities associated with specific corporate GHG emissions upon mandatory public disclosure. This
depthens the understanding of firms’ environmental impact on the community beyond mere firm-
level GHG information, subjecting firms to heightened scrutiny. Consequently, political costs of
the disclosure could materialize (Watts & Zimmerman (1978, 1990)): Regulators impose penalties
on non-compliant firms and signal potential future regulations, including cap-and-trade programs
or carbon taxes. Equity investors have the option to divest from firms facing elevated political
costs, while consumers can choose to boycott products linked to increased emissions.

Second, the publicly available aggregated facility GHG information at the firm level exposes
potential underestimations in previously reported firm-level emissions. This discrepancy arises
from the standardized nature of facility-level GHG information, encompassing both scope 1 (di-
rect) and scope 2 (indirect) emissions overseen by the EPA. This contrasts with voluntary firm-level
GHG disclosures, where certain firms may find it advantageous to underreport their emissions
through selective scope (usually only scope 1) and specific calculation methods, aligning with the
cheap talk theory (Farrell & Rabin (1996)). The heightened transparency of granular GHG infor-
mation, accessible to both corporate insiders and outsiders, creates incentives for firms to embrace
more socially responsible practices. Specifically, firms can strategically reduce their firm-level
GHG emissions, aiming to mitigate the negative feedback loop associated with mandatory facility-
level disclosure and enhance their public image. I term this mechanism of revealing wrongdoings
of firms from the societal perspective as a “sunshine mechanism,” and the subsequent drive for
change in firm behavior aligns with relevant stakeholders as the “sunshine effect.”

Whether the GHGRP induces changes in firm-level behavior remains an empirical question. First, as the program is not a direct regulation at the firm level, and the sample firms already furnish value-relevant information—specifically, their firm-level GHG emissions information—to the market (e.g., Matsumura et al. (2014)), the impact of the regulation itself is somewhat limited. Secondly, given that the information is disseminated through the website rather than through formal financial reports like the 10-K, the disclosure channel effect (e.g., Christensen et al. (2017)) might attenuate the actual impact of the GHGRP. This hypothesis assumes that investors attribute greater significance to information that is professionally audited and carries higher litigation risk.

To assess the impact of the granular disclosure mandate on firm-level emissions, I employ a generalized difference-in-differences (DID) research design. This design leverages firms’ staggered exposure to the facility-level GHG emissions disclosure mandate, which became effective on January 1st, 2010, but the release of this information started in 2012. The timing of a firm’s initial facility-level GHG emissions disclosure depends on whether the firm owns a facility emitting more than the reference amount in each reporting year. Consequently, the number of firms subject to the disclosure requirement varies annually, with firms entering and exiting the scope of the transparency regulation. In the analysis, I compare firm-years when a firm is first exposed to the mandate with other firm-years. This approach includes a control group comprising firms previously affected by the mandate and firms not yet exposed to it in a given year. By accounting for common firm characteristics and firm-fixed effects to address time-invariant differences between treated and control firms, and industry-year fixed effects to control time-varying industry-level shocks, I identify the average treatment effect on firms encountering the GHGRP for the first time in a specific year. Any alternative factors explaining the results would need to align with the timing of the initial facility-level GHG emissions mandate across firms.

I begin by examining the impact of granular transparency regulation on firm-level GHG emissions. My findings demonstrate that, on average, firms subject to the GHGRP exhibit a voluntary reduction in their GHG emissions by 9% compared to firms without regulated facilities. Notably,
this reduction became significant after the public dissemination of facility-level information, which began in 2012. These findings suggest that firms strategically lower their firm-level emissions in response to feedback derived from the public release of detailed GHG information, rather than solely due to the policy’s implementation itself in 2010.

To ensure the robustness of these findings and address potential alternative explanations, a series of tests were conducted. First, to establish a compelling link between the impact of granular transparency regulation and firms’ voluntary reductions in firm-level GHG emissions, I perform cross-sectional analyses. Firms’ incentives to reduce firm-level emissions upon disclosing facility-level GHG information are contingent on their cost-benefit analysis, weighing benefits such as mitigating negative stakeholder reactions and enhancing public image against potential costs like profit reduction due to decreased emissions. As firms disclose higher total aggregated facility emissions, they are likely to face increased scrutiny and more negative feedback. This is because a greater quantity of emissions implies, they are contributing a larger share of GHG-related externalities to society. Hence, the sunshine effect suggests that the degree of firm-level emissions reduction is associated with the total aggregated facility emissions. Consistent with expectations, I find a linear association between total aggregated facility-level emissions and firm-level emissions reduction, where a 1% increase in aggregated facility GHG emissions corresponds to a -0.7% reduction in firm-level GHG emissions. On the other hand, firms may strive to maintain profitability from existing facilities to maximize profit. Hence, firms will try to reduce GHG emissions by enhancing operational and production efficiency rather than divesting existing facilities. Consistent with expectations, I find no linear association between the number of facilities owned by firms and firm-level GHG reduction. These contrasting cross-sectional results suggest that firms strategically reduce emission quantity through increased operational and production efficiency while sustaining profitability without divestment of facilities.

Second, the DID methodology relies on similar pretrends for treated and control firms. To inspect the validity of this parallel-trend assumption, I examine the dynamic effect on firm-level emissions in the years before and after the first facility-level emissions disclosure, relative to control
trol firms. I confirm that firm-level emissions do not change significantly in the years prior to the first disclosure of facility-level emissions, supporting the parallel-trend assumption. Recent research by Goodman-Bacon (2021) and Baker et al. (2022) has highlighted the potential bias introduced by the staggered DID methodology. In my study, the inclusion of already-disclosed firms in the control group has the potential to introduce bias since the treatment effect may vary over time. To mitigate this concern, I employ the methodology introduced by Goodman-Bacon (2021), wherein I decompose the generalized difference-in-differences estimate into components derived from distinct sets of control firms. The decomposition analysis shows that the decline in firm-level emissions is predominantly attributed to the contrast with firms unaffected by GHGRP, rather than being influenced by the inclusion of already-disclosed firms in the control group.

Third, to address the potential explanation that the reduction in firm-level emissions might be attributed to a decrease in sales rather than firms’ voluntary reduction, I control for the influence of sales on firm-level emissions. Initially, I incorporate the logarithm of the sales variable, which is contemporaneously determined alongside the main policy variable. Subsequently, I use firm-level emissions scaled by contemporaneous sales as the dependent variable. Importantly, the main findings remain robust irrespective of the control variable or the scaling applied to the dependent variable. These robust tests further support the conclusion that the observed reductions in firm-level emissions in the study are primarily driven by the sunshine effect of the granular transparency regulation on voluntary disclosers.

To understand the potential mechanism driving the sunshine effect and discern the nature of negative feedback faced by firms from stakeholders, I explore three primary channels through which regulators, equity investors, and consumers exert pressure on firms through negative feedback. First, regulators play a foundational role in enhancing stakeholders’ awareness of the adverse externalities associated with specific corporate GHG emissions through mandatory public disclosure. The revealing mechanism allows a deeper understanding of firms’ environmental impact on the community beyond mere firm-level GHG information and subjects them to heightened scrutiny. Consequently, the political costs of disclosure may materialize (Watts & Zimmerman
For instance, in safeguarding the integrity of the GHGRP and ensuring accurate data accessibility for the public and policymakers, the EPA has initiated enforcement actions against firms that inadequately report their GHG emissions under the GHGRP. Furthermore, from 2012 to 2016, climate change and GHG emissions reduction were significant topics of discussion and action at both the federal and state levels. Anecdotal evidence suggests that the EPA explored extending the GHGRP to a nationwide cap-and-trade program. These examples illustrate the negative feedback that firms encounter through the regulatory pressure channel.

Second, I delve into the equity investor pressure channel, employing standard event study methodology to scrutinize the equity market’s response to the mandatory disclosure of facility-level GHG information. The benchmark model, incorporating three standard risk factors—Market, Small Minus Big, and High Minus Low factors by Fama & French (1993)—along with the Momentum factor by Carhart (1997), is used to calculate abnormal returns and isolate market effects linked to mandatorily disclosed GHG information. Spanning from 2012 to 2016, my study concentrates on seven disclosure dates of facility-level GHG information, covering a total of 787 firm-disclosure dates. I categorize instances where firms disclose higher aggregated facility-level emissions than the previously disclosed firm-level emissions as “bad news”. This classification is rooted in the market expectation that voluntarily disclosed total organizational emissions should surpass the summation of emissions from individual facilities within the organization. The incongruence implies that firms had underreported their overall emissions, aligning with the cheap talk theory (Farrell & Rabin (1996)). Conversely, I define instances where firms reveal lower aggregated facility-level emissions than those voluntarily disclosed as “no news”. I anticipate an average negative market reaction in cases of bad news but not in instances of no news. Consistent with this expectation, I observe an average negative market reaction of -1.26% in instances of underreporting, translating into an average loss of $126 million in market value. The negative stock market reactions observed from equity investors are one of the pressures that firms face due to the revealing mechanisms of granular transparency regulation.

Third, I explore the consumer pressure channel. In 2012, when the EPA initially disclosed...
facility-level GHG information to the public, anecdotal evidence revealed the presence of widespread environmental movements and boycotts strategically targeting companies perceived as significant contributors to climate change. An illustrative instance involved environmental groups and activists initiating campaigns urging consumers to boycott ExxonMobil, a company subject to the GHGRP. The call for a boycott arose from concerns about ExxonMobil’s role in climate change, its advocacy against environmental regulations, and allegations of disseminating misinformation about climate science. Activists effectively leveraged social media platforms and grassroots movements to disseminate information about ExxonMobil’s environmental impact, garnering attention and support through online campaigns, petitions, and boycott calls. Direct experimental evidence also supports this assertion; Beyer et al. (2023) find that informed consumers actively choose less carbon-intensive products, resulting in a notable reduction of up to 9.2% in their food-related carbon footprint. Previous studies (e.g., Leuz & Wysocki (2016), Grewal & Serafeim (2020), Christensen et al. (2021)) also highlight the influence of consumers in driving changes in firm behavior. Given that the GHGRP exposes negative externalities and instances of firms underreporting voluntarily disclosed firm-level emissions, I posit and test the hypothesis that firms subject to the GHGRP experience a more pronounced decline in sales compared to those not bound by such regulations. This expectation arises from the likelihood that environmentally conscious consumers are inclined to boycott products associated with elevated emissions. At a minimum, a firm’s regulatory status serves as an indicator for discerning consumer aversions towards a company’s environmental practices, because the GHGRP applies specifically to heavy-emitting firms with regulated facilities, and regulated firms are more likely to produce products with a higher environmental impact.

Consistent with expectations, my findings reveal that regulated firms, on average, experience a significant decline in sales of approximately 4% compared to their non-regulated counterparts. One might posit that the majority of the GHGRP firms’ sales reduction stems from the supply side. However, I argue that this is unlikely. Given that the GHGRP typically pertains to a facility, representing only a fraction of a firm’s operations, it is unlikely that firms would willingly curtail their production to “comply” with the program. Additional robustness tests support this
assertion, confirming that the GHGRP has no observable impact on inventory levels. If most of the sales reduction were to come from the supply side, such as intentional withholding of product sales or a reduction in total production, it would result in noticeable fluctuations in inventory levels. Consequently, the evidence suggests that there exists a consumer-driven decrease in sales, stemming from heightened pressure exerted by environmentally conscious consumers—a tangible manifestation of the negative feedback that firms encounter.

Collectively, the standardized transparency regulation acts as a “sunshine,” exposing specific emission sources of negative externalities and previous underreporting by firms. This exposure prompts stakeholders to engage with negative feedback to the firms, incentivizing them to reduce overall emissions. The objective of the strategic reduction is consistent with breaking the negative feedback loop and enhancing the company’s public image.

The main contribution of this paper is to provide evidence and rationale regarding how and why disaggregated-level GHG transparency regulation can influence firm-level behavior. A recent study by Bauckloh et al. (2023) employs vendor-estimated firm-level emissions and documents that the GHGRP does alter firm-level GHG emissions intensity but “not the raw emissions.” This finding contrasts with previous literature suggesting that facility-level GHG disclosure affects facility-level GHG emissions. For instance, Yang et al. (2021) focus on a single industry, utilizing facility-level emissions from power plants available both before and after GHGRP implementation. Their results unveil a “7% reduction in raw emissions” for power plants subject to GHGRP, compared to control power plants. Similarly, Tomar (2022), using Canadian facilities as a control group, documents a “7.9% reduction in raw emissions” among US facilities following GHGRP adoption, suggesting benchmarking as a reason for the observed effect. These two studies provide an insight: facility-level transparency regulation impacts facility-level behavior, rather than firm-level behavior. Comparing the three papers raises a valid question: why doesn’t the disclosure rule mechanically produce similar outcomes at the firm level, given that firm emissions, especially for Scope 1, are the sum of facility emissions? Conversely, one could argue that since firms operate globally, there may be a lack of rationale for U.S. GHG transparency regulation to
uniformly impact the entire organization. I reconcile these empirical contradictions and fill the
gap in the literature on mandatory GHG reporting programs in the United States by demonstrating
that disaggregated-level GHG transparency regulation influences firm-level behavior when there is
tangible stakeholder engagement with negative feedback to firms.

Second, this study contributes to the literature on mandatory firm-level GHG emissions reporting
in the United Kingdom. The literature utilizes that the Emissions Trading System (ETS) in
the European Union (EU) mandates facility-level emissions disclosure before and after the UK
firm-level GHG disclosure mandate. Downar et al. (2021) utilize ETS installation emissions data
and aggregate facility-level emissions for firms in EU countries. They find that firm-level GHG
transparency regulation in the United Kingdom has led to a reduction in aggregated facility-level
emissions by firms compared to other firms in EU countries. Using vendor-estimated firm-level
emissions in EU countries, Jouvenot & Krueger (2019) observe that the UK firm-level GHG trans-
parency regulation has resulted in reduced firm-level emissions for UK firms compared to those in
other countries. Using CDP data, Grewal (2024) finds that the UK firm-level GHG transparency
regulation affects the reduction of firm-level GHG levels and intensity. My paper differs from
theirs because I study the impact of disaggregated-level GHG transparency on firm-level behavior,
whereas they examine the opposite, aggregated-level GHG transparency regulation on facility-level
behavior or firm-level behavior. Therefore, my paper enriches the mandatory reporting program
literature by providing insights into the nuanced effects of transparency regulations at different
levels.

Third, this paper broadly contributes to the literature on the real effects of CSR-related report-
ing (e.g., Chen et al. (2018), Christensen et al. (2017), Johnson (2020), Rauter (2020)) and the field
of feedback effects in financial markets (Subrahmanyam & Titman (2001), Goldstein et al. (2013),
Bond et al. (2012)). Understanding the interplay between stakeholders such as consumers and
equity investors and their impact on corporate behavior provides insights into the implications of
CSR reporting and broader feedback effects in the capital market. Moreover, this study contributes
to the literature on disclosure policies and resource allocation (e.g., Kanodia & Sapra (2016), Leuz
& Wysocki (2016), Roychowdhury et al. (2019)) by demonstrating that disclosure policies implemented at the disaggregated level have subsequent impacts on resource allocation at the firm level, particularly in the presence of stakeholder engagement.

Finally, this study hold policy implications for regulators tasked with enforcing disclosure regulations to market discipline within firms (e.g., Leuz & Wysocki (2016)), especially regarding GHG reporting (US SEC (2022b)).¹ For instance, the U.S. Securities and Exchange Commission (SEC) has proposed amendments requiring registrants to provide specific climate-related information in their registration statements, including firm-level GHG emissions (US SEC (2022a)).² However, the proposed rule lacks standardization in calculating firm-level emissions.

This paper underscores the sunshine mechanism in disaggregated-level GHG transparency regulation, revealing that specific emission sources cause negative externalities on society and that firms had previously underreported their overall emissions. This revealing mechanism was enabled through the EPA’s standardization of facility-level GHG emissions, ensuring comparability of aggregated facility-level emissions among different firms, unlike voluntarily disclosed firm-level GHG emissions, which are subject to firms’ discretionary decisions such as selective scope and calculation methodology to their advantage. For instance, the EPA provides clear definitions of "direct" and "indirect" emissions and establishes a universal reporting framework, as outlined by the GHGRP.³

Providing consistent and comparable GHG information to stakeholders is crucial, enabling them to provide negative feedback and, in turn, fostering market discipline within firms. Consequently, GHG transparency regulation without standardization and comparability is unlikely to effectively uncover wrongdoings by certain firms, diminishing the potential for market discipline through stakeholder engagement.

The SEC’s proposed rule on Scope 3 GHG emissions also poses comparability challenges due to supply chain complexities. To address this, I recommend adopting a bottom-up approach,
aggregating facility-level emissions based on parent firms’ ownership percentage, similar to the methodology used in this study. This method avoids issues like double counting and ensures comparability across firms.

Of course, the EPA’s vigilant oversight of GHG emissions measurement, coupled with enforcement actions against inaccurate reporting, also exemplifies the regulatory role in maintaining market discipline within firms. Regulators should keep in mind that transparency regulation itself does not bring market discipline.

The remainder of the paper is organized as follows: Section 2 offers a detailed discussion of the institutional background and conducts a literature review. Section 2 develops the hypotheses. Section 4 elucidates the sample selection process and describes the data used. Section 5 provides the empirical results, while Section 6 delves into a potential underlying mechanism of the sunshine effect. Section 7 discusses the external validity of the sunshine effect. Finally, Section 8 concludes the study and outlines its policy implications.

2 Institutional Background and Related Literature

2.1 Greenhouse Gas Reporting Program

In response to the growing attention to greenhouse gas emissions, the Consolidated Appropriations Act of 2008 provided funding for the United States Environmental Protection Agency to develop a rule mandating reporting of greenhouse gas emissions from all sectors of the US economy under the Clean Air Act. This initiative led to the establishment of the Greenhouse Gas Reporting Program (GHGRP), which became effective on January 1st, 2010.

The GHGRP mandates GHG information disclosure for facilities emitting over certain thresh-
old\textsuperscript{7} metric tons of carbon dioxide equivalent (CO2e\textsuperscript{8}) per year to submit their annual emissions information to the EPA including both scope 1 (direct) and scope 2 (indirect) emissions. This establishes a universal framework for reporting, ensuring consistency and accuracy across industries and sectors.

After the verification process, \textsuperscript{9} the comprehensive facility-level GHG production quantities, along with ownership information for the parent entity that owns each facility, are published on the EPA’s website via the Facility Level Information on GreenHouse gases Tool (FLIGHT).\textsuperscript{10} Despite the GHGRP being implemented on January 1st, 2010, it wasn’t until 2012 that the facility-level emissions data for the corresponding reporting year became publicly available. For a detailed timeline of key events related to the Greenhouse Gas Reporting Program during the sample period, please refer to Table 1.

The GHGRP solely mandates reporting duty and does not require emissions reduction targets. The primary goal of the GHGRP is to collect essential emission information related to greenhouse gas emissions from major facilities. This information serves as a vital resource for a diverse range of stakeholders, including businesses, states, municipalities, investors, regulatory bodies, consumers, and researchers. It allows them to monitor and compare emissions across similar facilities, fostering well-informed decision-making processes in the realm of climate policy.

\textsuperscript{7}The disclosure thresholds for reporting GHG emissions under the GHGRP vary based on the source category of the facility or entity, such as power plants, refineries, or manufacturing facilities. The most applied threshold for GHG reporting is 25,000 metric tons of CO2e per year. Note that the threshold is set to ensure a reliable measure of GHG, as having too small a threshold can pose challenges in precise measurement.

\textsuperscript{8}Following provided emission calculation methodologies, different sources of greenhouse gas emissions, such as carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulfur hexafluoride (SF6), and nitrogen trifluoride (NF3), have their global warming potential, which indicates the amount of heat a GHG can trap in the atmosphere and impact the environment.

https://www.epa.gov/sites/default/files/2017-12/documents/ghgrp\_methodology\_factsheet.pdf

\textsuperscript{9}https://www.epa.gov/sites/default/files/2017-12/documents/ghgrp\_verification\_factsheet.pdf

\textsuperscript{10}https://ghgdata.epa.gov/ghgp/main.do
Table 1: Timeline of important Greenhouse Gas Reporting Program events

<table>
<thead>
<tr>
<th>Calendar Time</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>January 1, 2010</td>
<td>Greenhouse Gas Reporting Program was implemented, requiring facilities to measure and report their facility-level emissions to the EPA.</td>
</tr>
<tr>
<td>January 11, 2012</td>
<td>Facility-level GHG information for calendar year 2010 was first released to the public.</td>
</tr>
<tr>
<td>February 2, 2012</td>
<td>After revision, facility-level GHG information for calendar year 2010 was released again to the public.</td>
</tr>
<tr>
<td>February 5, 2013</td>
<td>Facility-level GHG information for calendar year 2011 released to the public.</td>
</tr>
<tr>
<td>October 23, 2013</td>
<td>Facility-level GHG information for calendar year 2012 released to the public.</td>
</tr>
<tr>
<td>September 30, 2014</td>
<td>Facility-level GHG information for calendar year 2013 released to the public.</td>
</tr>
<tr>
<td>October 5, 2015</td>
<td>Facility-level GHG information for calendar year 2014 released to the public.</td>
</tr>
<tr>
<td>October 3, 2016</td>
<td>Facility-level GHG information for calendar year 2015 released to the public.</td>
</tr>
</tbody>
</table>

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

In response to growing societal demands for GHG information, firms have increasingly chosen to voluntarily disclose their firm-level emissions. This pressure goes beyond shareholder concerns, involving various stakeholders, including regulators, investors, consumers, and society at large, all impacted by the externalities of corporate GHG emissions. The non-profit organization CDP (formerly the Carbon Disclosure Project) has played a crucial role in promoting voluntary disclosure. CDP actively encourages major global corporations to publicly share detailed information about their firm-level emissions through dedicated surveys.11 By 2010, a substantial 59% of S&P 500 companies in the United States had voluntarily disclosed their firm-level emissions data to CDP (the CDP (2010)). In addition to CDP surveys, some firms use various disclosure channels such as annual reports, sustainability reports, ESG data sheets, or their official corporate websites. Most firms typically disclose firm-level emissions, with a primary focus on scope 1 (direct emissions) only.

According to signaling theory (Spence (1978)), some firms may choose to disclose their firm-level emissions voluntarily as a means of communicating positive underlying qualities, compe-

gence, or future behavior. In contrast, the cheap talk theory (Farrell & Rabin (1996)) predicts that, due to the voluntary nature of disclosures, some firms have the flexibility to selectively determine the extent of emissions they disclose and the calculation methodology they employ. This strategic discretion allows firms to shape a specific image of their environmental performance.

2.3 Two Disclosure Levels of GHG Transparency Regulations and Literature of Mandatory GHG Reporting Programs

Policymakers around the world have instituted transparency regulations to disclose GHG emissions, employing two primary disclosure levels: facility-level and firm-level. The facility-level GHG emissions disclosure mandate requires reporting emissions from individual facilities, while the firm-level GHG emissions reporting mandate necessitates reporting emissions across the entire organization.

In the United States, the GHGRP stands out as an optimal exogenous shock for examining the impact of facility-level disclosure mandates. This is because it solely mandates reporting duty without imposing mandatory reductions. Yang et al. (2021) focus their analysis on the emissions of “power plants,” a sector subject to detailed reporting requirements even before the GHGRP. The EPA requires comprehensive emissions data from power plants, which is publicly available through the Emissions & Generation Resource Integrated Database (eGRID). Their findings reveal that power plants subject to the GHGRP reduced raw emissions by 7% compared to control power plants. Similarly, Tomar (2022) uses Canadian facilities as a control group and documents a 7.9% reduction in raw emissions among U.S. facilities following GHGRP implementation, with power plants excluded from the sample. Tomar (2022) suggests that benchmarking from the peer group induces a real effect on emission reduction at the facility level. The two studies underscore a key insight: facility-level GHG transparency regulation leads to shifts in aggregated facility-level behavior. However, a recent study by Bauckloh et al. (2023) employ vendor-estimated firm-level emissions and documents that the GHGRP alters firm-level GHG emissions intensity but “not the raw emissions.” Comparing the three papers raises a valid question: why doesn’t the disclosure
rule mechanically produce similar outcomes at the firm level, given that firm-level emissions, especially for Scope 1, are the sum of facility emissions? Conversely, one could argue that since firms operate globally, there may be a lack of rationale for U.S. GHG transparency regulation to uniformly impact the entire organization. This paper fills the gap in the mandatory reporting program literature of the United States by studying “how” and “why” transparency regulation at the disaggregated level can influence behavior at the aggregated level.

In the European Union (EU), the initial phase of the European Union Emissions Trading System (EU ETS) mandated industrial and energy sectors to report their GHG emissions at the facility level in 2005. The literature on firm-level mandatory reporting in the United Kingdom utilizes EU ETS facility-level emissions, which are available both before and after the implementation of the firm-level mandatory reporting in the United Kingdom in 2013. For instance, Downar et al. (2021) utilize facility-level emissions data from EU ETS installations between 2009 and 2018 to compute aggregated facility-level emissions for each firm owning facilities in EU countries. They find that the UK firm-level GHG disclosure mandate had reduced UK firms’ aggregated facility-level emissions compared to those of other firms in EU countries. Similarly, using vendor-estimated firm-level emissions, Jouvenot & Krueger (2019) find a 16% reduction in firm-level emissions using the same firm-level transparency regulation in the UK. Utilizing CDP data, Grewal (2024) discovers that UK firm-level GHG transparency regulations influence the reduction of firm-level GHG emissions and intensity. My paper differs from theirs because I study the impact of disaggregated-level GHG transparency on firm-level behavior, whereas they examine the opposite, aggregated-level GHG transparency regulation on facility-level behavior or firm-level behavior. While firm-level transparency regulation has proven effective in reducing aggregated facility-level emissions and firm-level emissions in the UK compared to other EU countries, the potential analogous effects of similar regulations in the United States remain uncertain. This uncertainty arises due to distinct institutional contexts and potential economic consequences (e.g., La Porta et al. (1997), Porta et al. (1998), La Porta et al. (2008), Daske et al. (2008), Leuz (2010), Daske et al. (2013)). Therefore, my paper enriches the mandatory reporting program literature by providing insights into the nuanced
effects of transparency regulations at different levels.

3 Hypothesis Development

3.1 Potential Sunshine Effect of Granular Transparency Regulation on Firm-level Behavior

The mandatory disclosure of facility-level GHG information can function as a "sunshine" mechanism. First, the detailed disclosure unveils how firms contribute to adverse societal externalities, such as air pollution and climate change, by exposing specific emission sources from their facilities. Stakeholders, including regulators, investors, and consumers, become aware of these negative externalities associated with corporate GHG emissions upon mandatory public disclosure. This goes beyond mere firm-level GHG information, subjecting firms to heightened scrutiny. Consequently, the political costs of disclosure may materialize (Watts & Zimmerman (1978, 1990)): Regulators can impose penalties on non-compliant firms and signal potential future regulations, including cap-and-trade programs or carbon taxes. Equity investors may choose to divest from firms facing elevated political costs, while environmentally conscious consumers can opt to boycott products linked to increased emissions.

Second, the publicly available aggregated facility-level GHG information at the firm level exposes potential underestimations in previously reported firm-level emissions. This discrepancy emerges from the standardized nature of facility-level GHG information, encompassing both Scope 1 (direct) and Scope 2 (indirect) emissions overseen by the EPA. This stands in contrast to voluntary firm-level GHG disclosures, where certain companies may find it advantageous to underreport their emissions through selective scope (usually only Scope 1) and specific calculation methods, aligning with the cheap talk theory (Farrell & Rabin (1996)). The heightened transparency of granular GHG information, accessible to both corporate insiders and outsiders, creates incentives for firms to adopt more socially responsible practices. Specifically, firms can strategically reduce their firm-level GHG emissions, aiming to mitigate negative feedback associated with mandatory
facility-level disclosure and enhance their public image. I term this mechanism of revealing wrong-doings by firms as a “sunshine mechanism,” and the subsequent drive for change in firm behavior aligns with relevant stakeholders as the “sunshine effect.”

The question of whether the GHGRP induces changes in firm-level behavior requires empirical investigation. Firstly, since the program does not directly regulate firms and the sample companies already disclose value-relevant information—specifically, their firm-level GHG emissions information—to the market (e.g., Matsumura et al. (2014)), the impact of the regulation itself appears somewhat limited. Secondly, considering that the information is disseminated through the website rather than through formal financial reports like the 10-K, the disclosure channel effect (e.g., Christensen et al. (2017)) might attenuate the actual impact of the GHGRP. This hypothesis posits that investors attribute greater significance to information that is professionally audited and carries a higher litigation risk, suggesting that the dissemination method could affect how investors perceive and respond to the disclosed GHG information.

To examine the sunshine effect, two hypotheses will be scrutinized. Firstly, the investigation will evaluate whether the sunshine effect is activated immediately as firms come under the policy’s implementation, beginning in the year 2010, even before any feedback is received. Secondly, it will assess whether the sunshine effect becomes apparent only after the public disclosure of facility-level GHG information and firms start receiving tangible feedback, a process that unfolds in the year 2012. The first set of hypotheses is articulated in the alternative form:

• **H1-1**: With the commencement of the policy in 2010, firms promptly decrease their firm-level GHG emissions.

This proactive approach stems from their anticipation of "potential" negative feedback resulting from heightened public scrutiny.

• **H1-2**: Firms commence reducing overall emissions only after the public disclosure of facility-level information in 2012.

This delayed response underscores the significance of tangible feedback in motivating firms to decrease overall emissions.
To establish a compelling link between detailed transparency regulation and firms’ voluntary reductions in firm-level GHG emissions, I conduct cross-sectional analyses. The willingness of firms to curtail their firm-level GHG emissions upon revealing their facility-level emissions is contingent on their cost-benefit analysis. Firms assess perceived benefits, such as mitigating negative stakeholder reactions and enhancing their public image, in comparison to costs like potential profit reduction due to decreased production or expenses associated with overall emissions reduction.

As firms disclose higher total aggregated facility emissions, they are likely to face increased scrutiny and more negative feedback from stakeholders, as it exposes a larger share of GHG-related externalities to society. Consequently, the sunshine effect suggests that the extent of firm-level emissions reduction is associated with the total aggregated facility emissions. However, given firms’ emphasis on maintaining profitability—considering the profit generated by existing facilities—they actively strive to enhance operational and production efficiency rather than divesting those facilities. These considerations lead us to the second set of cross-sectional hypotheses:

- **H2-1**: Firms exhibit greater reductions in their firm-level GHG emissions as they disclose higher aggregated facility-level emissions.
- **H2-2**: The extent of reduction in firm-level GHG emissions is independent of the disclosed total number of facilities owned.

To comprehend the potential mechanism driving the sunshine effect and discern the nature of negative feedback faced by firms from stakeholders, I explore three primary channels through which regulators, equity investors, and consumers exert pressure on firms through negative feedback.

First, regulators play a foundational role in raising stakeholders’ awareness of the adverse externalities linked to specific corporate GHG emissions through mandatory disclosure. This deepens the understanding of firms’ environmental impact on the community beyond mere firm-level GHG information, subjecting them to heightened scrutiny. Consequently, the political costs of disclosure could materialize (Watts & Zimmerman (1978, 1990)). For instance, in safeguarding the integrity of the program and ensuring accurate data accessibility for the public and policymakers, the EPA
has initiated enforcement actions against firms that inadequately report their GHG emissions under the GHGRP.\footnote{https://www.epa.gov/enforcement/enforcement-greenhouse-gas-reporting-program-hfc-importers} Moreover, from 2012 to 2016, climate change and GHG emissions reduction were significant topics of discussion and action at both the federal and state levels. For instance, California started incorporating the cap-and-trade program into the state’s facility-level transparency regulation in 2013. There is anecdotal evidence suggesting that the EPA explored extending the GHGRP to a nationwide cap-and-trade program. These examples illustrate the negative feedback that firms experience through the regulatory pressure channel.

Second, I delve into the equity investor pressure channel. The standardized transparency regulation acts as a sunshine mechanism, exposing instances where firms may have previously underreported their firm-level emissions. I analyze the equity market’s reaction to this revelation of underreporting. Underreporting is defined as cases where firms disclose higher aggregated facility emissions than voluntarily disclosed firm-level emissions, while overreporting occurs when firms disclose lower aggregated facility emissions than their firm-level emissions. I categorize underreporting as “bad news” because the market anticipates that the voluntarily disclosed total organizational emissions will exceed the sum of emissions from individual facilities within the organization. This incongruence suggests that firms had underreported their overall emissions through selective scope (usually only scope 1) and specific calculation methods, aligning with the cheap talk theory (Farrell & Rabin (1996)), and the market will perceive it negatively. Conversely, I define overreporting as “no news” because it is common sense that the entire organizational-level emissions are higher than the sum of emissions from the facilities. Hence, I hypothesize:

- **H3-1**: There is a negative stock price reaction when firms disclose the underreporting.
- **H3-2**: There is no negative stock price reaction when firms disclose the overreporting.

The negative stock market reaction in instances of underreporting demonstrates one form of negative feedback that firms receive through the GHGRP from the equity investors’ pressure channel.

Third, I investigate the consumer pressure channel. In 2012, when the EPA initially disclosed
facility-level GHG information to the public, anecdotal evidence sheds light on extensive environmental movements and boycotts strategically targeting companies perceived as significant contributors to climate change. A notable example involved environmental groups and activists launching campaigns urging consumers to boycott ExxonMobil, a firm subject to the GHGRP. The boycott call stemmed from concerns about ExxonMobil’s role in climate change, its lobbying against environmental regulations, and allegations of disseminating misinformation about climate science. Activists adeptly utilized social media platforms and grassroots movements to disseminate information about ExxonMobil’s environmental impact, drawing attention and support through online campaigns, petitions, and boycott calls. Direct experimental evidence also supports this assertion; Beyer et al. (2023) find that informed consumers actively choose less carbon-intensive products, resulting in a significant reduction of up to 9.2% in their food-related carbon footprint. Previous studies (e.g., Leuz & Wysocki (2016), Grewal & Serafeim (2020), Christensen et al. (2021)) also highlight the significance of consumers as a crucial stakeholder group, playing a key role in steering society toward a more environmentally sustainable future through a Corporate Social Responsibility (CSR) reporting mandate.

Given that the GHGRP reveals negative externalities of corporate emissions and instances of firms underreporting voluntarily disclosed firm-level emissions, I hypothesize that companies subject to GHGRP may experience a more pronounced decline in sales compared to those not subject to it. This expectation stems from the likelihood that environmentally conscious consumers are inclined to boycott products associated with elevated emissions. At a minimum, a firm’s regulatory status serves as an indicator for discerning consumer aversions toward a company’s environmental practices, as the GHGRP applies specifically to heavy-emitting firms with regulated facilities, and regulated firms are more likely to produce products with a higher environmental impact. Therefore, I hypothesize:

• **H4**: Firms affected by the GHGRP experience a greater reduction in sales compared to firms unaffected by the GHGRP.

The decrease in sales resulting from the consumer channel represents a manifestation of nega-
tive feedback received by firms.

4 Sample and Data

4.1 Sample Construction and Key Variables

I begin by constructing a sample of U.S. publicly listed firms that voluntarily disclosed their GHG emissions both before and after the implementation of the GHGRP policy. The data on firm-level GHG emissions are sourced from EiKon, an open-technology solution for financial markets professionals. Note that I exclusively use "Reported" firm-level emissions, which constitute "vendor-collected" data from the company, and do not incorporate "vendor-estimated" firm-level emissions in my analysis. The decision to exclude "vendor-estimated" emissions is grounded in the fact that when vendors estimate firm-level emissions, their models primarily rely on the total sales of firms. Consequently, it becomes challenging to discern whether the observed emissions change is a result of an actual change in emissions or a change in sales (e.g., Aswani et al. (2023) and Zhang (2022)). More importantly, there is no rational basis to assume that the economic agents perceive and make decisions based on this information because "vendor-estimated" firm-level emissions are not public information.

Firm characteristic variables are obtained from Compustat. To ensure data quality, only firms with complete information on common firm characteristics in the Compustat-CRSP merged database are included. Additionally, data on analyst following is gathered from the I/B/E/S database, and institutional holdings are sourced from the Thomson Reuters 13F database.

I retrieve annual facility-level GHG information, including emission production quantities and ownership details, from the EPA's FLIGHT database. Each facility ID is then matched with Compustat Identifiers (GVKEY) by comparing the legal name of the parent entity of each facility with the legal name of public firms. The totals of facility-level emissions and the total number

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13 The data was downloaded on April 10th, 2022.
14 https://ghgdata.epa.gov/ghgp/main.do
15 I utilize a Levenshtein distance algorithm (Levenshtein (1966)) to compare the names of public companies with
of facilities owned by the parent firm are aggregated. In rare cases where a single facility is owned by multiple parent firms, emissions are distributed based on each entity’s ownership percentage.

Because firms can invest or divest facilities that are affected by the GHGRP, the timing of a firm’s initial disclosure of facility-level GHG emissions depends on whether the firm owns any facility surpassing the reference amount in each reporting year. The total aggregated facility emissions and the total number of facilities owned by firms also fluctuate each year. To address this staggered GHGRP implementation across different fiscal years, the facility-level emissions data is merged with the corresponding voluntarily disclosed firm-level panel data. The main policy indicator variable \( GHGRP_{ft}^{2010} \) is constructed through this merging process. \( GHGRP_{ft}^{2010} \) is an indicator variable equal to 1 in the calendar year 2010, in which a firm is subject to the GHGRP for the first time and in all subsequent years, and zero otherwise. The purpose of this variable is to test H1-1, examining whether the sunshine effect operates immediately as firms anticipate "potential" negative feedback resulting from heightened public scrutiny.

To test H1-2, which posits that the sunshine effect only manifests after the dissemination of facility-level information and firms receive feedback, I construct another primary policy indicator variable \( GHGRP_{ft}^{2012} \). \( GHGRP_{ft}^{2012} \) is an indicator variable equal to 1 in the calendar year 2012 in which firms first disclose their facility-level GHG information and in all subsequent years, and zero otherwise. This variable ensures that firms have already received initial feedback from the public through the disclosure of facility emissions by the end of each fiscal year.

In total, the sample comprises 2,214 firm-year observations for 438 unique firms, covering the period from fiscal year 2007 to 2015. To mitigate the influence of outliers, all continuous control variables are winsorized at the 1st and 99th percentiles.

### 4.2 Descriptive Statistics

The summary statistics for the variables utilized in this study are presented in Table 2. For specific definitions of the variables, please see the appendix. The average of the natural logarithm of those of the parent entity of the facility.
Table 2: Summary statistics of key variables

<table>
<thead>
<tr>
<th>Panel A: Summary statistics</th>
<th>obs</th>
<th>mean</th>
<th>std</th>
<th>median</th>
</tr>
</thead>
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<tr>
<td>$\ln(firm_E)$</td>
<td>2214</td>
<td>13.57</td>
<td>2.28</td>
<td>13.47</td>
</tr>
<tr>
<td>$\ln(sale)$</td>
<td>2214</td>
<td>13.80</td>
<td>1.23</td>
<td>13.73</td>
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<tr>
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<td>2214</td>
<td>6.61</td>
<td>18.81</td>
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<tr>
<td>inventory</td>
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<td>0.09</td>
<td>0.06</td>
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<td>GHGRP</td>
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<td>0.31</td>
<td>0.46</td>
<td>0.00</td>
</tr>
<tr>
<td>$GHGRP \ln(E)$</td>
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<td>4.44</td>
<td>6.77</td>
<td>0.00</td>
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<tr>
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<td>28.93</td>
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<td>1.32</td>
<td>9.51</td>
</tr>
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<td>2214</td>
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<td>0.08</td>
<td>0.14</td>
</tr>
<tr>
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<td>0.42</td>
</tr>
<tr>
<td>ai</td>
<td>2214</td>
<td>0.57</td>
<td>0.41</td>
<td>0.49</td>
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<tr>
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<td>0.13</td>
<td>0.09</td>
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<td>0.03</td>
<td>0.02</td>
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<td>0.26</td>
<td>0.15</td>
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<td>ior</td>
<td>2214</td>
<td>0.78</td>
<td>0.15</td>
<td>0.80</td>
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<td>analyst</td>
<td>2214</td>
<td>2.79</td>
<td>0.50</td>
<td>2.89</td>
</tr>
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</table>

Aggregated facility emissions by both treated and control firms ($\ln(firm_E)$) is 13.57. For all firm-year observations, 31% of firm-year observations are affected by the GHGRP.

Table 3 presents the Pearson correlation matrix, revealing notable associations. There is a positive correlation between firm-level emissions ($\ln(firm_E)$) and sales ($\ln(sale)$), indicating that firms with higher sales tend to exhibit higher levels of GHG emissions. The company’s size ($size$) shows a positive correlation with firm-level emissions ($\ln(firm_E)$), suggesting that larger companies are linked to higher firm-level GHG emissions. Asset intensity ($ai$) also displays a positive correlation with firm-level emissions ($\ln(firm_E)$), implying that companies with more resource-intensive operations tend to emit higher levels of GHG. These findings suggest that larger and more resource-intensive companies are likely to have higher firm-level GHG emissions. There are no strong correlations observed among control variables.
Table 3: Pearson correlation matrix

<table>
<thead>
<tr>
<th></th>
<th>ln(firm_E)</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
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<td>2 ln(sale)</td>
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<tr>
<td>3 firm_E/sale</td>
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<tr>
<td>4 GHGRP</td>
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<td>5 GHGRP,ln(E)</td>
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<td>0.97</td>
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<tr>
<td>6 GHGRP,N</td>
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<td>0.18</td>
<td>0.21</td>
<td>0.41</td>
<td>0.52</td>
<td></td>
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<td>7 size</td>
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<td>0.83</td>
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<td>8 roa</td>
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<td>14 ior</td>
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<td>0.23</td>
<td>0.03</td>
<td>-0.18</td>
<td>0.01</td>
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</table>

Correlation coefficients significant at 5% are indicated in bold.
5 Empirical Analysis

5.1 Empirical Design

I employ a generalized difference-in-differences (DID) research design, adapted from Bertrand & Mullainathan (2003), to leverage the staggered exposure of firms to the GHGRP. The objective is to estimate the impact of the GHGRP on firm-level GHG emissions reduction using the Ordinary Least Squares (OLS) method.

The generalized DID equation utilized in the analysis is as follows:

\[
\ln(firm_E)_{fit} = \alpha_f + \alpha_{it} + \beta \ast GHGRP_{fit}^{2010 \text{ or } 2012} + \gamma \ast X_{ft} + \epsilon_{it}
\]  

Here, the subscript f indexes the firm, i indexes the industry, and t indexes the fiscal year. The dependent variable \(\ln(firm_E)_{fit}\) represents the natural logarithm of voluntarily disclosed firm-level emissions. The use of the logarithmic transformation allows for a more straightforward interpretation of the results in terms of percentage changes and mitigates the influence of outliers. \(GHGRP_{fit}^{2010}\) is an indicator variable equal to 1 in the calendar year 2010, in which a firm is subject to the GHGRP for the first time and in all subsequent years, and zero otherwise. On the other hand, \(GHGRP_{fit}^{2012}\) is an indicator variable equal to 1 in the calendar year 2012 in which firms first disclose their facility-level GHG information and in all subsequent years, and zero otherwise.

The model incorporates firm fixed effects (\(\alpha_f\)) and industry-year fixed effects (\(\alpha_{it}\)). Additionally, I implement an alternative specification that controls for both firm and year-fixed effects. Consistent with prior literature on mandatory greenhouse gas reporting (e.g., Downar et al. (2021), Yang et al. (2021), Tomar (2022)), the model includes control variables for common firm characteristics, such as firm size, market-to-book ratio, asset intensity, and book leverage. Additionally, I incorporate controls for operating performance, capital structure, institutional ownership, and analyst coverage. For variable definitions, please refer to Panel B in Table 2. Standard errors are clustered at the firm level to address the presence of serially correlated errors.
5.2 Main Results

Table 4 shows the main results examining hypotheses H1-1 and H1-2. Columns (1) and (3) specify firm and industry-year fixed effects, while columns (2) and (4) include firm and year fixed effects.

In columns (1) and (3), where the dependent variable is \( \ln(\text{firm}_E) \) the coefficient on the key variable of interest (\( GHGRP_{ft}^{2010} \)) does not exhibit statistical significance, leading to the rejection of H1-1. This implies that the sunshine effect does not operate immediately, as firms may not anticipate or ignore "potential" negative feedback resulting from heightened public scrutiny.

Conversely, in columns (2) and (4), the coefficient on the key variable of interest (\( GHGRP_{ft}^{2012} \)) demonstrates statistical significance at the 5% and 1% levels, respectively, supporting H1-2. Economically, this indicates that, on average, firms reduce their firm-level GHG emissions by 9% and 11.2%, respectively, following the public release of facility-level information. The differing outcomes observed between \( GHGRP_{ft}^{2010} \) and \( GHGRP_{ft}^{2012} \) suggest that firms strategically adjust their behavior in response to the public release of mandated information (e.g., in the calendar year 2012) rather than merely reacting to the timing of policy implementation (e.g., in the calendar year 2010).

5.2.1 Cross-sectional Analyses: Aggregated Facility Emissions and Number of Facilities Owned

To tighten the link between detailed transparency regulations and firms’ voluntary reductions in firm-level GHG emissions, I delve into cross-sectional analyses. In the initial step, I perform exploratory data analysis by closely examining the total aggregated facility-level emissions \( (GHGRP._{ln(E)}|GHGRP = 1) \) and the total number of facilities \( (GHGRP._{N}|GHGRP = 1) \) among firms exclusively subject to the GHGRP denoted as \( GHGRP = 1 \). Table 6 presents the summary statistics and histograms for this facility-level GHG information. The dataset comprises a total of 691 firm-year observations (obs). Surprisingly, the median of the natural logarithm of firm-level emissions by the GHGRP firms surpasses that of voluntary firm-level emissions by all firms (13.97 > 13.47). Notably, the average number of facilities owned by the GHGRP firms is 25, demonstrating substantial variability across different GHGRP firms with a standard deviation of 47. The
Table 4: Impact of Granular Transparency Regulation on Change in Firm-Level Emissions

<table>
<thead>
<tr>
<th></th>
<th>Dependent variable: $ln(firm_E)$</th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
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<td></td>
<td>(-0.30)</td>
<td>(-1.25)</td>
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<tr>
<td>$GHGRP_{ft}^{2012}$</td>
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<td>-0.090**</td>
<td>-0.112***</td>
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<tr>
<td></td>
<td>(-2.14)</td>
<td>(-2.64)</td>
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<tr>
<td>size</td>
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<td>0.644***</td>
<td>0.607***</td>
<td>0.601***</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(7.18)</td>
<td>(7.18)</td>
<td>(7.01)</td>
<td>(7.02)</td>
<td></td>
</tr>
<tr>
<td>bm</td>
<td>0.024</td>
<td>0.027</td>
<td>0.025</td>
<td>0.032</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.40)</td>
<td>(0.46)</td>
<td>(0.42)</td>
<td>(0.53)</td>
<td></td>
</tr>
<tr>
<td>ai</td>
<td>0.683**</td>
<td>0.668**</td>
<td>0.675**</td>
<td>0.696**</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(2.40)</td>
<td>(2.39)</td>
<td>(2.36)</td>
<td>(2.46)</td>
<td></td>
</tr>
<tr>
<td>bl</td>
<td>0.032</td>
<td>0.039</td>
<td>0.122</td>
<td>0.120</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.18)</td>
<td>(0.21)</td>
<td>(0.68)</td>
<td>(0.68)</td>
<td></td>
</tr>
<tr>
<td>cash</td>
<td>0.419**</td>
<td>0.395*</td>
<td>0.308</td>
<td>0.318</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(1.99)</td>
<td>(1.89)</td>
<td>(1.53)</td>
<td>(1.59)</td>
<td></td>
</tr>
<tr>
<td>roa</td>
<td>0.629</td>
<td>0.634</td>
<td>0.544*</td>
<td>0.525*</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(1.64)</td>
<td>(1.64)</td>
<td>(1.71)</td>
<td>(1.65)</td>
<td></td>
</tr>
<tr>
<td>div</td>
<td>0.834</td>
<td>0.616</td>
<td>1.342</td>
<td>0.977</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.94)</td>
<td>(0.69)</td>
<td>(1.47)</td>
<td>(1.08)</td>
<td></td>
</tr>
<tr>
<td>ior</td>
<td>0.009</td>
<td>0.001</td>
<td>-0.063</td>
<td>-0.054</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.05)</td>
<td>(0.01)</td>
<td>(-0.46)</td>
<td>(-0.39)</td>
<td></td>
</tr>
<tr>
<td>analyst</td>
<td>-0.047</td>
<td>-0.048</td>
<td>-0.031</td>
<td>-0.028</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(-1.09)</td>
<td>(-1.14)</td>
<td>(-0.74)</td>
<td>(-0.70)</td>
<td></td>
</tr>
<tr>
<td>Observations</td>
<td>2,214</td>
<td>2,214</td>
<td>2,214</td>
<td>2,214</td>
<td></td>
</tr>
<tr>
<td>Adj R2</td>
<td>0.984</td>
<td>0.984</td>
<td>0.984</td>
<td>0.984</td>
<td></td>
</tr>
<tr>
<td>Firm FE</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td></td>
</tr>
<tr>
<td>FF12-Year FE</td>
<td>YES</td>
<td>YES</td>
<td>NO</td>
<td>NO</td>
<td></td>
</tr>
<tr>
<td>Year FE</td>
<td>NO</td>
<td>NO</td>
<td>YES</td>
<td>YES</td>
<td></td>
</tr>
</tbody>
</table>

Robust t-statistics in parentheses

*** p<0.01, ** p<0.05, * p<0.1
Table 5: Descriptive Statistics for Facility-Level GHG Information Among Firms Subject to the GHGRP

<table>
<thead>
<tr>
<th></th>
<th>obs</th>
<th>mean</th>
<th>std</th>
<th>min</th>
<th>25%</th>
<th>50%</th>
<th>75%</th>
<th>max</th>
</tr>
</thead>
<tbody>
<tr>
<td>$GHGRP \cdot \ln(E)</td>
<td>GHGRP = 1$</td>
<td>691</td>
<td>14.22</td>
<td>2.80</td>
<td>8.08</td>
<td>11.86</td>
<td>13.97</td>
<td>16.50</td>
</tr>
<tr>
<td>$GHGRP \cdot N</td>
<td>GHGRP = 1$</td>
<td>691</td>
<td>25</td>
<td>47</td>
<td>1</td>
<td>3</td>
<td>8</td>
<td>24</td>
</tr>
</tbody>
</table>

minimum values for aggregated facility emissions and the number of facilities owned by GHGRP firms are 8.08 and 1, respectively. This implies that one GHGRP firm owns at least one facility emitting approximately 3300 ($\approx e^{8.08}$) tons of carbon dioxide equivalent (CO2e). On the other end of the spectrum, the maximum values for the natural logarithm of aggregated facility emissions and the number of facilities owned by GHGRP firms are 20.98 ($e^{20.98} \approx$ total 1,288,226,838 CO2e) and 301, respectively—remarkably high figures. This suggests the presence of certain GHGRP firms emitting excessive facility emissions with ownership of more than 300 facilities, thereby causing substantial negative externalities to society. Overall, the exploratory data analysis reveals that the extent of facility emissions by the GHGRP firms is notably high, raising the possibility that some GHGRP firms may emit even more aggregated facility-level emissions than what they voluntarily disclose at the firm level.

Next, I test whether the disclosure of aggregated facility emissions and the number of facilities
owned has a cross-sectional effect on the reduction in firm-level emissions using the following equation:

\[
\ln(firm_E)_{fit} = \alpha_f + \alpha_{it} + \beta \times \begin{cases} 
GHGRP_{ln(E)}^{2012} \\
OR \\
GHGRP_{N}^{2012}
\end{cases} + \gamma \times X_{ft} + \epsilon_{it}
\]

(2)

The empirical setting in the equation above aligns with the main Equation (1), but here, I substitute the policy variable \((GHGRP_{ft}^{2010} \text{ or } 2012)\) with \(GHGRP_{ln(E)}^{2012} \text{ or } GHGRP_{N}^{2012}\). \(GHGRP_{ln(E)}^{2012}\) represents the natural logarithm of aggregated facility emissions in the calendar year 2012, in which the firm first discloses and in all subsequent years, and is zero otherwise. The coefficient of this variable tests H2-1, assessing whether total aggregated facility-level emissions influence the reduction of firm-level emissions. On the other hand, \(GHGRP_{ln(E)}^{2012}\) indicates the total number of facilities owned by the GHGRP firms in the calendar year 2012, when the firm first discloses and in all subsequent years, and is zero otherwise. The coefficient of this variable tests H2-2, examining whether the number of facilities owned influences the reduction of firm-level emissions.

Table 6 presents the results of the hypothesis tests for H2-1 and H2-2. In columns (1) and (2), where the natural logarithm of voluntarily disclosed firm-level emissions \((\ln(firm_E))\) serves as the dependent variable, the coefficient on the focal variable \((GHGRP_{ln(E)}^{2012})\) achieves statistical significance at the 5% and 1% levels, respectively, providing empirical support for H2-1. This suggests that, upon disclosing higher total aggregated facility emissions, firms are inclined to subsequently reduce their firm-level emissions more following the public release of facility-level information. The estimated economic magnitude indicates that, on average, for every 1% increase in total aggregated facility emissions disclosed, firms tend to decrease firm-level emissions by 0.71%. The results are consistent with the notion that the sunshine effect operates more strongly when firms disclose higher total aggregated facility emissions. This is because such firms are prone to heightened scrutiny and more negative feedback, given their larger contribution to GHG-related
Table 6: Effect of Disclosing Total Facility-Level Emissions and Number of Facilities on Changes in Firm-Level Emissions

<table>
<thead>
<tr>
<th></th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>GHGRP ln(E)^ft_{2012}</strong></td>
<td>-0.0071** (-2.14)</td>
<td>-0.0078*** (-2.67)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>GHGRP N^ft_{2012}</strong></td>
<td></td>
<td>0.000 (0.13)</td>
<td>-0.000 (-0.68)</td>
<td></td>
</tr>
<tr>
<td>Observations</td>
<td>2,214</td>
<td>2,214</td>
<td>2,214</td>
<td>2,214</td>
</tr>
<tr>
<td>Adjusted R2</td>
<td>0.984</td>
<td>0.984</td>
<td>0.984</td>
<td>0.984</td>
</tr>
<tr>
<td>Controls</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
</tr>
<tr>
<td>Firm FE</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
</tr>
<tr>
<td>FF12-Year FE</td>
<td>YES</td>
<td>NO</td>
<td>YES</td>
<td>NO</td>
</tr>
<tr>
<td>Year FE</td>
<td>NO</td>
<td>YES</td>
<td>NO</td>
<td>YES</td>
</tr>
</tbody>
</table>

Robust t-statistics in parentheses

*** p < 0.01, ** p < 0.05, * p < 0.1

externalities in society.

On the other hand, transitioning to columns (3) and (4), where the impact of the number of facilities owned by firms on firm-level GHG reduction is examined, I find no evidence of the disclosure of the number of facilities owned contributing to the reduction of firm-level emissions, supporting H2-2. These divergent cross-sectional outcomes suggest that firms aim to curtail firm-level emissions by enhancing operational and production efficiency, rather than giving up profits through the divestment of existing facilities.

Specifications without tabulation, incorporating both variables **GHGRP ln(E)^ft_{2010}** and **GHGRP N^ft_{2010}**, reveal that neither variable holds statistical significance. This reaffirms the idea that tangible feedback from stakeholders, achieved through the public dissemination of information, is essential for eliciting sunshine effects on firm behavior.

5.2.2 Dynamic Effects and Goodman-Bacon Decomposition

To assess the validity of the parallel-trend assumption essential for the DID methodology, I investigate the dynamic effects on firm-level emissions in the years preceding and following the initial
facility-level emissions disclosure, compared to control firms. I maintain the same empirical setting as in the main equation (1) but introduce the dynamic effects of the policy variables in the following equation:

\[
\ln(firm_E)_{fit} = \alpha_f + \alpha_{it} + \beta_{2010+b} \sum_b GHGRP_{2010+b} + \gamma X_{ft} + \epsilon_{it} \tag{3}
\]

, where \( b = (-3, -2, -1, 0, 1, 2, 3, 4, 5) \)

The figure 1 visually illustrates the evolving influence of the GHGRP on firm-level emissions. Each black dot in the graph represents the coefficient value (\( \beta_{2010+b} \)) of the dynamic effects of the policy variable along with its respective 95% confidence interval. Statistically significant coefficients at the 5% level are highlighted by red lines within the confidence interval, while non-significant coefficients are indicated by blue lines. A horizontal green dotted line at zero signifies a lack of discernible economic impact of the GHGRP on firm-level emissions.

The coefficients corresponding to the pre-policy periods are statistically insignificant, supporting the parallel trend assumption. Similarly, the coefficients for the policy implementation year (\( GHGRP_{2010}^{fit} \)) and one year after the implementation (\( GHGRP_{2011}^{fit} \)) are also statistically insignificant, as indicated by the prevalence of blue lines within their respective confidence intervals.

In contrast, the coefficient for the year 2012, representing the initiation of GHGRP when facility GHG information is first released to the public (\( GHGRP_{2012}^{fit} \)), is both statistically and economically significant. Marked by red lines within the confidence intervals, this finding suggests a negative coefficient of -0.08 and a t-statistic of -2.47, indicating that the mandatory disclosure of facility-level emissions led to an 8% reduction in firm-level emissions. Note that this reduction trend is not enduring, as emission levels converge between the two groups one year later. This implies that firms strategically and temporarily curtail their emissions in response to the initial negative feedback from stakeholders. Presumably, as accumulated negative feedback from stakeholders grows, this strategic reduction pattern reoccurs with the policy variable (\( GHGRP_{2015}^{fit} \)),

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resulting in a 10% reduction in firm-level emissions compared to the control group.

Goodman-Bacon (2021) demonstrates that the generalized DID estimator essentially represents a weighted average of all conceivable standard DID estimates between treated and control observations. In the context of my study’s sample, the composition of the control group dynamically changes based on whether firms invest or divest facilities affected by the GHGRP each year. Recent studies by Goodman-Bacon (2021), Baker et al. (2022) point out the potential bias introduced when incorporating already-disclosed firms into the control group, as the treatment effect may vary over time. To address this concern, I employ the methodology proposed by Goodman-Bacon (2021) and decompose the generalized DID estimate into components based on different sets of control firms. To conduct the decomposition analysis, a balanced panel without control variables is necessary. Therefore, I limit the sample period from fiscal years 2010 to 2014, ensuring a robustly balanced panel.

Table 7 presents the results from the decomposition analysis, unveiling the primary drivers
Table 7: Goodman-Bacon Decomposition

<table>
<thead>
<tr>
<th></th>
<th>Coefficient</th>
<th>std. err</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall DID Estimate</td>
<td>-.104</td>
<td>.030</td>
</tr>
<tr>
<td>Early vs Late</td>
<td>.029</td>
<td>.028</td>
</tr>
<tr>
<td>Late vs Early</td>
<td>.067</td>
<td>.028</td>
</tr>
<tr>
<td>Early vs Late</td>
<td>-.170</td>
<td>.010</td>
</tr>
<tr>
<td>Late vs Early</td>
<td>.092</td>
<td>.005</td>
</tr>
<tr>
<td>Early vs Late</td>
<td>-.123</td>
<td>.001</td>
</tr>
<tr>
<td>Late vs Early</td>
<td>.016</td>
<td>.000</td>
</tr>
<tr>
<td>Never vs Timing</td>
<td>-.114</td>
<td>.924</td>
</tr>
</tbody>
</table>

behind the generalized DID estimates. The comparison involves the treatment group, consisting of firms affected by GHGRP at both early and late stages, with the control group of firms that have never been subject to GHGRP. Notably, the economic magnitude of the coefficient (Never vs Timing) closely mirrors that of the Overall DID Estimate with a weighting of 0.924. This suggests that the treatment effect of reducing firm-level GHG in this study is primarily driven by the contrast with firms never affected by GHGRP, rather than being influenced by the inclusion of already-disclosed firms in the control group. Thus, the Goodman-Bacon decomposition supports the existence of the sunshine effect of granular transparency regulation on the voluntary reduction of firm-level GHG emissions.

5.2.3 Addressing Alternative Explanation: Emission Changes and Sales Fluctuations

To address the potential alternative explanation that the primary driver of the reduction in firm-level emissions is a natural decline in sales rather than firms’ strategic efforts, I introduce a control variable representing the natural logarithms of total sales, determined contemporaneously with the policy variable in the main Equation (1) as follows:

$$\ln(firm_E)_{fit} = \alpha_f + \alpha_{it} + \beta \times GHGRP_{fit}^{2012} + \gamma \times X_{fit} + \ln(sale)_{fit}^{2012} + \varepsilon_{it}$$ (4)

Additionally, I replace the dependent variable in the main Equation (1) with firm-level emis-
Table 8: Unpacking the relationship between emission change and sales change

<table>
<thead>
<tr>
<th>Dependent variable</th>
<th>(1)</th>
<th>(2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \ln(firm_E)_{fit} )</td>
<td>-0.092**</td>
<td>-0.397***</td>
</tr>
<tr>
<td>( (-2.19) )</td>
<td>( (-2.15) )</td>
<td></td>
</tr>
<tr>
<td>( \ln(sale)_{fit} )</td>
<td>0.116**</td>
<td></td>
</tr>
<tr>
<td>( (2.34) )</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| Observations | 2,183 | 2,214 |
| Adjusted R-squared | 0.984 | 0.965 |
| Controls | YES | YES |
| Firm FE | YES | YES |
| FF12-Year FE | YES | YES |

Robust t-statistics in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Emissions scaled by contemporaneous sales. This scaled dependent variable enables an assessment of firm-level emissions reduction in relation to sales as follows:

\[
(firm_E/sale)_{fit} = \alpha_f + \alpha_{it} + \beta \times GHGRP_{fit-2} + \gamma \times X_f + \varepsilon_{it} \quad (5)
\]

Table 8 shows the testing results, consistently demonstrating that, whether accounting for sales with a control variable or scaling the dependent variable, the statistical significance of the main finding remains unchanged. The evidence effectively rules out the alternative explanation that observed firm-level emissions are due to a decrease in sales.
6 Potential Underlying Mechanism of the Sunshine Effect: Negative Feedback

6.1 Investor Pressure Channel

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

The analysis in Subsection 5.2.1 raises concerns about the potential voluntary underreporting of firm-level emissions. In this section, I provide evidence that certain firms indeed underreport their firm-level emissions, aligning with the cheap talk theory (Farrell & Rabin (1996)). Underreporting is defined when firms disclose higher total aggregated facility emissions compared to voluntarily disclosed firm-level emissions, while overreporting occurs when firms disclose lower total aggregated facility emissions. Table 9 presents summary statistics of instances where firms underreport and overreport their firm-level emissions across seven disclosure dates of facility-level GHG information (refer to Table 1). Out of 787 firm disclosure dates, there are 216 instances of underreporting and 571 cases of overreporting. The underreporting is substantial; for instance, the average of aggregated facility emissions is more than five times greater (158,494,470/30,168,442=5.25) than voluntarily disclosed firm-level emissions. This significant difference is also apparent when examining the standard deviations; the standard deviation of aggregated facility emissions is almost ten times greater compared to the standard deviation of firm-level emissions (352,543,078/35,442,249=9.94), indicating a substantial difference in variability. The range of underreporting is vast, with the minimum voluntarily disclosed firm-level emissions being four times greater than the minimum aggregated facility emissions for underreporting instances (131,527/32,761=4.01). The maximum values further highlight the magnitude of underreporting, with aggregated facility emissions nine times bigger than voluntarily disclosed firm-level emissions (1,288,226,838/143,000,000=9).
Table 9: Comparing Firm-Level Emission Reporting Discrepancies: Underreporting vs. Overreporting

<table>
<thead>
<tr>
<th></th>
<th>obs</th>
<th>mean</th>
<th>std</th>
<th>min</th>
<th>25%</th>
<th>median</th>
<th>75%</th>
<th>max</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Underreporting</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>firm emissions</td>
<td>216</td>
<td>30,168,442</td>
<td>35,442,249</td>
<td>32,761</td>
<td>4,000,000</td>
<td>18,710,486</td>
<td>37,550,000</td>
<td>143,000,000</td>
</tr>
<tr>
<td>facility emissions</td>
<td>216</td>
<td>158,494,470</td>
<td>352,543,078</td>
<td>131,527</td>
<td>7,550,589</td>
<td>33,492,787</td>
<td>734,106,96</td>
<td>1,288,226,838</td>
</tr>
<tr>
<td><strong>Overreporting</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>firm emissions</td>
<td>571</td>
<td>8,193,936</td>
<td>16,969,969</td>
<td>86,007</td>
<td>845,750</td>
<td>2,672,964</td>
<td>6,230,000</td>
<td>139,000,000</td>
</tr>
<tr>
<td>facility emissions</td>
<td>571</td>
<td>4,387,575</td>
<td>1,2317,942</td>
<td>32,27</td>
<td>805,24</td>
<td>426,798</td>
<td>2,171,592</td>
<td>129,873,159</td>
</tr>
</tbody>
</table>

Electronic copy available at: https://ssrn.com/abstract=4719736
I classify instances where the underreporting of firm-level emissions is uncovered through facility-level GHG information disclosure as “bad news.” This categorization is rooted in market expectations that firms will disclose lower facility emissions than their voluntarily disclosed firm-level emissions. This expectation arises from the comprehensive nature of firm-level emissions, which encompasses the entire organization, while facility-level emissions represent only a part of the firm. Even with the inclusion of Scope 2 (indirect) emissions in facility emissions, the notion that total aggregated facility emissions would surpass those of the entire organization is deemed nonsensical. Hence the market will perceive it negatively. Conversely, I define instances where the overreporting of firm-level emissions is revealed through facility-level GHG information disclosure as “no news,” as it is inherent that overall organizational emissions exceed the sum of facility-level emissions.

6.1.2 Standard Event Study Methodology

In the investor pressure channel, I investigate the stock market response to the public disclosure of facility GHG information. I employ a standard event study methodology to calculate the cumulative abnormal return over the event window [-5, +5] on the events that release facility-level GHG information as detailed in Table 1. The methodology can be expressed as follows:

\[ K_{it} = b_i[E(R_m) - R_f] + s_iE(SMB) + h_iE(HML) + m_iE(MOM) \]  

(6)

\[ e_{it} = R_{it} - K_{it} \]  

(7)

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

(8)

\[ CAR(-5, +5) = \sum_{t=-5}^{+5} AR_t \]  

(9)

In the given equations, \( i \) represents firm (security) and \( t \) corresponds to the announcement dates of facility-level GHG information. To isolate market effects linked to mandatorily disclosed
GHG information, the benchmark return \( K_{it} \) incorporates the Fama-French three factors (Fama & French (1996)) and the momentum factor (e.g., Jegadeesh & Titman (1993), Carhart (1997)).

Abnormal return \( e_{it} \) is the difference between the return conditional on the event and the expected return unconditional on the event. The average abnormal return \( AR_t \) indicates a sample of the cross-sectional mean abnormal return of \( N \) securities for any period \( t \). The cumulative abnormal return \( CAR(-5, +5) \) represents the abnormal performance measure the sum of each date’s average abnormal performance with an event window from -5 to + 5.

To evaluate H3-1, predicting a negative market reaction in instances of firms disclosing underreporting ("bad news"), I compute the cumulative abnormal return where \( t \) corresponds to instances of underreporting and examine its statistical significance. Conversely, to investigate H3-2, proposing no negative market reaction in instances where firms disclose overreporting, I calculate the cumulative abnormal return where \( t \) is associated with instances of overreporting and assess its statistical significance. Following Campbell et al. (1998), the test statistic is calculated as follows:

\[
T-stat = \frac{CAR(-5, +5)}{11 * \sigma^2(AR_t)}
\]

where \( \sigma^2(AR_t) \) is the variance of the one-date mean abnormal return and the value 11 indicates the total number of dates in the event window.

Table 10 provides the test results and visual representations. I observe an average negative market reaction of -1.26% when firms disclose underreporting, supporting H3-1. The economic magnitude of this negative market reaction corresponds to an average loss of $126 million in market value, a substantial figure considering the 11-day event window. The evidence shows that the market perceives the underreporting as bad news. In contrast, no average negative reaction is observed for instances of overreporting, aligning with H3-2.

The visual representation illustrates dynamic differences in market reactions between the two cases. The Y-axis represents the cumulative abnormal return, and the X-axis denotes the event window. The red line depicts the cumulative abnormal return for underreporting, while the blue line represents the cumulative abnormal return for overreporting. Both lines are shaded to reflect
the 95% confidence interval. A distinct downward pattern is evident during instances of under-reporting, while no discernible pattern emerges for over-reporting. These observed negative stock market reactions from equity investors exemplify one of the pressures that firms face due to the revealing mechanisms of granular transparency regulation.

### 6.2 Consumer Pressure Channel

To test H4, which posits that GHGRP firms experience more significant sales reductions compared to non-GHGRP firms, I employ the following regression equation:

\[
\ln(sale)_{fit} = \alpha_f + \alpha_t + \beta \times GHGRP^{2012}_{ft} + \gamma \times X_{ft} + \varepsilon_{it}
\] (10)
Table 11: Impact of the GHGRP on Change in Firm Sales

<table>
<thead>
<tr>
<th>Dependent variable</th>
<th>ln(sale)_{fit}</th>
</tr>
</thead>
<tbody>
<tr>
<td>$GHGRP_{fit}^{2012}$</td>
<td>-0.040** (-2.26)</td>
</tr>
</tbody>
</table>

Observations: 2,214  
Adjusted R-squared: 0.990  
Controls: YES  
Firm FE: YES  
FF12-Year FE: YES

Robust t-statistics in parentheses  
*** p<0.01, ** p<0.05, * p<0.1

The model maintains the same empirical settings as in the main equation (1), but with the dependent variable being the natural logarithm of total sales. I anticipate that the coefficient of the main policy variable will be negative. Table 11 presents the testing results. I find that, on average, firms subject to the GHGRP experience an additional 4% reduction in sales compared to firms unaffected by the GHGRP, supporting H4. A 4% sales reduction per year is economically significant. This evidence of sales reduction for GHGRP firms is consistent with anecdotal evidence that these firms faced widespread environmental movements and boycotts due to climate change concerns in 2012 when the EPA initially disclosed facility-level GHG information to the public.

6.2.1 Robustness Check: Assessing the Possibility of GHGRP Firms’ Sales Reduction from the Supply Side

In economic equilibrium, a firm’s total sales are determined by the intersection of consumer demand and the firm’s production supply. While some may posit that the majority of the GHGRP firms’ sales reduction stems from the supply side—specifically, the firm’s production supply—I argue against this notion. Given that the GHGRP typically pertains to a facility, representing only a fraction of a firm’s operations, it is unlikely that firms would willingly curtail their production to “comply” with the program. To strengthen the argument that a significant portion of the GHGRP
firms’ sales reduction comes from the consumer side rather than the supply side, I introduce the following equation. This equation maintains the same empirical setting as the main equation (1) but with inventory levels as the dependent variable.

\[
\text{Inventory}_{it} = \alpha_f + \alpha_{it} + \beta^* \text{GHGRP}^{2012}_{it} + \gamma^* X_{it} + \epsilon_{it} \tag{11}
\]

I expect that there should be noticeable fluctuations in inventory levels for the GHGRP firms if they are withholding product sales or reducing the total production quantity to comply with the GHGRP from the supply side. Table 12 presents the testing results, indicating that the GHGRP does not have an impact on the change in firms’ inventory levels both statistically and economically. The absence of an impact of the GHGRP on inventory levels supports the idea that the observed decrease in sales is not solely a consequence of firms’ production decisions but rather reflects an environmentally conscious consumer-driven reduction in sales.

## 7 External Validity of Sunshine Effect

While the focused examination of a specific sample of voluntary disclosers increases internal validity, it raises questions about the external validity of these findings due to the limited sample
It is crucial to note that the granular transparency regulation itself does not autonomously alter firm behavior. It is not the sole disclosure channel that induces changes in firm behavior. Tangible negative feedback from stakeholders triggered through the revealing mechanism of transparency regulation serves as an incentive for firms to improve their environmental practices and proactively address negative externalities.

The broader effectiveness of the sunshine effect in promoting positive environmental changes beyond the studied sample depends on how firms perceive the expected benefits of emissions reduction relative to the expected costs of emission reduction. Anticipated benefits include cutting negative feedback loops from stakeholders and enhancing public image. The expected benefits grow as the magnitude of the negative feedback increases. For instance, when a firm publicly discloses multiple high-emission facilities, stakeholders such as equity investors and consumers may respond with negative feedback, resulting in a negative market reaction or boycotting the product. In response, firms may choose to reduce firm-level emissions to mitigate negative feedback, improving operational and production efficiency in the short term or investing in cleaner technologies in the long run.

Conversely, some firms may consider that the expected costs of reducing emissions outweigh the expected benefits. As a result, they may prioritize short-term profits, emitting more GHG, and disregard negative feedback from stakeholders if the magnitude of negative feedback is small. In such cases, the sunshine effect has a limited impact, and the likelihood of positive environmental changes occurring becomes low. One-time negative feedback is not likely to induce permanent changes in firm behavior. For transparency regulations to effectively reduce GHG emissions, continuous and significant feedback from stakeholders is necessary so that firms perceive the expected benefit of reduction outweighs the expected cost of reduction.
8 Conclusion and Policy Implication

In this study, I investigate how and why transparency regulation at the disaggregated level influences behavior at the aggregated level. The key findings underscore the positive impact of facility-level GHG information disclosure on reducing firm-level emissions. The standardized and detailed transparency regulation acts as a “sunshine” mechanism, bringing specific emission sources causing negative externalities to society to light and exposing that firms had previously underreported their overall emissions. I systematically demonstrate that stakeholders, such as regulators, equity investors, and consumers, provide negative feedback to firms through awareness of wrongdoings exposed by the regulation. The observed reduction in firm-level emissions is consistent with firms’ strategic initiatives to mitigate negative feedback loops originating from mandated disclosure.

This study carries policy implications, particularly for regulators tasked with enforcing disclosure regulations aimed at driving market discipline within firms (Leuz & Wysocki (2016)). This is particularly relevant in the context of GHG reporting, as indicated by recent regulatory developments such as those proposed by the U.S. Securities and Exchange Commission (US SEC (2022b)). The SEC’s proposed amendments, requiring registrants to disclose specific climate-related information, including firm-level GHG emissions, are commendable steps toward increased transparency (US SEC (2022a)). However, the proposed rule lacks standardization in calculating firm-level emissions.

This study emphasizes the significance of a sunshine mechanism inherent in disaggregated-level GHG transparency regulation. By exposing specific emission sources that cause negative externalities on society and instances where firms had previously underreported their overall emissions, this mechanism evokes stakeholders’ engagement with negative feedback to firms, thereby fostering market discipline. The effectiveness of this revealing mechanism is attributed to the Environmental Protection Agency’s standardization of facility-level GHG emissions. For instance, as outlined by the GHGRP, the EPA provides clear definitions of "direct" and "indirect" emissions and

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establishes a universal reporting framework.\textsuperscript{18} In contrast to voluntarily disclosed firm-level GHG emissions, which are subject to discretionary decisions such as selective scope and calculation methods, the EPA’s standardization ensures comparability of aggregated facility-level emissions across different firms. Ensuring the provision of consistent and comparable GHG information to stakeholders is crucial, enabling them to provide negative feedback and, in turn, fostering market discipline within firms. Therefore, GHG transparency regulation without standardization and comparability may fall short of effectively uncovering wrongdoings by certain firms, diminishing the potential for market discipline through stakeholder engagement.

The SEC’s proposed rule on Scope 3 GHG emissions introduces additional challenges related to comparability due to the complexities of supply chains. To address this, I recommend adopting a bottom-up approach, similar to the methodology used in this study. This approach involves aggregating facility-level emissions based on parent firms’ ownership percentages, mitigating issues like double counting, and ensuring comparability across firms.

Of course, the EPA’s vigilant oversight of GHG emissions measurement under the GHGRP, coupled with enforcement actions against inaccurate reporting, exemplifies the regulatory role in maintaining market discipline within firms.\textsuperscript{19} Regulators should keep in mind that transparency regulation itself does not bring market discipline

\textsuperscript{18}https://www.ecfr.gov/current/title-40/chapter-I/subchapter-C/part-98?toc=1

\textsuperscript{19}https://www.epa.gov/enforcement/enforcement-greenhouse-gas-reporting-program-hfc-importers
## Appendix

### Variables definitions

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\ln(firm_E)$</td>
<td>natural logarithm of voluntarily disclosed firm-level GHG emissions (in metrics tons carbon dioxide equivalent (co2e))</td>
</tr>
<tr>
<td>$\ln(sale)$</td>
<td>natural logarithm of total sales (in millions)</td>
</tr>
<tr>
<td>$firm_E/sale$</td>
<td>firm-level GHG emissions divided by total sales</td>
</tr>
<tr>
<td>inventory</td>
<td>inventories-total divided by total asset</td>
</tr>
<tr>
<td>GHGRP</td>
<td>dummy variable, equals 1 if a firm possesses any facilities subject to the GHGRP transparency regulation</td>
</tr>
<tr>
<td>GHGRP_$\ln(E)$</td>
<td>natural logarithm of total aggregated facility-level GHG emissions subject to the GHGRP transparency regulation owned by each firm (in metrics tons carbon dioxide equivalent (co2e))</td>
</tr>
<tr>
<td>GHGRP_$N$</td>
<td>total number of facilities subject to the GHGRP transparency regulation owned by each firm</td>
</tr>
<tr>
<td>size</td>
<td>firm size, the natural logarithm of total assets</td>
</tr>
<tr>
<td>roa</td>
<td>return on assets (ib/at)</td>
</tr>
<tr>
<td>bm</td>
<td>book to market ratio</td>
</tr>
<tr>
<td>ai</td>
<td>asset intensity (ppegt/at)</td>
</tr>
<tr>
<td>cash</td>
<td>cash holdings (che/at)</td>
</tr>
<tr>
<td>div</td>
<td>dividend payout ratio ($(dvc+dvp)/at)$</td>
</tr>
<tr>
<td>bl</td>
<td>book leverage ratio ($(dltt+dltc)/at)$</td>
</tr>
<tr>
<td>ior</td>
<td>institutional ownership ratio</td>
</tr>
<tr>
<td>analyst</td>
<td>analyst following the natural logarithm of one plus the number of analysts following the company during the year</td>
</tr>
</tbody>
</table>
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