When climate-risk disclosures reduce green investment and welfare

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Abstract

Common wisdom suggests more disclosure about climate risk exposures improves welfare. We show that this need not be the case. A firm chooses whether to adopt a costly green project to maximize its stock price. When a firm's adoption of a green project is endogenous, more public disclosure of the project's climate risk exposure, or "greenness", *reduces* the likelihood of adoption and can *decrease* investor welfare. We characterize conditions under which mandatory disclosure of climate-risk exposure leads to lower welfare than no disclosure. Moreover, allowing firms to engage in costly, voluntary disclosure can lead to higher investor welfare than under no-disclosure or mandatory disclosure.

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Keywords: greenness, climate disclosure, welfare, risk sharing, climate regulation, abatement

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1 Introduction

"Investors get to decide which risks they want to take so long as companies raising money from the public make what President Franklin Roosevelt called 'complete and truthful disclosure'... These final rules build on past requirements by mandating material climate risk disclosures by public companies and in public offerings. The rules will provide investors with consistent, comparable, and decision-useful information, and issuers with clear reporting requirements."[1]
— Gary Gensler (former SEC Chair), March 2024

There has been widespread adoption of rules mandating climate-risk disclosures in recent years. For instance, the above quote is from a press-release announcing the Security and Exchange Commission's adoption of the final rule for "The Enhancement and Standardization of Climate-Related Disclosures for Investors" in March 2024. Similarly, in July 2023, the European Commission adopted the European Sustainability Reporting Standards (ESRS), which provide explicit disclosure requirements to report on environmental, social and governance issues in line with the Corporate Sustainability Reporting Directive (CSRD).

However, a number of these measures have already been scaled back. In March 2025, the SEC voted to end its defense of the same climate disclosure rules, describing them as "costly and unnecessarily intrusive," even as legal challenges to the rules proceed.[2] And in February 2025, the European Commission published the ESG Omnibus Simplification Package, which in addition to reducing the complexity of disclosur requirements, proposes to significantly reduce the scope of the ESRS.[3]

The rapidly changing regulatory landscape suggests that there is not yet consensus about the efficacy of such mandatory disclosure requirements. Standard intuition suggests that greater disclosure provides more information to investors which leads to higher welfare through more efficient investment and better hedging of climate risk. This is formalized by theoretical work which establishes that greater disclosure about a firm's risk-exposures leads to better risk-sharing across investors in settings where the firm's cash-flows are exogenously specified (e.g., see Smith (2023)).

When a firm *endogenously* affects its risk-exposure via investment decisions, however, we show that the impact of mandatory disclosure on welfare is more nuanced. We consider a setting in which a firm chooses whether to adopt a green project to maximize its stock price.

[1] SEC Adopts Rules to Enhance and Standardize Climate-Related Disclosures for Investors at https://www.sec.gov/newsroom/press-releases/2024-31.

[2] See SEC Votes to End Defense of Climate Disclosure Rules at https://www.sec.gov/newsroom/press-releases/2025-58.

[3] See Rowback on EU green rules will harm companies and investors from the Financial Times.

We show that the firm is more likely to adopt the green project when investors do not have any information about the climate-risk exposure, or greenness, of the project. Because a higher likelihood of adoption leads to better risk-sharing of climate shocks across investors, we show that investor welfare may be higher in an equilibrium with no disclosures relative to an equilibrium in which investors know the project's risk exposures perfectly. Using this comparison, we characterize sufficient conditions under which mandatory disclosure requirements worsen investor welfare and under which they improve welfare. Moreover, we find that under some conditions, a voluntary disclosure regime in which the firm chooses to pay a cost to produce a verifiable signal about climate exposures, can lead to higher investor welfare than the no-disclosure and full-disclosure regimes.

Model and intuition. A firm's manager decides whether to adopt a green project, which provides a hedge against an adverse climate shock, or continue with the status quo. The firm's stock is owned and traded by a continuum of risk-averse investors. A fraction of these, who we refer to as "green" investors, have a negative exposure to the climate shock, while the remaining investors do not. The cash-flows from the green project depend on its climate-risk exposure, or "greenness" — we refer to this as the firm's type. A greener project pays off more when climate outcomes are worse, and so provides a more useful hedge for green investors. The status quo project generates higher cash-flows than the green project on average, but these are uncorrelated with the climate risk shock. The firm's adoption decision maximizes its anticipated stock price.

For example, consider a power utility deciding whether to invest in solar and battery microgrids.[4] These systems are likely to be more expensive to set up and less efficient, and therefore might generate lower average cash flows. However, they remain online during blackouts from storms or wildfires and so pay off during adverse climate outcomes. Moreover, investors' exposure to such climate shocks vary with their location e.g., those living in wildfire prone California or storm-prone Gulf Coast regions are likely to be more exposed to weather-related power disruptions, and so are likely to benefit more from the ability to hedge this risk.[5]

We compare two scenarios. In the *full disclosure* equilibrium, investors observe both the

[4]See Home microgrids: a blueprint for the future of sustainable household energy? and How the US battery boom is shifting the power mix from the Financial Times.

[5]The above example is one where the climate shock poses a physical risk. However, our model can also be interpreted through the lens of transition risk. For instance, consider a consumer electronics firm that is considering investment in rechargeable battery technology for electric vehicle (EV) manufacturing (e.g., Giglio, Kelly, and Stroebel (2021)). Such investments are likely to benefit from regulatory changes that provide tax subsidies to encourage the purchase of EVs. Importantly, there is likely to be heterogeneity in the exposure of such risks across investors, depending on where they live (e.g., urban vs. rural) and industries they work at.

firm's adoption decision and its greenness before trading the stock. Conditional on adoption, the stock price strictly increases in the firm's greenness. Anticipating this, the firm uses a threshold strategy: it adopts the green project if and only if its type is higher than a threshold. In the *no-disclosure equilibrium*, investors observe the firm's adoption decision, but cannot observe its type before trading.[6] In this case, we show that there exists an equilibrium in which (i) the firm adopts the green project if and only if its type is sufficiently high and (ii) the stock price is independent of the adoption decision.

Importantly, we show that adoption of the green project is *more likely* under no disclosure than under full disclosure. In the full disclosure equilibrium, since investors observe the firm's greenness, the stock price accurately reflects the firm's type. In the no-disclosure equilibrium, investors cannot distinguish across types that choose to adopt the green project in equilibrium. This allows lower types (with less green projects), who would have chosen the status quo under full disclosure, to *pool* with higher types (with greener projects) by adopting the green project.

Mandatory disclosure and welfare. To characterize the impact of mandatory disclosure requirements, we then compare investor welfare under the full-disclosure and no-disclosure equilibria. Welfare increases in the ex-ante valuation of the stock since the firm's stock is held by investors in equilibrium. Moreover, given the heterogeneous exposure to adverse climate shocks, welfare increases in the ability of investors to hedge against and share climate risk.[7]

We show that if the firm's adoption decision is exogenously fixed, the full disclosure equilibrium always yields higher investor welfare. This is because, in the full-disclosure equilibrium, (i) the firm has a higher valuation, conditional on adopting a green project, and (ii) risk-sharing is more effective since investors are able to condition on the project's climate risk exposure when choosing their optimal portfolios. This result is consistent with existing work (e.g., Smith (2023)) and reflects the standard rationale presented for stricter climate disclosure requirements.

Once we account for the difference in equilibrium adoption across the two scenarios, however, we find that welfare can be *higher* in the no-disclosure equilibrium. This is because, all else equal, the firm's likelihood of adopting the green project is higher and, consequently, this improves the ability of green investors to share climate risk with brown investors. In particular, we show that no-disclosure is likely to generate higher welfare if (i) adoption

[6] One interpretation of the no disclosure scenario is that there is no credible way for firms to signal their climate risk exposure in this setting, even if they would like to, other than by adopting the green project. For instance, this might arise if investors interpret all firm disclosures about climate risk as uninformative cheap talk.

[7] We refer to "hedging" as the investors' ability to buy a security which pays off more in states with adverse climate shocks, and "risk-sharing" as investors' ability to trade a security exposed to climate shocks in order to reduce the cross-sectional heterogeneity in exposures to climate risk across investors.

of green projects under full disclosure is sufficiently low, or if (ii) per-capita endowment of the stock is sufficiently small and a sufficient mass of green projects have low climate-risk exposures (i.e., are not very green). In either of these cases, the incremental benefits from full disclosure (higher valuations and better risk-sharing due to knowledge of greenness) are offset by the increased likelihood of adoption under no-disclosure.

Voluntary disclosure. Our main results suggest that even in the absence of explicit costs (e.g., reporting costs), investor welfare under full disclosure may be lower than under no-disclosure. However, higher types (firms with greener projects) are worse off in the no-disclosure equilibrium since they would have strictly higher valuations if they were able to disclose their climate risk-exposure. As such, some higher types would be willing to pay a cost to provide a verifiable signal of their greenness to investors if they could.

To see the impact of such behavior, we consider a setting in which the firm can pay a cost to voluntarily disclose its greenness (as in Verrecchia (1983)). We show that there exists an equilibrium characterized by two thresholds: a disclosure threshold and an adoption threshold. Types above the disclosure threshold choose to adopt the green project and pay the cost to disclose their greenness to investors. Types between the adoption and disclosure thresholds adopt the green project, but do not disclose their type to investors. Finally, types below the adoption threshold do not adopt the green project, but instead maintain the status quo. Not surprisingly, in this costly disclosure equilibrium, we find that the likelihood of disclosure is lower than in the full-disclosure equilibrium (since disclosure is costly) and the likelihood of adoption is between the full-disclosure and no-disclosure equilibria.

Perhaps more surprisingly, we show that under some conditions, welfare can be higher in the costly disclosure equilibrium than under the no-disclosure and full-disclosure equilibria. This is more likely to happen when (i) per-capita endowment of the stock is sufficiently small, (ii) the adoption of the green project under full disclosure is not too low, and (iii) disclosure costs are neither too high nor too low. Condition (i) ensures that the welfare benefit from higher valuations due to disclosure is limited, while condition (ii) ensures the welfare benefit from greater adoption due to no-disclosure is limited. Under these conditions, neither full-disclosure nor no-disclosure dominate. An initial increase in disclosure costs (which leads to less disclosure) first increases welfare and then decreases welfare. We explicitly characterize the optimal disclosure cost, which maximizes investor welfare, and describe how it depends on the model's parameters.

Policy implications and extensions. Our analysis highlights that more precise climate-risk disclosures are not always welfare improving. When firms' investment choices are endogenous, full disclosure can discourage marginal firms from adopting green projects by removing the pooling benefits, which potentially leads to lower investor welfare. This mechanism implies that regulators should evaluate disclosure rules jointly with instruments that directly promote green investment (e.g., tax credits and subsidies) rather than using disclosure as a stand-alone lever.

Our analysis of the costly disclosure equilibrium suggests that, instead of adopting uniform disclosure requirements, the policymaker might be able to improve welfare by designing standards that combine transparency with targeted incentives, or implementing a greenness-certification framework which firms can voluntarily choose to adopt. This suggests an important additional role for "climate assurance" programs, which provide third party verification of firms' climate related disclosures.

Section 7 extends our analysis to other settings. In Section 7.1, we consider the impact of climate derivatives on our results. Our results suggest that building deeper markets for climate hedges and derivatives can attenuate the adverse investment effect of disclosure requirements, allowing regulators to capture the informational benefits of disclosure while minimizing unintended loss of risk-sharing benefits. In Section 7.2, we show that when brown firms endogenously choose whether to adopt abatement technologies, stronger disclosure requirements can lead to over-investment in such technologies (relative to a welfare-maximizing level). These results imply that evaluating the impact of disclosure requirements using "green investment" is nuanced: while more stringent requirements lead to higher adoption of abatement technologies, they can lead to lower adoption of adaption or resilience technologies.

Overview. The rest of the paper is organized as follows. Section 2 discusses the related literature. Section 3 presents the model and a discussion of important assumptions. Section 4 characterizes the no-disclosure and full-disclosure equilibria. Section 5 compares how welfare varies across these equilibria and characterizes sufficient conditions under which welfare is higher under no disclosure. Section 6 considers the case where the firm can engage in costly, voluntary disclosure, and characterizes conditions under which a finite disclosure cost maximizes investor welfare. Section 7 considers the impact of climate derivatives and how our results change for abatement technologies. Section 8 concludes by discussing empirical predictions and implications for regulatory policy. Unless noted otherwise, proofs and additional analysis are in the Appendix.

2 Related Literature

The most closely related papers are Banerjee, Breon-Drish, and Smith (2025) and Smith (2023). Both papers look at the welfare effects of trading securities with climate risk exposures when investors have heterogeneous climate risk exposures. Banerjee et al. (2025) consider a setting in which firms endogenously choose whether to invest in a green project, where the risk exposure of the project is commonly known to investors. They show that price-maximizing firms need not maximize investor welfare because they do not correctly account for hedging or risk-sharing benefits of green investment. Smith (2023) considers a setting in which a firm's climate risk-exposure is unknown to the investors, and shows that greater disclosure about risk-exposures can lead to better risk-sharing in a setting where firms' risk exposures are exogenously fixed.

We complement this earlier work by considering a setting in which (i) firm's endogenously choose whether to invest in green projects, and (ii) investors face uncertainty about the risk exposures of these projects. This allows us to uncover a novel and counterintuitive interaction absent from the earlier models: firms that would not have adopted green projects if their exposures were known by investors may choose to do so when exposures are not known, since this allows them to pool with firms with greener projects. As a result, although mandatory disclosure leads to better risk-sharing and higher welfare when firms' exposures are exogenously fixed, we show that it can lead to lower welfare when firms endogenously choose their projects.

A similar type of pooling arises in Gupta and Starmans (2025), who consider a multi-period setting in which firms can engage in, and scale up, green transition. They show that dynamic disclosure requirements that become increasingly more stringent can lead to more adoption than full transparency, because initially lax disclosure requirements can encourage adoption by less green firms. We view our analysis as complementary but distinct. First, the analysis in Section 7.2 shows that lower disclosure requirements can lead to less adoption of abatement technologies, and so the impact of disclosure requirements depends crucially on the type of "green investment." Second, by considering heterogeneous climate exposures across investors, instead of a representative investors setting, we highlight a distinct channel through which disclosure affects investor welfare through its impact on their ability to share climate risk.[8]

The signaling effect of adoption in these papers is in line with the literature on real effects of disclosure (Kanodia, Singh, and Spero (2005), Beyer and Guttman (2012), and Kanodia and Sapra (2016)). For example, Kanodia et al. (2005) show that when investors face uncertainty about a project's profitability, the manager tends to over-invest in order to signal higher profitability. Relative to this literature, our contribution is to focus on

[8]We assume that the firm does not choose the scale of the green project for tractability. Allowing for this possibility complicates the model significantly, since the firm can now signal its greenness by choosing a larger scale of operations in the no-disclosure case. At the same time, full disclosure results are not likely to change, since investors in our model can adjust their positions in stock, which is similar to scaling. While an analysis of this equilibrium is not within the scope of the current paper, we expect that the basic mechanism we focus on (i.e., more adoption with no disclosure and the possibility of higher welfare as a result) would still operate in such a setting.

disclosure of climate-risk exposures in a trading environment, allowing us to evaluate not only firm behavior but also the welfare of investors.

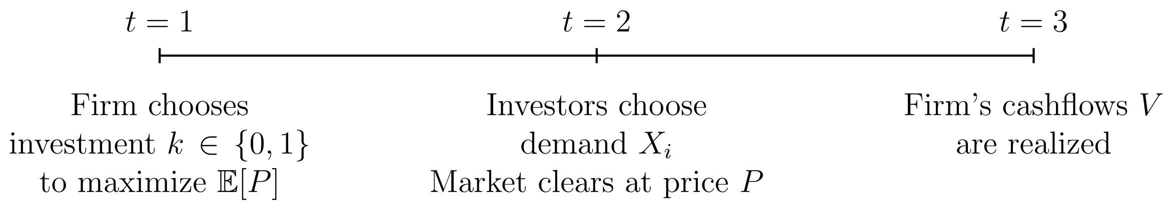
It is worth noting that our welfare results are distinct from the Hirshleifer (1971) effect, whereby more public information before trade reduces risk-sharing opportunities, and leads to lower welfare. Importantly, the Hirshleifer (1971) effect arises when the information is about the realization of the risk that investors are trying to hedge / share. In contrast, information in our setting is about the firm's risk-exposure. As Smith (2023) argues, more information about risk-exposures tends to lead to better risk sharing and higher welfare, when firms' project choices are fixed. In our setting, greater disclosure about risk exposures can reduce welfare by changing the investment decisions of firms, which is absent from these earlier papers.

Like us, Aghamolla and An (2023) consider a setting in which a manager chooses whether to adopt a green project, and then voluntarily chooses whether to disclose information about the financial and / or social value of the project if she observes it (as in Dye (1985), Jung and Kwon (1988)). The paper shows that the manager always uses a sanitization strategy for disclosure and may under- or over-invest in green technology when the fraction of green investors is sufficiently high or low, respectively. Relatedly, Xue (2025) considers a setting in which a firm's investment level in a risky project also affects its ESG performance (e.g., via emissions). The paper shows that more precise mandatory disclosure about ESG performance leads investors to trade more aggressively on their private information about cash-flows, which can lead to more efficient investment by the firm and a reduction in their emissions.

In contrast to these papers, where the preference for green projects is driven by tastes, the value of green projects is driven by investors' climate risk-exposures in our model. This allows us to characterize investor welfare as the aggregate expected utility across investors in the economy. Moreover, while mandatory ESG disclosures can lead to more investment in green projects in these papers, our analysis highlights a novel channel through which more information about disclosures always lead to less equilibrium investment in green projects. At the same time, the average 'greenness' of firms adopting the green project is higher under mandatory disclosure.

More generally, our paper is related to the growing literature on investor uncertainty and learning about risk-factor exposures (e.g., Armstrong, Banerjee, and Corona (2013), Heinle, Smith, and Verrecchia (2018), Beyer and Smith (2021), Smith (2023), Huang, Schneemeier, Subrahmanyam, and Yang (2025)). Relative to much of this existing literature, which focuses on the pricing implications of uncertainty about risk-factor loadings, our model studies the interaction of such uncertainty with endogenous investment decisions.

Figure 1: Timeline



Our paper also broadly contributes to the growing theoretical literature on climate risk.[9] In particular, like us, Pástor, Stambaugh, and Taylor (2021) show that green assets have lower cost of capital because they help hedge climate risk. In a related paper, Chen and Schneemeier (2025) study managerial incentives to manipulate the information in a feedback model where prices inform investment decisions. Piccolo, Schneemeier, and Bisceglia (2022) look at the effect of socially responsible investment on firms' abatement strategies emphasizing the importance of strategic complementarities. Friedman, Heinle, and Luneva (2024) study the implications of ESG reporting in an environment where the firm manager could exert a costly effort to improve the outcome.

3 Model

The timeline of events is summarized in Figure 1.

Payoffs. There are three dates $t \in \{1, 2, 3\}$ and two securities. The risk-free security is normalized to the numeraire. A share of the risky security is a claim to terminal per-share cash-flows V generated by the firm at date three, and trades on date two at price P. The per-capita supply of the shares is q.

Investors. There is a continuum of investors with mean-variance preferences over terminal wealth with risk aversion ρ, an initial endowment of q shares of the risky asset, and initial wealth of W_0. A mass m of these investors, indexed by $i = G$, are *green* investors, and have a negative exposure to climate shock, $\omega \sim N(0, 1)$ which is realized at date three.[10] The remaining mass $1 - m$ of investors, indexed by $i = B$, are standard or *brown* investors, and have no additional endowments. Given all available information at date two, investor

[9] This work includes Heinkel, Kraus, and Zechner (2001), Friedman and Heinle (2016), Pedersen, Fitzgibbons, and Pomorski (2021), Chowdhry, Davies, and Waters (2019), Goldstein, Kopytov, Shen, and Xiang (2021), Landier and Lovo (2025) and Oehmke and Opp (2025).

[10] The assumption that ω has unit variance can be thought of as a normalization.

$i \in \{G, B\}$ chooses trade X_i to maximize:

$$\mathbb{E}_{i,2}[W_i] - \frac{\rho}{2}\mathbb{V}_{i,2}[W_i] \tag{1}$$

where the terminal wealth W_i is given by:

$$W_i = W_0 + (q + X_i)V - X_i P - \mathbf{1}_{\{i=G\}}\omega. \tag{2}$$

Note that a positive realization of the climate shock ω, corresponds to an adverse climate outcome which reduces green investors' wealth and utility.

The firm. The firm has assets in place and access to a green project. At date one, the firm's manager decides whether or not to adopt the green project (i.e., chooses $k \in \{0, 1\}$) to maximize her expectation of the date two price P. If the manager chooses not to adopt the green project i.e., to remain "brown", then the terminal cash flows are given by:

$$V(k = 0) = \mu + \gamma + \sigma\eta \equiv V_b, \tag{3}$$

where $\eta \sim N(0, 1)$ is a cash-flow shock independent of ω, σ is the volatility of the cash-flows, μ is the expected cash-flow from the firm's assets in place and $\gamma \geq 0$ is the additional (expected) cash-flow from maintaining the status quo. Instead, if the manager chooses to adopt the green project, then the terminal cash flows are given by

$$V(k = 1) = \mu + \sigma\left(\beta\omega + \sqrt{1 - \beta^2}\eta\right) \equiv V_g(\beta) \tag{4}$$

where $\beta \in (0, 1] \sim F_\beta(\cdot)$ is the climate-risk factor loading, or "greenness", of the project available to the firm. When $\beta > 0$, the project's cash-flows are higher when climate outcomes are worse (ω is higher) — we refer to these projects as green projects. The manager knows the β of the project available to her, although investors may or may not. However, the manager's choice of project i.e., k is perfectly observed by the investors.

The specification in eq. (3)-(4) ensures that the total variance of cash flows is the same for green vs. brown projects. This allows us to isolate the impact of the adoption of green projects on the hedging benefit to G investors without affecting the total risk that investors have to bear. As we shall see below, this makes the analysis more tractable and the intuition for our results more clear. We also assume that the CDF $F_\beta(\cdot)$ is differentiable and strictly increasing, and that β, θ, and η are all mutually independent for tractability.

Information environment. For our main analysis, we characterize the equilibrium under two benchmark information scenarios. In Section 4.1, we consider the *full disclosure* equilibrium in which investors perfectly observe the climate exposure of the firm's green project when making their portfolio choice i.e., β is commonly known. In Section 4.2, investors do not observe the β of the project — we refer to this as the *no disclosure* equilibrium.[11]

Equilibrium. An equilibrium consists of trades $\{X_i\}_{i\in\{G,B\}}$, price P, and investment decisions $k(\beta) \in \{0,1\}$, such that (i) the investment decision k at date 1 maximizes expected price $\mathbb{E}[P]$, (ii) the trade X_i maximizes investor i's expected utility over terminal wealth W_i (given by eq.(2)), given the investment decision k and her information at date 2, and (iii) the equilibrium price P clears the market i.e.,

$$mX_G + (1-m)X_B = 0, \tag{5}$$

and (iv) the manager's and investors' beliefs are consistent with Bayes' Rule at every date.

As is common in models with endogenous investment, in general there can exist multiple equilibria with each characterized by a different investment policy. We focus on the class of **threshold equilibria**. A threshold equilibrium is an equilibrium which is characterized by an adoption threshold $\bar{\beta}$, such that the manager adopts the green project ($k = 1$) if and only if the firm's type $\beta \geq \bar{\beta}$. This is a natural class of equilibria to focus on. For instance, in the full disclosure equilibrium, the equilibrium price is increasing in the firm's climate risk exposure β and so the price maximization objective naturally leads to a threshold strategy. More generally, restricting focus to this class is helpful for tractability and expositional clarity.

3.1 Discussion of Assumptions

Green versus Brown projects. Our definition is consistent with the classification in the empirical literature (e.g., Bolton and Kacperczyk (2021a) and Hsu, Li, and Tsou (2023)) in that, in equilibrium, green projects will carry a price premium relative to brown projects due to their desirability for hedging. More generally, our model captures the notion that green projects and firms provide a hedge against adverse climate outcomes. The assumption that the brown project generates higher average cash-flows (i.e., $\gamma \geq 0$) is meant to capture a key tradeoff: brown (or status quo) projects are often more profitable than green projects, even if they are less desirable from a climate risk perspective.

[11]In Section 6, we consider a setting in which the firm manager can choose to verifiably disclose the greenness of the project at date one by paying a cost. We refer to this as the *costly disclosure* equilibrium.

We assume that the firm does not incur a cost when adopting a green project for notational simplicity. As we shall see, what matters for project choice is the incremental payoff of choosing the green project instead of the brown. Incorporating an additional cost of adopting the green project, say κ, would be equivalent to assuming the average cash flows is given by $\gamma + \kappa$. We also assume that green and brown projects have the same volatility of cash flows to focus on the channel driven by β. One could incorporate different levels of volatility (e.g., allow for different σ across brown and green projects), but this complicates the analysis without qualitatively changing the results.

We assume that investors can observe a firm's project choice, which is a common assumption in the literature (Grossman and Hart (1980), Aghion and Tirole (1997)). In practice, public firms often disclose major capital investment decisions in SEC filings, making these decisions observable to investors. Moreover, public firms are subject to analysts' scrutiny, as well as the risk of fraud and misreporting allegations.

More generally, our analysis assumes that the status quo project does not have an exposure to climate shocks. One could instead consider a setting in which the status quo project is positively exposed to adverse climate shocks, and the firm is choosing whether to engage in abatement. As we discuss in Section 7.2, the economic forces that arise in this case are similar to those in the main specification. In particular, the welfare loss under full disclosure arises because such requirements restrict investors' ability to share climate risk among themselves.

Managerial objective and investor preferences. We take the manager's objective (to maximize expected price) as given. The assumption is consistent with the large empirical literature which documents that managers are often incentivized with short-term, price contingent contracts (e.g., equity grants and options), and is common in the theoretical literature. Assuming that the manager's objective was to maximize a weighted average of the expected price and firm value would not qualitatively change our results — in fact, it would tend to lead to further under-investment in green projects since the expected cash flows of the firm are higher with the status quo.

In principle, one could achieve the first best investment rule by ensuring that the manager maximizes aggregate investor welfare. However, this is unlikely to be feasible in practice. However, our analysis suggests that because the price does not fully reflect the welfare benefits of green adoption, there may be a role for climate-based compensation (e.g., bonuses linked to climate targets) in improving investor welfare (see also Banerjee et al. (2025)).

We assume that investors have mean-variance preferences for tractability. In the full disclosure setting, our equilibrium is unchanged if we assume that investors have exponential utility. However, in the no disclosure and voluntary disclosure settings, the payoffs for green projects are mixtures of normal distributions, and characterizing equilibria under the assumption of exponential utility is not analytically tractable. As such, one can interpret mean-variance preferences as a second-order Taylor approximation to more general utility functions.

Market incompleteness and demand for hedging. The heterogeneity in investors' exposure to climate risk is in line with the modeling approach of Pástor et al. (2021), Banerjee et al. (2025) and Smith (2023), and is consistent with the evidence documented by Giglio, Maggiori, Stroebel, Tan, Utkus, and Xu (2025) who report that a substantial fraction of ESG investing is driven by climate hedging motives.

We model the preference for green stocks using a risk-based model of climate risk. The result that there is more adoption under no-disclosure can also arise in settings where green investors have pro-social preferences or feel a "warm glow" from investing in green projects (e.g., Gupta and Starmans (2025)). However, this assumption has implications for our welfare analysis. Specifically, in our setting, the welfare-maximizing level of adoption trades off the benefit from risk-sharing against the cost of investing in projects that generate lower costs. In contrast, in settings with heterogeneous beliefs or pro-social preferences, characterizing investor utility is more ambiguous.

Our main results on welfare rely on the assumption that markets are incomplete. Green investors are exposed to climate risk and benefit from the firm's adoption of the green project because (i) it allows them insure against adverse climate outcomes and (ii) it allows them to share some of this risk with brown investors. One concern is that the latter channel would not operate if investors could also trade insurance contracts or derivative securities that are exposed to climate shocks. In Appendix 7.1, we show that unless the derivative provides a perfect exposure to ω (and is not exposed to any other shocks), the qualitative implications of our model survive.

In practice, however, hedging using derivatives and insurance contracts is difficult because (i) existing derivatives do not provide a complete hedge against a variety of climate shocks, and (ii) counter-parties may be unable to pay out in the event of a climate disaster.[12] In part, (i) arises because investors' exposures to such risks is heterogeneous (e.g., Ilhan, Krueger, Sautner, and Starks (2023)) and because existing weather derivatives inherently tend to have shorter maturities than climate shocks (e.g., see Giglio et al. (2021)).[13] Survey

[12]For instance, Engle, Giglio, Kelly, Lee, and Stroebel (2020) show that an equity portfolio designed to hedge climate risk is at most 30% correlated with news about such risk.

[13]Moreover, different types of investments may be required to hedge different dimensions of climate risk e.g., green energy stocks might be useful to hedge against carbon-transition risk, but not as useful for sea-level

evidence suggests that investors find these risks difficult to hedge (e.g., Krueger, Sautner, and Starks (2020), Pástor et al. (2021)) and investors appear to tilt their portfolios toward green stocks instead (e.g., Pastor, Stambaugh, and Taylor (2023)). Consistent with (ii), there has been a rapid increase in the issuance of catastrophe bonds by insurance companies following the recent surge in the incidence of climate disasters (e.g., see "Catastrophe bond sales hit record as insurers offload climate risks" from the Financial Times).

4 Analysis

In this section, we characterize the equilibria in our model under two benchmark scenarios. We first consider the case where investors can observe the climate risk exposure of the firm before trading in Section 4.1. In Section 4.2, we characterize the equilibrium when investors do not observe the firm's risk exposure, but form beliefs based on the prior distribution.

4.1 Full Disclosure Equilibrium

We solve for the equilibrium by working backwards.

Date 2. Since all investors observe the project choice $k = 1$ and the climate risk exposure β for the firm, we can compute the optimal demand from investors across the two scenarios. Under mean-variance preferences and normally distributed payoffs, the optimal demand takes the standard mean-variance form.

If the green project is not adopted (i.e., $k = 0$), then the optimal demand from investors is

$$X_B = \frac{\mu + \gamma - P_b}{\rho\sigma^2} - q \quad \text{and} \quad X_G = \frac{\mu + \gamma - P_b}{\rho\sigma^2} - q, \tag{6}$$

where we denote the equilibrium price of the firm with the brown project as P_b. The market clearing condition in eq. (5) implies that the price is given by:

$$P_b = \mu + \gamma - \rho\sigma^2 q. \tag{7}$$

Similarly, if the green project is adopted (i.e., $k = 1$), then the optimal demand from investors is

$$X_B = \frac{\mu - P_g}{\rho\sigma^2} - q \quad \text{and} \quad X_G = \frac{\mu - P_g + \beta\rho\sigma}{\rho\sigma^2} - q, \tag{8}$$

rise.

where we denote the equilibrium price of the firm with the green project as P_g. Relative to the brown scenario, demand from B investors is lower because mean cash flows are lower (by γ). The demand from G investor is also affected by the $\beta\rho\sigma^2$ term, which captures the benefit that the green project offers in hedging the climate risk exposure for G investors. Market clearing implies that the price of the stock with the green project is given by:

$$P_g = \mu + m\beta\rho\sigma - \rho\sigma^2 q. \tag{9}$$

Intuitively, a greener project is more valuable for hedging for G investors, and this leads to a higher price via the $m\beta\rho\sigma$ term.

Date 1. Anticipating these equilibrium prices, the firm manager chooses to adopt the green project if and only if $\Delta P(\beta) \geq 0$, where

$$\Delta P(\beta) \equiv P_g - P_b = m\beta\rho\sigma - \gamma. \tag{10}$$

Since ΔP is increasing for all relevant β's, the manager uses a threshold strategy for her adoption decision, as summarized in the following result.

Proposition 1. *Suppose investors can observe β when the firm adopts a green project. Then a unique equilibrium exists and is such that (i) the firm adopts the green project if and only $\beta \geq \beta_{FD}$, and (ii) the equilibrium price is given by*

$$P = \begin{cases} \mu + \gamma - \rho\sigma^2 q & \text{if } k = 0 \\ \mu + m\beta\rho\sigma - \rho\sigma^2 q & \text{if } k = 1 \end{cases},$$

where the adoption threshold is given by

$$\beta_{FD} = \min\left\{\frac{\gamma}{m\rho\sigma}, 1\right\}.$$

The threshold β_{FD} is (weakly) increasing in γ but (weakly) decreasing in m, ρ and σ^2.

Intuitively, the firm only invests in the green project when its greenness is sufficiently high. The threshold β_{FD} reflects the tradeoff that the firm faces when deciding whether or not to adopt the green project. A higher expected return γ on the status quo makes the green project less attractive and so the threshold increases. On the other hand, a higher fraction m of G investors, higher risk aversion ρ (against climate risk) and a higher risk from climate shocks (higher σ^2) make investing in the green project more valuable and so lower the threshold β_{FD}. Moreover, when γ is sufficiently high, or m, ρ or σ are sufficiently low (i.e., so that $\frac{\gamma}{m\rho\sigma} > 1$), the firm is always better off by not adopting the green project.

4.2 No Disclosure Equilibrium

Now consider the case in which, at date 2, investors observe whether or not the firm adopts the green project (i.e., observes k), but do not observe the climate risk factor loading β of the green project. In practice, this scenario captures a setting in which firms cannot credibly communicate their types to investors. This could either be because costs of verifiably disclosing such information is prohibitively expensive (this is a special case of our analysis in Section 6), or because firms can only engage in cheap talk and investors treat this as uninformative.

We focus on threshold equilibria. Specifically, we conjecture, and then verify, that the firm adopts the green project if and only if $\beta \geq \beta_{ND}$ for a threshold β_{ND}. First note that when the green project is not adopted, the optimal demand from investors is unchanged and given by eq. (6), and this implies that the price is given by eq. (7) as before. However, as we show in the proof of Proposition 2, under the conjectured adoption strategy, the optimal demand from investors conditional on the green project being adopted is given by:

$$X_B = \frac{\mu - P_g}{\rho\sigma^2} - q \quad \text{and} \quad X_G = \frac{\mu - P_g + \mathbb{E}[\beta|\beta \geq \beta_{ND}]\rho\sigma}{\rho\sigma^2} - q. \tag{11}$$

Moreover, the market clearing condition implies that the equilibrium price is given by:

$$P_g = \mu + m\mathbb{E}[\beta|\beta \geq \beta_{ND}]\rho\sigma - \rho\sigma^2 q. \tag{12}$$

The price is analogous to the full disclosure equilibrium, except that investors do not observe the firm's β, and so instead price the firm using the conditional expected factor loading, conditional on investing in the green project i.e., $\mathbb{E}[\beta|\beta \geq \beta_{ND}]$.

The threshold β_{ND} is pinned down by the indifference condition of the threshold type: when the firm's $\beta = \beta_{ND}$, the manager should be exactly indifferent between adopting the green project and not, which implies that

$$\underbrace{\mu + \gamma - \rho\sigma^2 q}_{=P_b} = \underbrace{\mu + m\mathbb{E}[\beta|\beta \geq \beta_{ND}]\rho\sigma - \rho\sigma^2 q}_{=P_g}. \tag{13}$$

This implies the following result.

Proposition 2. *Suppose investors cannot observe β, but can observe whether or not the* *firm adopts a green project. Then, there exists a unique threshold equilibrium and is such that (i) the firm adopts the green project if and only $\beta \geq \beta_{ND}$, and (ii) the equilibrium price is given by*

$$P = \mu + \gamma - \rho\sigma^2 q,$$

irrespective of whether the firm adopts the green project, where the adoption threshold is implicitly defined as the solution to

$$\mathbb{E}[\beta|\beta \geq \beta_{ND}] = \min\left\{\frac{\gamma}{m\rho\sigma}, 1\right\},$$

if $\mathbb{E}[\beta] < \min\left\{\frac{\gamma}{m\rho\sigma}, 1\right\}$, and $\beta_{ND} = 0$ otherwise. The threshold β_{ND} is (weakly) increasing in γ but (weakly) decreasing in m, ρ and σ^2.

The key difference from the full disclosure equilibrium is that investors do not observe the factor loading β of the firm's project when pricing it, and so price all "green" firms the same. As a result, the firm's adoption strategy is pinned down by the threshold type β_{ND} such that, conditional on firm with $\beta > \beta_{ND}$ adopting the green project (i.e., P_g), the price of the firm is equal to the price if it had not adopted the project (i.e., P_b). The comparative statics for the threshold are analogous to those in the full disclosure equilibrium, given that $\mathbb{E}[\beta|\beta \geq \beta_{ND}]$ is increasing in β_{ND}. And as before, if γ is sufficiently high or m, ρ or σ are sufficiently low (such that $\frac{\gamma}{m\rho\sigma} > 1$), then no type adopts the green project.

Given the equilibria in Propositions 1 and 2, we have the following corollary.

Corollary 1. *Adoption of the green project is more likely under no disclosure than under full disclosure i.e., $\beta_{ND} \leq \beta_{FD}$.*

Mathematically, this follows from the observation that for a threshold $\bar{\beta}$, $\mathbb{E}[\beta|\beta \geq \bar{\beta}] \geq \bar{\beta}$. Since the threshold type of firm in each equilibrium is indifferent between adopting the green project and not, this implies that

$$\mu + m\beta_{FD}\rho\sigma - \rho\sigma^2 q = P_g = \mu + m\mathbb{E}[\beta|\beta \geq \beta_{ND}]\rho\sigma - \rho\sigma^2 q,$$

which implies $\beta_{FD} = \mathbb{E}[\beta|\beta \geq \beta_{ND}]$, which in turn implies the result.

Intuitively, the result arises because in the no-disclosure equilibrium, types with $\beta \in [\beta_{ND}, \beta_{FD})$ can pool with higher types by adopting the green project because their factor loading cannot be observed or inferred by investors. While these types end up with the same prices in the two equilibria (in both cases, they are priced at P_b), they make different project choices (adopt green in the no-disclosure equilibrium and brown in the full-disclosure equilibrium), and this can lead to different levels of investor welfare (as we shall explore in Section 5).

5 Welfare impact of mandatory disclosure

In this section, we characterize the impact of mandatory disclosure requirements on investor welfare by comparing how welfare differs across the full-disclosure and no-disclosure benchmarks. Contrary to common wisdom, we provide sufficient conditions under which investor welfare is higher under no-disclosure than under full disclosure. Importantly, as we discuss in Section 5.3, this arises because the firm's adoption decision endogenously differs across the two regimes.

5.1 Full Disclosure Equilibrium

We first consider the full-disclosure equilibrium. We begin by computing an ex-interim measure of welfare and then take expectations to compute an ex-ante measure. Because investors can condition on the green project's β before trading at date 2, we can express the price $P(k,\beta)$ of the firm, conditional on k and β, as

$$P(k,\beta) = \mu + \gamma - \rho\sigma^2 q + (m\beta\rho\sigma - \gamma)\mathbf{1}_{\{k=1\}}.$$

Plugging this into the optimal demand for each type of investor, and simplifying yields:

$$\begin{aligned} u_B &= W_0 + q(\mu+\gamma) - \frac{\rho}{2}q^2\sigma^2 + \left(\frac{\rho}{2}m^2\beta^2 - q\gamma\right)\mathbf{1}_{\{k=1\}}, \quad \text{and} \\ u_G &= W_0 + q(\mu+\gamma) - \frac{\rho}{2}(q^2\sigma^2+1) + \left(\frac{\rho}{2}(2q\beta\sigma + (1-m)^2\beta^2) - q\gamma\right)\mathbf{1}_{\{k=1\}}, \end{aligned}$$

where u_B and u_G denote the (ex-interim) expected utility of B and G investors, respectively, under full information. This implies that the total investor welfare, conditional on k, can be expressed as:

$$u_{FD}(k,\beta) = \underbrace{W_0 + q\,P(k,\beta)}_{\text{exp. value of endowments}} - \underbrace{\frac{\rho}{2}m}_{\text{climate risk exposure}} + \underbrace{\frac{\rho}{2}\left(q^2\sigma^2 + m(1-m)\beta^2\mathbf{1}_{\{k=1\}}\right)}_{\text{risk-sharing benefits}}. \quad (14)$$

Investor welfare can be decomposed into three components. The first component captures the (ex-ante) expected value of their endowments of cash (i.e., W_0) and stock (i.e., $qP(k,\beta)$). The second component reflects the baseline disutility from the G investors' exposure to climate risk, as reflected by the $-\frac{\rho}{2}m$ term.

The third component reflects the net risk-sharing benefits from trading the stock. This includes the benefit from sharing q units of cash-flow risk (reflected by the $q^2\sigma^2$ term), and the benefit from sharing the aggregate exposure to climate risk (as captured by the $m(1-m)\beta^2$ term). Note that there is no sharing of climate risk when either (i) the firm does not adopt the green project (i.e., $k = 0$) or (ii) there is no heterogeneity across investors (i.e., $m(1-m) = 0$) — in either case, the risk-sharing benefit from this last component is zero. Moreover, note that the expected utility benefit from risk-sharing is increasing in the climate risk exposure β or greenness of the new project (since we assume $\beta \in [0, 1]$).

We can define the net welfare benefit of adoption as follows

$$\Delta u_{FD} = u_{FD}(1, \beta) - u_{FD}(0, \beta) = q\,\Delta P(\beta) + \frac{\rho}{2} m(1-m)\beta^2$$

At date 1, taking the manager's adoption rule $k^*(\beta)$ as given, we can average over possible β's to compute the ex-ante aggregate welfare. We summarize this in the following result.

Proposition 3. *In the full disclosure equilibrium, ex-ante investor welfare is given by:*

$$EU_{FD} = u_0 + \int_{\beta_{FD}}^{1} \Delta u_{FD}(k, \beta)\, dF(\beta)$$

$$= \underbrace{W_0 + q(\mu + \gamma) - \frac{\rho}{2}\left(q^2\sigma^2 + m\right)}_{\equiv u_0} + (1 - F(\beta_{FD})) \left(\underbrace{q \times (m\rho\sigma\mathbb{E}[\beta|\beta \geq \beta_{FD}] - \gamma)}_{\textit{price increase with disclosure}} + \underbrace{\frac{\rho}{2} m(1-m)\mathbb{E}[\beta^2|\beta \geq \beta_{FD}]}_{\textit{risk-sharing benefit from green adoption with disclosure}} \right). \qquad (15)$$

The "baseline" component, u_0, reflects the expected utility from the initial endowment of cash and stock after accounting for the cash-flow and climate risk that investors have to bear in aggregate under the assumption that the firm maintains the status quo. The "green adoption" component reflects the expected **net** impact of some types adopting the green project. This includes the difference in the expected price between the green and brown projects (i.e., $q \times (m\rho\sigma\mathbb{E}[\beta|\beta \geq \beta_{FD}] - \gamma)$) and the additional utility benefit that investors derive from improved risk sharing.

The above result also clarifies that, in general, the adoption decision of a price-maximizing manager will not generally lead to welfare maximization. In general, a price maximizing manager will tend to under-invest in green projects because she ignores the risk-sharing benefits that arise from adopting such projects i.e., she ignores the last term in (14).

Figure 2 provides an illustration of this result. Specifically, the figure plots the incremental benefit from adoption, Δu_{FD}, as a function of the project's greenness. The welfare gain from adoption is the shaded area under the curve (i.e., the shaded area when β_{FD}). However, the socially optimal threshold for adoption is when $\Delta u_{FD}(\beta) = 0$. As such, the white triangular area under the curve represents the welfare loss due to unrealized risk-sharing benefits.

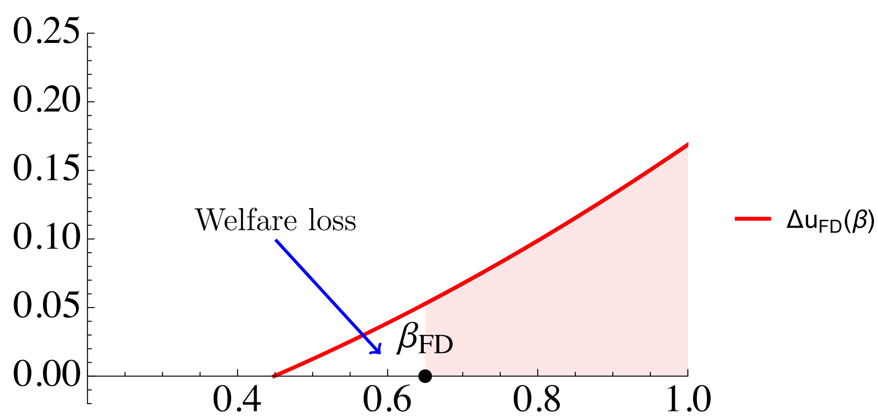
More explicitly, the welfare maximizing rule implies that firms with $\beta \geq \beta_W$ should adopt the green project, where

$$\beta_W \equiv \frac{\gamma}{\sqrt{\left(\frac{1}{2}\rho\sigma m\right)^2 + \frac{1}{2q}\rho m(1-m)\gamma} + \frac{1}{2}\rho\sigma m} < \frac{\gamma}{\rho\sigma m} \equiv \beta_{FD} \tag{16}$$

The wedge between the market-based solution and the welfare-maximizing choice decreases with the stock endowment q. Intuitively, a larger endowment in the stock increases the importance of the stock price for investor welfare and aligns this objective with that of a price-maximizing manager. The wedge decreases when investors become more homogeneous, because in this case the benefits of risk-sharing are limited.

Figure 2: Incremental welfare from adoption under full disclosure

The shaded region corresponds to the welfare gain from adoption of the green project when the price-maximizing manager chooses $k = 1$ if and only if $\beta \geq \beta_{FD}$. The parameters are $m = 0.5$, $q = 0.25$, $\sigma = 1$, and $\rho = 1$, $\gamma = 0.325$.



5.2 No Disclosure Equilibrium

Now we consider no-disclosure equilibrium, in which investors observe the firm's project choice k but not its exposure β. Note that when investors make their trading decisions, they have observed the firm's project choice k. Thus we can condition on k when computing expected utility (before trading). As in Section 4.2, the manager adopts the green project only if $\beta \geq \beta_{ND}$. Moreover, because investors cannot distinguish among types that adopt green projects, they do not adjust their portfolios efficiently. As a result, the ex-interim welfare is now given by:

$$u_{ND}(k) = W_0 + qP - \frac{\rho}{2}m + \frac{\rho}{2}\left(q^2\sigma^2 + m(1-m)\mathbb{E}[\beta|\beta > \beta_{ND}]^2 \mathbf{1}_{\{k=1\}}\right), \tag{17}$$

where $P = \mu + \gamma - \rho\sigma^2 q$. Relative to the expression in (14), there are two differences. First, because types are indifferent between adopting the green project or not, the price of the firm does not depend on β. Second, the risk-sharing benefit from adoption is constant across all types that choose to adopt the green project (i.e., it is driven by $\mathbb{E}[\beta|\beta > \beta_{ND}]$).

Similar to the previous case, we can define the net welfare benefit of adoption as follows

$$\Delta u_{ND} = u_{ND}(1) - u_{FD}(0) = \frac{\rho}{2}m(1-m)\mathbb{E}[\beta|\beta > \beta_{ND}]^2$$

As before, we can compute the ex-ante aggregate welfare by averaging over possible β's, as summarized by the following result.

Proposition 4. *In the no disclosure equilibrium, ex-ante investor welfare is given by:*

$$\begin{aligned} EU_{ND} &= u_0 + \int_{\beta_{ND}}^{1} \Delta u_{ND}\, dF(\beta) \\ &= \underbrace{W_0 + q(\mu+\gamma) - \frac{\rho}{2}\left(q^2\sigma^2 + m\right)}_{\text{baseline welfare}} \\ &\quad + \underbrace{(1 - F(\beta_{ND}))\left(\frac{\rho}{2}m(1-m)\mathbb{E}[\beta|\beta \geq \beta_{ND}]^2\right)}_{\text{risk-sharing benefit without disclosure}}. \end{aligned} \tag{18}$$

In the no disclosure equilibrium, the adoption of a green project does not lead to a price change, and so the only impact of adoption is through the additional utility benefit that investors derive from improved risk sharing.

5.3 Welfare comparison

To better understand how EU_{ND} compares to EU_{FD}, we begin by characterizing the difference between the two for general distributions and deriving sufficient conditions under which one type of equilibrium generates higher welfare. We then focus on the special case where β has a uniform distribution, where we can derive closed form expressions and comparative statics results.

Given the expressions above, note that the welfare difference can be expressed as:

$$\Delta \equiv EU_{FD} - EU_{ND} = \underbrace{\int_{\beta_{FD}}^{1} \left(\Delta u_{FD}(\beta) - \Delta u_{ND}(\beta)\right)\, dF(\beta)}_{\equiv \Delta_1} - \underbrace{\int_{\beta_{ND}}^{\beta_{FD}} \Delta u_{ND}\, dF(\beta)}_{\equiv \Delta_2} \tag{19}$$

Figure 3 illustrates this decomposition when β has a uniform distribution. The first component, Δ_1, is the difference in welfare between full-disclosure and no-disclosure assuming a fixed adoption threshold i.e., assuming all types $\beta \geq \beta_{FD}$ adopt the green project. This is captured by the red triangular area in Figure 3, and reflects the incremental benefit from better disclosure. This component is always positive, since

$$\Delta_1 = (1 - F(\beta_{FD})) \left(\begin{array}{c} \underbrace{q\left\{m\rho\sigma\mathbb{E}[\beta|\beta > \beta_{FD}] - \gamma\right\}}_{\text{diff in price}} \\ + \underbrace{\frac{\rho}{2} m(1-m)\left\{\mathbb{E}[\beta^2|\beta > \beta_{FD}] - \beta_{FD}^2\right\}}_{\text{diff in risk-sharing}} \end{array} \right) > 0$$

The first term captures the fact that conditional on adopting a green project, the firm has a higher price in the full disclosure equilibrium than in the no-disclosure equilibrium — the net difference in price is $\mathbb{E}[\beta|\beta > \beta_{FD}] - \gamma$ on average. The second term reflects the increased benefit from risk-sharing that investors enjoy under the full disclosure equilibrium, because they can condition on the firm's β and hold optimal hedging portfolios. This is captured by the difference $\mathbb{E}[\beta^2|\beta > \beta_{FD}] - \beta_{FD}^2$.

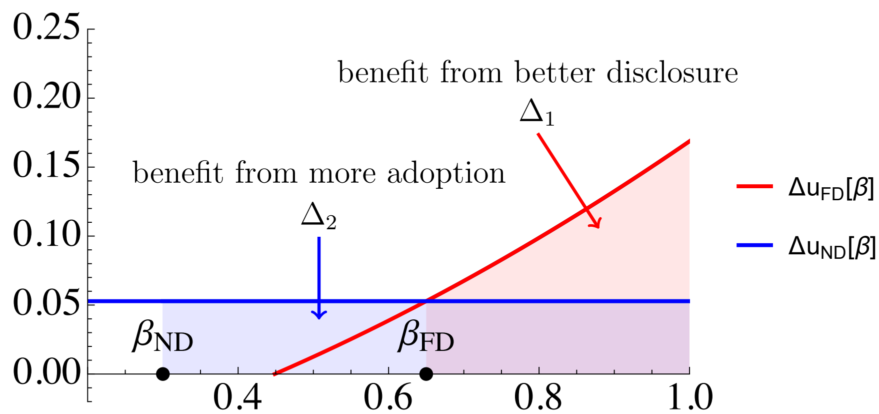
The full disclosure equilibrium yields higher utility across both these dimensions, and so $\Delta_1 > 0$ always. In fact, the above expressions highlight that if the firm's adoption decision was exogenous (i.e., for any exogenous adoption threshold $\bar{\beta} \geq \beta_{FD}$), welfare is always higher under full-disclosure than under no-disclosure. This captures the common wisdom that greater disclosure is often welfare improving, which underlies much of the existing regulatory policy. However, it fails to account for the impact that **endogenous** investment (project adoption) can have on welfare.

The second component, Δ_2, reflects this in our analysis. Specifically, Δ_2 measures the risk-sharing impact across the two equilibria that result from different adoption thresholds. This is captured by the blue rectangular area in Figure 3. Recall that $\beta_{ND} \leq \beta_{FD}$, so that green adoption is higher with no disclosure, because lower types can pool with higher types in the no disclosure equilibrium. The net benefit from adoption for these types is always positive i.e., $\Delta_2 > 0$.

Whether full disclosure yields higher welfare depends on the relative magnitude of Δ_1

Figure 3: Incremental welfare from adoption under full vs no disclosure

The shaded regions corresponds to the welfare gain under full disclosure (adoption $\beta > \beta_{FD}$) and no disclosure (adoption $\beta > \beta_{ND}$) cases. The parameters are $m = 0.5$, $q = 0.25$, $\sigma = 1$, and $\rho = 1$, $\gamma = 0.325$, and β follows a uniform distribution, i.e., $\beta \sim U[0,1]$.



and Δ_2. The above characterizations imply the following result.

Proposition 5. *Welfare is higher under full disclosure than under no disclosure (i.e., $\Delta > 0$) if and only if*

$$q > \frac{\rho}{2} m(1-m) \frac{(1-F(\beta_{ND}))\big(\mathbb{E}[\beta \mid \beta \geq \beta_{ND}]\big)^2 - (1-F(\beta_{FD}))\mathbb{E}[\beta^2 \mid \beta \geq \beta_{FD}]}{(1-F(\beta_{FD}))\big(m\rho\sigma\mathbb{E}[\beta \mid \beta \geq \beta_{FD}] - \gamma\big)}. \quad (20)$$

(1) All else equal, welfare is higher under full disclosure than under no disclosure, if (i) q is sufficiently large (i.e., $q \to \infty$), (ii) m is sufficiently large (i.e., $m \to 1$), or (iii) $\mathbb{E}[\beta|\beta > x] > 2x$ for $x \in [\beta_{ND}, \beta_{FD}]$ (i.e., $f(\beta)$ has a heavy right tail).
(2) All else equal, welfare is higher under no disclosure than under full disclosure, if (i) $(\beta_{FD} - \beta_{ND})\ h(\beta_{ND}) > 2\ln\left(\frac{1}{\beta_{FD}}\right)$, where $h(x) = \frac{f(x)}{1-F(x)}$ is a hazard function (i.e., $f(\beta)$ has a light right-tail) and q is sufficiently small (i.e., $q \to 0$), or (ii) γ is sufficiently large (i.e., $\frac{\gamma}{m\rho\sigma} \to 1$).

The condition in (20) follows from rearranging the expression for $\Delta > 0$. The results in the sufficient conditions in parts (1) and (2) are intuitive. For instance, when q is sufficiently large, the benefit from price increase under full disclosure is sufficiently large to dominate the remaining terms in Δ (all of which do not depend on q). Similarly, all else equal, when m approaches 1, the potential increase in risk-sharing benefits that may arise from no disclosure approach zero, since the economy is populated by green investors only. However, in this case, the benefit from the price increase under full disclosure still arises, and as a result, $\Delta > 0$.

Finally, when the distribution of β has a heavy right tail, Δ is positive even when endowment in stock is small. Intuitively, this is because the change in the threshold (from β_{ND} to β_{FD}) does not lead to a substantial enough reduction in types who adopt and the average type conditional on adoption remains high, which implies $\Delta > 0$.[14]

In contrast, when the distribution of factor loadings is more concentrated towards zero, the increase in the adoption threshold from β_{ND} to β_{FD} imply that a relatively large fraction of types choose not to adopt the green project under full-disclosure and this leads to a significant drop in risk-sharing. Moreover, in this case we can show that when q becomes arbitrarily small, then the benefit from the higher price under full disclosure approaches zero. In this case, the risk-sharing benefits from increased investment in green projects can dominate and welfare is higher under no disclosure i.e., $\Delta < 0$.[15] Additionally, we can show that for any distribution of β, as γ approaches its upper bound, this leads to almost no adoption under full disclosure. At the same time, under no disclosure, the green project is still adopted, which leads to higher welfare.

5.3.1 Uniform Distribution of β

While Proposition 5 provides a characterization of when the no-disclosure equilibrium generates higher welfare, the relevant condition in (20) is in terms of endogenous objects (i.e., in terms of β_{FD} and β_{ND}). In this subsection, we further assume that the distribution of climate exposure β is given by $\beta \sim U[0,1]$. This allows us to characterize the welfare difference Δ explicitly in terms of exogenous model parameters.

First note that when β has a standard uniform distribution, we can show that β_{ND} has a tractable closed form:

$$\beta_{ND} = 2\beta_{FD} - 1, \quad \text{where} \quad \beta_{FD} = \frac{\gamma}{m\rho\sigma}.$$

Then, the welfare difference is given by:

$$\Delta = \frac{q(m\rho\sigma - \gamma)^2}{2m\rho\sigma} + \frac{(1-m)\left(5\gamma^3 + m^3\rho^3\sigma^3 - 6\gamma^2 m\rho\sigma\right)}{6m^2\rho^2\sigma^3}.$$

The following result characterizes sufficient conditions under which we can rank welfare under the full disclosure and no-disclosure equilibria.

[14] Graphically, in this case, the area of the red triangular area is larger than the area of the blue rectangle in Figure 3.

[15] In this case, the area of the blue rectangular area is larger than the red triangular area in Figure 3.

Proposition 6. *Suppose the firm's climate risk exposure is distributed as $\beta \sim U[0,1]$. Then, the welfare is higher under no-disclosure if and only if γ is sufficiently large i.e., $\Delta \leq 0$ if and only if $\gamma^* \leq \gamma \leq m\rho\sigma$, where*

$$\gamma^* = m\rho\sigma \frac{1 - k + \sqrt{k^2 + 18k + 20}}{10} \qquad \textit{for} \quad k = \frac{3q\sigma}{1-m}.$$

Figure 4 provides an illustration of the above result for various parameter values. Specifically, the shaded area corresponds to regions of the parameter space where $\Delta < 0$ i.e., welfare is higher under no disclosure.

We can make several observations. First, as panel (a) illustrates, when investors become more homogeneous, i.e., $m \to 0$ or $m \to 1$, the benefits of risk sharing disappear and only the risk premium remains, which implies full disclosure yields higher welfare. Second, as panel (b) illustrates, the region of parameters where no disclosure yields higher welfare shrinks as q increases. This is because, all else equal, an increase in q implies the difference in price across the two equilibria has a larger impact on welfare (see the expression for Δ_1). Panel (c) and (d) illustrate that the region of parameters where the no disclosure equilibrium has higher welfare increases with both ρ and σ. All else equal, an increase in either parameter implies that the benefits from risk-sharing increase.

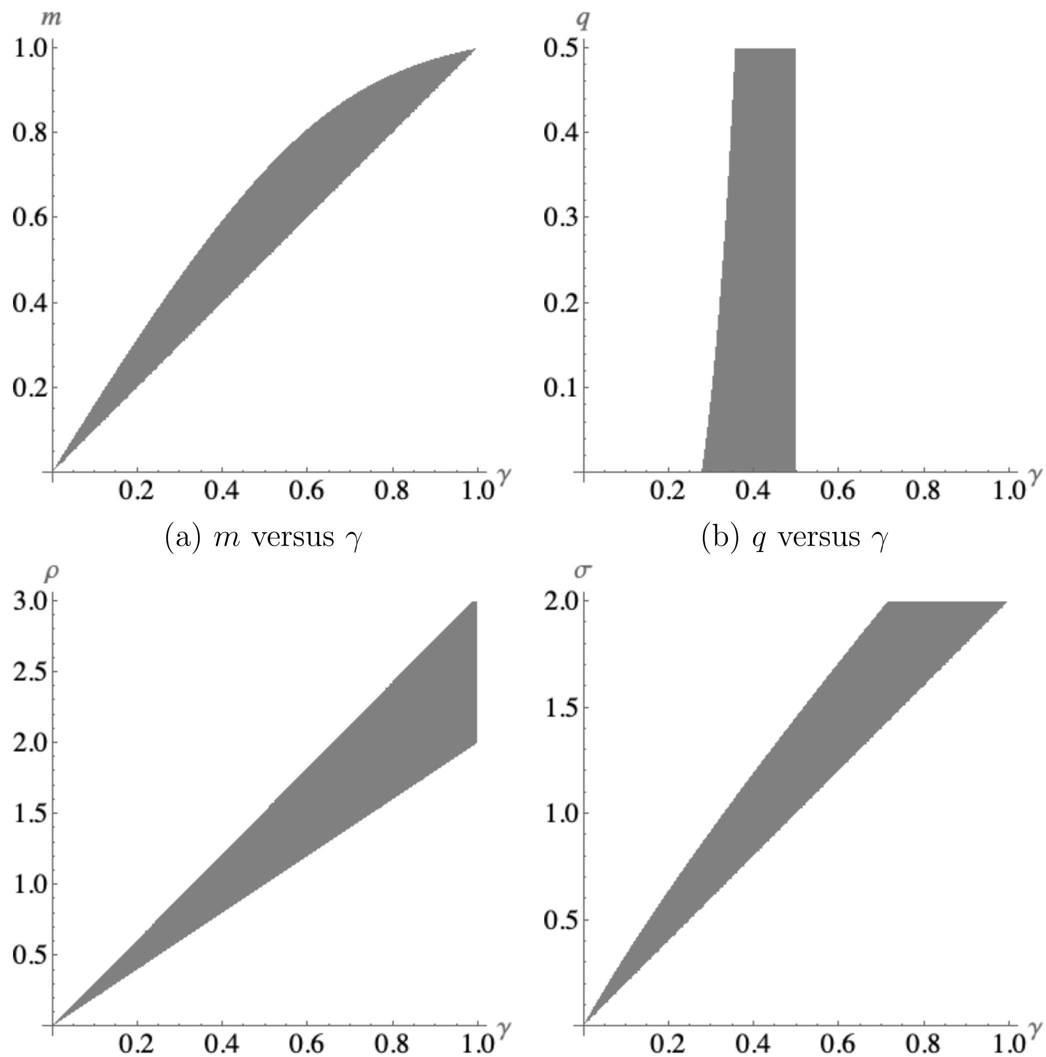
Together, Propositions 5 and 6 provide an ordering of welfare under the full and no disclosure equilibria. These two cases provide natural benchmarks which allow us to evaluate the impact of mandatory climate disclosure requirements on welfare. We show that mandatory disclosure requirements unambiguously improve welfare when the firm's decision to adopt a green project is exogenously fixed, since it leads to higher valuations (expected price) and improved risk-sharing. However, once we allow the firm to endogenously choose whether or not to adopt the project, given the market price, we show that such requirements can reduce welfare by decreasing the types of firms that choose to adopt the green project.

6 Voluntary disclosure and welfare

The analysis in the previous section highlights important tradeoffs between the no-disclosure and full-disclosure equilibrium. On the one hand, more types adopt the green project under the no-disclosure equilibrium, and this can improve investor welfare under certain conditions. However, higher types (i.e., with $\beta > \beta_{FD}$) are worse off in this case since they receive at most P_g in equilibrium, but would have strictly higher valuations under full disclosure. As such, some high types would be willing to pay a cost to verifiably disclose their type to investors if this were feasible.

Figure 4: Parameters where welfare is higher under non-disclosure

The shaded region corresponds to regions of the parameter space in which welfare is higher under non-disclosure than under full disclosure. Unless specified, the parameters are: $m = 0.5$, $q = 0.25$, $\sigma = 1$, and $\rho = 1$.



(a) m versus γ (b) q versus γ

(c) ρ versus γ (d) σ versus γ

To consider this possibility, we now allow firms to engage in voluntary disclosure. Specifically, suppose that the firm can pay a cost $c > 0$ to verifiably disclose the β before date two (as in Verrecchia (1983)) - denote the manager's decision to disclose by $d \in \{0, 1\}$. The cost reflects the direct and indirect costs of revealing the climate exposure of the green project that the firm has access to.

Classic literature emphasizes direct costs of producing and disseminating information (Verrecchia (2001), Simunic (1980)), proprietary costs or competitive disadvantage (Hayes and Lundholm (1996), Ellis, Fee, and Thomas (2012)), and regulatory costs (Rogers and Stocken (2005)). We can also interpret the cost c as a fee paid to an independent auditor, who can verify the information provided by the manager (Reid, Carcello, Li, Neal, and Francis (2019))

The following result characterizes an equilibrium in this setting.

Proposition 7. *Suppose the firm can pay a cost c to verifiably disclose β to investors before trading. Then, there exists a unique equilibrium that satisfies the Intuitive Criterion. The equilibrium is characterized by two thresholds $\underline{\beta}_{CD} < \bar{\beta}_{CD}$ such that: (i) a firm of type $\beta \geq \bar{\beta}_{CD}$ adopts the green project and pays c to disclose β (chooses $k = 1, d = 1$), (ii) a firm of type $\beta \in [\underline{\beta}_{CD}, \bar{\beta}_{CD})$ adopts the green project but does not disclose β (chooses $k = 1, d = 0$), (iii) a firm of type $\beta < \underline{\beta}_{CD}$ adopts the brown project and does not disclose β (chooses $k = 0, d = 0$), and (iv) the equilibrium price is given by:*

$$P = \begin{cases} \mu + \gamma - \rho\sigma^2 q & \text{if } k = 0 \text{ and } d = 0 \\ \mu + \gamma - \rho\sigma^2 q & \text{if } k = 1 \text{ and } d = 0 \\ \mu + m\beta\rho\sigma - \rho\sigma^2 q - c & \text{if } k = 1 \text{ and } d = 1 \end{cases},$$

where the thresholds are implicitly defined as the solution to:

$$\bar{\beta}_{CD} = \min\left\{\frac{c+\gamma}{m\rho\sigma}, 1\right\} \quad \text{and} \quad \mathbb{E}[\beta | \bar{\beta}_{CD} > \beta \geq \underline{\beta}_{CD}] = \min\left\{\frac{\gamma}{m\rho\sigma}, 1\right\}.$$

Moreover, adoption of the green project is (weakly) higher than under full disclosure but (weakly) lower than under no disclosure, and there is (weakly) less disclosure of β than under full disclosure i.e., $\beta_{ND} \leq \underline{\beta}_{CD} \leq \beta_{FD} \leq \bar{\beta}_{CD}$. In particular, if $c = 0$, then $\bar{\beta}_{CD} = \underline{\beta}_{CD} = \beta_{FD}$; if $c > m\rho\sigma^2 - \gamma$, then $\bar{\beta}_{CD} = 1$ and $\underline{\beta}_{CD} = \beta_{ND}$.

The nature of the equilibrium is similar to those in the full disclosure and no-disclosure equilibria, but is characterized by two indifference conditions. Intuitively, note that, conditional on disclosure, the firm's stock price is increasing in its β. This implies that types with sufficiently high β will choose to voluntarily disclose their climate exposures, and there is a threshold type $\bar{\beta}_{CD}$ which is exactly indifferent between doing so and pooling with other adopters i.e.,

$$\underbrace{\mu + m\bar{\beta}_{CD}\rho\sigma^2 - \rho\sigma^2 q - c}_{\text{payoff from green + disclosure}} = \underbrace{\mu + m\mathbb{E}[\beta | \bar{\beta}_{CD} > \beta \geq \underline{\beta}_{CD}]\rho\sigma^2 - \rho\sigma^2 q}_{\text{payoff from green + non-disclosure (pooling)}}.$$

For types below $\bar{\beta}_{CD}$, investors cannot observe the firm's factor loading but only whether or not it adopts the green project. This is analogous to the no-disclosure equilibrium: there is a threshold type $\underline{\beta}_{CD}$ which is exactly indifferent between adopting the green project and pooling with higher types and choosing the brown project i.e.,

$$\underbrace{\mu + m\mathbb{E}[\beta|\bar{\beta}_{CD} > \beta \geq \underline{\beta}_{CD}]\rho\sigma^2 - \rho\sigma^2 q}_{\text{payoff from green + non-disclosure}} = \underbrace{\mu + \gamma - \rho\sigma^2 q}_{\text{payoff from brown project}} .$$

Simplifying these indifference conditions gives us the characterization of the thresholds in Proposition 7.

Moreover, the above also imply that all else equal, adoption of the green project is (weakly) higher than under full disclosure but (weakly) lower than under no disclosure. Intuitively, the costly disclosure equilibrium facilitates some pooling, which leads to more adoption relative to full disclosure, but not as much as under the no-disclosure equilibrium. On the other hand, since disclosure is costly, fewer types disclose than under the full disclosure equilibrium.

6.1 Welfare

Given the characterization of the equilibrium in Proposition 7, one might expect that the costly disclosure equilibrium yields an intermediate level of welfare, since the equilibrium leads to more green adoption than the full disclosure equilibrium and more disclosure of β than the no-disclosure equilibrium. However, as we show next, this need not always be the case.

Recall that in the costly disclosure equilibrium, the firm follows the threshold strategy, when types $\beta > \bar{\beta}_{CD}$ pay c to disclose their exposure, types $\underline{\beta}_{CD} \leq \beta \leq \bar{\beta}_{CD}$, adopt the green project without disclosing their exposure and the remaining types adopt the brown project, where the thresholds are specified in Proposition 7. Then, we can characterize the aggregate investor welfare when $\beta > \bar{\beta}_{CD}$ as:

$$\bar{u}_{CD}(\beta) = W_0 + q\,P_g(\beta) - \frac{\rho}{2}m + \frac{\rho}{2}\left(q^2\sigma^2 + m(1-m)\beta^2\right) \tag{21}$$

When $\beta < \bar{\beta}_{CD}$, the aggregate welfare can be characterized as:

$$\underline{u}_{CD} = W_0 + qP_b - \frac{\rho}{2}m + \frac{\rho}{2}\left(q^2\sigma^2 + m(1-m)\mathbb{E}\left[\beta\middle|\,\beta \in [\underline{\beta}_{CD}, \bar{\beta}_{CD}]\right]^2 \mathbf{1}_{\{\beta \geq \underline{\beta}_{CD}\}}\right) \tag{22}$$

Similar to the benchmark cases, we can define the net welfare benefit of adoption as

$$\Delta u_{CD}(\beta) = \left\{q\Delta P + \frac{\rho}{2}m(1-m)\beta\right\}\mathbf{1}_{\{\beta > \bar{\beta}_{CD}\}}$$

$$+\frac{\rho}{2}m(1-m)\mathbb{E}\Big[\beta\Big|\,\beta\in[\underline{\beta}_{CD},\bar{\beta}_{CD}]\Big]^2\mathbf{1}_{\{\beta\in[\underline{\beta}_{CD},\bar{\beta}_{CD}]\}}$$

As a result, we can compute the ex-ante aggregate welfare by averaging over possible β's. We summarize this in the following result.

Proposition 8. *In the costly disclosure equilibrium, ex-ante investor welfare is given by:*

$$\begin{aligned}
EU_{CD} &= u_0+\int_{\underline{\beta}_{CD}}^{1}\Delta u_{CD}(\beta)\,dF(\beta)\\
&= \begin{array}{c}
\underbrace{W_0+q\left(\mu+\gamma\right)-\frac{\rho}{2}\left(q^2\sigma^2+m\right)}_{\textit{baseline welfare}}\\
+\underbrace{(1-F(\bar{\beta}_{CD}))q\left(m\rho\sigma\mathbb{E}[\beta|\beta>\bar{\beta}_{CD}]-c-\gamma\right)}_{\textit{price increase with disclosure}}\\
+\frac{\rho}{2}m(1-m)\left(\begin{array}{c}\underbrace{\left(1-F(\bar{\beta}_{CD})\right)\mathbb{E}\left[\beta^2\big|\,\beta>\bar{\beta}_{CD}\right]}_{\textit{risk-sharing benefit with disclosure}}\\
+\underbrace{\left(F(\bar{\beta}_{CD})-F(\underline{\beta}_{CD})\right)\mathbb{E}\left[\beta\big|\,\beta\in[\underline{\beta}_{CD},\bar{\beta}_{CD}]\right]^2}_{\textit{risk-sharing benefit with adoption but no disclosure}}\end{array}\right)
\end{array}
\end{aligned}\tag{23}$$

Consistent with the decomposition of welfare from the no-disclosure and full-disclosure equilibria, welfare in the costly disclosure equilibrium is affected by (i) higher price for types that choose to disclose (i.e., $\beta>\bar{\beta}_{CD}$), (ii) risk-sharing benefits from types that adopt the green project and disclose their type (i.e., $\beta>\bar{\beta}_{CD}$), and (iii) risk-sharing benefits from types that adopt the green project but do not disclose their type (i.e., $\underline{\beta}_{CD}\leq\beta\leq\bar{\beta}_{CD}$).

To gain further intuition, note that one can express Δu_{CD} as

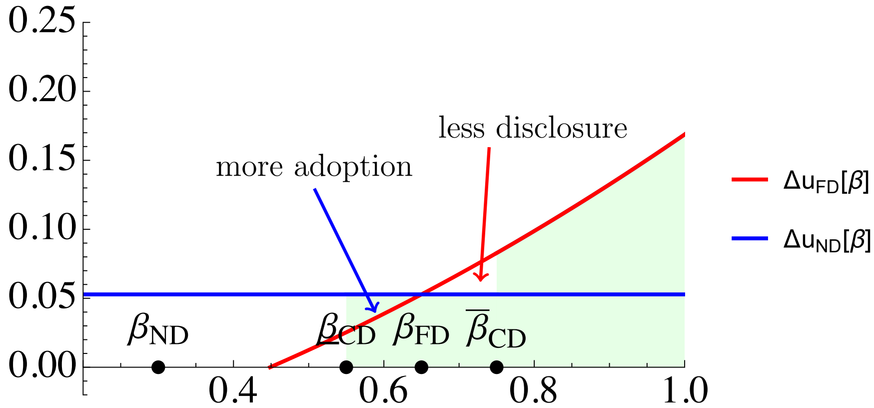
$$\Delta u_{CD}(\beta)=(\Delta u_{FD}(\beta)-qc)\times\mathbf{1}_{\{\beta>\bar{\beta}_{CD}\}}+\Delta u_{ND}\times\mathbf{1}_{\{\beta\in[\underline{\beta}_{CD},\bar{\beta}_{CD}]\}}\tag{24}$$

Intuitively, if we assume that the disclosure cost is paid back as a subsidy, rather than lost as deadweight, voluntary disclosure balances the two opposing forces at play: the information benefit of disclosure (Δ_1) and the increase in adoption (Δ_2). Figure 5 provides an illustration of this by plotting welfare under costly disclosure gross of the disclosure cost. Imposing a disclosure cost c reduces welfare by discouraging disclosure (as the threshold shifts from β_{FD} to $\bar{\beta}_{CD}$), but it simultaneously increases welfare by encouraging adoption (as the threshold for adoption moves from β_{FD} to $\underline{\beta}_{CD}$).

For a more concrete characterization, let us again consider the case where the distribution of climate exposure β is uniform i.e., $\beta\sim U[0,1]$. Further, if we assume that $c<m\rho\sigma-\gamma$,

Figure 5: Incremental welfare (gross of disclosure costs) under costly disclosure

The shaded regions corresponds to the welfare gain under costly disclosure. The parameters are $m = 0.5$, $q = 0.25$, $\sigma = 1$, and $\rho = 1$, $\gamma = 0.325$, and β follows a uniform distribution, i.e., $\beta \sim U[0,1]$.



one can show that

$$EU_{CD} = \begin{array}{l} W_0 + q(\mu+\gamma) - \frac{\rho}{2}\left(q^2\sigma^2 + m\right) + \frac{1}{2}qm\rho\sigma\left(1-\bar{\beta}_{CD}\right)^2 \\ +\frac{\rho}{2}m(1-m)\left(\left(\bar{\beta}_{CD} - \underline{\beta}_{CD}\right)\left(\frac{\gamma}{m\rho\sigma}\right)^2 + \frac{1}{3}\left(1-\bar{\beta}_{CD}^3\right)\right) \end{array}$$

where

$$\bar{\beta}_{CD} = \frac{c+\gamma}{m\rho\sigma} \quad \text{and} \quad \underline{\beta}_{CD} = \frac{\gamma - c}{m\rho\sigma}.$$

Notice that an increase in the cost of disclosure has a direct impact on welfare through less disclosure by highest types (i.e. $\bar{\beta}_{CD}$ increases in c). This leads to lower expected prices for these types and lower risk-sharing benefits. At the same time, a higher cost encourages more firms to adopt the green project (i.e., $\underline{\beta}_{CD}$ decreases in c), which improves risk-sharing benefits due to adoption.

Plugging this into the expression for EU_{CD} implies:

$$EU_{CD} = W_0 + q\left(\mu - c + \frac{(c+\gamma)^2}{2m\rho\sigma} + \frac{m\rho\sigma}{2}\right) - \frac{\rho}{2}q^2\sigma^2 - \frac{1}{6}m(m+2)\rho - \frac{(1-m)\left(c^3+\gamma^3+3\gamma c^2 - 3\gamma^2 c\right)}{6m^2\rho^2\sigma^3}. \tag{25}$$

In particular, the above expression implies that an increase in the cost of disclosure need not always lead to a loss in welfare, as we summarize in the following result.

Proposition 9. *Suppose the firm's climate risk exposure is distributed as* $\beta \sim U[0,1]$ *and* $q < \frac{\gamma^2}{m\rho\sigma - \gamma} \times \frac{1-m}{2m\rho\sigma^2}$. *If* $\frac{\gamma}{m\rho\sigma} > 1/\sqrt{2}$, *then welfare is maximized when no firms engage in costly* *disclosure i.e., $c^* \geq m\rho\sigma - \gamma$. If $\frac{\gamma}{m\rho\sigma} < 1/\sqrt{2}$, then welfare is maximized for an intermediate disclosure cost $c^* \in (0, m\rho\sigma - \gamma)$, where*

$$c^* = \frac{mq\rho\sigma^2 + \sqrt{2\gamma^2(1-m)^2 - m^2q\rho^2\sigma^3(2(1-m) - q\sigma)}}{1-m} - \gamma. \tag{26}$$

In this case, c^* is increasing in γ, and decreasing in q, m, ρ, σ.

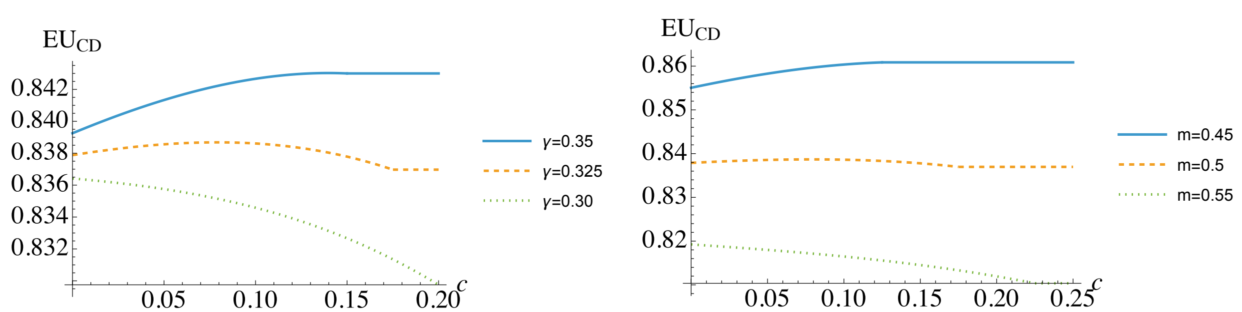
Figure 6 provides an illustration of these effects: it plots welfare as a function of the disclosure cost for various values of γ (panel (a)) and m (panel (b)). When the per-capita endowment of shares q is sufficiently large, or equivalently, γ is sufficiently low (or m is sufficiently high) (dotted lines), welfare is decreasing in c. In this case, welfare is dominated by the benefit from higher valuations when more types disclose.

In contrast, when q is sufficiently small, welfare can increase with disclosure costs. To gain some intuition, recall that $\frac{\gamma}{m\rho\sigma} = \beta_{FD}$ i.e., it is the threshold type under full disclosure. Moreover, note that an increase in disclosure costs has two effects: it decreases the proportion of types that disclose (increases threshold $\bar{\beta}_{CD}$) but increases the proportion of types that adopt the green project (decreases threshold $\underline{\beta}_{CD}$).

When q is small and $\beta_{FD} = \frac{\gamma}{m\rho\sigma}$ is sufficiently high, this implies that even in the absence of disclosure costs, a relatively small fraction of firms would adopt (and disclose). In this case, when disclosure costs increase, the benefit from increased adoption by non-disclosing firms always outweighs the cost from reduced disclosure of high types, and so welfare always increases with cost.

Figure 6: Welfare under the costly disclosure equilibrium

The figure plots welfare in the costly disclosure equilibrium as a function of the disclosure cost c, for different parameter values. Unless specified, other parameters are set to: $m = 0.5$, $q = 0.25$, $\sigma = 1$, $\rho = 1$, $\mu = 0$, $\gamma = 0.325$, and $W_0 = 1$.



(a) EU_{CD} versus c for different γ (b) EU_{CD} versus c for different m

More interestingly, when $\beta_{FD} = \frac{\gamma}{m\rho\sigma}$ is not too large, then welfare is maximized when a fraction of types incur the cost to disclose their risk exposures, but not all types do so (dashed lines). In this case, an initial increase in the disclosure cost (starting from $c = 0$) actually leads to an increase in welfare — specifically,

$$\left.\frac{\partial EU_{CD}}{\partial c}\right|_{c=0} = -q\left(1 - \frac{\gamma}{m\rho\sigma}\right) + \frac{\gamma^2(1-m)}{2m^2\rho^2\sigma^3} > 0,$$

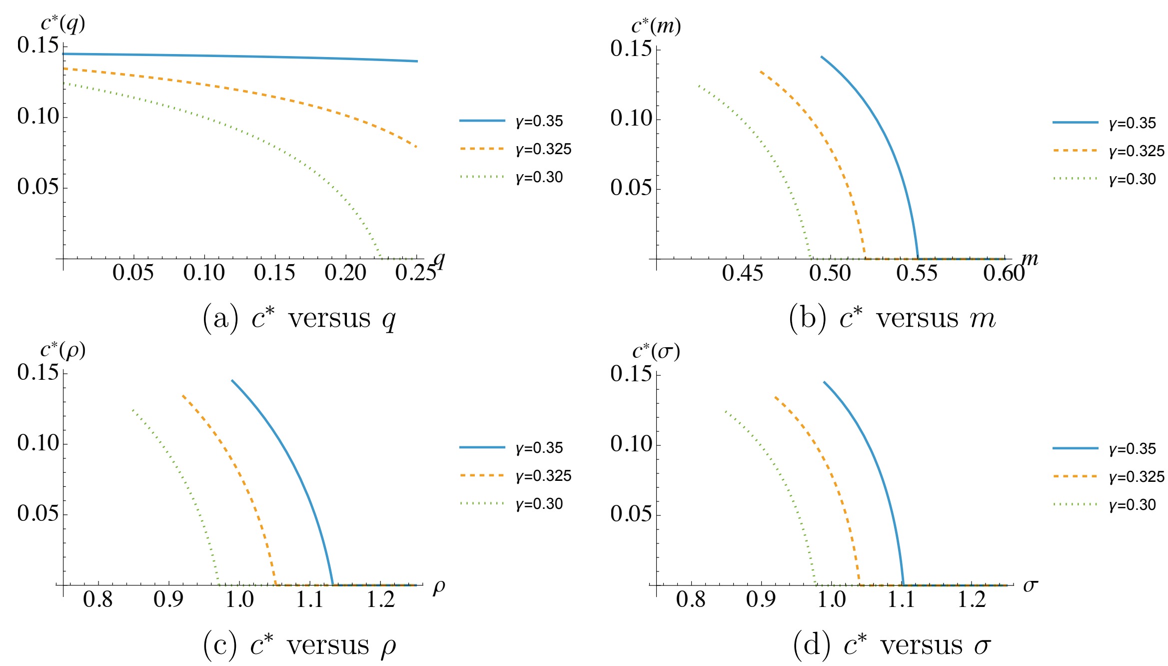
since q is sufficiently small. Intuitively, the decrease in the expected price of the stock (due to less disclosure) is dominated by the increase in risk-sharing benefits due to greater adoption of green projects. However, when the disclosure cost is sufficiently high, further increases lead to a decrease in welfare. In fact, we have:

$$\left.\frac{\partial EU_{CD}}{\partial c}\right|_{c=m\rho\sigma-\gamma} = -\frac{(1-m)}{\sigma}\left(\frac{1}{2} - \frac{\gamma^2}{m^2\rho^2\sigma^2}\right) < 0$$

when $\beta_{FD} = \frac{\gamma}{m\rho\sigma}$ is sufficiently low. In this case, the incremental benefit from higher adoption is not sufficiently large to offset the loss in welfare due to worse risk-sharing (due to less disclosure). This is because the initial level of adoption in the full disclosure case was relatively high, i.e., $\beta_{FD} < \frac{\sqrt{2}}{2}$. As a result, welfare is maximized for an intermediate disclosure cost c^* as characterized above.

Figure 7: Welfare-maximizing disclosure cost c^*

The figure plots the welfare maximizing disclosure cost c^* as a function of parameters. Unless specified, other parameters are set to: $m = 0.5$, $q = 0.25$, $\sigma = 1$, $\rho = 1$, and $\gamma = 0.325$.



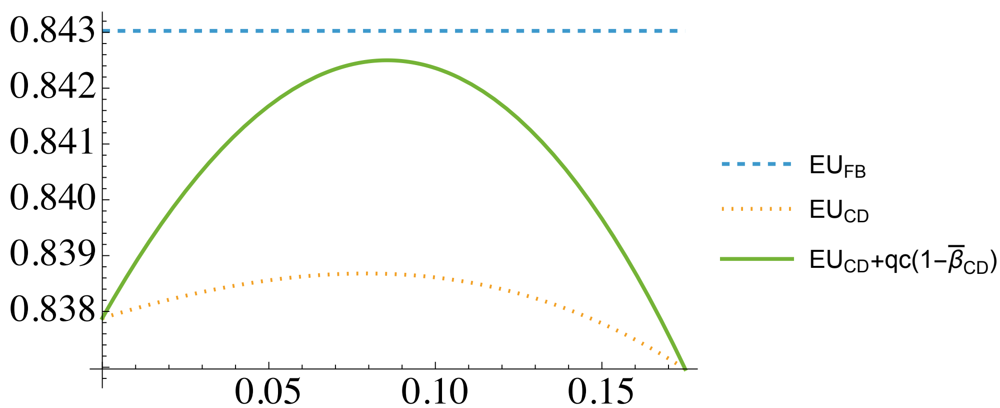
(a) c^* versus q (b) c^* versus m

(c) c^* versus ρ (d) c^* versus σ

Figure 7 provides an illustration of how the welfare maximizing c^* varies with parameters of the model. All else equal, c^* is increasing in γ, but decreasing in q, m, ρ and σ. This comparative statics shows the underlying trade-off between the informational value of disclosure Δ_1 and the value of increased adoption Δ_2. Intuitively, when stock endowment q is higher, the effect of mispricing on investor welfare is more pronounced (Δ_1 is higher). Thus, the optimal c^* is smaller to incentivize more disclosure. Second, m, ρ and σ amplify the benefits of risk sharing and increase the baseline level of adoption (i.e., decrease β_{FD}). This weakens the marginal effect of c through increased adoption. Thus, optimal c^* is lower so that the informational benefits are preserved. In contrast, a higher opportunity cost γ lowers adoption, and increases the importance of higher adoption rate achieved by increasing c^*.

Figure 8: First-best level of welfare

The figure plots the first-best level of welfare (dashed) and the welfare under costly disclosure with (solid) and without (dotted) a refund of the disclosure costs. The parameters are set to: $m = 0.5$, $q = 0.25$, $\sigma = 1$, and $\rho = 1$, $\gamma = 0.325$.



By optimally charging a disclosure cost for verifiable disclosure and then refunding the cost to investors, a policymaker can achieve outcomes that are closer to the first best than under no-disclosure or full-disclosure. Figure 8 provides an illustration. Recall that the welfare loss under full disclosure comes from the manager's under-investment in the green project. The first best outcome is achieved all types $\beta \geq \beta_W$ adopt the green project and disclosure — in this case, the welfare is given by

$$EU_{FB} \equiv u_0 + \int_{\beta_W}^{1} \Delta u_{FD}(\beta)\, dF(\beta),$$

where β_W is the welfare-maximizing threshold given by equation (16). This is characterized by the dashed line in Figure 8.

As characterized by Proposition 9, the policymaker can achieve higher welfare than full- or no-disclosure by optimally choosing an intermediate disclosure cost — this is characterized by the dotted line. Moreover, by refunding the (expected) incurred disclosure costs (i.e., $q \times c \times (1 - F(\bar{\beta}_{CD}))$) to investors, one can achieve even higher outcomes — this is plotted as the solid line in Figure 8. However, one can show that, generically, the difference in welfare between first best and costly disclosure is always positive.

The above result highlights a role for disclosure regulation. Importantly, in contrast to common wisdom, reducing or eliminating disclosure costs need not improve welfare. Instead, a regulator may be able to improve welfare by making disclosure requirements about climate risk exposure more stringent, especially when the per-capita endowment of shares q is sufficiently low. We discuss these and other implications in the next section.

7 Extensions

In this section, we explore how our benchmark results about welfare under the no disclosure and full disclosure equilibria change under alternate assumptions. In Section 7.1, we characterize how our results change when investors can also trade a derivative contract which provides them an imperfect hedge against climate shocks. In Section 7.2, we consider a setting where the firm decides whether to maintain a "brown" status quo, which has an exposure to climate shocks, or adopt an abatement technology. The details of the analysis in each case are presented in Appendix B.

7.1 Climate derivatives

In this section, we summarize how our results change when investors have access to a derivative contract that provides a partial hedge to climate shocks. Suppose that in addition to the risk-free security and the risky stock, investors can trade a derivative security, which is in zero net supply and has a payoff:

$$D = a\,\omega + \sqrt{1 - a^2}\zeta$$

where $a \in [0, 1]$ and where $\zeta \sim N(0, 1)$ is a source of (basis) risk independent of climate shocks. Here a parameterizes the hedging effectiveness of the derivative — as a increases, the derivative security becomes a better hedge for climate risk.

As we show in Appendix B.1, the key takeaways of our analysis are unaffected unless a is sufficiently large. Specifically, we show that because the derivative is assumed to be in zero net supply, the price of the stock is unaffected by the presence of the derivative in either equilibrium. This implies that the threshold equilibria are characterized by the same thresholds as in our main analysis i.e., β_{FD} and β_{ND}. As a result, we show that green adoption is higher under the no-disclosure equilibrium than under the full disclosure equilibrium.

While investment thresholds are unaffected by the presence of the derivative, the risk sharing benefits are. Specifically, as the derivative becomes a better hedge (i.e., $a \to 1$), investors use the derivative to share risk and so the firm's decision to adopt has a smaller impact on their welfare along this dimension. In fact, when the derivative offers a perfect hedge (i.e., $a = 1$), the firm's adoption offers no additional risk sharing benefits, and so the welfare ranking depends completely on the price increase under full disclosure. Under the assumption that risk exposures are uniformly distributed, one can show the following result.

Proposition 12. *Suppose the firm's climate risk exposure is distributed as $\beta \sim U[0,1]$ and investors have access to a derivative with correlation a.*
(1) All else equal, welfare is higher under full-disclosure if a is sufficiently large.
(2) All else equal, welfare is higher under no-disclosure if and only if γ is sufficiently large (as characterized by Proposition 6) and a is sufficiently small.

Overall, the analysis of this section suggests that while investor welfare and, in particular, risk-sharing benefits are affected by the presence of a climate derivative, the key economic channels that we highlight in our analysis still arise as long as the derivative does not offer a perfect hedge (i.e., as long as $a < 1$). This also suggests that optimal disclosure policy should account for the presence of derivatives: more stringent disclosure requirements may become more desirable as the ability of investors to hedge their risks using derivative markets improves and the climate risk market becomes more complete.

7.2 Abatement technologies

Our main analysis focuses on green adoption decisions: a firm chooses whether to invest in a green project that pays off when climate outcomes are worse. In practice, another important dimension of climate-focused investments is abatement of brown projects. We extend our analysis to these settings in this section.

Specifically, suppose the firm's assets in place are brown i.e., the terminal cash flows from the status quo are given by

$$V(k=0) = \mu + \gamma - \sigma\left(\beta\omega + \sqrt{1-\beta^2}\,\eta\right) \equiv V_b(\beta),$$

where $\omega \sim N(0,1)$ is the climate shock as before, $\eta \sim N(0,1)$ is independent of ω, and $\beta \in [0,1]$ reflects the "brownness" of the project. In particular, note that when climate outcomes are worse ($\omega > 0$), the firm's cash flows from the status quo are lower. Further, suppose the firm can adopt an abatement technology which eliminates the exposure to climate risk, but also leads to a reduction in cash flows of γ i.e., conditional on abatement, the firm's terminal cash flows are

$$V(k=1) = \mu - \sigma\eta \equiv V_g.$$

As we show in Appendix B.2, when investors can observe both the adoption decision and the "brownness" of the status-quo project, the equilibrium prices can be expressed as:

$$P_g = \mu - q\rho\sigma^2, \quad \text{and} \quad P_b(\beta) = \mu - q\rho\sigma^2 - (m\rho\sigma\,\beta - \gamma).$$

This implies that the price change due to adoption of the abatement technology is

$$\Delta P(\beta) \equiv P_g - P_b(\beta) = m\rho\sigma\,\beta - \gamma$$

Note that in this case, the benefit from adoption is the same as in the main analysis (see (10)). As such, the adoption threshold is the same as well: a firm adopts the abatement technology if and only if $\beta \geq \beta_{FD}$, where $\beta_{FD} = \min\{1, \frac{\gamma}{m\rho\sigma}\}$ as before.

However, the interpretation of adoption is different: firms with a large adverse climate exposure choose to adopt the abatement technology to avoid a large price discount. This implies that in the no-disclosure equilibrium, the decision not to adopt is interpreted by investors as the firm having a (relatively) low exposure β. Under no disclosure, this implies that there exists a threshold equilibrium in which the firm adopts the abatement technology if and only if $\beta \geq \beta_{ND}$, where

$$\mathbb{E}[\beta|\beta < \beta_{ND}] = \min\left\{\frac{\gamma}{m\rho\sigma}, 1\right\} = \beta_{FD}.$$

Importantly, this implies that $\beta_{FD} \leq \beta_{ND}$ i.e., there is **less** adoption of the abatement technology under no-disclosure than under full-disclosure. When there is no way for firms to verifiably disclose their type, more brown types engage in a form of "greenwashing" by maintaining the status quo, since this pools them with types that have smaller climate risk exposures. The above result suggests that the impact of disclosure policy on adoption of abatement technologies can be very different than the adoption of other green projects.

Interestingly, however, the implications for investor welfare are more in line with our main analysis. To see this, note that adoption of the abatement technology leads to (i) a potential price change (under the full disclosure equilibrium), and (ii) a **reduction** in risk-sharing benefits. In fact, as we show in the appendix, the net welfare benefit of adoption under full disclosure is given by:

$$\Delta u_{FD} = u_{FD}(1,\beta) - u_{FD}(0,\beta) = q\Delta P(\beta) - \frac{\rho}{2}m(1-m)\beta^2.$$

This implies that full disclosure leads to *over-investment* in abatement technologies, relative to the welfare maximizing level. As a result, one can show that no-disclosure can improve welfare by reducing this over-investment. We summarize a set of sufficient conditions in the following result.

Proposition 14. *Suppose the firm's climate risk exposure is distributed as $\beta \sim U[0,1]$. Then, ex-ante investor welfare is higher under no disclosure than under full disclosure (i.e., $\Delta \equiv EU_{FD} - EU_{ND} < 0$) if and only if*

$$\gamma > \frac{3}{5}\frac{m}{1-m}q\rho\sigma^2.$$

The sufficient condition is intuitive and aligns with the results from our main analysis. Specifically, no disclosure generates higher welfare when the incremental benefit from higher valuations under full-disclosure are dominated by the incremental benefits of improved risk-sharing under no-disclosure. This is more likely when, all else equal, q is sufficiently small (analogously to Proposition 5) or when γ is sufficiently large (as in Proposition 6).

8 Implications and Conclusions

We characterize the welfare implications of mandatory disclosures about climate risk exposures on investor welfare. We show that when firms endogenously choose whether or not to adopt a green project, mandating greater disclosure about climate risk exposures reduces the likelihood of adoption and can reduce investor welfare. Intuitively, when investors can perfectly observe risk-exposures, only sufficiently green types invest. However, when investors face uncertainty about risk exposures, less green firms can pool with more green firms by adopting the green project and improving risk-sharing benefits for investors.

Empirical predictions. Our analysis speaks to the recent empirical literature that documents the real effects of mandatory disclosure requirements.[16] Our analysis suggests that one must be cautious in testing this relation. Specifically, our main analysis predicts that firms which are subject to increased mandatory climate disclosure requirements should see a

[16] See, for example, Chen, Hung, and Wang (2018), Jouvenot and Krueger (2019), Bolton and Kacperczyk (2021b), Sautner, Van Lent, Vilkov, and Zhang (2023), and Spaans, Derwall, Huij, and Koedijk (2024) and the survey by Christensen, Hail, and Leuz (2021).

decrease in the adoption of *new* green projects. However, our analysis in Section 7.2 implies that such policy changes should lead to a *reduction* in the adoption of abatement technologies. One could test this using a difference in difference approach around the adoption of new climate disclosure rules (e.g., the SEC rule adoption), the inclusion of firms into the scope of certain rules (e.g., firms entering the CSRD), or the staggered implementation of such disclosures across different locations or for different firms. Importantly, our analysis suggests that it is crucial to distinguish different types of "green investment" when testing these predictions.

A common implication for both types of investment is that an increase in mandatory climate disclosure requirements should lead to a larger price improvement conditional on adoption of green technology. Consistent with this prediction, Jouvenot and Krueger (2019) find that following the introduction of mandated greenhouse gas disclosure in the U.K., stock prices became sensitive to the level of reported emissions. By contrast, they find no evidence that earnings announcement returns of European control firms during the same reporting season were related to GHG emissions.

There is a growing literature that establishes that voluntary disclosure of ESG information is incrementally informative about firms' investment decisions. For instance, using guidelines from the Sustainability Accounting Standards Board to train a machine learning algorithm, Rouen, Sachdeva, and Yoon (2024) show that ESG reports contain incremental material information not revealed in 10-K reports, which is linked to a reduction in negative ESG incidents in following years. Our analysis of the costly disclosure scenario predicts that after a rise in exogenous reporting costs (e.g., higher assurance or auditing fees, more stringent requirements), one should observe fewer voluntary disclosures about climate risk exposures, but *more* project adoptions by non-disclosing firms. A key challenge in testing this prediction is empirically distinguishing investment in green projects from disclosures about the risk-exposure of such projects.

Another implication of our analysis is that adoption of green projects should be associated with increases in valuation only in environments with mandatory / stringent climate risk-disclosure requirements. In the absence of such requirements, the price reaction to such investment decisions should be more muted. Finally, in settings where firms can engage in voluntary disclosure of verifiable information, such disclosures should be accompanied by positive price reactions, and larger reactions for "greener" firms with more green investors.

Policy implications. Our analysis suggests caution in subjecting firms to uniform mandatory disclosure requirements. Crucially, we show that mandatory disclosure requirements reduces adoption of new green investment but can encourage adoption of abatement technologies, and hence disclosure regulation should be different across different types of green investment. Specifically, we show that mandatory disclosure is more likely to decrease welfare when either (i) adoption of green projects under mandatory disclosure is sufficiently low, or (ii) per-capita endowment of stock is sufficiently small and green projects tend to have low climate-risk exposures. As such, mandating more stringent disclosure requirements for larger firms (i.e., with large q) or when adopting "greener" projects might improve welfare.

Our analysis also implies that regulators should evaluate disclosure rules together with instruments that affect real investment (e.g., tax credits, subsidies for green investment, carbon taxes). Since mandating more disclosure alone reduces adoption of green projects, one could mitigate the negative impact on welfare by pairing such disclosure requirements with direct incentives to encourage green investment. Similarly, our analysis in Section 7.1 suggests that access to better climate insurance contracts and derivatives (which allow investors to share climate risk) reduce the negative impact that lower green adoption has on welfare, and consequently increase the (relative) benefits of mandatory disclosure.

The result that, with voluntary disclosures, the optimal disclosure cost may be non-zero for some parameter configurations suggests a role for more stringent disclosure standards without mandating all firms provide such information. This might be implementable in the form of a climate-risk certification system, with strict requirements and high standards for what constitutes a green investment. Another implementation is through "climate assurances", which offer third-party verification or auditing of a firm's climate-related disclosures (e.g., emissions reporting, transition plans, risk exposure).[17] Relatedly, Gipper, Ross, and Shi (2025) document a sharp increase in the number of firms with ESG assurance over the last decade.

Finally, one can interpret the pooling by low β types in the no-disclosure equilibrium as a form of *green-washing*: these firms engage in adopting green projects which they would choose not to do if investors had more precise information about climate risk exposures. Under this interpretation, our analysis suggests that green-washing might be associated with higher investor welfare, even though such behavior leads to less precise information about risk exposures.

Future work. Our model is stylized for tractability and expositional clarity, but can be extended in a number of natural directions. Given that the pooling induced by less precise disclosures can be welfare enhancing, it would be interesting to study whether a coarse or tiered disclosure system (e.g., ratings) dominates precise climate risk-disclosures from a regulatory perspective. It would also be interesting to see how welfare changes in a setting

[17] For instance, the Climate Disclosure Project (CDP) sends out standardized questionnaires to firms, asking them to disclose data on climate risk changes, greenhouse emissions and targets, and impact on the environment, and then provides scores to investors, banks and customers who use this information to assess firms' climate risks and strategies.

in which firms can engage in disclosure manipulation i.e., by producing misleading signals about their project's risk-exposure. We leave these avenues for future work.

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A Proofs

With some abuse of notation, in what follows we will denote the terminal payoff as

$$V_k = \mu + \gamma_k + \sigma \left(\beta_k \omega + \sqrt{1 - \beta_k^2} \eta \right)$$

for $k \in \{0, 1\}$, where $\gamma_0 = \gamma, \beta_0 = 0$, and $\gamma_1 = 0, \beta_1 = \beta$.

A.1 Proof of Proposition 1

Investor i trades in the firm with payoff V_k to maximize their utility:

$$\begin{aligned} u_i(\beta_j) &= (q + X_i)(\mu + \gamma_k) - X_i P_k - \tfrac{\rho}{2} \left(((q + X_i)\beta_k \sigma - \mathbf{1}_{\{i=G\}})^2 + (q + X_i)^2 \sigma^2 (1 - \beta_k^2) \right) \\ &= (q + X_i)(\mu + \gamma_k) - X_i P_k - \tfrac{\rho}{2} \left(-\mathbf{1}_{\{i=G\}} 2(q + X_i)\beta_k \sigma + \mathbf{1}_{\{i=G\}}^2 + (q + X_i)^2 \sigma^2 \right) \end{aligned}$$

The first order condition with respect to X_i implies:

$$q + X_i = \frac{\mu + \gamma_k - P_j + \rho \beta_k \sigma \mathbf{1}_{\{i=G\}}}{\rho \sigma^2}$$

And the market clearing condition $\int X_i di = 0$ implies:

$$P_j = \mu + \gamma_j + \rho \beta_j \sigma m - q \rho \sigma^2.$$

Thus, depending on the adoption decision, the price of the stock is

$$\begin{aligned} P_b &= \mu + \gamma - q \rho \sigma^2 \\ P_g(\beta) &= \mu + m \rho \beta \sigma - q \rho \sigma^2 \end{aligned}$$

Note that the payoff from adopting the green project is strictly increasing in the firm's type β. This implies there is a unique threshold strategy such that the manager adopts the green project iff:

$$\Delta P(\beta) \equiv P_g(\beta) - P_b \geq 0 \quad \Leftrightarrow \quad m \beta \rho \sigma_\omega^2 - \gamma \geq 0 \quad \Leftrightarrow \quad \beta \geq \tfrac{\gamma}{m \rho \sigma} \equiv \beta_{FD}$$

Notice that exposure β is constrained: $\beta \in [0, 1]$. Thus, if the expected return of the status quo is very high, the green project is never adopted: $\beta_{FD} = 1$. Thus, $P(\beta) = P_b$ if $\beta < \beta_{FD}$, and $P(\beta) = P_g(\beta)$ for $\beta \geq \beta_{FD}$. $\square$

A.2 Proof of Proposition 2

Now, investor i does not observe the firm's exposure β. Instead, given the conjectured threshold equilibrium where the firm adopts the green project iff $\beta \geq \beta_{ND}$, investor i maximizes the following objective:

$$U_i = \begin{array}{c} (q+X_i)(\mu+\gamma_k) - X_i P \\ -\frac{\rho}{2}\left(-\mathbf{1}_{\{i=G\}}\mathbf{1}_{\{k=1\}}\, 2(q+X_i)\mathbb{E}\left[\beta \middle| \beta \geq \beta_{ND}\right]\sigma + \mathbf{1}^2_{\{i=G\}} + (q+X_i)^2\sigma^2\right) \end{array}$$

The first order condition with respect to X_i implies:

$$q + X_i = \frac{\mu + \gamma_k - P_k + \rho\sigma\mathbb{E}\left[\beta \middle| \beta \geq \beta_{ND}\right]\mathbf{1}_{\{i=G\}}\mathbf{1}_{\{k=1\}}}{\rho\sigma^2},$$

and the market clearing condition then yields:

$$P_k = \mu + \gamma_k + m\rho\mathbb{E}[\beta|\beta \geq \beta_{ND}]\sigma\mathbf{1}_{\{k=1\}} - q\rho\sigma^2.$$

Thus, conditional on the adoption decision, the price of the stock is

$$\begin{aligned} P_b &= \mu + \gamma - q\rho\sigma^2 \\ P_g &= \mu + m\rho\mathbb{E}[\beta|\beta > \beta_{ND}]\sigma - q\rho\sigma^2. \end{aligned}$$

Note that, in equilibrium, the manager must be indifferent between adopting the green project or not. This implies the threshold β_{ND} is pinned down by: $P_g = P_b$, or equivalently,

$$\mathbb{E}[\beta|\beta > \beta_{ND}] \geq \tfrac{\gamma}{m\rho\sigma} \equiv \beta_{FD}.$$

Moreover, since investor beliefs have to satisfy Bayes' rule

The manager adopts the green project iff:

$$\Delta P(\beta) \geq 0 \Leftrightarrow \quad m\mathbb{E}[\beta|\beta > \beta_{ND}]\rho\sigma - \gamma \geq 0 \Leftrightarrow \quad \mathbb{E}[\beta|\beta > \beta_{ND}] \geq \tfrac{\gamma}{m\rho\sigma} \equiv \beta_{FD}$$

A.3 Proof of Corollary 1

For any continuous distribution $\beta \sim F()$ and any $\beta_{FD} < 1$, it holds that $\mathbb{E}[\beta|\beta > \beta_{FD}] > \beta_{FD}$. Note that the tail expectation is a decreasing function: $\mathbb{E}[\beta|\beta > x]$ is decreasing in x. Together, this implies that for $\mathbb{E}[\beta|\beta > \beta_{ND}] = \beta_{FD}$ to hold, it must be that $\beta_{ND} < \beta_{FD}$.

In the case when $\beta_{FD} = 1$, $\beta_{ND} = \beta_{FD} = 1$.

A.4 Proof of Proposition 3

For the equilibrium described in Proposition 1, the welfare is given by:

$$U_i(\beta_j) = qP + \tfrac{1}{2}\tfrac{(\mu+\gamma_j+\rho\beta\sigma\mathbf{1}_{\{i=G\}}-P)^2}{\rho\sigma^2} - \tfrac{\rho}{2}\mathbf{1}^2_{\{i=G\}}$$

Then,

$$\begin{aligned}
U_B(\beta_j) &= qP(\beta_j) + \tfrac{1}{2}\tfrac{(-\rho\beta_j\sigma m+q\rho\sigma^2)^2}{\rho\sigma^2} = qP(\beta_j) + \tfrac{1}{2}\rho(-\beta_j m + q\sigma)^2 \\
U_G(\beta_j) &= qP(\beta_j) + \tfrac{1}{2}\tfrac{((1-m)\,\beta_j\rho\sigma+q\rho\sigma^2)^2}{\rho\sigma^2} - \tfrac{\rho}{2} = qP(\beta_j) + \tfrac{1}{2}\rho((1-m)\beta_j + q\sigma)^2 - \tfrac{\rho}{2} \\
U(\beta_j) &= qP(\beta_j) + \tfrac{1}{2}\rho\left(m(1-m)\beta_j^2 + q^2\sigma^2\right) - \tfrac{\rho}{2}m
\end{aligned}$$

Then, the welfare-maximizing threshold is defined as the solution to this equation:

$$q\left(-\gamma + \rho\beta\sigma m\right) + \tfrac{1}{2}\rho m(1-m)\beta^2 = 0$$

the only economically relevant root is $\beta_W = \frac{\gamma}{\sqrt{\left(\frac{1}{2}\rho\sigma m\right)^2 + \frac{1}{2q}\rho m(1-m)\gamma} + \frac{1}{2}\rho\sigma m}$

We can find the first-best ex-ante welfare level:

$$EU^*_{FB} = u_0 + \int_{\beta_W}^{1} \Delta u_{FD}(\beta)dF(\beta)$$

Under uniform distribution, it becomes

$$\begin{aligned}
EU^*_{FD} &= u_0 + \int_{\beta_W}^{1}\left(q\,m\rho\sigma\,\left(\beta-\beta_{FD}\right) + \frac{\rho}{2}m(1-m)\beta^2\right)dF(\beta) \\
&= u_0 + \left(q\,m\rho\sigma\,\left(\frac{1}{2}\left(1-\beta_W^2\right) - \beta_{FD}\left(1-\beta_W\right)\right) + \frac{\rho}{2}m(1-m)\frac{1}{3}\left(1-\beta_W^3\right)\right) \\
&= u_0 + m\rho\,\left(q\sigma\,\left(\frac{1}{2}\left(1+\beta_W\right) - \beta_{FD}\right)\left(1-\beta_W\right) + \frac{1}{6}(1-m)\left(1-\beta_W^3\right)\right)
\end{aligned}$$

where

$$\beta_W + \tfrac{1}{2}\frac{1-m}{q\sigma}\beta_W^2 = \beta_{FD}$$

Then,

$$\begin{aligned}
EU^*_{FD} &= u_0 + \frac{1}{2}m\rho\,\left(q\sigma\,\left(\left(1-\beta_W\right) - \frac{1-m}{q\sigma}\beta_W^2\right)\left(1-\beta_W\right) + \frac{1}{3}(1-m)\left(1-\beta_W^3\right)\right) \\
&= u_0 + \frac{1}{2}m\rho\,\left(1-\beta_W\right)^2\left\{q\sigma + \frac{1}{3}(1-m)(1+2\beta_W)\right\}
\end{aligned}$$

A.5 Proof of Proposition 4

For the equilibrium described in Proposition 1, the welfare is given by:

$$U(k) = qP + \tfrac{1}{2}\rho\left(m(1-m)\mathbb{E}[\beta_j|\beta_j > \beta_{ND}]^2 \mathbf{1}_{\{k=1\}} + q^2\sigma^2\right) - \tfrac{\rho}{2}m$$

Thus, we can compute the ex-ante welfare taking the firm's choice as given:

$$EU_{ND} = q(\mu+\gamma) + \tfrac{\rho}{2}(1-F(\beta_{ND}))m(1-m)\mathbb{E}[\beta_j|\beta_j > \beta_{ND}]^2 - \tfrac{\rho}{2}\left(m + q^2\sigma^2\right)$$

A.6 Statement and Proof of Lemma 1

We establish the following lemma, which will be helpful in the following results.

Lemma 1. *If $q \to 0$ and holding other parameters fixed, (i) if $(\beta_{FD} - \beta_{ND})\, h(\beta_{ND}) > 2\ln\left(\frac{1}{\beta_{FD}}\right)$, where $h(x) = \frac{f(x)}{1-F(x)}$ is the hazard function (i.e., $f(\beta)$ has a light right-tail), then $\Delta < 0$; (ii) if $\mathbb{E}[\beta|\beta > x] > 2x$ for $x \in [\beta_{ND}, \beta_{FD}]$ (i.e., $f(\beta)$ has a heavy right tail), then $\Delta > 0$.*

Proof. Note that when $q \to 0$,

$$\begin{aligned}\Delta = \Delta_1 - \Delta_2 = (1-F(\beta_{FD}))\mathbb{E}[\beta^2|\beta > \beta_{FD}] - (1-F(\beta_{ND}))\mathbb{E}[\beta|\beta > \beta_{ND}]^2 > \\ (1-F(\beta_{FD}))\mathbb{E}[\beta|\beta > \beta_{FD}]^2 - (1-F(\beta_{ND}))\mathbb{E}[\beta|\beta > \beta_{ND}]^2\end{aligned}$$

Denote $S(x) := (1-F(x))\mathbb{E}[\beta|\beta > x]^2 = \frac{1}{1-F(x)}\left(\int_x^1 \beta dF(\beta)\right)^2$. Then, note that

$$\begin{aligned}S'(x) &= \tfrac{f(x)}{(1-F(x))^2}\left(\int_x^1 \beta dF(\beta)\right)^2 - \tfrac{2}{1-F(x)}\int_x^1 \beta dF(\beta)\,(-xf(x)) \\ &= \tfrac{f(x)}{1-F(x)}\int_x^1 \beta dF(\beta)\,(\mathbb{E}[\beta|\beta > x] - 2x)\end{aligned}$$

Thus, the sign of $S'(x)$ is the same as the sign of $(\mathbb{E}[\beta|\beta > x] - 2x)$. $\mathbb{E}[\beta|\beta > x] > 2x$ implies that β has a heavy right tail. When this holds for $x \in (\beta_{ND},\ \beta_{FD})$, $S(\beta_{FD}) - S(\beta_{ND}) > 0 \Rightarrow \Delta > 0$.

To get a sufficient condition for $\Delta < 0$, we can consider the following upper bound

$$\Delta < (1-F(\beta_{FD})) - (1-F(\beta_{ND}))\beta_{FD}^2.$$

This upper bound turns negative when

$$\frac{1 - F(\beta_{FD})}{1 - F(\beta_{ND})} < \beta_{FD}^2$$

Holding fixed γ, m, ρ and σ, we can now analyze for what distributions of β the above inequality should hold. Denote $G(x) \equiv -\ln(1 - F(x))$ the anti-derivative of the hazard function $h(x) = \frac{f(x)}{1-F(x)}$. Then the condition above could transform into:

$$e^{G(\beta_{ND}) - G(\beta_{FD})} < e^{\ln(\beta_{FD}^2)} \Leftrightarrow \quad G(\beta_{FD}) - G(\beta_{ND}) > 2\ln\left(\frac{1}{\beta_{FD}}\right)$$

The latter inequality implies $\int_{\beta_{ND}}^{\beta_{FD}} h(\beta)d\beta > 2\ln\left(\frac{1}{\beta_{FD}}\right)$ which is guaranteed to hold when

$$(\beta_{FD} - \beta_{ND}) \times h(\beta_{ND}) > 2\ln\left(\frac{1}{\beta_{FD}}\right)$$

Thus, all else equal, the hazard function should be large enough, which is equivalent to a lighter right tail of distribution. □

A.7 Proof of Proposition 5

(1) First, recall that the welfare difference is given by

$$\begin{aligned}
\Delta = & \begin{array}{c} q\,(1 - F(\beta_{FD}))\big\{m\rho\sigma\mathbb{E}[\beta|\beta > \beta_{FD}] - \gamma\big\} \\ +\frac{\rho}{2}m(1-m)\big\{(1 - F(\beta_{FD}))\mathbb{E}[\beta^2|\beta > \beta_{FD}] - (1 - F(\beta_{ND}))\mathbb{E}[\beta|\beta > \beta_{ND}]^2\big\} \end{array} > 0 \\
\Leftrightarrow q > & \frac{\rho}{2}m(1-m)\frac{(1 - F(\beta_{FD}))\mathbb{E}[\beta^2|\beta > \beta_{FD}] - (1 - F(\beta_{ND}))\mathbb{E}[\beta|\beta > \beta_{ND}]^2}{(1 - F(\beta_{FD}))\big\{m\rho\sigma\mathbb{E}[\beta|\beta > \beta_{FD}] - \gamma\big\}}
\end{aligned}$$

But notice that the numerator can be negative under some parameters/ distributional assumptions, which implies that the above inequality holds for every $q \geq 0$. In particular, it holds when the distribution of β has a fat right tail by Lemma 1.

Second, notice that as $m \to 1$, the right-hand side goes to 0, which implies that the welfare difference Δ is positive for any $q > 0$.

(2) Consider the case when $\beta_{FD} = \frac{\gamma}{m\rho\sigma} \to 1$

Notice that as $\beta_{FD} \to 1$, it follows that $\beta_{ND} \to 1$. Thus, we can use a Taylor approximation of the conditional expectation $\mathbb{E}[\beta|\beta > x] \equiv g(x)$.

Note that $g(x) \to 1$ as $x \to 1^-$. At the same time, we can show $g'(x) = \frac{f(x)}{1-F(x)}\,(g(x) - x)$

and which has the following limit as $x \to 1^-$:

$$\lim_{x\to 1^-} g'(x) = f(x)\tfrac{0}{0} = f(1)\frac{\lim_{x\to 1^-}\{g'(x)-1\}}{\lim_{x\to 1^-}\{-f(x)\}} = 1 - \lim_{x\to 1^-} g'(x) \quad \Rightarrow \quad \lim_{x\to 1^-} g'(x) = \frac{1}{2}$$

Then, we can use the following approximation around $x = 1$:

$$g(x) = 1 + \tfrac{1}{2}(x-1) + o(x)$$

Thus, $\mathbb{E}[\beta|\beta > \beta_{ND}] \approx \frac{1+\beta_{ND}}{2}$ as $\beta_{ND} \to 1^-$. Then, $\beta_{ND} = 2\beta_{FD} - 1$ as $\beta_{FD} \to 1^-$. If we rearrange this, we can notice that β_{FD} converges to 1 faster than β_{ND}:

$$\frac{\beta_{FD}-1}{\beta_{ND}-1} = \frac{1}{2}$$

Next, we can notice that $\Delta_1 \to 0$ as $\beta_{FD} \to 1^-$, so we can ignore that term and focus on Δ_2. We can approximate Δ_2 using a first-order Taylor approximation. Using the same notation as in our proof of Lemma 1, we can decompose:

$$\Delta_2 = S(\beta_{FD}) - S(\beta_{ND})$$

Then, notice that $S(1) = 0$ and $\lim_{x\to 1^-} S'(x) = f(1) \times (1-2) = -f(1) \leq 0$. Thus,

$$\Delta_2 \approx f(1)(1-\beta_{FD}) - f(1)(1-\beta_{ND}) = -f(1)\,(1-\beta_{FD}) < 0$$

To show that this term dominates Δ_1 in the limit, let's also decompose Δ_1 using a first-order Taylor expansion at 1. First, recall that

$$\begin{aligned}\Delta_1 =& (1-F(\beta_{FD}))\Big(q\,m\rho\sigma\big\{\mathbb{E}[\beta|\beta > \beta_{FD}] - \beta_{FD}\big\} \\ &+ \frac{\rho}{2}m(1-m)\big\{\mathbb{E}[\beta^2|\beta > \beta_{FD}] - \mathbb{E}[\beta|\beta > \beta_{FD}]^2\big\}\Big)\end{aligned}$$

Notice that

1. $(1-F(\beta_{FD}))\mathbb{E}[\beta|\beta > \beta_{FD}] \approx 0 - f(1)\,(\beta_{FD}-1) + o\,(\beta_{FD})$
2. $(1-F(\beta_{FD}))\beta_{FD} \approx 0 - f(1)\,(\beta_{FD}-1) + o\,(\beta_{FD})$
3. $(1-F(\beta_{FD}))\mathbb{E}[\beta^2|\beta > \beta_{FD}] \approx 0 - f(1)\,(\beta_{FD}-1) + o\,(\beta_{FD})$

which leads to the following first-order Taylor approximation: $\Delta_1 \approx o(\beta_{FD})$, from which we can conclude that Δ_2 dominates Δ_1 as $\beta \to \beta_{FD}$, since $\Delta_2 \approx -\frac{\rho}{2}m(1-m) \times f(1)(1-\beta_{FD}) + o\,(\beta_{FD})$

A.8 Proof of Proposition 6

The welfare difference is given by:

$$\Delta = (1-\beta_{FD})\left(q\Big\{m\rho\sigma\frac{1+\beta_{FD}}{2}-\gamma\Big\}+\tfrac{\rho}{2}m(1-m)\frac{1+\beta_{FD}-5\beta_{FD}^2}{3}\right)$$

Note that

$$\Delta < 0 \Leftrightarrow \quad qm\rho\sigma\frac{1-\beta_{FD}}{2}+\tfrac{\rho}{2}m(1-m)\frac{1+\beta_{FD}-5\beta_{FD}^2}{3}<0$$

Hence, there exists $\beta^* = \frac{1-k+\sqrt{k^2+18k+21}}{10}$, where $k=\frac{3q\sigma}{1-m}$, such that $\Delta<0$ holds only for $\beta_{FD}\in[\beta^*,1]$. Equivalently, $\Delta<0 \Leftrightarrow \quad \gamma > m\rho\sigma\beta^*$.

A.9 Proof of Proposition 7

We conjecture, and then verify, that firms with high exposure, $\beta > \bar{\beta}_{CD}$, are willing to pay cost c to disclose their type and be priced at $P_g(\beta) = \mu - c + m\beta\rho\sigma - \rho\sigma^2 q$. Additionally, firms with intermediate exposure, $\beta \in [\underline{\beta}_{CD}, \bar{\beta}_{CD}]$, adopt the green project without disclosing their exposure, which leads to the price of $\bar{P}_g = \mu + m\mathbb{E}\big[\beta\big|\beta\in[\underline{\beta}_{CD},\bar{\beta}_{CD}]\big]\rho\sigma - \rho\sigma^2 q$. The remaining firms adopt the brown project and are priced at $P_b = \mu+\gamma-\rho\sigma^2 q$.

The threshold type $\bar{\beta}_{CD}$ is indifferent between paying the cost c to disclose its exposure or not:

$$P_g(\bar{\beta}_{CD}) = \bar{P}_g$$

At the same time, the lower threshold is determined by the following indifference condition:

$$\bar{P}_g = P_b$$

Then,

$$\mathbb{E}\big[\beta\big|\,\beta\in[\underline{\beta}_{CD},\bar{\beta}_{CD}]\big] = \tfrac{\gamma}{m\rho\sigma} = \bar{\beta}_{CD} - \tfrac{c}{m\rho\sigma}$$

Note that for $\beta > \bar{\beta}_{CD}$, the welfare is given by

$$U_i(\beta_j) = qP_g(\beta_j) + \tfrac{1}{2}\rho\left(m(1-m)\beta_j^2 + q^2\sigma^2\right) - \tfrac{\rho}{2}m$$

For $\beta\in\big[\underline{\beta}_{CD},\bar{\beta}_{CD}\big]$, the welfare is

$$U_i(\beta_j) = qP_b + \tfrac{1}{2}\rho\left(m(1-m)\mathbb{E}\big[\beta\big|\,\beta\in[\underline{\beta}_{CD},\bar{\beta}_{CD}]\big]^2 + q^2\sigma^2\right) - \tfrac{\rho}{2}m.$$

A.10 Proof of Proposition 8

Recall that

$$\bar{u}_{CD}(\beta) = W_0 + q\,P_g(\beta) - \frac{\rho}{2}m + \frac{\rho}{2}\left(q^2\sigma^2 + m(1-m)\beta^2\right)$$

and

$$\underline{u}_{CD} = W_0 + qP_b - \frac{\rho}{2}m + \frac{\rho}{2}\left(q^2\sigma^2 + m(1-m)\mathbb{E}\big[\beta\big|\,\beta \in [\underline{\beta}_{CD}, \bar{\beta}_{CD}]\big]^2 \mathbf{1}_{\{\beta \geq \underline{\beta}_{CD}\}}\right)$$

while the aggregated welfare is given by $u_{CD}(\beta) = \bar{u}_{CD}(\beta) \times \mathbf{1}_{\{\beta > \bar{\beta}_{CD}\}} + \underline{u}_{CD} \times \mathbf{1}_{\{\beta \in [\underline{\beta}_{CD}, \bar{\beta}_{CD}]\}}$

To estimate ex-ante investor welfare, we integrate over all values of β:

$$EU_{CD} = \int_0^1 u_{CD}(\beta) dF(\beta)$$

which gives us the expression.

A.11 Proof of Proposition 9

Recall that when β is uniformly distributed, welfare is equal to:

$$\begin{aligned} EU_{CD} = W_0 + q(\mu+\gamma) - \frac{\rho}{2}\left(q^2\sigma^2 + m\right) + \frac{1}{2}qm\rho\sigma\left(1 - \bar{\beta}_{CD}\right)^2 \\ + \frac{\rho}{2}m(1-m)\left(\left(\bar{\beta}_{CD} - \underline{\beta}_{CD}\right)\left(\frac{\gamma}{m\rho\sigma}\right)^2 + \frac{1}{3}\left(1 - \bar{\beta}_{CD}^3\right)\right) \end{aligned}$$

Then, for $c \in [0, m\rho\sigma - \gamma]$

$$(EU_{CD})'_c = -q\left(1 - \bar{\beta}_{CD}\right) + \frac{\rho}{2}m(1-m)\left(2\left(\frac{\gamma}{m\rho\sigma}\right)^2 - \bar{\beta}_{CD}^2\right)\frac{1}{m\rho\sigma}$$

At $c = 0$,

$$\begin{aligned} (EU_{CD})_c\Big|_{c=0} = -q\left(1 - \frac{\gamma}{m\rho\sigma}\right) + \frac{\rho}{2}m(1-m)\left(\frac{\gamma}{m\rho\sigma}\right)^2\frac{1}{m\rho\sigma} > 0 \\ \Leftrightarrow \frac{\rho}{2}m(1-m)\left(\frac{\gamma}{m\rho\sigma}\right)^2\frac{1}{m\rho\sigma - \gamma} > q \end{aligned}$$

When endowment is small, a decrease in prices does not affect welfare too much, while risk-sharing benefits are increasing. This leads to an overall increase in welfare.

At $c = m\rho\sigma - \gamma$,

$$(EU_{CD})_c \Big|_{c=m\rho\sigma-\gamma} = \frac{\rho}{2}m(1-m)\left(2\left(\frac{\gamma}{m\rho\sigma}\right)^2 - 1\right)\frac{1}{m\rho\sigma} < 0$$
$$\Leftrightarrow \beta_{FD} < \frac{\sqrt{2}}{2}$$

In other words, if the level of green adoption is relatively high in the full disclosure case, then by increasing the cost of disclosure to an extreme level, we lose welfare.

When these two conditions hold, we get a single root c^* within the interval $[0,\ m\rho\sigma - \gamma]$, which is given by

$$c^* = K - \gamma + \sqrt{(K-\gamma)^2 + \gamma^2 + 2\,K(-m\rho\sigma + \gamma)} \qquad K = q\,\frac{m\rho\sigma^2}{1-m}$$

or

$$c^* = K - \gamma + \sqrt{K^2 - 2K\,m\rho\sigma + 2\gamma^2}$$

We can also argue that $(EU_{CD})_{cc} < 0$ at $c = c^*$ by construction.

Next, notice that $(EU_{CD})_{cq} < 0$, i.e., the marginal effect of price decrease is exacerbated with higher endowment. Thus, by implicit function theorem, $c_q^* < 0$.

Similarly, $(EU_{CD})_{c\rho} < 0$, $(EU_{CD})_{c\sigma} < 0$ and $(EU_{CD})_{cm} < 0$, while $(EU_{CD})_{c\gamma} > 0$. Intuitively, m, ρ and σ amplify the risk-sharing benefits and on the other hand, lead to a higher adoption, all of which increases the marginal effect of changes in c. At the same time, higher γ leads to a lower adoption, which results in $c_\gamma^* > 0$

Recall that

$$q < \frac{\rho}{2}m(1-m)\left(\frac{\gamma}{m\rho\sigma}\right)^2\frac{1}{m\rho\sigma - \gamma}$$
$$\Rightarrow K < \frac{1}{2}(m\rho\sigma)^2\frac{\gamma^2}{(m\rho\sigma)^2}\frac{1}{m\rho\sigma-\gamma} = \frac{\frac{1}{2}\gamma^2}{m\rho\sigma - \gamma} < \frac{\frac{1}{4}}{1-\frac{1}{\sqrt{2}}}m\rho\sigma < m\rho\sigma$$

Comparative Statics:

$$c_\gamma^* = -1 + \frac{2\gamma}{\sqrt{K^2 - 2K\,m\rho\sigma + 2\gamma^2}} > 0 \quad \Leftrightarrow 2\gamma^2 > K(K - 2m\rho\sigma)$$

which holds under the constraints: $K < m\rho\sigma$ which makes the RHS negative.

Similarly,

$$c_K^* = 1 + \frac{K - m\rho\sigma}{\sqrt{K^2 - 2K\,m\rho\sigma + 2\gamma^2}} < 0 \Rightarrow c_q^* < 0$$

while

$$c_{\rho}^{*}=c_{K}^{*}\times q\tfrac{m}{1-m}\sigma^{2}-\frac{Km\sigma}{\sqrt{K^{2}-2K\,m\rho\sigma+2\gamma^{2}}}=\frac{K}{\rho}\left(1+\frac{K-2m\rho\sigma}{\sqrt{K^{2}-2K\,m\rho\sigma+2\gamma^{2}}}\right)<0$$

B Extensions

This appendix provides details about the extensions we introduce in Section 7. The relevant proofs are in Appendix B.3.

B.1 Impact of a climate derivative

In this appendix, we provide additional details about the extension we introduce in Section 7.1. We begin by characterizing the equilibria and welfare under full-disclosure and no-disclosure, and then provide sufficient conditions under which either scenario generates higher welfare.

Full disclosure equilibrium. Investors can trade in both the firm and the derivative. We can show that investor i's demand for firm in this case is given by

$$\begin{aligned} q+X_{i}&=\frac{\mu+\gamma\mathbf{1}_{\{k=0\}}+\mathbf{1}_{\{i=G\}}\mathbf{1}_{\{k=1\}}\rho\beta\sigma-P}{\rho\sigma^{2}}-\frac{a\beta\mathbf{1}_{\{k=1\}}}{\sigma}y_{i}\\ y_{i}&=a\mathbf{1}_{\{i=G\}}-\tfrac{P_{D}}{\rho}-a\beta\mathbf{1}_{\{k=1\}}\sigma(q+X_{i})\end{aligned}$$

Note that the instruments are substitutes, since both are used for hedging the climate risk. When one instrument provides a higher exposure or costs less, investors demand more of it, and thus they need less of the other instrument in their portfolio.

The market clearing conditions $\int_{i}X_{i}di=0=\int_{i}y_{i}di$ imply that the prices are given by: imply that, in the full disclosure equilibrium, the prices are given by:

$$P_{FD}(k,\beta)=\mu+\gamma-q\rho\sigma^{2}+(m\rho\beta\sigma-\gamma)\mathbf{1}_{\{k=1\}} \tag{27}$$

$$P_{D}=\rho a\left(m-\sigma\beta q\mathbf{1}_{\{k=1\}}\right) \tag{28}$$

Intuitively, if the firm adopts the green project (i.e., if $k=1$), both the stock and the derivative are substitute hedges for climate risk. The price of each security is increasing in its own correlation with climate risk. Further, because the derivative is in zero net supply, its presence has no effect on the stock price $P(k,\beta)$. In contrast, because the stock is in positive supply, an increase in its supply q (when $k=1$) reduces the hedging value of the derivative for investors, and consequently decreases its price P_{D}.

Since the stock price is unaffected by the presence of the derivative, so is the project choice of the manager. As in Proposition 1, the manager adopts the green project if and only if $\beta > \beta_{FD}$. Following steps analogous to those in Section 5, we can show that interim welfare, conditional on project choice k, can be expressed as

$$u_{FD,D}(k,\beta) = \underbrace{W_0 + q\,P_{FD}(k,\beta)}_{\text{exp. value of endowments}} - \underbrace{\frac{\rho}{2}m}_{\text{climate risk exposure}} + \underbrace{\frac{\rho}{2}\left(q^2\sigma^2 + m(1-m)\mathcal{B}_{FD}(k)\right)}_{\text{risk-sharing benefits}}, \quad (29)$$

where risk-sharing benefits depend on

$$\mathcal{B}_{FD}(k) = \frac{(1-2a^2)\beta^2\mathbf{1}_{\{k=1\}} + a^2}{1 - a^2\beta^2\mathbf{1}_{\{k=1\}}}.$$

This expression captures the fact that investors derive risk-sharing benefits from trading in the climate derivative as well as the stock.[18] To gain some intuition, note that when the derivative is perfect (i.e., $a = 1$), $\mathcal{B}_{FD}(k) = 1$. On the other hand, when the derivative is uncorrelated with climate shocks (i.e., $a = 0$), then $\mathcal{B}_{FD}(k) = \beta^2\mathbf{1}_{\{k=1\}}$ — this corresponds to the benchmark without a derivative. Moreover, holding fixed β and k, hedging benefits from the derivative increase with its correlation with climate risk i.e., $\mathcal{B}_{FD}(k)$ is increasing in a.

Importantly, when the derivative is imperfect (i.e. $0 < a < 1$), the risk-sharing benefits higher than without the derivative (i.e., $\mathcal{B}_{FD}(k) > \beta^2\mathbf{1}_{\{k\}}$) and are increasing in the firm's exposure (i.e., $\mathcal{B}_{FD}(k)$ is increasing in β). In other words, as long as the derivative is imperfect, the key friction from our benchmark analysis still arises: the firm's project choice affects the risk-sharing benefit for investors, even though this is not internalized by the manager maximizing the stock price.

As before, we can compute the ex-ante aggregate welfare by averaging over possible β's, as summarized by the following result.

Proposition 10. *In the full disclosure equilibrium, ex-ante investor welfare is given by:*

$$EU_{FDD} = \int_0^1 u_{FDD}(\mathbf{1}_{\{\beta \geq \beta_{FD}\}}, \beta)dF(\beta)$$

[18] In expression (14), $\mathcal{B}_{FD}(k)$ is replaced by $\beta^2\mathbf{1}_{\{k=1\}}$.

$$= \begin{array}{c} \underbrace{W_0 + q(\mu+\gamma) - \frac{\rho}{2}\left(q^2\sigma^2 + m\right)}_{\textit{baseline welfare}} \\ +(1-F(\beta_{FD})) \left(\begin{array}{c} \underbrace{q \times (m\rho\sigma\mathbb{E}[\beta|\beta \geq \beta_{FD}] - \gamma)}_{\textit{price increase with disclosure}} \\ + \quad \underbrace{\frac{\rho}{2} m(1-m)\mathbb{E}\left[\frac{\beta^2 - 2a^2\beta^2 + a^2}{1-a^2\beta^2} \middle| \beta \geq \beta_{FD}\right]}_{\textit{risk-sharing benefit from green adoption with disclosure}} \end{array} \right) \end{array}. \tag{30}$$

No disclosure equilibrium. Now consider the case in which, at date 2, investors observe whether or not the firm adopts the green project (i.e., observes k), but do not observe the climate risk factor loading β of the green project. At this date, investors can trade in both the stock and the derivative. Similarly to Section 4.2, we conjecture and verify that a threshold equilibrium where only firms with exposure $\beta \geq \beta_{ND}$ adopt the green project is the only Bayesian Nash Equilibrium in pure strategies.

Moreover, in the no-disclosure equilibrium, prices can be expressed as:

$$P_{ND}(k) = \mu + \gamma - q\rho\sigma^2 + (m\rho\mathbb{E}[\beta|\beta > \beta_{ND}]\sigma - \gamma)\mathbf{1}_{\{k=1\}} \tag{31}$$

$$P_D = \rho a\left(m - \sigma\mathbb{E}[\beta|\beta > \beta_{ND}]q\right) \tag{32}$$

Again, the price of the stock remains unaffected by the presence of derivative and so β_{ND} is given by the characterization in Proposition 2. Moreover, the total interim welfare, conditional on k, can be expressed as:

$$u_{ND,D}(k) = \underbrace{W_0 + q\,P_{ND}(k,\beta)}_{\text{exp. value of endowments}} - \underbrace{\frac{\rho}{2}m}_{\text{climate risk exposure}} + \underbrace{\frac{\rho}{2}\left(q^2\sigma^2 + m(1-m)\mathcal{B}_{ND}(k)\right)}_{\text{risk-sharing benefits}}, \tag{33}$$

where risk-sharing benefits depend on

$$\mathcal{B}_{ND}(k) \equiv \frac{\mathbb{E}[\beta|\beta > \beta_{ND}]^2 - 2a^2\mathbb{E}[\beta|\beta > \beta_{ND}]^2 + a^2}{1 - a^2E[\beta|\beta > \beta_{ND}]^2}\mathbf{1}_{\{k=1\}}.$$

As with full disclosure, if the derivative offers a perfect hedge (i.e., $a = 1$), then $\mathcal{B}_{ND}(k) = 1$ — the risk-sharing benefits are independent of the firm's adoption decision, since investors use the derivative to share climate risk perfectly.

However, when $a < 1$ so that the derivative offers imperfect risk-sharing, adoption of the green project facilitates better risk-sharing across investors, as in the benchmark without the derivative. Moreover, since more types adopt the green project under no-disclosure (recall $\beta_{ND} < \beta_{FD}$), the trade-off that drives welfare in Section 5 still obtains in the presence of a derivative, as long as $a < 1$.

As in Section 5, we can compute the ex-ante welfare under the full disclosure and no-disclosure equilibria by averaging $u_{FD,D}$ and $u_{ND,D}$ over possible β's. The following result characterizes the ex-ante welfare of investors for an arbitrary a under no disclosure

Proposition 11. *In the no disclosure equilibrium, ex-ante investor welfare is given by:*

$$EU_{NDD} = \int_0^1 u_{NDD}(\mathbf{1}_{\{\beta \geq \beta_{ND}\}}, \beta) dF(\beta)$$
$$= \begin{array}{c} \underbrace{W_0 + q(\mu+\gamma) - \frac{\rho}{2}\left(q^2\sigma^2 + m\right)}_{\textit{baseline welfare}} \\ + \underbrace{(1-F(\beta_{ND}))\left(\frac{\rho}{2} m(1-m)\frac{\mathbb{E}[\beta|\beta>\beta_{ND}]^2 - 2a^2\mathbb{E}[\beta|\beta>\beta_{ND}]^2 + a^2}{1-a^2E[\beta|\beta>\beta_{ND}]^2}\right)}_{\textit{risk-sharing benefit without disclosure}} \end{array}. \tag{34}$$

Given the above results, the following result characterizes how the ranking of ex-ante welfare is affected by the presence of a derivative.

Proposition 12. *Suppose the firm's climate risk exposure is distributed as $\beta \sim U[0,1]$ and investors have access to a derivative with correlation a.*
(1) All else equal, welfare is higher under full-disclosure if a is sufficiently large.
(2) All else equal, welfare is higher under no-disclosure if and only if γ is sufficiently large (as characterized by Proposition 6) and a is sufficiently small.

B.2 Abatement

Assume that the brown project's payoff decreases with ω, and firms can adopt a green project to hedge this exposure (e.g. via abatement technology). Formally,

$$V(k=0) = \mu + \gamma - \sigma\left(\beta\omega + \sqrt{1-\beta^2}\,\eta\right) \equiv V_b(\beta), \tag{35}$$

$$V(k=1) = \mu - \sigma\eta \equiv V_g \tag{36}$$

Suppose that the green project can fully hedge against the impact of climate risk but leads to a reduction in cash-flows by γ (e.g. it is costly to shift from the status quo). Notice that $\mathbb{V}(V_b) = \mathbb{V}(V_g(\beta)) = \sigma^2$, i.e., the aggregate risk of each project is the same, but its composition changes. In particular, the green project is not exposed to climate risk, while brown projects have varying exposure: $\beta \in [0,\, 1]$.

Under full disclosure, analogous calculations to those in our main analysis imply that:

$$q + X_i = \frac{\mu + \gamma \mathbf{1}_{\{k=0\}} - P_j - \rho\beta\sigma\, \mathbf{1}_{\{k=0\}}\mathbf{1}_{\{i=G\}}}{\rho\sigma^2}$$

And the market clearing condition $\int X_i di = 0$ implies:

$$P(k, \beta) = \mu - q\rho\sigma^2 - (m\rho\sigma\,\beta - \gamma)\mathbf{1}_{\{k=0\}}.$$

Notice that firms adopt the green project if and only if $\Delta P(\beta) = m\rho\sigma\beta - \gamma \geq 0 \Leftrightarrow \beta \geq \beta_{FD}$, as before. However, the interpretation changes: firms with higher exposure to negative climate outcomes adopt project G to avoid a large price discount.

Under *no disclosure*, the adoption of green projects is *lower*. Now, investors interpret the decision not to adopt as a positive signal: firms that prefer the brown project must have a low exposure β. Moreover, using the same arguments as before, we can show that there exists a unique threshold equilibrium where investors believe that types $\beta < \beta_{ND}$ choose the brown project, and this is consistent with managers' equilibrium strategies. In this equilibrium, $\gamma - m\rho\sigma\mathbb{E}[\beta|\beta < \beta_{ND}] = 0$, and thus $\beta_{ND} \geq \beta_{FD}$.

For the equilibrium described above, under full disclosure, the welfare is given by:

$$U_i(\beta, k) = qP(k, \beta) + \tfrac{1}{2}\tfrac{(\mu+\gamma\mathbf{1}_{\{k=0\}} - \rho\beta\sigma k=0\mathbf{1}_{\{i=G\}} - P(k,\beta))^2}{\rho\sigma^2} - \tfrac{\rho}{2}\mathbf{1}^2_{\{i=G\}}$$

This implies:

$$\begin{aligned}
U_B(\beta,\, k) &= qP(k, \beta) + \tfrac{1}{2}\rho\left(\beta m\mathbf{1}_{\{k=0\}} + q\sigma\right)^2 \\
U_G(\beta,\, k) &= qP(k, \beta) + \tfrac{1}{2}\rho((m-1)\beta\mathbf{1}_{\{k=0\}} + q\sigma)^2 - \tfrac{\rho}{2} \\
U(\beta,\, k) &= qP(k, \beta) + \tfrac{1}{2}\rho\left(m(1-m)\beta^2\mathbf{1}_{\{k=0\}} + q^2\sigma^2\right) - \tfrac{\rho}{2}m
\end{aligned}$$

We can find the welfare gain from green adoption:

$$\Delta u(\beta) = U(\beta, 1) - U(\beta, 0) = q\Delta P(\beta) - \frac{1}{2}\rho m(1-m)\beta^2$$

Notice that the green adoption decreases risk-sharing benefits, and therefore firms *over-invest* relative to the welfare optimum. However, under no disclosure, as we have shown above, fewer firms adopt the green project, which restores some of the lost risk-sharing benefits. This could be summarized in the following proposition:

Proposition 13. *(a) Under full disclosure (when investors can observe β when the firm adopts a green project), there exists a unique equilibrium and is such that (i) the firm adopts* *the green project if and only $\beta \geq \beta_{FD}$ (same as in Proposition 1), and (ii) the equilibrium price is given by*

$$P(\beta, k) = \begin{cases} \mu + \gamma - m\beta\rho\sigma - \rho\sigma^2 q & \text{if } k = 0 \\ \mu - \rho\sigma^2 q & \text{if } k = 1 \end{cases},$$

(b) Under no disclosure (when investors can only observe the adoption decision), there exists a unique threshold equilibrium and is such that (i) the firm adopts the green project if and only $\beta \geq \bar{\beta}_{ND}$, and (ii) the equilibrium price is given by

$$P = \mu - \rho\sigma^2 q,$$

irrespective of whether the firm adopts the green project, where the adoption threshold is implicitly defined as the solution to

$$\mathbb{E}[\beta|\beta \leq \bar{\beta}_{ND}] = \frac{\gamma}{m\rho\sigma}.$$

if $\mathbb{E}[\beta] > \frac{\gamma}{m\rho\sigma}$, and $\bar{\beta}_{ND} = 1$ otherwise. The threshold $\bar{\beta}_{ND}$ is (weakly) increasing in γ but (weakly) decreasing in m, ρ and σ^2.
*(c) The full disclosure equilibrium is characterized by **over-investment** in the green project. Under no disclosure, **fewer** firms adopt the green project, i.e., $\bar{\beta}_{ND} > \beta_{FD}$.*

As before, we can interpret the last result as an unintended benefit of greenwashing. Under no disclosure, firms with relatively *high* exposure to negative climate shock can pool with firms with lower exposure in the brown project. In other words, firms take advantage of the uncertainty about exposure to pretend that they have a lower exposure β than they actually do. Since the adoption of the green project is costly (results in the loss of γ), fewer firms adopt the green project under no disclosure.

Investors can *benefit* from lower adoption of the green project. Intuitively, brown projects have an exposure to climate risk and therefore allow investors to share risk via adjusting their positions. However, these risk-sharing benefits are not factored in by the manager who maximizes the stock price.

In what follows, we further assume that the distribution of climate exposure β is given by $\beta \sim U[0, 1]$. This allows us to compare the welfare level under each information regime.

Proposition 14. *Suppose the firm's climate risk exposure is distributed as $\beta \sim U[0,1]$ and investors have access to a derivative with correlation a. Then, ex-ante investor welfare is* *higher under no disclosure than under full disclosure (i.e., $EU_{ND} > EU_{FD}$) if and only if*

$$\frac{1}{2}q\gamma < \frac{5}{6}\rho m(1-m)\beta_{FD}^2.$$

B.3 Proofs of Extensions

B.3.1 Proof of Proposition 10

Each trader maximizes

$$U_i(\beta_j) = \mathbb{E}[W_i] - \tfrac{\rho}{2}\mathbb{V}(W_i)$$

With a stake in firm j equal to $q + X_{i,j}$ and the derivative stake being y_i, the welfare is

$$W_i = W_0 + qP_j + (q + X_{i,j})(V_j - P_j) + y_i(D - P_D) - \mathbf{1}_{\{i=G\}}\omega.$$

$$\mathbb{E}[W_i] = W_0 + qP_j + (q + X_{i,j})\left(\mu + \gamma_j - P_j\right) + y_i(-P_D)$$

$$\mathbb{V}(W_i) = (q + X_{i,j})^2\sigma^2 + \lambda_i^2 + y_i^2 - 2\,\lambda_i\,\beta_j\,\sigma(q + X_{i,j}) - 2\,a\,\lambda_i\,y_i + 2\,a\,\beta_j\,\sigma(q + X_{i,j})y_i$$

$$z \;=\; \begin{bmatrix} q + X_{i,j} \\ y_i \end{bmatrix}, \qquad c \;=\; \begin{bmatrix} \mu + \gamma_j - P_j \\ -P_D \end{bmatrix}, \qquad h \;=\; \lambda_i \begin{bmatrix} \beta_j\,\sigma \\ a \end{bmatrix}, \qquad H \;=\; \begin{bmatrix} \sigma^2 & a\beta_j\sigma \\ a\beta_j\sigma & 1 \end{bmatrix}.$$

$$W_0' \;:=\; W_0 + qP_j - \tfrac{\rho}{2}\,\lambda_i^2.$$

$$U_i(z) \;=\; W_0' + (\,c + \rho h)^\top z \;-\; \tfrac{\rho}{2}\,z^\top H\,z.$$

$$\nabla_z U_B = 0 \quad\Longrightarrow\quad \rho\,H\,z^\star = c + \rho h \quad\Longrightarrow\quad z^\star \;=\; \tfrac{1}{\rho}\,H^{-1}\big(c + \rho h\big).$$

$$H^{-1} \;=\; \tfrac{1}{\sigma^2\,\delta}\begin{bmatrix} 1 & -a\beta_j\sigma \\ -a\beta_j\sigma & \sigma^2 \end{bmatrix}, \qquad \delta \;:=\; \big(1 - a^2\beta_j^2\big) > 0.$$

The explicit solution:

$$\begin{aligned} X^{\star}_{i,j} &= \tfrac{\mu+\gamma_j-P_j+\rho\beta_j\,\lambda_i\,\sigma\,(1-a^2)+a\beta_j\sigma P_D}{\rho\,\delta\,\sigma^2} - q, \\ y^{\star}_i &= \tfrac{-a\beta_j\sigma(\mu+\gamma_j-P_j)-\rho\lambda_i\,a\beta_j^2\sigma^2-\sigma^2 P_D+\rho\lambda_i\sigma^2 a}{\rho\,\delta\,\sigma^2} \end{aligned}$$

and the welfare is

$$U_i(z^*) = W_0' + \frac{1}{2\rho}(\,c+\rho h)^{\top} H^{-1}(\,c+\rho h)$$

Market clearing implies:

$$mX_{G,j} + (1-m)X_{B,j} = 0 = m\,y_G + (1-m)\,y_B$$

Thus,

$$\begin{aligned} P_j &= \mu + \gamma_j + \rho\beta_j\,m\sigma(1-a^2) + a\beta_j\sigma P_D - q\rho\sigma^2\left(1-a^2\beta_j^2\right) \\ P_D &= -\frac{a\beta_j}{\sigma}\,(\mu+\gamma_j-P_j) - \rho m\,a\beta_j^2 + \rho m a \end{aligned}$$

which simplifies to $P_D = \rho a\,(m-\beta_j\sigma q)$ and $P_j = \mu+\gamma_j+\rho\,(\beta_j m\sigma - q\sigma^2)$. Then, the equilibrium positions are given by:

$$\begin{aligned} X^{\star}_{i,j} &= \tfrac{(\lambda_i-m)\beta_j m(1-a^2)}{\delta\,\sigma}, \\ y^{\star}_i &= \tfrac{a\beta_j^2\times m(1-a^2)-\lambda_i a\beta_j^2+\lambda_i a}{\delta} - a\beta_j\sigma q - \tfrac{P_D}{\rho} = \tfrac{am\times(\beta_j^2-a^2\beta_j^2)-\lambda_i a\left(\beta_j^2-1\right)}{\delta} - am = \tfrac{a(\lambda_i-m)\left(1-\beta_j^2\right)}{\delta} \end{aligned}$$

The welfare could further be simplified:

$$\begin{aligned} U_i(z^*) = W_0' + \frac{1}{2\rho\,\sigma^2\,\delta}\Big[&\left(\mu+\gamma_j-P_j+\lambda_i\rho\beta_j\sigma\right)^2 - 2a\beta_j\sigma\left(\mu+\gamma_j-P_j+\lambda_i\rho\beta_j\sigma\right)(-P_D+\lambda_i\rho a) \\ &+ \sigma^2\left(-P_D+\lambda_i\rho a\right)^2\Big] \end{aligned}$$

$$\begin{aligned} U_i(z^*) &= W_0' + \frac{1}{2\rho\,\sigma^2\,\delta}\left(\mu+\gamma_j-P_j+\lambda_i\rho\beta_j\sigma - a\beta_j\sigma\left(-P_D+\lambda_i\,\rho\,a\right)\right)^2 + \frac{1}{2\rho}\left(-P_D+\lambda_i\,\rho\,a\right)^2 \\ &= W_0 + qP_j - \frac{\rho}{2}\lambda_i^2 + \frac{\rho}{2\delta}\left(q\sigma\delta + (\lambda_i-m)\,\beta_j\left(1-a^2\right)\right)^2 + \frac{\rho}{2}\left((\lambda_i-m)+q\beta_j\sigma\right)^2 a^2 \\ &= W_0 + qP_j - \frac{\rho}{2}\lambda_i^2 + \frac{\rho}{2}\left(q^2\sigma^2\delta + 2\,q\sigma\,\left(\lambda_i-m\right)\beta_j\left(1-a^2\right) + \frac{1}{\delta}\left(\lambda_i-m\right)^2\beta_j^2\left(1-a^2\right)^2\right) \\ &+ \frac{\rho}{2}\left((\lambda_i-m)^2 + 2(\lambda_i-m)\,q\beta_j\sigma + q^2\beta_j^2\sigma^2\right)a^2 \end{aligned}$$

$$
\begin{aligned}
&= W_0 + qP_j - \frac{\rho}{2}\lambda_i^2 + \frac{\rho}{2}q^2\sigma^2 + \rho q\sigma\,(\lambda_i - m)\,\beta_j\left(1-a^2\right) + \rho(\lambda_i - m)a^2\,q\beta_j\sigma \\
&+ \frac{\rho}{2\delta}\,(\lambda_i - m)^2\,\beta_j^2\left(1-a^2\right)^2 + \frac{\rho}{2\delta}(\lambda_i - m)^2 a^2\left(1 - a^2\beta_j^2\right) \\
&= W_0 + qP_j - \frac{\rho}{2}\lambda_i^2 + \frac{\rho}{2}q^2\sigma^2 + \rho q\sigma\,(\lambda_i - m)\,\beta_j + \frac{\rho}{2\delta}\,(\lambda_i - m)^2\left(\beta_j^2 - 2a^2\beta_j^2 + a^2\right)
\end{aligned}
$$

Then,

$$
U = W_0 + qP_j - \frac{\rho}{2}m + \frac{\rho}{2}q^2\sigma^2 + \frac{\rho}{2\delta}\,(1-m)\,m\left(\beta_j^2 - 2a^2\beta_j^2 + a^2\right)
$$

B.3.2 Proof of Proposition 12

Part (1) of the above result follows from the observation that, in the limit as $a \to 1$, risk-sharing benefits across the two equilibria coincide because they do not depend on the adoption decision of the firm. In this case, welfare is higher under the full-disclosure equilibrium since green firms have higher valuations in this case.

Part (2) follows from the observation that when $a = 0$, the comparison between the two equilibria coincides with that in Proposition 6, the adoption thresholds in either equilibrium do not depend on a, and the risk-sharing benefits are continuous functions of a. This implies that for parameters such that $EU_{ND} > EU_{FD}$ in the absence of a derivative (i.e., when $a = 0$), this should also be true in the presence of a derivative for a sufficiently close to zero.

B.3.3 Proof of Proposition 14

Under full disclosure,

$$
U(\beta, k) = q\left(\mu + (\gamma - m\rho\sigma\beta)\,\mathbf{1}_{\{k=0\}} - \rho\sigma^2 q\right) + \tfrac{1}{2}\rho\left(m(1-m)\beta^2\mathbf{1}_{\{k=0\}} + q^2\sigma^2\right) - \tfrac{\rho}{2}m
$$

Ex-ante welfare, before observing the adoption decision, could be estimated by aggregating over all the firm types:

$$
EU_{FD} = q\mu - \frac{\rho}{2}\left(q^2\sigma^2 + m\right) + \int_0^{\beta_{FD}} \left(q\left(\gamma - m\rho\sigma\beta\right) + \frac{\rho}{2}m(1-m)\beta^2\right) dF(\beta)
$$

Denote $u_0 \equiv q\mu - \frac{\rho}{2}\left(q^2\sigma^2 + m\right)$ the baseline level of utility.

Under uniform distribution, i.e., $\beta \sim U([0,1])$, this becomes:

$$
\begin{aligned}
EU_{FD} &= u_0 + \left(q\left(\gamma\beta_{FD} - \frac{1}{2}m\rho\sigma\beta_{FD}^2\right) + \frac{\rho}{2}m(1-m)\frac{1}{3}\beta_{FD}^3\right) \\
&= u_0 + \frac{1}{2}\left(q\gamma + \rho m(1-m)\frac{1}{3}\beta_{FD}^2\right)\beta_{FD}
\end{aligned}
$$

Under no disclosure, the welfare is given by:

$$U(k) = q\left(\mu - \rho\sigma^2 q\right) + \tfrac{1}{2}\rho\left(m(1-m)\mathbb{E}[\beta|\beta < \beta_{ND}]^2\mathbf{1}_{\{k=0\}} + q^2\sigma^2\right) - \tfrac{\rho}{2}m$$

Ex-ante welfare, before observing the adoption decision, could be estimated by aggregating over all the firm types:

$$EU_{ND} = u_0 + \frac{\rho}{2}m(1-m)\mathbb{E}[\beta|\beta < \beta_{ND}]^2\beta_{ND}$$

where β_{ND} is given by $\mathbb{E}[\beta|\beta < \beta_{ND}] = \frac{\beta_{ND}}{2} = \frac{\gamma}{m\rho\sigma} \Leftrightarrow \ \beta_{ND} = 2\beta_{FD}$

Then, no disclosure welfare dominates full disclosure iff:

$$EU_{ND} > EU_{FD} \Leftrightarrow \ \frac{\rho}{2}m(1-m)\beta_{FD}^2\ \beta_{ND} > \frac{1}{2}\left(q\gamma + \rho m(1-m)\frac{1}{3}\beta_{FD}^2\right)\beta_{FD}$$
$$\Leftrightarrow \frac{5}{6}\rho m(1-m)\beta_{FD}^2 > \frac{1}{2}q\gamma \Leftrightarrow \quad \gamma > \frac{3}{5}\frac{m}{1-m}q\rho\sigma^2$$