ESG Disclosure, Market Forces, and Investment Efficiency

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Abstract

This paper examines the role of Environmental, Social, and Governance (ESG) disclosure in changing firm investment when investors value both financial and ESG implications of the investment. We identify conditions under which ESG disclosure is needed for channeling investors' tastes for ESG into firm investment. We also characterize the optimal precision of ESG disclosure that sustains efficient investment. While it is tempting to think that more precise ESG disclosure is desirable when investors care more about ESG, we show the intuition is incomplete because it overlooks the fact that stronger tastes for ESG change how investors use information. Analyzing interactions between ESG disclosure and the price effect of tastes sheds light on the demand for and the design of ESG disclosure.

Keywords: ESG Disclosure; Tastes; Investment; Real effects of disclosure.

JEL Classifications: D82; G14; M41

1 Introduction

Environmental, Social, and Governance (ESG) issues are related to discussions on corporate social responsibility (CSR), which has long received attention in economics. In 1970, Milton Friedman published his famous essay "The social responsibility of business is to increase its profits." It has been recognized that Friedman's view is consistent with the social goals stated in the 2019 Business Roundtable Report, such as "delivering value to our customers" or "investing in our employees", to the extent that these goals generate long-term value for shareholders. Subsequent studies have also identified situations where CSR goes beyond maximizing profits, be it short-term or long-term. One situation is where a firm's actions impose negative consequences to society (e.g., pollutions or health hazards), in which case it is more efficient to restrain firms from certain actions than to have shareholders undo the negative consequences (e.g., Bénabou and Tirole, 2010).

Many ESG issues share the feature discussed above. On the environmental side of ESG, it is more efficient for companies to reduce pollution in the first place than have someone clean it up afterwards. On the social side of ESG, it is more desirable for pharmaceutical companies to avoid over-marketing addictive drugs than have the society deal with the aftermath of an opioid crisis. As shareholders have become increasingly concerned about ESG issues in recent years, it is conceivable that they have some desire for corporations to engage in ESG-friendly activities on their behalf. The question is how to ensure that firms take actions in accordance with shareholders' tastes for ESG issues. One solution is to rely on market forces (to use Fama's terminology). For example, Fama (2020) argues that when investors value environmental issues, "dirty" firms are punished by lower stock price, which incentivizes firms to become "clean" and, hence, be rewarded via higher prices.

The growing interest in ESG issues has also triggered a call for ESG disclosure. Starting October 2022, the European Union requires large companies to publish regular reports on the social and environmental impacts of their activities. The call for ESG disclosures is driven in part by the belief that they help move firm actions towards more sustainable goals. For example, the final report regarding climate-related disclosure submitted to European Commission states that "[climate-related disclosure] will help smooth the transition to a more sustainable, low-carbon and climate-resilient economy."[1] In March 2022, the U.S. Securities and Exchange Commission (SEC) also proposed rule changes that would require registrants to include climate-related disclosures in their periodic reports.[2]

While the focus on disclosure is intuitively appealing, the real effects of ESG disclosure on firm actions, such as investments, are not well-understood and difficult to predict (Christensen et al., 2021). Many important questions are unanswered. For example, when is ESG disclosure needed for the purpose of ensuring the firm makes investment in accordance with shareholders' tastes for ESG issues? Second, how will ESG disclosure affect firm investment efficiency? In particular, will more precise ESG disclosure always change investments for the better, or can it introduce new inefficiency? Third, what is the optimal precision of ESG disclosure policy and how does it change with respect to its determinants? These questions are the subject of this paper.

In the model, the firm chooses an investment that affects its profits and ESG performance. Firm profits are maximized when the marginal return of investment equals its marginal cost. To capture the negative consequence that firm actions impose on ESG, higher investments are assumed to generate, on average, higher emissions. (An alternative example is that spending more on promoting addictive drugs increases the likelihood of opioid misuse.) Investors care about both financial and ESG implications of the investment, as in Hart and Zingales (2017). To incorporate market forces in Fama's argument above, we assume that the firm chooses the investment to maximize its stock price. Price is formed in a noisy rational expectation equilibrium populated with a continuum of risk-averse investors, as in Diamond and Verrecchia (1981). Investors do not perfectly observe firm investment, and they rely on private and public signals to assess firm profit and ESG performance prior to trading.

We start with analyzing pricing implications of investors' pro-ESG preferences/tastes in a

[1]Sustainable finance teg report climate related disclosures, published in January 2019.
[2]https://www.sec.gov/news/press-release/2022-46

benchmark where the distribution of firm profits and carbon emissions are given exogenously. Consistent with Fama (2020), we show that market price reflects the investors' taste for ESG: "dirty" firms are punished by a lower stock price, and the price drop is more severe when investors place higher weights on ESG factors. However, if investors do not observe the firm's ESG performance, an increase in the investors' tastes for ESG lowers stock price but *fails* to change firm investment. This market failure is caused by investors not directly observing the underlying investment (they only observe noisy signals of it.) Because of the information asymmetry, investors always attach some weight to the conjectured emissions (based on the conjectured investment) that the firm takes as given and cannot change. If there is no signal about a firm's actual/realized emissions, investors' disutility regarding emissions can only be priced based on their conjectured prior beliefs. While the conjecture is correct *in equilibrium*, the lack of information on actual emissions disconnects the firm's investment choice from the price drop it expects to see in the market. This is where ESG disclosure can help: it restores the market's ability to channel investors' pro-ESG tastes into firm investment.

The efficiency implications of ESG disclosure are subtler. We show that the firm over-invests (hence, emissions are too high) in the absence of ESG disclosures. In contrast, perfect ESG disclosure incentivizes the firm to under-invest in the sense that it gives up too much profit to achieve a desirable ESG performance.[3] We characterize the optimal precision of ESG disclosure in closed form. The optimal ESG disclosure ensures that the firm, by maximizing its stock price, makes the same investment that its ESG-concerned investors would have chosen themselves to balance the financial and environmental implications of the investment. To the extent that "[corporate social responsibility] is the delegated exercise of prosocial behaviour on behalf of stakeholders" (Bénabou and Tirole, 2010), our analysis shows that ESG disclosure plays a crucial role in determining the efficiency of the delegation.

It is tempting to think that more precise ESG disclosures are desirable when investors become more ESG concerned (i.e., place a higher weight on environmental factors and, hence,

[3]All else equal, a firm will invest more (less) if its price is more responsive to profits (emissions). A perfect ESG disclosure makes price overly sensitive to reported emissions relative to profits, causing under-investment.

a lower weight on financial returns). We show this intuitive thinking is incomplete: the fact that improving ESG disclosure *can* move investments towards the desired level does not mean that one should improve the disclosure. What is missing in the intuitive thinking is the role of market forces (i.e., price effect of tastes). More precise ESG disclosure is needed only if market forces fail to move the investment sufficiently. Once we account for interactions with market forces, we show that the *optimal* precision of ESG disclosure actually decreases as investors become more ESG concerned. Intuitively, if we fix the quality of ESG disclosure at a level that is optimal for a given preference, an increase in investors' tastes for ESG will change their trading (hence, pricing of their information) in a way that inflates the firm's perceived social cost of investment more than the underlying change in the investors' tastes. Therefore, the precision of the optimal ESG disclosure decreases to undo the inflated social cost of investment that market forces impose on the firm. The result cautions against the temptation to focus on regulating ESG disclosures to *directly* change firm behaviors. Instead, one can think of ESG disclosures as interventions designed to iron out inefficiency that market forces would otherwise experience. More precise ESG disclosure is needed if market forces fail to move investment sufficiently, while less ESG disclosure is justified if market forces have gone overboard.

We also show that the optimal ESG disclosure increases in the quality of non-ESG information investors observe, such as firms' earnings reports. The endogenous positive relation predicts more precise ESG disclosures in countries that historically feature high quality financial reports. If a country has an overall opaque financial information environment, our model predicts that mandating strict ESG disclosure will incentivize firms to sacrifice too much financial return in exchange for favorable ESG performance.

The way we study ESG disclosure falls into the literature on real effects of disclosure (e.g., Gigler et al., 2014; Kanodia and Lee, 1998; Kanodia et al., 2005; Kanodia and Sapra, 2016). We contribute to the real effects literature by introducing investors' pro-ESG *tastes*, which have been a defining feature in prior studies on ESG investing and is believed to have disciplinary effect on firm behaviors (e.g., Heinkel et al., 2001; Fama and French, 2007; Fama, 2020; Pástor et al., 2021). The novelty of the paper is to show interdependencies between ESG disclosure and market forces (i.e., price effect of tastes) in moving firm investments towards efficient levels. On the one hand, we show that, when investments are not directly observed by investors, market forces alone change stock price but fail to influence firm investment no matter how strongly investors care about ESG. This is where ESG disclosure is needed: such disclosure helps to properly channel investors' ESG tastes into firm investment. On the other hand, investors' tastes determine how they use information, which has novel implications for how precise ESG disclosure should be. The results shed lights on the demand for and the design of ESG disclosure.

Literature. Prior studies have examined mechanisms that investors with pro-social preferences can use to influence firm actions. Hart and Zingales (2017) study a firm's choice between a "clean" project with less profits and a "dirty" project with higher profits. Shareholders care about profits and the social benefit of the "clean" project. They show that polling the investors through a referendum allows shareholders to honestly express their social objectives. To avoid shareholders being overwhelmed by the ongoing referenda related to firms' operation decisions, they propose the formation of mutual fund specializing in voting on ESG issues.

Pro-social investors can also influence firm operations through costly shareholder activism. Gollier and Pouget (2014) show that a pro-social large investor can convert non-responsible firms into responsible ones (and make positive abnormal returns in doing so) if the investor can commit to a long-term investing horizon. Their mechanism has the pro-social activist buy a "dirty" firm, change its production to be "clean", and then sell it back to the market. Chowdhry et al. (2019) study how a pro-social investor counters a profit-focused owner's tendency to overemphasize profits via joint financing. In particular, the pro-social investor provides the owner with a subsidy based on the anticipated pro-social effort chosen by the owner ex post. To credibly commit to a higher pro-social effort, the owner sells a fraction of firm's cash flow claim, which softens her focus on profits. Friedman and Heinle (2021) study free-riding problems atomistic shareholders face and provide conditions under which shareholders can overcome the free-riding problem.

In the models discussed above, shareholders influence firm actions through direct "engagement," either via costless voting or costly activism. The mechanism in the current paper has investors "vote with their feet." That is, shareholders express their pro-social preferences by choosing how many firm shares to buy or sell in the capital market, and the pricing of their trades aggregates their preferences.

Friedman et al. (2021) also study a price-based mechanism, in which a manager exerts unobservable efforts that affect the firm's ESG and cash flow. The manager's efforts are captured by a performance measure, i.e., ESG performance. Building on the notion of performance measure congruity in Feltham and Xie (1994), they compare managerial efforts, firm price, and ESG performance across different performance measure regimes, e.g., cash-flow congruity vs. ESG congruity.[4] They introduce uncertainty about the manager's objective function and study strategic misreporting of the ESG performance in a way analogous to earnings management. We do not consider misreporting. Our focus is to study how the precision of ESG disclosure affects firm investment and the related efficiency implications. The congruity parameters that govern the ESG performance are exogenous in Friedman et al. (2021), and we characterize the optimal ESG measure that maximizes investment efficiency.

On the technical side, Goldstein and Yang (2015) and Goldstein et al. (2022) extend standard noisy rational expectation equilibrium models to incorporate multiple fundamentals. They focus on asset pricing and price informativeness implications, and assume that distributions of multiple fundamentals are uncorrelated and given exogenously. In contrast, multiple fundamentals in this paper – profits and carbon emissions – are correlated and depend on the endogenous investment. (Our model is simpler in other aspects, e.g., there are no heterogeneous beliefs.) Modeling endogenous correlations between profits and ESG performance is consistent with Hart and Zingales (2020), who argue that corporate social responsibility is particularly relevant "in situations where profit and social consequences are inextricably connected."[5]

[4] Bonham and Riggs-Cragun (2022) also study a moral hazard model and how ESG activities can be motivated by incorporating ESG metrics in executive compensation contracts.

[5] Hart and Zingales (2020) writes: "Friedman acknowledged that shareholders might have ethical concerns, but he implicitly assumed that a company's profit and social objectives are separable.... But we are interested

2 Model Setup

The model consists of a continuum of investors and a firm that chooses an investment $k \geq 0$. Firm profit v depends on its investment k as

$$v(k) = \lambda k - \frac{k^2}{2} + \psi, \tag{1}$$

where $\lambda > 0$ is the marginal return of the investment and $\frac{k^2}{2}$ is the cost of investment. The noise term $\psi \sim N(0, \tau_v^{-1})$ in (1) is normally distributed with precision τ_v. Assuming a constant marginal return λ and a quadratic cost function does not drive our results. The model can be extended to more general specifications so long as the expected profit $v(k)$ is strictly concave and, hence, achieves its maximum at a unique k.

The first tradeoff the paper aims to capture is that firm actions impose negative consequences on ESG, e.g., pollution or health hazards. To capture the tradeoff simply, we assume that, on average, larger investments impose greater impact on the firm's ESG performance F as follows:

$$F(k) = f(k) + \phi, \text{ with } f'(k) > 0, \tag{2}$$

where the noise term ϕ is normally distributed with a zero mean and variance τ_F^{-1}. Examples of investments with negative ESG impact include resources devoted to promoting addictive drugs to doctors or building new oil-producing facilities. The negative ESG consequence F can be thought of as the potential health hazard (e.g., an opioid crisis) in the drug-promoting example and as carbon emissions in the oil-producing example. The assumption $f'(k) > 0$ in (2) captures the fact that more drug promotions tend to increase the likelihood of over-prescription of the drug, and that more oil production often results in higher emissions.[6] As will be discussed

in situations where profit and social consequences are inextricably connected."

[6]Firm profits $v(k)$ are typically maximized at an intermediate level of investment in both examples. In the drug-promoting example, the concavity of $v(k)$ can arise from the diminishing return of marketing efforts. Concavity of $v(k)$ in the oil-producing example can be driven by an increasing cost of production, because easy extractions are often produced first.

later, we allow for any increasing function $f(k)$ as long as its second derivative $f''(k)$ is not too negative. That is, $f(k)$ can be convex, linear, or mildly concave.

The firm chooses the investment k to maximize its stock price p, which is determined in a noisy rational expectations equilibrium (REE) similar to Diamond and Verrecchia (1981) and Hellwig (1980). There is a continuum of investors $i \in [0, 1]$ and a risk-free asset that serves as the numeraire. Investors are assumed to have a constant absolute risk averse (CARA) utility function with a common risk-aversion parameter $\rho > 0$. Noise traders supply ϵ units of the firm's share per capita and $\epsilon \sim N(0, \tau_\epsilon^{-1})$ is normally distributed.[7] Apart from being commonly used in disclosure models, assuming that the firm maximizes its stock price suits our purpose to examine the claim that higher stock price rewarded to "clean" product incentivizes firms to take ESG-friendly actions.

The second building block of the model is that we incorporate investors' pro-ESG preferences/tastes into a canonical REE model, which typically assumes that investors only care about the financial returns of their investment decisions. In standard REE models, the investor utility function is $-exp(-\rho x_i)$, where $x_i = (v - p)q_i$ is investor i's wealth if she invests q_i shares at the unit price p and receives a unit liquidation value v. Following Hart and Zingales (2017) and Pástor et al. (2021), we use the following specification to incorporate investors' disutility associated with investing q_i shares into a firm with emissions F: (We use the emissions interpretation of the ESG performance F in the reminder of the paper to keep exposition concrete and concise.)

$$x_i = \underbrace{(v - p)q_i}_{\text{Financial Returns}} - \underbrace{s \times F\, q_i}_{\text{Social Consideration}}. \tag{3}$$

The parameter $s \geq 0$ captures investor pro-ESG preference/taste (i.e., social awareness), and the canonical REE models discussed above correspond to the case of $s = 0$. One can think of Fq_i in (3) as investor i's "share" of the firm's total carbon emissions F. The idea is, given the firm's total emissions F, a pro-ESG investor bears more disutility if she owns a higher

[7] Assuming a zero average supply, $E[\epsilon] = 0$, is without loss of generality. Assuming $E[\epsilon] > 0$ will introduce an extra term to the price function that depends on $E[\epsilon]$ along with other exogenous parameters in the model, but will not affect any of the endogenous choices.

percentage of the firm (i.e., a higher q_i).

Some discussion of investors' preference (3) is in order. Social Consideration in (3) is not about how much pollution an investor physically consumes, but about investors disliking investing in a company that pollutes. For example, Tirole (2017) writes "An investor might not want his savings to be invested in an enterprise that deals with countries that do not respect human rights, or subcontracts with suppliers who use child labor or produce weapons or tobaccos; to avoid doing so, the investors might be prepared to sacrifice a bit of his return." Including social awareness in the investor's objective has become standard in studies on ESG investing (e.g., Fama and French, 2007; Zerbib, 2019; Pástor et al., 2021; Bansal et al., 2022). One can also add to (3) a disutility that investor i suffers due to her physical consumption of emissions (e.g., the water she drinks is contaminated) by adding a disutility term that is tied to the emissions F but is *independent* of her shareholding q_i. We have verified that the addition does not qualitatively change the equilibrium analysis.[8]

Further, while substituting x_i in (3) to the utility function $-exp(-\rho x_i)$ is a simple monotonic transformation, the implicit assumption is that investors are averse to the risks in their exposure to firm ESG performance, Fq_i. The risk-averse assumption, see also in Pástor et al. (2021), is consistent with Avramov et al. (2022) who provide evidence that uncertainty about corporate ESG performance reduces the demand of ESG-sensitive institutional investors. Modeling investors' risk concern about firm ESG performance seems consistent with practitioners and regulators' views that a main role of ESG disclosure is to help investors better understand their exposures to ESG-related risks. For example, Nasdaq considers risk mitigation as a main factor in its "ESG Reporting Guideline", and SEC's asset management advisory committee emphasizes disclosure of ESG risks in its "Recommendations for ESG" published in 2021.

We assume that investors do *not* directly observe the investment choice k. Instead, they rely on public disclosure and private signals to assess firm profit v and ESG performance F. This information asymmetry is an important feature of the model and we have more to say

[8]The addition will not change the investor's demand function (4) and, therefore, does not affect the price function, the equilibrium investment, or the design of ESG disclosure.

about its implications at the end of Section 3. Besides the usual justifications for unobservable investment (e.g., Gigler et al., 2014; Kanodia and Lee, 1998; Kurlat and Veldkamp, 2015), firms may have incentives and means to hide from the public about investments that impose negative consequences on ESG. For example, Purdue Pharma and McKinsey & Company have been secretive about the program they develop to identify and target doctors who are likely to prescribe opioids in large quantities. McKinsey started to work for Purdue Pharma since 2004. However, the nature and the size of the program remained largely unknown before the opioid crisis triggered intense legal investigations in recent years. House committee on oversight and reform repeatedly criticized the lack of transparency during the investigation process, which McKinsey defended based on client confidentiality agreements.[9]

Firm issues an earnings report $R = v + \zeta$ prior to trading. We assume $\zeta \sim N(0, \tau_R^{-1})$ and the precision τ_R captures the quality of the earnings report. Each investor $i \in [0, 1]$ also observes a private signal $y_i = v + \eta_i$ about profit v, where $\eta_i \sim N(0, \tau_\eta^{-1})$ is independently distributed across all investors. To highlight the role of ESG disclosure and to maintain tractability, we assume in the main model that information about the firm's ESG performance F comes solely from its ESG disclosure. In Section 6, we extend the analysis to incorporate investors' idiosyncratic private signals about F and demonstrate the robustness of our main results using numerical examples.

An equilibrium is a collection of the investment choice k, investors' trading strategies, and a linear pricing function such that:

(1) each investor forms a conjecture $\hat{k}$ and trades to maximize her expected payoff $E[-exp(-\rho x_i)]$, where x_i is defined in (3). Stock price p is formed to clear the stock market.

(2) the firm takes the price function as given and chooses k ex ante to maximize $E[p]$.

(3) conjectures are correct in equilibrium, i.e., $k = \hat{k}$.

[9] Purdue Pharma paid total \$86 million consulting fees to McKinsey. In 2021, McKinsey paid 573 million to settle investigations into its role in helping "turbocharge" opioid sales. For house committee's complaints about the lack of transparency and client confidentiality, see https://oversight.house.gov/news/press-releases/oversight-committee-grills-mckinsey-company-on-its-role-in-nation-s-opioid.

3 Demand for ESG Disclosure

This section assumes away ESG disclosure and illustrates when such a disclosure is needed for the purpose of ensuring the firm makes investment in accordance with investors' tastes for ESG.

3.1 Pricing with Exogenous Distributions

We start by taking the distribution of the firm profit v and carbon emissions F as given and study how the market-clearing price aggregates investors' underlying tastes for ESG. The analysis sets a foundation used in studying the extent to which the price effect of investor tastes influences the firm's endogenous investment choice.

Because investors care about the firm's financial profit v as well as its emissions F, it is not surprising that an investor i's demand q_i for the firm's share depends on both factors and can be expressed as

$$q_i = \frac{\mathbb{E}\left(v - sF|\mathcal{F}_i\right) - p}{\rho \operatorname{var}\left(v - sF|\mathcal{F}_i\right)}, \tag{4}$$

where $\mathcal{F}_i$ is investor i's information set. For a given price p and posterior risk assessment $\operatorname{var}\left(v - sF|\mathcal{F}_i\right)$, the demand for the firm's share increases if the investor expects a higher profit v or a lower carbon footprint F.

Integrating q_i over the continuum of investors and imposing the market-clearing condition

$$\int_i q_i \, di = \varepsilon,$$

we determine the equilibrium pricing function by comparing its coefficients. The steps used to determine the linear pricing function are a standard exercise and, hence, are omitted in the main text for brevity. The result below summarizes the linear pricing function given the distribution of the firm profits $v \sim N(\mu_v, \tau_v^{-1})$ and its carbon footprint $F \sim N(\mu_F, \tau_F^{-1})$. We assume the first moments $\mu_v, \mu_F > 0$, which is guaranteed once we endogenize firm investment.

Lemma 1 *Given the distribution of profit v and emissions F, the linear price function is $p =$*

$\alpha_0 + \alpha_v v + \alpha_R \zeta - \alpha_\epsilon \epsilon$ *and satisfies* $E[p] = \mu_v - s\,\mu_F$. *An increase in investors' ESG preferences lowers stock price:* $\frac{dE[p]}{ds} < 0$.

Proof. All proofs are in the Appendix. ■

The result is intuitive and serves as a validation for the approach we use to incorporate investors' pro-ESG tastes. Several features on the asset pricing side are worth pointing out. First, Lemma 1 shows that, on average, the market-clearing price correctly aggregates investors' tradeoffs between financial returns and ESG. This can be seen by noting that the expected price $E[p] = E[v] - s \times E[F]$ increases in the firm's expected profits and decreases in the expected emissions, and the relative weight, s, placed on the emissions matches the investors' underlying taste for ESG in (3).[10] Second, the *taste-driven price reaction* $\frac{dE[p]}{ds} < 0$ is consistent with prior studies and is related to the disciplinary role of "market forces" discussed in the literature (e.g., Fama and French, 2007; Friedman and Heinle, 2016; Fama, 2020). Given $\frac{dE[p]}{ds} < 0$, one would expect that a firm will have stronger incentives to become "clean" if its shareholders place a higher weight s on environmental implications of the investment. The next section examines the limitations of the taste-driven market forces in changing firm investment and illustrates the demand for ESG disclosure in our model.

3.2 Endogenous Investment and the Demand for ESG Disclosure

This subsection analyzes the main model in which firm profits v and carbon emissions F are connected through an endogenous investment choice. Recall from Lemma 1 that emissions are punished more severely when investors are more ESG concerned, i.e., higher s. It seems intuitive that the firm will respond to more ESG-concerned investors by scaling back its emission-generating investment. The following result challenges the connection between the taste-driven price reaction $\frac{dE[p]}{ds} < 0$ and firm investment choices.

[10] $E[p] = \mu_v - s\,\mu_F$ holds after we introduce ESG disclosure in later sections.

Proposition 1 *In the absence of ESG disclosure, an increase in the investors' social awareness s lowers the expected price $E[p]$ but does not change firm investment. The firm chooses $k^{\emptyset} \equiv \lambda$ no matter how strongly its investors care about ESG.*

The result may appear surprising. If more ESG-concerned investors punish a "dirty" firm via a steeper price drop, why would not the firm scale back its emission-generating investment? The market breakdown is caused by investors not directly observing firm investment. (Corollary 1 below also introduces a public disclosure of k.) To understand the result, note that while the market price $E[p] = \mu_v - s * \mu_F$ correctly reflects the disutility investors attach to the firm's carbon footprint F *in equilibrium*, the price is formed in a process that is only partially responsive to the investment choice. Because investors do not directly observe the investment, they always attach some weight to the conjectured emissions (based on the conjectured investment) that the firm takes as given and cannot change. If there is no signal about firm's actual/realized emissions, investors' disutility regarding emissions can only be priced based on their conjectured level. This can be seen by examining the price function in Lemma 1 and expressing the expected price as $E[p] = \alpha_0(\hat{k}) + \alpha_v E[v|k]$. Note that the investors' conjecture $\hat{k}$ affects the price function only through the intercept $\alpha_0(\hat{k})$, which will be ignored when the firm chooses k upfront to maximize price, i.e., $\max_k E[p] = \max_k \alpha_v E[v|k]$. In other words, the lack of disclosure on the firm's ESG performance F disconnects the actual investment k the firm chooses from the price drop it expects to see in the stock market.[11]

It is clear that information asymmetry regarding firm investment is critical in the argument. Because firms discuss their investments in public fillings, one may wonder if such a public report would qualitatively change the argument above. To address the question, suppose that the firm reports $I = k + \omega$ about its investment k, with $\omega \sim N(0, \tau_\omega^{-1})$. The corollary below shows that we continue to see the disconnection between the taste-driven price reaction $\frac{dE[p]}{ds} < 0$ and firm investment (in Proposition 1) as long as the investment is reported with some noise.

[11] We show in Section 6.2 that adding idiosyncratic private signals about F can partially restore the connection. The point here is that the taste-driven price reaction $\frac{dE[p]}{ds} < 0$ *alone* cannot change firm actions and, for that to happen, it is necessary for investors to observe signals about the firm's realized ESG performance F.

Corollary 1 *Proposition 1 holds whenever investment k is reported with noise, i.e., $\tau_\omega < \infty$.*

To understand this result, note that the firm's ESG performance $F = f(k) + \phi$ and reported investment $I = k + \omega$ are related through the investment k. If k were drawn from an exogenous distribution by nature, investors would use the reported I to update their beliefs of k, and, hence, their expected carbon footprint F. The difference here is that k is an endogenous choice, which is critical in understanding Corollary 1. Because the equilibrium is in pure strategies, the investors view their conjectured $\hat{k}$ as a constant and, hence, attribute any difference between the reported investment I and their conjecture $\hat{k}$ to noise, ω. In other words, rational expectations in a pure-strategy equilibrium imply that investors attach probability one to their equilibrium conjecture $\hat{k}$ (of the endogenous investment) and, therefore, will not update $\hat{k}$ based on noisy signals. This simple yet thought-provoking reasoning is formalized in Bagwell (1995) and Kanodia et al. (2005), who summarize the idea as "noisy signals of endogenous actions have no information content."

It is important to reconcile our results to prior studies that argue the disciplinary role of market forces (e.g., Fama, 2020; Friedman and Heinle, 2016; Pástor et al., 2021). For example, Fama (2020) writes "market forces already address ESG issues." All these studies assume that the prior distribution of ESG performance is publicly observed, which, in a model with endogenous investments like ours, is equivalent to assuming that investments are publicly observed. If firm investment were observable in the model, our results would be consistent with Fama (2020) in that market forces (i.e., the price effect of tastes $\frac{dE[p]}{ds} < 0$ in Lemma 1) *alone* would be sufficient to incentivize firms to make efficient investments, and there would be *no need* for disclosing ESG performance F. What we have shown is that, for investments that are not perfectly observed by outside investors (e.g., resources Purdue Pharma devoted to promoting opioid drugs), taste-driven market forces alone have trouble changing firm investment choices, and this is where ESG disclosure is needed. Moreover, the value of disclosing a firm's ESG performance cannot be replaced by non-ESG disclosures or even by noisy measures of the ESG investment itself, i.e., the input. These results offer a justification for providing a separate disclosure on firms' ESG performance.

4 Investment Efficiency and Optimal ESG Disclosure

This section studies how ESG disclosure affects investment efficiency and characterizes the optimal ESG disclosure. Denote by D the ESG disclosure that measures firm's ESG performance F as follows

$$D = F + \xi, \tag{5}$$

where the noise term $\xi \sim N(0, \tau_\xi^{-1})$ is normally distributed with a precision τ_ξ. Different ESG disclosure policies in the model are characterized by different disclosure precisions $\tau_\xi \geq 0$.

The first step towards the characterization of the optimal ESG disclosure is to ask: what is an efficient investment when investor preference consists of financial and pro-social components? The paper takes the view that "[corporate social responsibility] is the delegated exercise of prosocial behaviour on behalf of stakeholders" (Bénabou and Tirole, 2010). Therefore, a natural benchmark is one where a representative investor chooses the investment herself to balance the financial and environmental implications of the investment. That is, the investor chooses k to maximize her payoff:

$$\mathbb{E}\left[-exp\left(-\rho\left[v(k) - sF(k)\right]\right)\right], \tag{6}$$

where profits $v(k)$ and emissions $F(k)$ are specified in (1) and (2).

Denote by k^{FB} the sustainable investment under the efficient benchmark. Given the normal-exponential setup, maximizing the utility above is equivalent to maximizing its certainty equivalent $E[v(k) - sF(k)] - \frac{\rho}{2}\text{var}[v(k) - sF(k)]$. When the investor chooses k herself, we can express $\text{var}[v(k) - sF(k)] = \frac{1}{\tau_v} + \frac{s^2}{\tau_F}$ as a function of model parameters. It is therefore without loss to characterize k^{FB} from maximizing $E[v(k) - sF(k)]$ alone. The first-order condition is

$$\lambda = k^{FB} + sf'(k^{FB}). \tag{First-best}$$

It follows that $\frac{dk^{FB}}{ds} < 0$. That is, investors who care more about environmental impact of the investment would scale back the emission-generating investment. The second-order condition of the optimization problem requires $f''(k) \geq -\frac{1}{s}$, which is our maintained assumption discussed following Equation (2).

The proposition below compares k^{FB} to the investment $k^{\emptyset}$ under no-ESG disclosure (i.e., $\tau_\xi = 0$) and k^P under perfect ESG disclosure (i.e., $\tau_\xi \to \infty$).

Proposition 2 (Different types of inefficiency) *The firm over-invests without ESG disclosure and under-invests with perfect ESG disclosure. That is,*

$$k^{\emptyset} > k^{FB} > k^P. \tag{7}$$

Proposition 2 demonstrates two types of inefficient investment. When carbon emissions are not disclosed, the firm invests too much and, hence, emits too much greenhouse gases. In comparison, perfect ESG disclosure causes under-investment, which means that the firm gives up too much financial profits in exchange for achieving a more desirable ESG performance.[12] The result adds tension to the discussion in the previous section. It shows that while ESG disclosure helps to bridge investors' pro-ESG preferences to firm investment, the efficiency implications of ESG disclosure are subtler. Compared to the no-ESG disclosure scheme analyzed in Proposition 1, requiring too much ESG disclosure swings firm behaviors from one type of inefficiency to another. Therefore, what matters from an efficiency point of view is *how to disclose*, which is equivalent to finding the optimal ESG-disclosure precision τ_ξ defined in (5).

Can we choose the precision of ESG disclosure so that it properly balances the financial and environmental impacts of the investment in a way that implements the investment k^{FB} that the investors would choose themselves? To answer the question, we first establish the equilibrium for a given precision $\tau_\xi > 0$ of ESG disclosure and study how a change in τ_ξ would

[12]The under-investment result echoes Kanodia et al. (2005) who show that more precise disclosure can reduce efficiency. Related, Aghamolla and An (2021) compare investment efficiency between voluntary and mandatory ESG disclosure and show that mandatory disclosure can lower investment efficiency.

affect the investment the firm chooses in equilibrium. The next result summarizes the subgame equilibrium for a given precision of ESG disclosure and is important to understanding the countervailing forces in constructing the optimal ESG disclosure.

Lemma 2 *Given a ESG disclosure quality $\tau_\xi \geq 0$, the linear price function is*

$$p = \alpha_0 + \alpha_v v + \alpha_R \zeta - \alpha_F D - \alpha_\epsilon \epsilon, \tag{8}$$

and the equilibrium k is the solution to $\alpha_v(\lambda - k) - \alpha_F f'(k) = 0$. The price coefficients satisfy

$$\frac{d\alpha_F}{d\tau_\xi} > 0 \text{ and } \frac{d\alpha_v}{d\tau_\xi} > 0. \tag{9}$$

It is intuitive that the price function will be more responsive to ESG disclosure D when it becomes more precise, i.e., $\frac{d\alpha_F}{d\tau_\xi} > 0$. In comparison, the result $\frac{d\alpha_v}{d\tau_\xi} > 0$ may appear surprising. Why would more precise ESG disclosure make price more responsive to firm profits v, even though the ESG disclosure $D = F + \xi$ contains no information about profits? The thinking behind the spillover effect rests on the risk considerations associated with the investors' ESG exposure in their portfolios. Recall that investors are uncertain about firm's ESG performance F at the time of trading. More precise ESG disclosure lowers the uncertainty that investors face regarding their exposures to firm's ESG performance F. In response to the lower uncertainty (i.e., lower risk), investors trade more aggressively on their information, be it financial-related or ESG-related. The intensive trading better aggregates investors' signals $y_i = v + \eta_i$ about firm profits and explains the spillover result $\frac{d\alpha_v}{d\tau_\xi} > 0$ in (9).

We analyze how a more precise ESG disclosure affects α_F and its spillover effect on α_v in (9) because the two price coefficients are important in determining firm investments. This can be seen by expressing expected stock price, $E[p|k, \hat{k}] = \alpha_0(\hat{k}) + \alpha_v E[v|k] - \alpha_F E[F|k]$, as a function of the actual investment k chosen by the firm and the investors' conjecture $\hat{k}$ that the firm takes as given. It follows that

$$\frac{dE[p|k,\hat{k}]}{dk} = \alpha_v \frac{dE[v|k]}{dk} - \alpha_F \frac{dE[F|k]}{dk}.$$

That is, in an attempt to maximize its stock price, the firm internalizes the investors' disutility associated with its emissions F to the extent captured by the *sensitivity* of price to F, which is captured by the price coefficient α_F. Similarly, the price coefficient α_v is the sensitivity of price to profits v and it captures the extent to which the firm internalizes the investors' utility derived from a higher financial return.

A higher α_F (and α_v) in the price function can therefore be thought of as an increase in the firm's perceived marginal cost of investment (and marginal benefit). The result $\frac{d\alpha_F}{d\tau_\xi} > 0$ and $\frac{d\alpha_v}{d\tau_\xi} > 0$ in Lemma 2 means that improving the quality τ_ξ of ESG disclosure has two countervailing forces to the firm's investment choice. A higher τ_ξ increases the firm's perceived marginal cost of investment via a higher price coefficient α_F, while, at the same time, increases its perceived marginal benefit of investment via a higher α_v. The net effect on the equilibrium investment depends on how fast a more precise ESG disclosure increases the firm's perceived marginal cost (via α_F) *relative to* the marginal benefit (via α_v). This can be seen by re-writing the first-order condition in Lemma 2 as follows:

$$\lambda = k^* + \frac{\alpha_F(\tau_\xi)}{\alpha_v(\tau_\xi)} f'(k^*). \tag{10}$$

It is instructive to use (10) to explain the two types of inefficient investment seen in Proposition 2. One can verify that $\frac{\alpha_F(\tau_\xi)}{\alpha_v(\tau_\xi)} = 0$ under no-ESG disclosure by setting $\tau_\xi = 0$ and that $\frac{\alpha_F(\tau_\xi)}{\alpha_v(\tau_\xi)} = \left(1 + \frac{\tau_v}{\tau_\eta + \tau_p + \tau_R}\right) s$ under perfect ESG disclosure by setting $\tau_\xi \to \infty$. Comparing to the first-order condition $\lambda = k^{FB} + sf'(k^{FB})$ used to determine the efficient k^{FB}, we note that the firm underestimates the investors' marginal disutility $sf'(k^{FB})$ associated with emissions under the no-ESG disclosure regime, and overestimates $sf'(k^{FB})$ under perfect ESG disclosure. This explains the over- and under-investment results in Proposition 2.

The analysis above offers a way to characterize the optimal precision of ESG disclosure. If there exists a precision τ_ξ^* under which $\frac{\alpha_F(\tau_\xi^*)}{\alpha_v(\tau_\xi^*)} = s$, the condition (10) used to determine the firm's investment k^* will coincide with (First-best) used to determine the investors' desired investment k^{FB}. In this case, τ_ξ^* perfectly aligns the firm's incentive in maximizing price to the investors' underlying social-vs-financial tradeoff. The proposition below verifies the existence of such ESG-disclosure quality τ_ξ^* and presents its closed-form expression.

Proposition 3 (Optimal ESG Disclosure) *A unique ESG disclosure precision* $0 < \tau_\xi^* < \infty$ *incentivizes the firm to choose the first-best investment* k^{FB} *and*

$$\tau_\xi^* = \tau_F \left(\frac{r^2 \tau_F^2 \tau_\eta^2 \tau_\epsilon}{\left(s^2 \tau_v + \tau_F\right)^2} + \tau_\eta + \tau_R \right) \tau_v^{-1}. \tag{11}$$

To the extent that "[corporate social responsibility] is the delegated exercise of prosocial behaviour on behalf of stakeholders" (Bénabou and Tirole, 2010), the result shows ESG disclosure is crucial in determining the efficiency of the delegation. The thinking behind the result is reminiscent of the goal congruency literature in managerial accounting, which studies the design of performance measures to align incentives in principal-agent settings (e.g., Reichelstein, 1997; Dutta and Reichelstein, 2005). For example, the principal uses residual income instead of GAAP earnings in compensation contracts to ensure that agents with different horizons will make the investment that is optimal from the principal's point of view. Just as it is difficult to ensure that an agent shares the same investment horizon as the principal, it is unrealistic to expect that firm executives value the financial-vs-social tradeoff the same way as investors do. Proposition 3 shows that ESG disclosure plays an important role in aligning incentives between investors and corporate executives. In doing so, investors can ignore the executives' personal traits (such as social and political views) and tie their pay to the firm's stock price, which is a common practice to compensate executives.

5 Determinants of the Optimal ESG Disclosure

Analysis so far has shown that ESG disclosure is crucial in ensuring firms invest in accordance with investors' tastes for ESG. This section analyzes comparative statics of the optimal precision of ESG disclosure. The analysis yields interesting empirical and regulatory implications.

We start by examining how the optimal precision τ_ξ^* of ESG disclosure would change if investors care more about the environmental impact of firm actions, i.e., a higher ESG taste s. This question has immediate regulatory implications because ESG disclosures are introduced, at least in part, to change firm's behaviors towards sustainable goals. It is tempting to think that more precise ESG disclosure is desirable if investors' pro-social preference s is higher. In fact, one can check that increasing the quality of ESG disclosure in the neighborhood of the optimal τ_ξ^* incentivizes the firm to lower the emission-generating investment, which is consistent with what more socially concerned investors would prefer.[13] However, as shown in the next result, the fact that improving ESG disclosure *can* lower the investment towards the desired level does not mean that we should improve the disclosure.

Proposition 4 *The optimal precision of ESG disclosure decreases in the investors' taste for ESG. That is,* $\frac{d\tau_\xi^*}{ds} < 0$.

To understand the counter-intuitive result, recall that τ_ξ^* is chosen to align the firm's tradeoff between social cost and financial benefit of the investment to the tradeoff in the eyes of the investors, i.e.,

$$\underbrace{\frac{\alpha_F(\tau_\xi^*, s)}{\alpha_v(\tau_\xi^*, s)}}_{\text{Corporate social tradeoff}} = \underbrace{s}_{\text{Investors' social tradeoff}}. \tag{12}$$

The notation on the left-hand side of (12) highlights the interactions between ESG disclosure τ_ξ^* and the price effect of investor tastes s.

Denote by $G(\tau_\xi^*, s) \equiv \frac{\alpha_F(\tau_\xi^*,s)}{\alpha_v(\tau_\xi^*,s)} - s$. One can apply the implicit function theorem to $G(\tau_\xi^*, s) =$

[13] Proposition 2 shows k^{FB} decreases in s. It is easy to verify that improving ESG disclosure around its the optimal level lowers the firm investment, i.e., $\frac{dk^*}{d\tau_\xi}|_{\tau_\xi=\tau_\xi^*} < 0$.

0 and obtain $\frac{d\tau_\xi^*}{ds} = -\frac{\partial G/\partial s}{\partial G/\partial \tau_\xi^*}$. Using the fact that $\partial G/\partial \tau_\xi^* > 0$ at the optimal τ_ξ^*, we show that

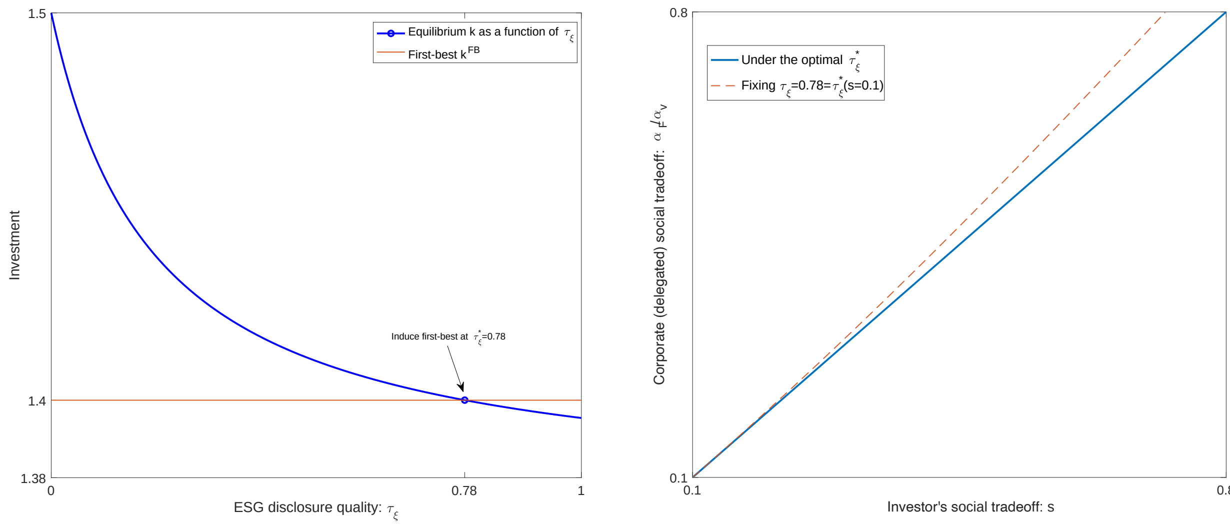
$$\frac{d\tau_\xi^*}{ds} \propto -\partial G/\partial s \;=\; \underbrace{1}_{\text{Direct Effect}} \;-\; \underbrace{\frac{d\frac{\alpha_F}{\alpha_v}}{ds}}_{\text{Indirect Effect}} \;<0. \tag{13}$$

The direct effect in (13) is obtained by differentiating "Investors' social tradeoff" in (12). It captures the intuitive argument discussed prior to the proposition: as investors care more about environmental impact of investment (and, hence, prefer a lower k^{FB}), there is a call for more precise ESG disclosure τ_ξ to elevate the firm's perceived social cost of investment.

The counter-intuitive result $d\tau_\xi^*/ds < 0$ is driven by the Indirect Effect in (13), which is obtained from differentiating "Corporate social tradeoff" in (12). Recall that α_F/α_v is the extent to which the firm internalizes its shareholders' social tradeoff. The Indirect Effect, $\frac{d\frac{\alpha_F}{\alpha_v}}{ds}$, captures how the price effect of tastes s will move corporate social tradeoff (holding the quality of ESG disclosure $\tau_\xi^* > 0$ constant). It is easy to verify $\frac{d\frac{\alpha_F}{\alpha_v}}{ds} > 0$ because α_F increases in s and α_v decreases in s. Intuitively, as investors care more about ESG factors, their tradings and, hence, stock price will be more sensitive to the ESG disclosure and less sensitive to profits. To understand the negative sign in front of the Indirect Effect in (13), note that $\frac{d\frac{\alpha_F}{\alpha_v}}{ds} > 0$ means a stronger taste for ESG already elevates the firm's perceived social cost of investment, which offsets the need to improve ESG disclosure for the same purpose.

Figure 1 illustrates the intuition using a numerical example in which $f(k) = k, \lambda = 1.5, \tau_v = 0.5, \tau_R = 0, \tau_F = 0.2$, and $\rho = \tau_\eta = \tau_\epsilon = 1$. In Panel (a), we fix investors' ESG taste at $s = 0.1$. The downward curve plots the equilibrium investment as a function of a given ESG disclosure quality τ_ξ. The optimal $\tau_\xi^* = 0.78$ is determined when the equilibrium investment intersects with the efficient $k^{FB} = 1.4$.

While Panel (a) shows that increasing the quality τ_ξ of ESG disclosure can lower investment, Panel (b) illustrates why the optimal τ_ξ^* decreases when investors care more about environmental impact of investment (i.e., a higher s) and, hence, prefer a lower investment. The 45-degree line plots corporate social tradeoff under the optimal τ_ξ^*, whose closed-form is given in Proposition



(a) Optimal ESG Disclosure given $s = 0.1$

(b) Investor vs. corporate social tradeoff

Figure 1: Numerical examples illustrating Proposition 4

3. The fact that it is a 45-degree line shows τ^*_ξ fully aligns corporate social tradeoff to the investors' social tradeoff s. The dotted line in Panel (b) is a counterfactual analysis: it plots what corporate social tradeoff would have been had we fixed the quality of disclosure precision at $\tau_\xi = 0.78$, which is the optimal ESG disclosure for $s = 0.1$ characterized in panel (a). Note that the dotted line lies everywhere above the 45-degree line, suggesting that the taste-driven market forces have caused the firm to overestimate the social cost of investment. That is, if we fix ESG-disclosure quality $\tau_\xi = 0.78$, an increase in investors' social preference s changes their tradings (hence, stock price) in ways that inflate the corporate social tradeoff more than the change to the underlying investors' ESG taste. Therefore, the optimal ESG disclosure quality decreases, which will lower the firm's perceived social cost of investment and restore the induced corporate social tradeoff α_F/α_v to the level justified by its investors' social tradeoff, s.

The next result shows how the optimal quality of ESG disclosure would change with respect to the quality of non-ESG information that investors observe.

Proposition 5 *The optimal precision of ESG disclosure increases as investors' information about the financial profit is more precise. That is,* $\frac{d\tau^*_\xi}{d\tau_\eta} > 0$ *and* $\frac{d\tau^*_\xi}{d\tau_R} > 0$.

Similar to the argument developed following Proposition 4, one can understand the result by comparing how the quality of information about profit affects "Corporate social tradeoff" relative to "Investors' social tradeoff" in (12). It is easy to see that information quality does not change "Investors' social tradeoff", which is the investors' underlying pro-ESG preference s. In comparison, more precise information on financial profit (i.e., a higher τ_η or τ_R) reduces the "Corporate social tradeoff", $\frac{\alpha_F}{\alpha_v}$ by increasing α_v. Take a higher τ_η for example, investors trade more intensively on their private information $y_i = v + \eta$ when the information is more precise, and the intense trading makes price more responsive to firm profits, i.e., a higher α_v. The fact that a higher τ_η reduces "Corporate social tradeoff" yet does not change "Investors' social tradeoff" means that, from the investors' point of view, the firm under-estimates the social cost of the investment (i.e., $\frac{\alpha_F}{\alpha_v} < s$). In this case, the optimal ESG disclosure quality τ_ξ^* increases, which will make the price more responsive to ESG disclosure and restores corporate social tradeoff to investors' social tradeoff s.

Proposition 5 makes a novel point that the optimal ESG disclosure depends on the quality of the company's non-ESG related information. Given the endogenous relationship, the result predicts more precise ESG disclosures in countries that historically feature high quality financial reports. If a country has an overall opaque financial information environment, our model predicts that mandating strict ESG disclosure has the risk of incentivizing firms to sacrifice too much financial returns in exchange for favorable ESG performance. The inter-dependence between ESG and non-ESG information also raises concern about mandating a uniform ESG disclosure requirement for all firms. To the extent that overall quality of a firm's financial information is associated with its size and industry, our model suggests that ESG disclosure requirements should consider firm size and industry.

The analysis in this section suggests that one can think of ESG disclosures as interventions designed to iron out inefficiency that (taste-driven) market forces would otherwise experience. To answer how the ESG disclosure would change in response to a change in the economy (e.g., a parameter of the model), the paper cautions against the temptation to focus exclusively on regulating ESG disclosures in order to *directly* change firm behaviors. That is, the fact that improving ESG disclosure *can* move investments towards sustainable goals does not mean that we should improve disclosure. A better approach seems to first analyze how market forces would change as a result of the parameter change and the nature of market inefficiency. ESG disclosure is then adjusted to iron out the market inefficiency after the parameter change. More precise ESG disclosure is needed if market forces fail to move investment sufficiently, while less ESG disclosure is justified if market forces have gone overboard.

6 Extension

6.1 Incorporating investment with positive social consequences

Investment studied in the main model imposes negative consequences (e.g., pollution and health hazards) on ESG issues. In this subsection, we incorporate an ESG-improving investment that is designed to help ESG by reducing emissions F. Denote by $c \geq 0$ the firm's investment in reducing emissions, e.g., installing a carbon capture facility. Such an investment reduces the firm's emissions by $g(c)$ at a cost of $\frac{c^2}{2}$. We augment firm profit v in (1) by incorporating the cost of carbon capturing $\frac{c^2}{2}$:

$$v(k,c) = \lambda k - \frac{k^2}{2} - \frac{c^2}{2} + \psi, \tag{14}$$

and modify emissions F in (2) to incorporate the effect of carbon reducing $g(c)$, with $g'(c) > 0$:

$$F(k,c) = f(k) - g(c) + \phi. \tag{15}$$

As in the main model, we first establish the efficient k^{FB} and c^{FB} that pro-ESG investors would choose themselves to balance the financial and environmental implications of the two investments. We showed in the main model that k^{FB} is determined from $\lambda = k^{FB} + sf'(k^{FB})$.

Similarly, the efficient carbon reducing investment c^{FB} is determined from

$$c^{FB} = s\, g'(c^{FB}),$$

which equates the marginal cost of the investment to its marginal benefit in reducing emissions (weighted by investor social preference s.)

The paper assumes that investors do not directly observe the carbon capture investment c. Arguably, this assumption is not applicable to all types of investment: how many carbon credits a firm buys over public platforms is often observable. Nonetheless, the investment made by the firm internally is relatively hard to be observed by external investors. Such internal investment can entail ESG-targeted research and development (e.g., developing a less addictive drug formulation) and choosing how often to operate a firm's carbon-reducing facilities in the production process.

When firm investment is not directly observed, we show in the main model that ESG disclosure ($D = F + \xi$) is essential in channeling the investors' pro-ESG preferences into firm investment decisions. In addition, more precise ESG disclosure may not necessarily improve investment efficiency. These results are true for the carbon reducing investment c as well. The following proposition shows that the optimal precision τ_ξ^* of the ESG disclosure derived in Proposition 3 of the main model also incentivizes the firm to undertake the efficient carbon capture investment c^{FB}.

Proposition 6 *The optimal precision* $\tau_\xi^* = \tau_F \left(\frac{r^2 \tau_F^2 \tau_\eta^2 \tau_\epsilon}{(s^2 \tau_v + \tau_F)^2} + \tau_\eta + \tau_R \right) \tau_v^{-1}$ *of ESG disclosure obtained in the main model incentivizes the firm to choose the efficient* k^{FB} *and* c^{FB}.

The fact that τ_ξ^* can implement k^{FB} and c^{FB} at the same time is because the two investments are additively separable in the model. We are not claiming that the separable structure applies to all investments. All we are saying is that the mechanism in the paper is not unique to discouraging investments that are damaging to ESG, and the argument can be extended to promoting investments that have positive ESG consequences. The key tension underlying our mechanism is that "profit and social consequences are inextricably connected" (using Hart and Zingales' language). Here, carbon capture is good for ESG but is costly to implement. In other words, there is a tradeoff between maximizing profit and maximizing ESG performance.

6.2 Incorporating private signals about ESG

The analysis so far has assumed away investors' private signals about firm carbon footprint F to maintain tractability. In this section, we relax the assumption and demonstrate the robustness of our analytical results presented in the main model. Suppose that, in addition to observing the ESG disclosure $D = F + \xi$, each investor i observes a private signal x_i about firm emissions F as follows

$$x_i = F + \delta_i, \tag{16}$$

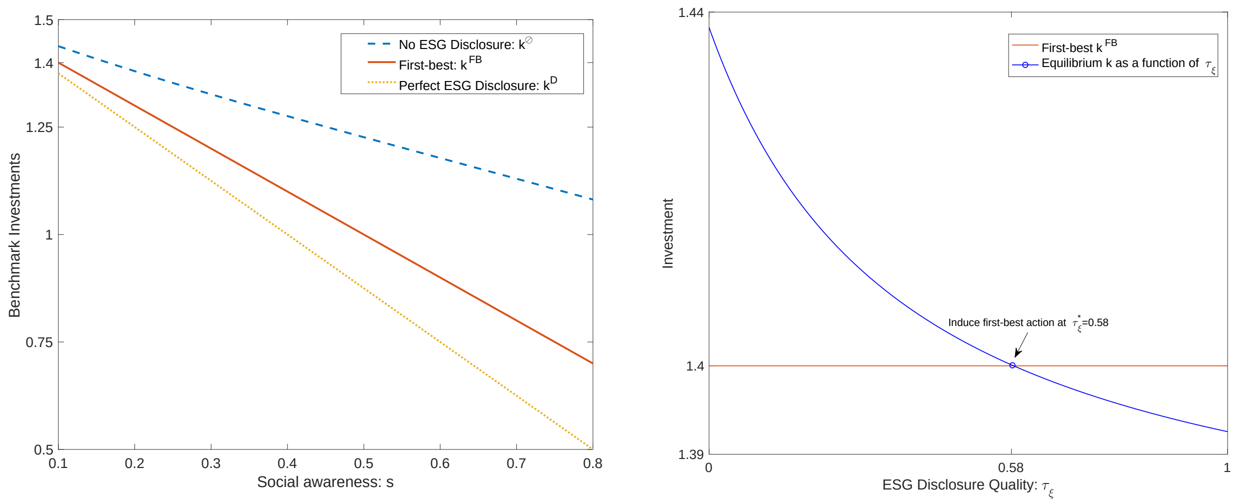
where $\delta_i \sim N(0, \tau_\delta^{-1})$ is independently distributed across investors and from other variables in the model.

Incorporating private signals x_i changes the market-clearing price function. One can follow the standard guess and verify approach to obtain the linear price function as follows:

$$p = \alpha_0 + \alpha_v v + \alpha_R \zeta - \alpha_F F - \alpha_\xi \xi - \alpha_\epsilon \epsilon. \tag{17}$$

It is worth noting a difference between the price function (17) above and the price function $p = \alpha_0 + \alpha_v v + \alpha_R \zeta - \alpha_F (F + \xi) - \alpha_\epsilon \epsilon$ in Lemma 2. The main model features $\alpha_F = \alpha_\xi$ because investors cannot distinguish the disclosure noise ξ from the fundamental F when the sum of the two (i.e., ESG disclosure $D = F + \xi$) is the *only* signal about F they observe. Introducing another signal x_i about F helps the investors to partially separate the noise ξ in ESG disclosure, explaining the separation of $\alpha_\xi \xi$ in the price function (17).

While characterizing the price function (17) is conceptually straightforward, the price coefficients can only be solved numerically. The reminder of the discussion uses numerical examples to illustrate that the results in the main model continue to hold qualitatively. In all the exam-



(a) Benchmark investments decrease in s

(b) Optimal ESG disclosure given $s = 0.1$

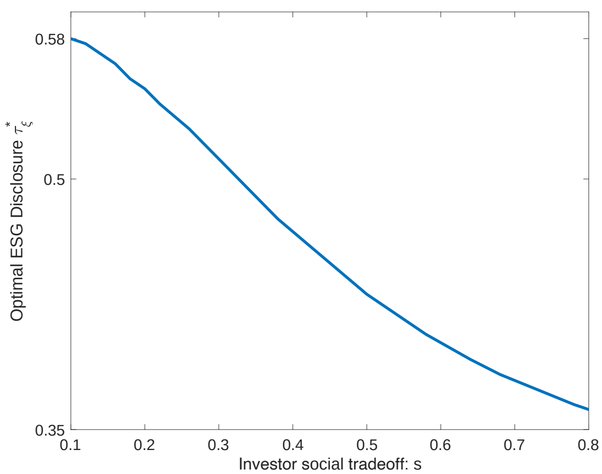
Figure 2: Investments

ples discussed below, we use the same numerical values shown in Figure 1 for easy comparison and set the precision of private signals x_i to be $\tau_\delta = 0.1$.

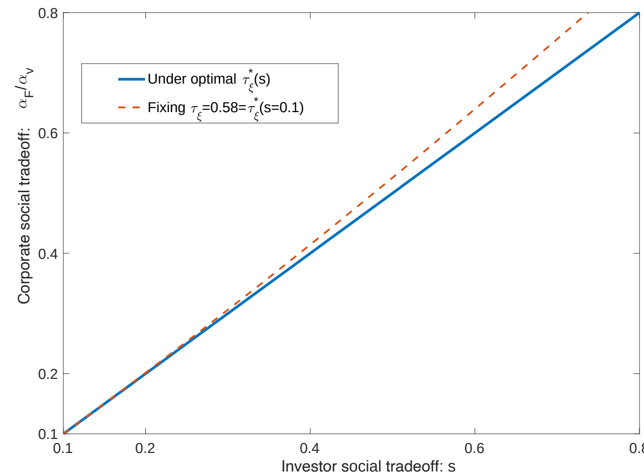
Figure 2 illustrates firm investments and the role of ESG disclosure in transforming firm investment. Panel (a) compares the efficient investment k^{FB}, investment $k^{\emptyset}$ without ESG disclosure, and k^P under perfect ESG disclosure. The ordering of $k^{\emptyset} > k^{FB} > k^P$ seen in the figure is consistent with Proposition 2 in the main model.[14] In Panel (b), we fix investor social awareness at $s = 0.1$ and characterize the optimal ESG-disclosure quality. The downward slope is the equilibrium investment k^* as a function of the quality of ESG disclosure $\tau_\xi \geq 0$. The optimal $\tau_\xi^* = 0.58$ is obtained when k^* intersects with $k^{FB} = 1.4$ given $s = 0.1$. Recall from Figure 1 that the optimal precision of ESG disclosure is $\tau_\xi^* = 0.78$ in the absence of private signals about F. The fact that τ_ξ^* is lower in Figure 2 (after introducing private signals) suggests a substitutive relation between public and private signals about ESG performance.

Figure 3 illustrates how the optimal ESG disclosure quality τ_ξ^* would change as investors are more concerned about environment implications of the investment, i.e., as s increases. Panel

[14]The no-ESG disclosure investment $k^{\emptyset}$ decreases in s, which is different from $\frac{dk^{\emptyset}}{ds} = 0$ in the main model. The point is that taste-driven price reactions *alone* cannot change firm actions and, for that to happen, it is necessary for investors to learn about firm's actual ESG performance F. Investors learn about F solely from ESG disclosure in the main model, and they also learn from private signal x_i in the extension.



(a) Optimal ESG Disclosure Quality τ_ξ^*

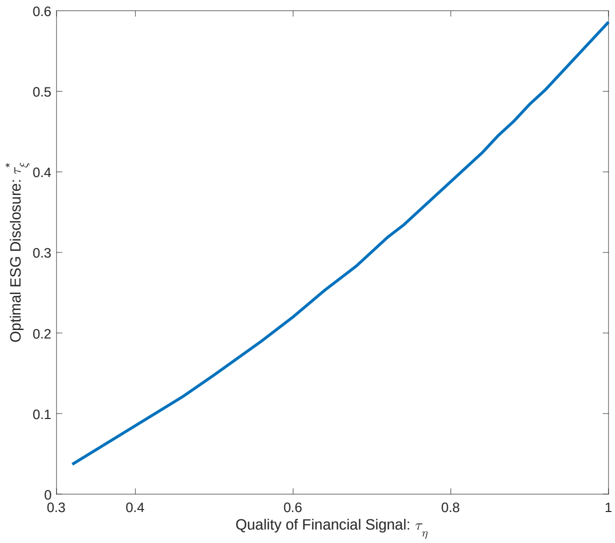


(b) Investor vs. corporate social tradeoff

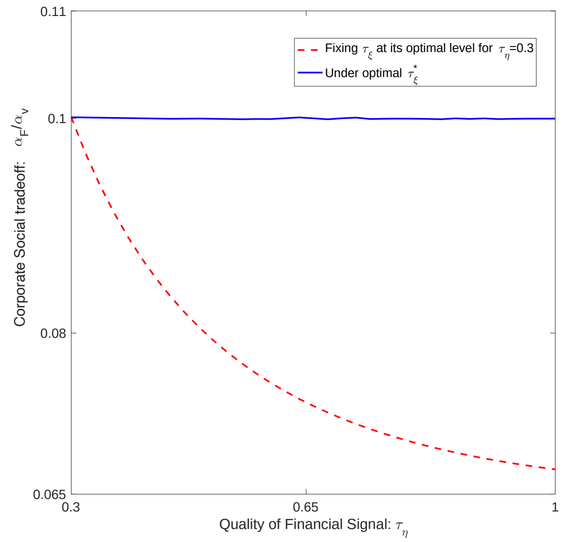
Figure 3: Robustness of Proposition 4

(a) echoes the counter-intuitive result $\frac{d\tau_\xi^*}{ds} < 0$ shown in Proposition 4 and panel (b) illustrates the intuition. The 45-degree line in Figure 3 plots corporate social tradeoff $\frac{\alpha_F}{\alpha_v}$ under the optimal quality of ESG disclosure τ_ξ^*. The dotted line in panel (b) plots what the corporate social tradeoff would be if we were to fix the ESG disclosure quality at $\tau_\xi = 0.58$ (i.e., the optimal level given $s = 0.1$) as we increase investor tastes for ESG. Investigating the dotted line shows that the taste-driven market forces cause the firm to over-estimate the social cost of investment relative to the investors' preferences. This can be seen by noting that the dotted line is above the 45-degree line. Therefore, the concern after considering market forces has changed from trying to convince the firm to internalize more social cost of investment to trying to undo the inflated marginal cost that market forces have imposed. The optimal ESG disclosure τ_ξ^* decreases in order to bring the dotted line back to the 45-degree line.

Figure 4 shows how the optimal ESG disclosure τ_ξ^* would change as investors' financial-related information becomes more precise (while holding $s = 0.1$). The upward plot in Panel (a) is consistent with the result $\frac{d\tau_\xi^*}{d\tau_\eta} > 0$ shown in Proposition 5. Panel (b) illustrates the intuition. As financial information becomes more precise (i.e., higher τ_η), optimal ESG disclosure τ_ξ^* is adjusted so that the firm's social tradeoff aligns the investors' social tradeoff $s = 0.1$. The



(a) Optimal ESG Disclosure Quality τ_ξ^*



(b) Corporate social tradeoff

Figure 4: Robustness of Proposition 5

dotted line in panel (b) plots what the firm's induced social tradeoff would be if we were to fix ESG disclosure quality at the level that is optimal for the lowest $\tau_\eta = 0.3$, i.e., fixing $\tau_\xi = \tau_\xi^*(\tau_\eta = 0.3)$. The fact that the dotted line lies below the solid line means that, without changing ESG disclosure, more precise financial information changes investors' trading (and, hence price) in a way that induces the firm to under-estimate the social cost of investment. In response, the optimal ESG disclosure increases, which encourages the firm to internalize more social cost of investment and brings the dotted line up to the optimal level.

7 Conclusion

This paper studies the role of ESG disclosure in transforming firm investment when its shareholders' preferences include both financial and pro-ESG elements. We show that, as long as external investors do not perfectly observe firm investments, disclosing ESG performance is essential in ensuring the firm makes investment in accordance with investors' tastes for ESG. Further, the fact that ESG disclosure is correlated with existing non-ESG disclosures (e.g., reported investment) does not make ESG disclosure less valuable. This is because the statistical correlation between a firm's ESG performance and its non-ESG disclosures is after the fact/in equilibrium, but has limited value in changing investments in the first place. The results call for a separate ESG disclosure and are relevant to regulators and standard setters because changes in disclosure requirements involve cost-benefit analysis (Schipper, 2010).

The efficiency implications of ESG disclosure are subtler. We show that improving ESG disclosure could shift the economy from over-investment (i.e., the firm pollutes too much to obtain higher profits) to under-investment (i.e., the firm gives up too much profits to be "clean"). We characterize the optimal precision of ESG disclosure that maximizes investment efficiency, i.e., balances the financial and environmental implications of the investment. While it is tempting to think that more ESG disclosures are desirable when shareholders are more concerned about ESG factors, we show that the intuition is incomplete because it overlooks the fact that stronger tastes for ESG change how investors use information. If we fix the precision of ESG disclosure at a level that is optimal for a given preference, stronger tastes for ESG will change investor trading in a way that inflates the firm's perceived social cost of investment more than the change to the investors' underlying tastes. Therefore, the precision of the optimal ESG disclosure decreases to undo the inflated social cost of investment that market forces impose on the firm. The paper also predicts that the optimal precision of ESG disclosure increases in the quality of non-ESG information investors observe.

Collectively, our results suggest that one can think of ESG disclosure as interventions designed to iron out inefficiency that taste-driven market forces would otherwise experience. The fact that improving ESG disclosure can move investment towards efficient goals does not mean that one should improve the disclosure. Instead, more precise ESG disclosure is needed only if market forces fail to move investment sufficiently, while less ESG disclosure is justified if market forces have gone overboard.

One limitation of our model is that we are agnostic about how ESG disclosures affect other stakeholders such as employees, customers, and suppliers. While the shareholder-centric view is standard in economic analysis, this focus is nonetheless limiting.[15] ESG disclosures are likely to influence firms' relationships with other stakeholders too, creating intangible assets or liabilities. It seems interesting to extend the idea of the model to study how ESG disclosures influence firms' relationships with other stakeholders. In addition, the model has only one firm and, hence, cannot capture the public good aspect of ESG. It would be interesting to study the role of ESG disclosures in addressing "the tragedy of the commons" (e.g., Ostrom, 1990) in a model with multiple firms.

[15]Fama (2020) argues that the focus on shareholder is due to contract cost. Hart and Zingales (2020) note that "Under Delaware law, which controls the vast majority of a corporate America, directors are elected by shareholders, and, according to Leo Strine Jr., a Delaware judge, directors owe their loyalty to those who elect them."

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A Appendix

Proof of Lemma 1. Investor's payoff function is $-exp(-\rho x_i)$, where $x_i = (v-p)q_i - sFq_i = (v-p-sF)q_i$ follows (3). Denote by $\mathcal{F}_i$ the information set investor i observes prior to trade. We know that

$$\mathbb{E}\left(x_i|\mathcal{F}_i\right) = q_i[E(v-sF|\mathcal{F}_i)-p],$$
$$\text{var}\left(x_i|\mathcal{F}_i\right) = q_i^2 \text{var}\left(v-sF|\mathcal{F}_i\right).$$

It is a known result that $\mathbb{E}[-exp(-\rho x_i)|\mathcal{F}_i] = -exp(-\rho\, CE_i)$, and $CE_i = \mathbb{E}\left(x_i|\mathcal{F}_i\right) - \frac{\rho}{2}\text{var}\left(x_i|\mathcal{F}_i\right)$ is the certainty equivalent. One can use the expressions above to obtain the following:

$$\mathbb{E}[-exp(-\rho x_i)|\mathcal{F}_i] = -exp[-\rho q_i\left(\mathbb{E}(v-sF|\mathcal{F}_i)-p\right) + \frac{\rho^2}{2}q_i^2\text{var}(v-sF|\mathcal{F}_i)].$$

Taking the first-order condition, we obtain agent i's demand conditional on her information $\mathcal{F}_i$ as

$$q_i = \frac{\mathbb{E}\left(v-sF|\mathcal{F}_i\right)-p}{\rho\,\text{var}\left(v-sF|\mathcal{F}_i\right)}, \tag{A.1}$$

and it verifies (4).

For $\mathcal{F}_i = \{p, y_i, R\}$ (i.e., without ESG disclosure), we guess and verify the following linear pricing function:

$$p = \alpha_0 + \beta v + \gamma R - \alpha_\epsilon \epsilon, \tag{A.2}$$

where the coefficients can depend on the investors' conjecture $\hat{k}$ (among other parameters of the model) but not on k, which is unobservable by assumption. Note that the price p is informationally equivalent to

$$m \doteq \frac{p-\alpha_0-\gamma R}{\beta} = v - \frac{\alpha_\epsilon}{\beta}\epsilon, \tag{A.3}$$

which is a noisy signal of v with variance $\frac{\alpha_\epsilon^2}{\beta^2\tau_\epsilon}$. To calculate investor i's demand (A.1), note that $(v - sF, y_i, m, R)$ follows a multivariate normal distribution as follows

$$\begin{bmatrix} v - sF \\ y_i \\ m \\ R \end{bmatrix} \sim N\left(\begin{bmatrix} \mu_v - s\mu_F \\ \mu_v \\ \mu_v \\ \mu_v \end{bmatrix}, \begin{bmatrix} \frac{1}{\tau_v} + \frac{s^2}{\tau_F} & \frac{1}{\tau_v} & \frac{1}{\tau_v} & \frac{1}{\tau_v} \\ \frac{1}{\tau_v} & \frac{1}{\tau_v} + \frac{1}{\tau_\eta} & \frac{1}{\tau_v} & \frac{1}{\tau_v} \\ \frac{1}{\tau_v} & \frac{1}{\tau_v} & \frac{1}{\tau_v} + \frac{\alpha_\epsilon^2}{\beta^2 \tau_\epsilon} & \frac{1}{\tau_v} \\ \frac{1}{\tau_v} & \frac{1}{\tau_v} & \frac{1}{\tau_v} & \frac{1}{\tau_v} + \frac{1}{\tau_R} \end{bmatrix} \right). \tag{A.4}$$

The conditional distribution of $v - sF$ given a realized $\mathcal{F}_i = (y_i, m, R)$ is also normal, with

$$\mathbb{E}\left(v - sF | \mathcal{F}_i\right) = \mu_v - s\mu_F + [\frac{1}{\tau_v}, \frac{1}{\tau_v}, \frac{1}{\tau_v}] \begin{bmatrix} \frac{1}{\tau_v} + \frac{1}{\tau_\eta} & \frac{1}{\tau_v} & \frac{1}{\tau_v} \\ \frac{1}{\tau_v} & \frac{1}{\tau_v} + \frac{\alpha_\epsilon^2}{\beta^2 \tau_\epsilon} & \frac{1}{\tau_v} \\ \frac{1}{\tau_v} & \frac{1}{\tau_v} & \frac{1}{\tau_v} + \frac{1}{\tau_R} \end{bmatrix}^{-1} \begin{bmatrix} y_i - \mu_v \\ m - \mu_v \\ R - \mu_v \end{bmatrix},$$

and

$$\text{var}\left(v - sF | \mathcal{F}_i\right) = \frac{1}{\tau_v} + \frac{s^2}{\tau_F} - [\frac{1}{\tau_v}, \frac{1}{\tau_v}, \frac{1}{\tau_v}] \begin{bmatrix} \frac{1}{\tau_v} + \frac{1}{\tau_\eta} & \frac{1}{\tau_v} & \frac{1}{\tau_v} \\ \frac{1}{\tau_v} & \frac{1}{\tau_v} + \frac{\alpha_\epsilon^2}{\beta^2 \tau_\epsilon} & \frac{1}{\tau_v} \\ \frac{1}{\tau_v} & \frac{1}{\tau_v} & \frac{1}{\tau_v} + \frac{1}{\tau_R} \end{bmatrix}^{-1} \begin{bmatrix} \frac{1}{\tau_v} \\ \frac{1}{\tau_v} \\ \frac{1}{\tau_v} \end{bmatrix}.$$

Substituting the conditional mean and variance into (A.1), one can solve for a market-clearing price p from the following market-clearing condition

$$\int_i q_i \, di = \epsilon, \tag{A.5}$$

and verify that the resulting market-clearing price p takes the linear form conjectured in (A.2). The equilibrium price function is determined by comparing the coefficients in the market-clearing price p obtained above to those in the conjectured (A.2). In particular, we show that the price coefficients can be characterized recursively as:

$$\beta = 1 - \frac{\alpha_0 + s\mu_F}{\mu_v}\frac{(\tau_R + \tau_v)}{\tau_v}, \gamma = \frac{\tau_R(1-\beta)}{\tau_R + \tau_v}, \alpha_\epsilon = \sqrt{\frac{\beta^2\tau_\epsilon(1-\beta)}{\beta(\tau_v + \tau_\eta + \tau_R) - \tau_\eta}}, \tag{A.6}$$

and α_0 is the unique real root of a cubic polynomial, whose expression is omitted for brevity. Substituting $R = v + \zeta$ into (A.2) and letting $\alpha_v = \beta + \gamma$ and $\alpha_R = \gamma$, we rewrite the price function as shown in the Lemma:

$$p = \alpha_0 + \alpha_v v + \alpha_R \zeta - \alpha_\epsilon \epsilon. \tag{A.7}$$

Straightforward algebra verifies $\frac{d\alpha_0}{d\mu_F} = -s$ and $\frac{d\alpha_v}{\mu_F} = \frac{d\alpha_v}{\mu_v} = 0$ (after substituting α_0). Further, it follows $E[p] = \alpha_0 + \alpha_v\mu_v = \mu_v - s\mu_F$, from which we know $\frac{dE[p]}{ds} < 0$. ■

Proof of Proposition 1. Given the price function $p = \alpha_0 + \alpha_v v + \alpha_R\zeta - \alpha_\epsilon\epsilon$ shown in (A.7), we can express the expected price as follows:

$$E[p|k, \hat{k}] = \alpha_0(\hat{k}) + \alpha_v E[v|k].$$

The expression is a function of the actual investment k chosen by the firm and the investors' conjecture $\hat{k}$, which enters the intercept α_0 via $\mu_v(\hat{k}) = \lambda\hat{k} - \frac{\hat{k}^2}{2}$ and $\mu_F(\hat{k}) = f(\hat{k})$. It follows that

$$\frac{dE[p|k, \hat{k}]}{dk} = \alpha_v \frac{dE[v|k]}{dk}.$$

The derivation above uses the fact that the firm takes the price coefficients α_v as given and, hence, cannot change it by choosing a different k. Substituting $E[v|k] = \lambda k - \frac{k^2}{2}$ from (1), we rewrite the first-order condition characterizing $k^\emptyset$ as

$$\alpha_v \left(\lambda - k^\emptyset\right) = 0, \tag{A.8}$$

from which we conclude $k^\emptyset = \lambda$. To complete the characterization of the equilibrium, we apply rational expectations by letting $\hat{k} = k^{\emptyset} = \lambda$ solved above. This ensures that the endogenous beliefs $\mu_v(\hat{k}) = \lambda\hat{k} - \frac{\hat{k}^2}{2}$ and $\mu_F(\hat{k}) = f(\hat{k})$ that investors hold are correct in equilibrium. ■

Proof of Corollary 1. Reasoning of the result follows Bagwell (1995) and is summarized in the text. We sketch the idea by conjecturing a linear price function as follows:

$$p = \alpha_0 + \beta v + \gamma R - \alpha_\epsilon \epsilon + \alpha_I g(I),$$

where $g(I)$ is a real-valued function of the reported investment $I = k + \omega$. Observing p is informationally equivalent to knowing $m = \frac{p - \alpha_0 - \gamma R - \alpha_I g(I)}{\beta} = v - \frac{\alpha_\epsilon}{\beta}\epsilon$. From an investor's point of view, $(v - sF, y_i, m, R, I)$ follows a multivariate normal distribution:

$$\begin{bmatrix} v - sF \\ y_i \\ m \\ R \\ I \end{bmatrix} \sim N\left(\begin{bmatrix} \lambda\hat{k} - \frac{\hat{k}^2}{2} - sf(\hat{k}) \\ \lambda\hat{k} - \frac{\hat{k}^2}{2} \\ \lambda\hat{k} - \frac{\hat{k}^2}{2} \\ \lambda\hat{k} - \frac{\hat{k}^2}{2} \\ \hat{k} \end{bmatrix}, \begin{bmatrix} \frac{1}{\tau_v} + \frac{s^2}{\tau_F} & \frac{1}{\tau_v} & \frac{1}{\tau_v} & \frac{1}{\tau_v} & 0 \\ \frac{1}{\tau_v} & \frac{1}{\tau_v} + \frac{1}{\tau_\eta} & \frac{1}{\tau_v} & \frac{1}{\tau_v} & 0 \\ \frac{1}{\tau_v} & \frac{1}{\tau_v} & \frac{1}{\tau_v} + \frac{\alpha_\epsilon^2}{\beta^2 \tau_\epsilon} & \frac{1}{\tau_v} & 0 \\ \frac{1}{\tau_v} & \frac{1}{\tau_v} & \frac{1}{\tau_v} & \frac{1}{\tau_v} + \frac{1}{\tau_R} & 0 \\ 0 & 0 & 0 & 0 & \frac{1}{\tau_\omega} \end{bmatrix} \right). \quad \text{(A.9)}$$

The last column of the covariance matrix echoes the result that "noisy signals of endogenous actions have no information content" (using the language in Kanodia et al., 2005). In particular, investors take their equilibrium conjecture $\hat{k}$ as given and attribute any difference between I and $\hat{k}$ to the noise term ω, which is independent of other random variables in the model.

We calculate $q_i = \frac{\mathbb{E}(v - sF|\mathcal{F}_i) - p}{\rho \operatorname{var}(v - sF|\mathcal{F}_i)}$ and show $\frac{dq_i}{d\tau_\omega} = 0$ for any $0 < \tau_\omega < \infty$. One can verify that $\alpha_I = 0$ in the conjectured price function $p = \alpha_0 + \beta v + \gamma R - \alpha_\epsilon \epsilon + \alpha_I g(I)$ and other coefficients are the same as those in (A.2) of Lemma 1. Therefore, the firm chooses the same k as in Proposition 1. ■

Proof of Proposition 2. The investment $k^{\emptyset}$ without ESG disclosure is characterized in Proposition 1. Claim 1 below summarizes the investment k^P under perfect ESG disclosure.

Claim 1 *Investment* k^P *is determined from* $\frac{\tau_R+\tau_\eta+\tau_p}{\tau_R+\tau_v+\tau_\eta+\tau_p}(\lambda - k^P) - sf'(k^P) = 0$.

Proof of Claim 1. We characterize equilibrium in three steps. In the first step, we reason from the investors' perspective and solve for the linear pricing function, taking the investors' conjecture $\hat{k}$ as given. In particular, we guess and verify the following linear pricing function:

$$p = \alpha_0 + \beta_v v + \gamma R - \alpha_F F - \alpha_\epsilon \epsilon, \tag{A.10}$$

where the coefficients can depend on the conjectured $\hat{k}$ but not on the actual k.

When firm carbon footprint F is perfectly revealed, investors' trading decision degenerates to trading an asset with only *one* uncertain fundamental v. This is the case studied in most prior REE models, and we follow standard process and characterize price coefficients in closed-form as follows:[16]

$$\begin{aligned}\alpha_0 = \frac{\tau_v}{\tau_v + \tau_R + \tau_\eta + \tau_p}(\lambda\hat{k} - \frac{\hat{k}^2}{2}),\ \beta = \frac{\tau_\eta + \tau_p}{\tau_v + \tau_R + \tau_\eta + \tau_p},\\ \gamma = \frac{\tau_R}{\tau_v + \tau_R + \tau_\eta + \tau_p}, \alpha_F = s, \alpha_\epsilon = \frac{1}{r\tau_\eta}\frac{\tau_\eta + \tau_p}{\tau_v + \tau_R + \tau_\eta + \tau_p},\end{aligned}$$

where $\tau_p = (\tau_\eta r)^2 \tau_\epsilon$ is the precision of price used as an independent signal of v and $r = 1/\rho$. (One can also obtain the price coefficients shown above by substituting $\tau_F \to \infty$ to Lemma 1 and replacing prior μ_F with the perfectly disclosed F.) Substituting $R = v + \zeta$ into (A.11), we rewrite the price function as follows by letting $\alpha_v = \beta + \gamma$ and $\alpha_R = \gamma$:

$$p = \alpha_0 + \alpha_v v + \alpha_R \zeta - \alpha_F F - \alpha_\epsilon \epsilon. \tag{A.11}$$

In the second step, we reason from the firm's point of view. The firm takes the market conjecture $\hat{k}$ and the pricing function (A.11) as given and chooses k to maximize expected price, i.e.,

$$\max_k \mathbb{E}[p|\hat{k}, k] = \alpha_0(\hat{k}) + \alpha_v E[v|k] - \alpha_F E[F|k].$$

[16] See, for example, Xue and Zheng (2021) Proposition 1 for a detailed derivation.

Substituting price coefficients from above, we differentiate $\mathbb{E}[p|\hat{k}, k]$ with respect to k and obtain the first-order condition that characterize the optimal k^P as follows:

$$\frac{\tau_R + \tau_\eta + \tau_p}{\tau_R + \tau_v + \tau_\eta + \tau_p}(\lambda - k^P) - sf'(k^P) = 0, \tag{A.12}$$

as stated in Claim 1.

In the third step, we impose rational expectations, i.e., setting $\hat{k} = k^P$ as characterized in (A.12). This ensures that investors' prior belief $\mu_v(\hat{k}) = \lambda\hat{k} - \frac{\hat{k}^2}{2}$ is correct in equilibrium and, hence, the conjectured price function is correct in equilibrium. ■

Having shown Claim 1, we prove the result by comparing the conditions used to determine investments $k^\emptyset$ (under no-ESG disclosure) and k^P (under perfect ESG disclosure) to the condition below that characterize the efficient k^{FB} (derived in the text):

$$\lambda = k^{FB} + sf'(k^{FB}) \tag{First-best}$$

It follows from Proposition 1 and Equation (A.12) that we can express the first-order conditions used to determine $k^\emptyset$ and k^P as

$$\lambda = k^\emptyset, \tag{No ESG disclosure}$$

and

$$\lambda = k^P + \left(1 + \frac{\tau_v}{\tau_R + \tau_\eta + \tau_p}\right) sf'(k^P). \tag{Perfect ESG disclosure}$$

The right-hand sides of the two first-order conditions above are the marginal cost of investment perceived by the firm, and λ on the left-hand sides is the perceived marginal benefit. Comparing (First-best) and (No ESG disclosure), one can see that the firm fails to internalize the investors' disutility $sf'(k^{FB})$ tied to F in the absence of ESG disclosure. This explains the over-investment result $k^\emptyset > k^{FB}$. In contrast, the $\left(1 + \frac{\tau_v}{\tau_R+\tau_\eta+\tau_p}\right)$ term in (Perfect ESG disclosure) means that the firm's perceived marginal cost of investment is inflated relative to that in the efficient benchmark, resulting in an under-investment $k^P < k^{FB}$. The finding $k^P < k^{FB} < k^\emptyset$

verifies the proposition. ■

Proof of Lemma 2. The equilibrium for a given $\tau_\xi \geq 0$ is solved in three steps. We first solve for the linear pricing function, taking the market conjecture $\hat{k}$ as given. In the second step, we endogenize the firm's investment choice k, taking the investors' conjecture $\hat{k}$ and the price function as given. The equilibrium is then determined after imposing rational expectations, i.e., $\hat{k} = k$.

For $\mathcal{F}_i = \{p, y_i, R, D\}$ (i.e., with ESG disclosure $D = F + \xi$), we guess and verify the following linear pricing equilibrium:

$$p = \alpha_0 + \beta v + \gamma R - \alpha_F D - \alpha_\epsilon \epsilon, \tag{A.13}$$

The market price p is informationally equivalent to

$$m = \frac{p - \alpha_0 - \gamma R + \alpha_F D}{\beta} = v - \frac{\alpha_\epsilon}{\beta}\epsilon, \tag{A.14}$$

which is a noisy signal of profits v with variance $\frac{\alpha_\epsilon^2}{\beta^2 \tau_\epsilon}$. To calculate an investor's demand $q_i = \frac{\mathbb{E}(v - sF|\mathcal{F}_i) - p}{\rho \operatorname{var}(v - sF|\mathcal{F}_i)}$ in (4), we know that $(v - sF, y_i, m, D, R)$ follows a multivariate normal distribution as follows:

$$\begin{bmatrix} v - sF \\ y_i \\ m \\ D \\ R \end{bmatrix} \sim N \left(\begin{bmatrix} \lambda\hat{k} - \frac{\hat{k}^2}{2} - sf(\hat{k}) \\ \lambda\hat{k} - \frac{\hat{k}^2}{2} \\ \lambda\hat{k} - \frac{\hat{k}^2}{2} \\ f(\hat{k}) \\ \lambda\hat{k} - \frac{\hat{k}^2}{2} \end{bmatrix}, \begin{bmatrix} \frac{1}{\tau_v} + \frac{s^2}{\tau_F} & \frac{1}{\tau_v} & \frac{1}{\tau_v} & -s\frac{1}{\tau_F} & \frac{1}{\tau_v} \\ \frac{1}{\tau_v} & \frac{1}{\tau_v} + \frac{1}{\tau_\eta} & \frac{1}{\tau_v} & 0 & \frac{1}{\tau_v} \\ \frac{1}{\tau_v} & \frac{1}{\tau_v} & \frac{1}{\tau_v} + \frac{\alpha_\epsilon^2}{\beta^2\tau_\epsilon} & 0 & \frac{1}{\tau_v} \\ -s\frac{1}{\tau_F} & 0 & 0 & \frac{1}{\tau_F} + \frac{1}{\tau_\xi} & 0 \\ \frac{1}{\tau_v} & \frac{1}{\tau_v} & \frac{1}{\tau_v} & 0 & \frac{1}{\tau_v} + \frac{1}{\tau_R} \end{bmatrix} \right). \tag{A.15}$$

Note that $\hat{k}$ does not enter the variance-covariance matrix because the investors treat their equilibrium conjecture $\hat{k}$ as a constant.

Following similar steps illustrated in Lemma 1, we can characterize the conditional distribution of $v-sF$ given $\mathcal{F}_i=(y_i,m,R,D)$. That is, we calculate $\mathbb{E}(v-sF|\mathcal{F}_i)$ and $\operatorname{var}(v-sF|\mathcal{F}_i)$ given $\mathcal{F}_i=(y_i,m,R,D)$, and, hence investor i's demand $q_i=\frac{\mathbb{E}(v-sF|\mathcal{F}_i)-p}{\rho\operatorname{var}(v-sF|\mathcal{F}_i)}$. A market-clearing price p is obtained from $\int_i q_i\,di=\epsilon$, and we characterize the linear price function by comparing the price coefficients in the market-clearing price p obtained above to those in (A.13).

To simplify notation, let $\hat{\mu}_v\equiv\lambda\hat{k}-\frac{\hat{k}^2}{2}$ and $\hat{\mu}_F\equiv f(\hat{k})$ be the investors' prior mean of profits and emissions as a function of their conjecture $\hat{k}$ (to be solved endogenously). We obtain

$$
\begin{aligned}
\beta &= 1-\frac{\alpha_0+\frac{s\hat{\mu}_F\tau_F}{\tau_F+\tau_\xi}}{\hat{\mu}_v}\times\frac{\tau_R+\tau_v}{\tau_v},\quad \gamma=\frac{\tau_R(1-\beta)}{\tau_R+\tau_v},\\
\alpha_\epsilon &= \sqrt{\frac{\beta^2\tau_\epsilon(1-\beta)}{\beta(\tau_v+\tau_\eta+\tau_R)-\tau_\eta}},\quad \alpha_F=\frac{\tau_\xi}{\tau_\xi+\tau_F}s,
\end{aligned}
$$

and α_0 is the unique real root of a cubic polynomial, whose expression is omitted for brevity. Substituting $R=v+\zeta$ into (A.13), we rewrite price function as follows by and letting $\alpha_v=\beta+\gamma$ and $\alpha_R=\gamma$:

$$
p=\alpha_0+\alpha_v v+\alpha_R\zeta-\alpha_F F-\alpha_\epsilon\epsilon. \tag{A.16}
$$

Substituting α_0 into α_v above, one can verify that the coefficients satisfies $\frac{d\alpha_v}{d\hat{\mu}_F}=\frac{d\alpha_v}{d\hat{\mu}_v}=0$. We can therefore conclude

$$
\frac{d\alpha_v}{d\hat{k}}=\frac{d\alpha_R}{d\hat{k}}=\frac{d\alpha_\epsilon}{d\hat{k}}=\frac{d\alpha_F}{d\hat{k}}=0. \tag{A.17}
$$

That is, the investors' conjecture $\hat{k}$ only affects the intercept α_0 in the price function (A.16) via $\hat{\mu}_F$ and $\hat{\mu}_v$, while other coefficients (i.e., $\alpha_v,\alpha_R,\alpha_\epsilon$, and α_F) are independent of $\hat{k}$. In addition, straightforward but tedious algebra verifies

$$
\frac{d\alpha_F}{d\tau_\xi}>0\text{ and }\frac{d\alpha_v}{d\tau_\xi}>0.
$$

In the second step, we endogenize the investment. The firm takes market conjecture $\hat{k}$ and the price function (A.16) as given and chooses k to maximize the following (recall $D=F+\xi$

and $E[\xi] = 0$):

$$\mathbb{E}[p|\hat{k}, k] = \alpha_0(\hat{k}) + \alpha_v E[v|k] - \alpha_F E[F|k].$$

When choosing investment k, the firm takes the price function (hence, the price coefficients) as given. It follows

$$\frac{dE[p|k, \hat{k}]}{dk} = \alpha_v \frac{dE[v|k]}{dk} - \alpha_F \frac{dE[F|k]}{dk}.$$

The first-order condition characterizing the optimal k^* is $\alpha_v(\tau_\xi)(\lambda - k^*) - \alpha_F(\tau_\xi)f'(k) = 0$, which can be restated as

$$\lambda = k^* + \frac{\alpha_F(\tau_\xi)}{\alpha_v(\tau_\xi)} f'(k^*). \tag{A.18}$$

Recall from (A.17) that $\frac{\alpha_F(\tau_\xi)}{\alpha_v(\tau_\xi)}$ is independent of $\hat{k}$. Therefore, we can treat $\frac{\alpha_F(\tau_\xi)}{\alpha_v(\tau_\xi)}$ as a constant and solve the equilibrium k^* from the first-order condition above without worrying about an additional fixed-point problem involving $\frac{\alpha_F(\tau_\xi)}{\alpha_v(\tau_\xi)}$.

Having characterized $k^*(\tau_\xi)$, we impose rational expectations $\hat{k} = k^*(\tau_\xi)$. This ensures that the prior beliefs $\mu_v(\hat{k}) = \lambda\hat{k} - \frac{\hat{k}^2}{2}$ and $\mu_F(\hat{k}) = f(\hat{k})$ that investors hold are correct in equilibrium, and, hence, the conjectured price function coincides with the actual market-clearing price. ■

Proof of Proposition 3. Comparing the first-order condition (A.18) to $\lambda = k^{FB} + sf'(k^{FB})$ in (First-best), we note that the two conditions will be the same if there exists a τ_ξ^* such that

$$\frac{\alpha_F(\tau_\xi^*)}{\alpha_v(\tau_\xi^*)} = s.$$

Using the price coefficients in Lemma 2, we solve τ_ξ^* as

$$\tau_\xi^* = \tau_F \left(\frac{r^2 \tau_F^2 \tau_\eta^2 \tau_\epsilon}{(s^2 \tau_v + \tau_F)^2} + \tau_\eta + \tau_R \right) \tau_v^{-1}.$$

where $r = \frac{1}{\rho}$ is the inverse of the investors' risk-aversion ρ. ■

Proof of Proposition 4. Straightforward algebra shows

$$\frac{d\tau_\xi^*}{ds} = -\frac{4sr^2\tau_F^3\tau_\eta^2\tau_\epsilon}{(\tau_F + s^2\tau_v)^3} < 0,$$

which verifies the proposition. ■

Proof of Proposition 5. Straightforward algebra shows

$$\frac{d\tau_\xi^*}{d\tau_\eta} = \frac{1 + \frac{2r^2\tau_F^2\tau_\eta\tau_\epsilon}{(\tau_F+s^2\tau_v)^2}}{\tau_v}\tau_F > 0,$$

and

$$\frac{d\tau_\xi^*}{d\tau_R} = \frac{\tau_F}{\tau_v} > 0.$$

which verifies the proposition. ■

Proof of Proposition 6. The proof follows similar steps shown in the proof of Lemma 2. So, we only sketch the main steps of the argument. Given a precision $\tau_\xi \geq 0$ of ESG disclosure, the linear price function takes the form of $p = \alpha_0 + \alpha_v v + \alpha_R \zeta - \alpha_F D - \alpha_\epsilon \epsilon$, as shown in (A.16). Denote by $\hat{\mu}_v \equiv \lambda \hat{k} - \frac{\hat{k}^2}{2} - \frac{\hat{c}^2}{2}$ and $\hat{\mu}_F \equiv f(\hat{k}) - g(\hat{c})$ the prior mean of profits and emissions as a function of investors' conjecture $\hat{k}$ and $\hat{c}$, which will be solved endogenously. Same steps shown in (A.17) can be used to show that the investors' conjecture $\hat{k}$ and $\hat{c}$ only affect the intercept α_0 in the price function via $\hat{\mu}_F$ and $\hat{\mu}_v$, but not other price coefficients: $\alpha_v, \alpha_R, \alpha_\epsilon$, or α_F.

The firm takes the linear price function as given and chooses k and c to maximize

$$\mathbb{E}[p|\hat{k}, \hat{c}, k, c] = \alpha_0(\hat{k}, \hat{c}) + \alpha_v E[v|k, c] - \alpha_F E[F|k, c],$$

where we use $D = F + \xi$ and $E[\xi] = 0$.

When choosing investment k, the firm takes the price coefficients as given. It follows that

$$\frac{dE[p|\hat{k}, \hat{c}, k, c]}{dk} = \alpha_v \frac{dE[v|k, c]}{dk} - \alpha_F \frac{dE[F|k, c]}{dk},$$

and

$$\frac{dE[p|\hat{k}, \hat{c}, k, c]}{dc} = \alpha_v \frac{dE[v|k, c]}{dc} - \alpha_F \frac{dE[F|k, c]}{dc}.$$

The first-order conditions that characterize the optimal k^* and c^* are

$$\lambda = k^* + \frac{\alpha_F(\tau_\xi)}{\alpha_v(\tau_\xi)} f'(k^*),$$

and

$$c^* = \frac{\alpha_F(\tau_\xi)}{\alpha_v(\tau_\xi)} g'(c).$$

We show in the text that k^{FB} and c^{FB} are determined from $\lambda = k^{FB} + sf'(k^{FB})$ and $c^{FB} = s\, g'(c^{FB})$, respectively. It is clear that if there exists a precision τ_ξ^* under which $\frac{\alpha_F(\tau_\xi^*)}{\alpha_v(\tau_\xi^*)} = s$, the firm's investments k^* and c^* will coincide with the investors' preferred k^{FB} and c^{FB}. Note that the solution τ_ξ^* to $\frac{\alpha_F(\tau_\xi^*)}{\alpha_v(\tau_\xi^*)} = s$ is characterized in Proposition 3. ■