ESG Disclosure, Market Forces, and Firm Investment

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Abstract

This paper examines the impact of Environmental, Social, and Governance (ESG) disclosure on firm investment. I identify conditions under which ESG disclosure is needed to channel investors' tastes for ESG into firm investment, and 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, I show this intuition is incomplete because it overlooks the fact that stronger tastes for ESG change how investors use information. Extending the analysis to a large economy, I show that mandating more precise climate disclosure than would be voluntarily provided motivates self-interested firms to act on common interests in reducing emissions. That is, a regulator can leverage disclosure mandate to achieve a similar result as a Pigovian tax in motivating firms to internalize the externalities of climate-related investments.

Keywords: ESG investing; Delegated philanthropy; Tragedy of the commons; 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 social goals, such as delivering value to customers or investing in 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. 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 (EU) 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 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 are not well-understood and difficult to predict (Christensen et al., 2021). Many important questions are unanswered. First, whether and when is ESG disclosure needed for the purpose of ensuring the firm makes investment in accordance with shareholders' tastes for ESG? Second, does an increasing emphasis on ESG necessarily mean we need more precise disclosure? Third, under what circumstances should ESG disclosure be mandated rather than left to the discretion of individual firms? This paper presents a model intended to address these questions, which relate to the demand, the design, and the implementation of ESG disclosure.

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 tradeoff between maximizing profits and ESG performance, higher investments are assumed to generate, on average, higher emissions. (The argument also holds for "green" investments that reduce emissions at a cost.) Investors care about both financial and environmental implications of the investment, as in Hart and Zingales (2017). The firm chooses its investment to maximize its stock price. Price is formed in a noisy rational expectation equilibrium model populated with a continuum of risk-averse investors. Investors do not observe firm investment, and they rely on private and public signals to assess firm profit and ESG performance prior to trading.

Consistent with prior studies, I show that "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 disconnection is caused by

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

investors not observing firm investment choices. If there is no signal about a firm's emissions, pricing of emissions can only be based on the conjectured level, which, in turn, depends on the conjectured investment. While price is correct *in equilibrium*, the absence of information about firm emissions makes its price non-responsive to a change in the realized emissions. The firm responds by choosing a profit-maximizing investment regardless of how strongly investors care about ESG. Investors anticipate this choice and price the firm accordingly. This is where ESG disclosure can help: it makes price responsive to the actual emissions, restoring the ability of market price to channel investors' pro-ESG tastes into firm investment decisions.

The efficiency implications of ESG disclosure are subtler. Strict ESG disclosure requirement could shift the firm from polluting too much to giving up too much profits to be "clean". I characterize the optimal precision of ESG disclosure. The optimal 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), this paper shows that ESG disclosure plays a crucial role in determining the efficiency of the delegation. The thinking behind "delegated philanthropy" also relates to the goal congruency literature, which studies the design of performance measures to align incentives in principal-agent settings (e.g., Reichelstein, 1997; Dutta and Reichelstein, 2005).[3]

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, a lower weight on financial returns). I 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). Once we account for interactions with market forces, I show that the optimal precision of ESG disclosure often decrease as investors become more

[3]Arya et al. (2022) examine the information content of insiders' tax-motivated philanthropic behavior, i.e., share donations.

ESG concerned. Intuitively, if we fix the quality of ESG disclosure at a level that is optimal for a given preference, a stronger taste for ESG changes how investors use their information (hence, pricing of 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. A better approach is to 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.

The model is extended to shed light on the ongoing debate about mandating climate disclosure.[4] In particular, I extend the analysis to a large economy, and model the externalities of firms' climate-related investments by assuming that an increase in *total* emissions decreases firms' productivities (or increases their operating costs). While a lower total emissions would benefit all firms, each firm has incentives to free-ride on others' emission-cutting efforts. The equilibrium has firms pollute more than the socially optimal level — a standard result akin to "the tragedy of the commons." My contribution relates to firms' disclosure choices. I show the free-rider problem underlying firms' investment decisions percolates into their voluntary disclosure choices. That is, even if a firm's disclosure is costless and is uninformative about other firms, there will still be an under-provision of climate disclosure and over-pollution if disclosure is voluntary. In this case, mandating a more precise climate disclosure than would be voluntarily provided motivates self-interested firms to act on common interests in reducing emissions. The result indicates that the regulator can leverage disclosure mandate and market forces jointly to achieve similar results as a Pigovian tax in motivating firms to internalize the externalities of their climate-related investments.

Literature. The way I model ESG activities follows the view that CSR is a "delegated

[4]Christensen et al. (2021) write: "the current policy debate in the U.S. revolves largely around the question of a mandate that explicitly impose CSR reporting requirements on companies".

philanthropy" (e.g., Bénabou and Tirole, 2010; Tirole, 2017). Considering investors' pro-ESG *tastes* has been a defining feature in models studying ESG investing (e.g., Fama, 2020; Pástor et al., 2021). This paper highlights interdependencies between ESG disclosure and market forces (i.e., price effect of tastes) in motivating sustainable investments. On the one hand, I show that ESG disclosure is necessary to ensure that firms invest in accordance with investors' pro-ESG tastes. On the other hand, investors' tastes determine how they use information. In particular, it is logically incomplete to say that more precise ESG disclosure is desirable simply because investors care more about it. The other result is that disclosure mandate can be leveraged to create tax-like incentives in dealing with externalities of firms' climate-related investments. This finding has regulatory implications as a reporting mandate is often viewed as less intrusive than imposing taxes (e.g., Christensen et al., 2021).

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. They show that polling the investors through a referendum allows shareholders to honestly express their social objectives. 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. Chowdhry et al. (2019) study how a pro-social investor counters a profit-focused owner's tendency to overemphasize profits via joint financing. Friedman and Heinle (2021) study the free-riding problem atomistic shareholders face in carrying out costly governance activities. Bonham and Riggs-Cragun (2022) show ESG efforts can be motivated by incorporating ESG metrics in executive compensation contracts.[5]

In the models discussed above, shareholders influence firm actions through "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

[5] De Bettignies and Robinson (2018) study a model in which a government imposes a cap on "pollution". They show the profit-seeking firm can simultaneously lobby for a loose cap and hire socially responsible employees.

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. They introduce uncertainty about the manager's objective function and study strategic misreporting of the ESG performance in a way analogous to earnings management. I do not consider misreporting. My focus is to study how the precision of ESG disclosure affects firm investment and the related efficiency implications.

My results on mandatory climate disclosure is related to Admati and Pfleiderer (2000) and Dye (1990) who show the value of mandating more precise disclosure than firms' voluntary choice. In their studies, one firm's disclosure is informative about other firms' valuation. Smith (2023) compares mandatory and voluntary disclosure from a risk-sharing perspective. The mechanism behind this paper is different because a firm's disclosure is uninformative about others and there is no diversification benefit in the model. Instead, it is the free-rider problem underlying firms' investment decisions that causes an under-provision of voluntary disclosure. This mechanism complements prior studies and speaks specifically to the challenge that firms face in reducing emissions. In this regard, Ostrom (1990) reviews models studying problems that individuals face when governing the common good, as is the case with reducing emissions, and concludes that: "At the heart of each of these models is the free-rider problem."

On the technical side, Goldstein and Yang (2015) and Pástor et al. (2021) study noisy rational expectation equilibrium models that feature multiple fundamentals. They focus on asset pricing and price informativeness, while assuming exogenous distributions of the fundamentals. In contrast, the multiple fundamentals in this paper – profits and emissions – depend on an endogenous investment. (This model is simpler in other aspects, e.g., there are no heterogeneous beliefs.) Modeling the dual impacts of firm investment is intended to capture "situations where profit and social consequences are inextricably connected (Hart and Zingales, 2020)."[6]

The remainder of the paper proceeds as follows. Section 2 presents the model. Section 3

[6] Hart and Zingales (2020) argue that CSR is more relevant in this case. They writes: "Friedman acknowledged that shareholders might have ethical concerns, but he implicitly assumed that a company's profit and social objectives are separable. This is true for the example he used in his article: corporate charity. ... But we are interested in situations where profit and social consequences are inextricably connected."

illustrates the demand for ESG disclosure, and Section 4 derives its optimal precision. Section 5 illustrates why investors caring more about ESG does not mean that more precise disclosure is desirable. Extending to a large economy, Section 6 offers a rationale for mandating more precise climate disclosure than would be voluntarily provided. Section 7 presents extensions (e.g., including a carbon-reducing investment), and Section 8 concludes.

2 Model Setup

The model consists of a continuum of investors and a firm that chooses an investment $k \geq 0$. (A multi-firm setting is analyzed in Section 6.) 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.

The first building block of the model is that firms face a tradeoff between maximizing profits and ESG performance. To capture the tradeoff simply, I assume that, on average, larger investments impose a greater impact on the firm's ESG performance F as follows:

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

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 and building oil-producing facilities. The negative ESG consequence, F, can be thought of as the potential health hazard or as greenhouse gas (GHG) emissions. The assumption $f'(k) > 0$ 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. I allow for any increasing function $f(k)$ satisfying $f(0) = f'(0) = 0$ and $f''(k) \geq 0$.

While the main model considers an investment with negative ESG consequence, this choice is solely to facilitate exposition. In Section 7, I add a "green" investment that has positive ESG consequences (e.g., reducing GHG emissions), and obtain essentially the same results there. The key tension underlying the mechanism is that firm faces a tradeoff between maximizing profit and maximizing ESG performance. For example, carbon capturing is good for ESG but is costly to implement. This tension aims to capture "situations where profit and social consequences are inextricably connected (Hart and Zingales, 2020)."

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). 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 utility function with a common risk-aversion parameter $\rho > 0$. Noise traders supply ϵ units of the firm's share per capita, where $\epsilon \sim N(0, \tau_\epsilon^{-1})$ is normally distributed with a precision τ_ϵ.

The second building block of the model is that it incorporates investors' pro-ESG tastes into a canonical REE model, which typically assumes that investors only care about financial returns. 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 price p and receives the profit v. Following Pástor et al. (2021) and Goldstein et al. (2022), I use the following specification to incorporate investors' disutility associated with investing q_i shares into a firm with emissions, F:

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

The parameter $s \geq 0$ captures investor ESG tastes/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 emissions F. The idea is, given the firm's total emissions, a pro-ESG investor bears more disutility if she owns a higher percentage of the firm (i.e., a higher q_i).

Some discussion of investors' preference 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. One can incorporate the disutility that investor i suffers due to her physical consumption of emissions into Equation (3) by substracting another term that is tied to the emissions F but is *independent* of her shareholding q_i. I have verified that this additional term does not qualitatively change the equilibrium analysis.[7] Further, substituting x_i in (3) into the utility function $-exp(-\rho x_i)$ implicitly assumes that investors are averse to the risks in their exposure to the firm's ESG performance. The risk-averse assumption 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 to be also consistent with regulators' view, such as the SEC, that a main role of ESG disclosure is to help investors better understand their exposures to ESG-related risks.

I assume that investors do not directly observe the firm's investment choice k. Besides the usual justifications for unobservable investment (e.g., Kanodia and Lee, 1998; Kurlat and Veldkamp, 2015), firms may have incentives and means to hide from the public about investments that have negative ESG consequences. For example, Purdue Pharma and McKinsey & Company have been secretive about the program they developed to target doctors who are likely to prescribe opioids in large quantities. McKinsey started to work for Purdue in 2004, but the program remained largely unknown before the opioid crisis triggered intense legal investigations in recent years. The House Committee on Oversight and Reform repeatedly criticized the lack of transparency during the investigation process, which McKinsey defended based on client confidentiality agreements.[8]

Investors rely on public and private signals to assess the firm's profit v and ESG performance F for their trading decisions. The firm issues an earnings report $R = v + \zeta$ prior to trading. I

[7]Incorporating the extra term 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.

[8]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, see https://oversight.house.gov/news/press-releases/oversight-committee-grills-mckinsey-company-on-its-role-in-nation-s-opioid.

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, I assume in the main model that information about the firm's ESG performance F comes solely from its ESG disclosure. In Appendix B, I consider investors' private signals about F and demonstrate the robustness of the main results. The sequence of events is as follows.

- At $t = 0$, disclosure quality is specified.
- At $t = 1$, the firm chooses its investment k.
- At $t = 2$, investors trade after observing signals about v and F; market price is formed.
- At $t = 3$, uncertainties are revealed, and players consume.

A premise of the paper is that certain stakeholders care about firm emissions. The main model focuses on shareholders' social awareness, which is standard in models studying ESG investing (e.g., Hart and Zingales, 2017; Zerbib, 2019; Pástor et al., 2021). Section 7 presents an alternative setup in which a firm's emissions prompt *other stakeholders*, such as customers, to take actions that negatively affects firm's future cash flow (e.g., via reduced market demand for carbon-intensive products). I obtain similar results under the alternative setup in which investors are concerned only about the *financial* implications of the emissions.

3 Demand for ESG Disclosure

This section assumes away any ESG disclosure, and illustrates when such a disclosure is needed to ensure the firm makes investment in accordance with investors' tastes for ESG. I start the analysis with taking the distribution of the firm profit v and carbon emissions F as given and examining the price effect of the investors' pro-ESG tastes.

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 emission F.

Integrating q_i over the continuum of investors and imposing the market-clearing condition, $\int_i q_i \, di = \varepsilon$, I 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 $F \sim N(\mu_F, \tau_F^{-1})$. I 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 consistent with Pástor et al. (2021). Two features of the price function are nothworthy. First, the market-clearing price correctly aggregates investors' trade-offs between financial returns and ESG considerations. 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. In addition, the relative weight, s, placed on the emissions matches the investors' taste for ESG in (3). Second, the *taste-driven price reaction* $\frac{dE[p]}{ds} < 0$ is consistent with the intuition that emissions will be punished more severely when investors are more ESG concerned. 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 in the absence of ESG disclosure.

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 breakdown is caused by investors not directly observing firm investment. 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. This can be seen by examining the price function in Lemma 1 and expressing the expected price as $E[p] = \alpha_0(\hat{k}) + \alpha_v E[v|k]$, where $\hat{k}$ is the investors's conjectured investment. If there is no signal about firm's actual/realized emissions F, emissions can only be priced based on the conjectured level via the intercept $\alpha_0(\hat{k})$ as a function of the conjectured investment, $\hat{k}$. The firm takes investors' conjecture $\hat{k}$ as given and, hence, cannot change the expected price drop, $\alpha_0(\hat{k})$. In other words, the lack of information 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. The firm ends up choosing a profit-maximizing investment, $k = \lambda$, and discards its environmental implications. Investors anticipates this investment choice and price the firm accordingly.[9]

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

[9] Adding idiosyncratic private signals about F would partially restore the connection between the investors' tastes and firm's investment choice. 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 realized ESG performance, F. In Appendix B, I show that considering private signals about F does not qualitatively change the design of the public ESG disclosure.

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.

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. When 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 worth reconciling my results to prior studies that argue the disciplinary role of market forces (e.g., Fama, 2020; Friedman and Heinle, 2016). All these models assume that the prior distribution of ESG performance is publicly observed, which, in a model with endogenous investments, is equivalent to assuming that investments are observed by external investors. If firm investment were observable in this paper, market forces *alone* (i.e., the price effect of tastes $\frac{dE[p]}{ds} < 0$) would be sufficient to motivate the efficient investment, and there would be *no need* for disclosing the firm's ESG performance F. What I have shown in this section is that, for investments that are not perfectly observed by outside investors, 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 even if they are correlated after the fact. These results call for a separate disclosure of firms' ESG performance, F.

4 Design of ESG Disclosure

This section studies how ESG disclosure affects firm investment 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 the sustainable k^{FB} from maximizing $E[v(k) - sF(k)]$ alone. The first-order condition is

$$\lambda = k^{FB} + sf'(k^{FB}). \tag{7}$$

The next question is, can we choose the precision of ESG disclosure so that the firm, by maximizing its price, undertakes the investment k^{FB} that investors would choose themselves? To answer the question, I first establish the equilibrium for a given precision $\tau_\xi > 0$ of ESG disclosure and study how a change in τ_ξ would 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 $p = \alpha_0 + \alpha_v v + \alpha_R \zeta - \alpha_F D - \alpha_\epsilon \epsilon$ and the equilibrium k is the solution to $\alpha_v(\lambda - k) - \alpha_F f'(k) = 0$. The price coefficients satisfy*

$$\frac{d\alpha_F}{d\tau_\xi} > 0 \text{ and } \frac{d\alpha_v}{d\tau_\xi} > 0. \tag{8}$$

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 (8).

I analyze how a more precise ESG disclosure affects α_F and its spillover effect on α_v in (8) 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:

$$\lambda = k^* + \frac{\alpha_F(\tau_\xi, s)}{\alpha_v(\tau_\xi, s)} f'(k^*). \tag{9}$$

One can think of the ratio, $\frac{\alpha_F(\tau_\xi^*, s)}{\alpha_v(\tau_\xi^*, s)}$, as the weight that the firm places on the environmental implication of its investment relative to financial implications. The notation $\frac{\alpha_F(\tau_\xi^*, s)}{\alpha_v(\tau_\xi^*, s)}$ emphasizes its dependence on the quality of ESG quality τ_ξ and on the investor tastes, s. If there exists a precision τ_ξ^* under which $\frac{\alpha_F(\tau_\xi^*, s)}{\alpha_v(\tau_\xi^*, s)} = s$, the condition (9) used to determine the firm's investment k^* will coincide with (7) 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 preferences. The proposition below verifies the existence of such ESG-disclosure quality τ_ξ^* and presents its closed-form expression.

Proposition 2 *A unique ESG disclosure precision* $0 < \tau_\xi^* < \infty$ *incentivizes the firm to choose* *the sustainable investment k^{FB} and*

$$\tau_\xi^* = \tau_F \left(\frac{r^2 \tau_F^2 \tau_\eta^2 \tau_\epsilon}{(s^2 \tau_v + \tau_F)^2} + \tau_\eta + \tau_R \right) \tau_v^{-1}. \tag{10}$$

Recall the paper takes the view that "[corporate social responsibility] is the delegated exercise of prosocial behaviour on behalf of stakeholders" (Bénabou and Tirole, 2010). The analysis in this section shows that ESG disclosure plays a crucial role in determining the efficiency of the delegation and, hence, the sustainable investment chosen in equilibrium. The argument sets a foundation used in the analysis in subsequent sections.

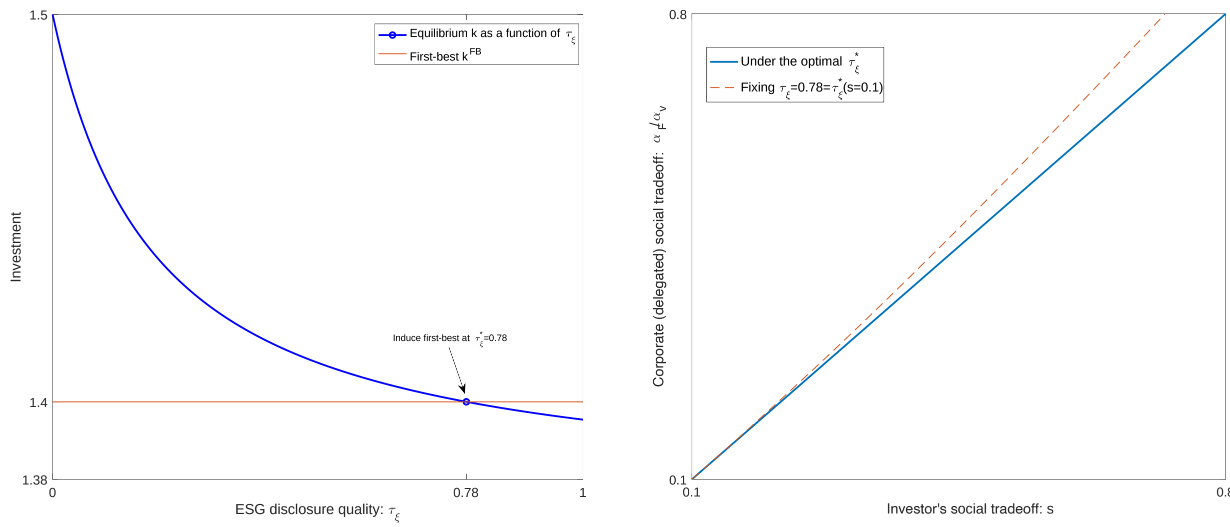
5 Tastes and the Optimal Disclosure

The model offers novel implications regarding the design and implementation of ESG disclosure. In this section, I study 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 s. This question has immediate regulatory implications because ESG disclosures are introduced, at least in part, to change firm's behaviors towards sustainable goals. For example, a 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."

It is tempting to think that more precise ESG disclosure is desirable when investors care more about it. Figure 1 - Panel (a) illustrates this intuitive thinking using a numerical example in which $f(k) = k, \lambda = 1.5, \tau_v = 0.5, \tau_R = 0, \tau_F = 0.2, \rho = \tau_\eta = \tau_\epsilon = 1$, and $s = 0.1$. The downward curve plots the firm's investment choice as a function of the quality of ESG disclosure. The optimal precision $\tau_\xi^* = 0.78$ is determined when the equilibrium investment intersects with $k^{FB} = 1.4$ that investors would choose themselves. Two facts in the figure are noteworthy. First, more ESG-concerned investors prefer a lower k^{FB}. (That is, the horizontal line in Panel (a) is decreasing in s.) Second, increasing the quality of ESG disclosure incentivizes the firm to lower its investment, as shown in the downward-sloping curve. It is therefore tempting to conclude that the optimal ESG disclosure τ_ξ^* is increasing in the tastes for ESG, s.

However, the next result shows the fact that improving ESG disclosure *can* lower the investment towards the desired level does not mean that we should improve the disclosure.

Proposition 3 *The precision of the optimal ESG disclosure decreases in investors' ESG tastes. That is,* $\frac{d\tau_\xi^*}{ds} < 0$.



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

(b) Investor vs. Corporate social tradeoff

Figure 1: Numerical examples illustrating Proposition 3

The key to understanding the counter-intuitive result is that stronger tastes for ESG change how investors use information. Panel (b) in Figure 1 illustrates the intuition. The 45-degree line plots the induced corporate social tradeoff, captured by $\frac{\alpha_F}{\alpha_v}$ in (9), under the optimal τ_ξ^*. The fact that it is a 45-degree line shows τ_ξ^* fully aligns the corporate social tradeoff with 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 I fixed the quality of disclosure precision at $\tau_\xi = 0.78$, which is the optimal ESG disclosure for $s = 0.1$ shown 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 paying "too much" attention to the social cost of investment. That is, if I fix ESG-disclosure quality $\tau_\xi = 0.78$, an increase in investors' social preference s changes their trading (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 corporate social tradeoff to the level justified by the investors' social tradeoff, s.

Formally, recall that τ_ξ^* is chosen to align the firm's social tradeoff to the tradeoff in the eyes of the investors, i.e.,

$$\underbrace{\frac{\alpha_F(\tau_\xi^*, s)}{\alpha_v(\tau_\xi^*, s)}}_{\text{Corporate social tradeoff}} = \underbrace{s}_{\text{Investors' social tradeoff}}. \tag{11}$$

Fixing the quality of disclosure, it follows from $\alpha_F = s\frac{\tau_\xi^*}{\tau_\xi^*+\tau_F}$ that an increase in s already makes price more responsive to the reported emissions and, hence, raises the "Corporate social tradeoff" in (11). This is because a higher s increases the relevance of emission F in investors' portfolio decisions, and investors rationally rely more on the reported emissions. The result $\frac{d\tau_\xi^*}{ds} < 0$ occurs because a higher s increases "Corporate social tradeoff" *faster* than "Investors' social tradeoff", as seen in Panel (b) of Figure 1. To understand the intuition, note that a higher s not only increases the numerator $\alpha_F = \frac{\tau_\xi^*}{\tau_\xi^*+\tau_F}s$ in (11) but also reduces the denominator $\alpha_v = \frac{\tau_p^v+\tau_\eta+\tau_R}{\tau_p^v+\tau_\eta+\tau_R+\tau_v}$ by lowering τ_p^v, that is, by reducing the information that price contains about profit v. This is because an increase in ESG tastes changes how investors use their information: it decreases the *relevance* of profit v and increases the *risk* investors face by raising $\text{var}(v - sF|\mathcal{F})$. Both effects make the investors trade less intensively on their private signals about v, reducing the information content of price τ_p^v and, hence, the price sensitivity to profit α_v.

Note that I am *not* claiming a stronger taste for ESG would always call for a lower quality of ESG disclosure. The unconditional result $\frac{d\tau_\xi^*}{ds} < 0$ shown in Proposition 3 is due to the lack of private signals about emissions. In Appendix B, I examine an alternative setting in which the investors observe private signals about F and show $\frac{d\tau_\xi^*}{ds} < 0$ holds for $s < \sqrt{\tau_F/\tau_v}$.

My goal is to point out the logical incompleteness behind the conventional wisdom that firms should improve ESG disclosure simply because investors care more about ESG. While intuitive, this argument overlooks the fact that a change in investors' tastes also changes how they use information. In particular, stronger tastes for ESG (i) increase (and decrease) the relevance of information about emissions (and profit, respectively), and (ii) increases the risks investors face by raising $\mathrm{var}(v - sF|\mathcal{F})$. These two effects determine how intensively investors trade on their information, which, in turn, influences the design of ESG disclosure.

More broadly, the analysis cautions against the temptation to focus on regulating ESG disclosures in order to *directly* change firm behaviors. In particular, the fact that improving ESG disclosure can move investment towards efficient goals does not mean that one should improve the disclosure. A better approach seems to be to think of ESG disclosures as interventions designed to iron out inefficiency that (taste-driven) 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.

6 A Theory for Mandating Climate Disclosure

The model can be used to shed light on the ongoing debate about mandating climate disclosure. Such a mandate already exists in the EU (e.g., Directive 2022/2464). In 2022, the SEC issued a proposal "The Enhancement and Standardization of Climate-Related Disclosures for Investors", which would require registrants to disclose emissions in their periodic reports. Christensen et al. (2021) state: "the current policy debate in the U.S. revolves largely around the question of a mandate that explicitly imposes CSR reporting requirements on companies."

As noted in Christensen et al. (2021), a main argument *against* mandating climate disclosure is that firms will reveal the information voluntarily in a way that balances the *private* costs and benefits of disclosure. I start with showing that the model fully acknowledges firms' voluntary disclosure incentives. In particular, if a firm can choose the quality of its climate disclosure freely to maximize its expected price, it will choose the same τ_ξ^* as in Proposition 2 *voluntarily.* To understand the result, one can examine the price function in Lemma 2 and verify the expected price satisfies

$$E[p] = E[v(k) - sF(k)] = \lambda k - \frac{k^2}{2} - sf(k). \tag{12}$$

It is easy to see that $E[p]$ achieves its maximum when the investment k satisfies $\lambda = k + sf'(k)$. Recall from (9) that the firm chooses its investment according to $\lambda = k + \frac{\alpha_F(\tau_\xi)}{\alpha_v(\tau_\xi)} f'(k)$, and Proposition 2 shows setting $\tau_\xi = \tau_\xi^*$ ensures $\frac{\alpha_F(\tau_\xi)}{\alpha_v(\tau_\xi)} = s$. Therefore, setting $\tau_\xi = \tau_\xi^*$ at $t = 0$ ensures the investment k that the firm chooses at $t = 1$ satisfies $\lambda = k + sf'(k)$ and, hence, maximizes price in (12). The result is intuitive. Shareholders' valuation is the highest when they believe that the investment chosen by the firm matches their tastes. Therefore, a firm aiming to maximize its valuation has incentives to commit to its shareholders that it will invest in accordance to their tastes, and the way to do this is to choose the quality of disclosure τ_ξ^* upfront as in Proposition 2 because it ensures $\frac{\alpha_F(\tau_\xi^*)}{\alpha_v(\tau_\xi^*)} = s$.

Having reconciled firm incentives to disclose voluntarily, this section offers a rationale for mandating climate disclosure. Extend the model to a large economy with a continuum of firms. Each firm $i \in [0,1]$ chooses an investment $k_i \geq 0$, and its financial profit $v(k_i) = \lambda k_i - \frac{k_i^2}{2} + \psi_i$ and emissions $F(k_i) = f(k_i) + \phi_i$ are determined as in (1) and (2). Firm i's earnings report $R_i = v(k_i) + \zeta_i$ and ESG disclosure $D_i = F(k_i) + \xi_i$ are defined as before. All the noise terms (i.e., ψ_i, ϕ_i, ζ_i, and ξ_i) are independent of each other and across different firms.

The fact that noise terms are independent across firms assumes away risk sharing or information spillover between firms, which have been proposed in prior studies as a rationale for mandating disclosure (e.g., Smith, 2023). The argument here exploits the externalities caused by firms' endogenous investments and the free-rider problem they face in reducing emissions. To introduce the externalities of climate-related investments into the model analyzed previously, I assume that the marginal return of investment, λ, is decreasing in the *aggregated* emissions, $\overline{F} = \int_j F(k_j)dj$. That is,

$$\overline{\lambda} \equiv \overline{\lambda}\left(\overline{F}\right) \geq 0, \text{ with } \overline{\lambda}'(\cdot) < 0. \tag{13}$$

Tying aggregated emissions to firm productivity is a standard approach to modeling externalities of emissions (e.g., Tresch, 2022, Cha. 7).[10] It is helpful to first analyze the equilibrium under *voluntary disclosure*, in which firm $i \in [0,1]$ chooses the quality of its climate disclosure τ_ξ^i at $t = 0$ and invests k_i at $t = 1$ to maximize its expected price. I confine attention to symmetric equilibrium in which firms choose the same strategy and, hence, drop the script i whenever it does not cause confusion. The result below summarizes the symmetric equilibrium under voluntary disclosure.

Lemma 3 *Under voluntary disclosure, each firm chooses the quality of its climate disclosure $\tau_\xi^V = \tau_\xi^*$ as in Proposition 2. The equilibrium investment k^V is the unique solution to*

$$\overline{\lambda}\left(f(k^V)\right) = k^V + s \times f'(k^V). \tag{14}$$

The thinking behind the result is as follows. Firm i takes other firms' investment choices and, hence, the equilibrium $\overline{\lambda}$ in (13) as given. As argued at the beginning of this section, a firm chooses its disclosure quality τ_ξ^* upfront to ensure $\frac{\alpha_F(\tau_\xi^*)}{\alpha_v(\tau_\xi^*)} = s$, because doing so leads to a price-maximizing investment. Substituting $\frac{\alpha_F(\tau_\xi^*)}{\alpha_v(\tau_\xi^*)} = s$ into the firm's first-order condition (9), we know a firm that anticipates an investment k^V from others will choose its disclosure τ_ξ^i and investment k_i so that $\overline{\lambda} = k_i + s \times f'(k_i)$. The symmetric equilibrium is determined when the firm's best response k_i coincides with the investment k^V it expects from others, as in (14).

There is *over-pollution* under voluntary disclosure. To see this, suppose a single conglomerate owned all the firms $i \in [0,1]$ and chose a *socially optimal* investment k^S to balance its financial and environmental impacts on the aggregated level. That is, k^S is chosen to maximize $\int_i [v_i(k) - sF_i(k)]\, di = \overline{\lambda} k - \frac{k^2}{2} - sf(k)$.[11] Substituting $\overline{F} = \int_j F(k)dj = f(k)$ into $\overline{\lambda} \equiv \overline{\lambda}(\overline{F})$,

[10] Alternatively, one can add an additional cost to profit function $v(k_i)$ and assume its marginal cost is increasing in the total emissions $\overline{F}$. The additional cost could be attributable to firms buying carbon credits to meet the emission target. If all firms pollute more, the unit price of carbon credits (i.e., marginal cost) will be higher due to the increased demand. I obtain qualitatively similar results under this alternative approach to modeling externalities.

[11] The aggregate is deterministic because the noises terms are integrated away by the laws of large numbers.

one obtain the first-order condition that characterizes k^S as:

$$\overline{\lambda}\left(f(k^S)\right) = k^S + s\, f'(k^S) + |\frac{d\overline{\lambda}}{d\overline{F}}|\, f'(k^S)\, k^S. \tag{15}$$

The term $|\frac{d\overline{\lambda}}{d\overline{F}}|\, f'(k^S)$ in (15) is the externality of a higher investment in lowering productivity (via aggregated emissions). This externality is overlooked in the individual firm's decision (14) because each firm takes others' investments (hence, $\overline{\lambda}$) as given when choosing its investment. Even though a reduction in total emissions increases all firms' valuations via a higher $\overline{\lambda}$, each firm has incentives to free ride on others' emission-cutting actions. The result is that all firms emit too much relative to the socially optimal level, i.e., $k^V > k^S$. This is a standard result and is similar to "the tragedy of the commons", referring to the degradation of the environment whenever many individuals use a resource in common (Hardin, 1968).

A regulator can mitigate the tragedy of the commons by mandating the quality of climate disclosure, τ_ξ^M. Recall from (9) that a firm chooses its investment according to $\lambda = k + \frac{\alpha_F}{\alpha_v} f'(k)$. Therefore, a regulator aiming to implement the socially optimal k^S in a decentralized economy must ensure that it satisfies the firm's first-order condition

$$\overline{\lambda}\left(f(k^S)\right) = k^S + \frac{\alpha_F(\tau_\xi^M)}{\alpha_v(\tau_\xi^M)} f'(k^S), \tag{16}$$

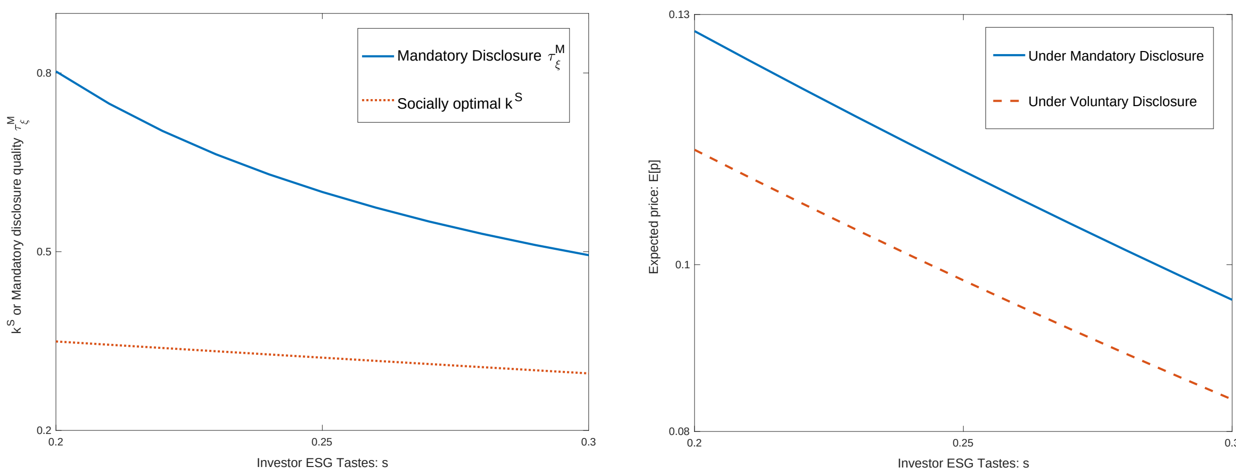
To implement k^S, the regulator needs to align a firm's perceived marginal cost of investment with its social cost at $k = k^S$, i.e., to align the right-hand sides of (16) and (15). That is,

$$\underbrace{\frac{\alpha_F(\tau_\xi^M)}{\alpha_v(\tau_\xi^M)} \times f'(k^S)}_{\text{Private Cost}} = \underbrace{\left(s + |\frac{d\overline{\lambda}}{d\overline{F}}|\, k^S\right) \times f'(k^S)}_{\text{Social Cost}}. \tag{17}$$

A sufficient condition to ensure a solution to (17) is $\frac{\tau_v\, s}{\tau_R+\tau_\eta+\tau_p} > -\frac{d\overline{\lambda}}{d\overline{F}}\, k|_{k=k^S}$, that is, the left-hand side of (17) is greater than its right-hand side as the mandate $\tau_\xi^M \to \infty$. Investigating (15) shows that the socially optimal k^S is independent of signal precisions, such as τ_v and τ_η.

Hence, the sufficient condition $\frac{\tau_v s}{\tau_R+\tau_\eta+\tau_p} > -\frac{d\overline{\lambda}}{d\overline{F}} k|_{k=k^S}$ imposes restrictions on the (exogenous) precision parameters. I assume the condition is satisfied so that k^S can be implemented.[12]

Proposition 4 *A regulator avoids the tragedy of the commons by mandating τ_ξ^M, which is more precise than would be voluntarily provided (i.e., $\tau_\xi^M > \tau_\xi^V$) and implements the socially optimal k^S. Moving from voluntary disclosure τ_ξ^V to mandating τ_ξ^M increases stock valuation $E[p]$.*



(a) Implementing k^S by mandating τ_ξ^M

(b) Price Impacts

Figure 2: Illustration of Proposition 4, assuming $f(k) = k$ and $\overline{\lambda} = \frac{1}{1+\overline{F}}$.

Figure 2 illustrates the proposition using a numerical example in which $\rho = \tau_v = \tau_\epsilon = 1$, $\tau_F = 0.5$, and $\tau_\eta = 0.2$. Panel (a) plots the socially optimal investment k^S and the mandatory disclosure quality τ_ξ^M that implements the investment. It is intuitive to see that investors who care more about emissions (i.e., a higher s) prefer a smaller k^S. Similar to Proposition 3, however, the fact that investors care more about emissions does *not* mean we need to mandate more precise climate disclosures. Panel (b) shows that mandating more precise disclosure than would be voluntarily provided increases stock valuation. Intuitively, the mandate avoids the tragedy of commons – it results in a lower aggregated emissions and, hence, a higher productivity

[12]Even if the condition is not satisfied, it is still valuable to mandate a more precise climate disclosure than what firms would provide voluntarily, as doing so reduces k^V sustained under voluntary disclosure towards k^S.

$\overline{\lambda}$ for all firms. This result offers a rationale for Downar et al. (2021) who show that mandatory reporting of GHG emissions results in a decrease in aggregate emissions among affected firms, without adversely affecting their financial operating results.

Proposition 4 can be compared to Admati and Pfleiderer (2000) and Dye (1990), who show the value of mandating more precise disclosure than firms' voluntary choice. Their argument is based on the assumption that one firm's disclosure is informative about other firms. The mechanism behind my result is different because one firm's disclosure is uninformative about others.[13] Instead, it is the free-rider problem underlying firms' endogenous investments that causes an under-provision of voluntary disclosure, i.e., $\tau_\xi^V < \tau_\xi^M$. The intuition can be illustrated by examining (14) and (17). Under voluntary disclosure, a firm sets its disclosure quality τ_ξ^* to ensure $\frac{\alpha_F}{\alpha_v} = s$ because doing so will result in a price-maximizing investment. Examining (17) shows that $\frac{\alpha_F}{\alpha_v} > s$ is necessary to implement the socially optimal k^S. While $\frac{\alpha_F}{\alpha_v} > s$ can be achieved by improving climate disclosure, a firm will not do so voluntarily because such a disclosure choice will make its investment deviate from the price-maximizing level.

The analysis shows that the free-rider problem underlying firms' investment decisions percolates into their voluntary disclosure choices. Hence, there will be an under-provision of climate disclosure and over-pollution if disclosure is voluntary. Mandating a climate disclosure more precise than would be provided voluntarily has the potential to motivate rational, self-interested firms to act on common interests in reducing emissions. The result indicates that a regulator can leverage disclosure mandate and market forces to motivate firms to internalize the externalities of climate-related investments.

The next result follows Proposition 4. It shows how the mandated climate disclosure would change with respect to the quality of traditional, financial information that investors observe.

Proposition 5 *The precision of the mandatory climate disclosure increases in the quality of earnings reports and private information about profits. That is,* $\frac{d\tau_\xi^M}{d\tau_\eta} > 0$ *and* $\frac{d\tau_\xi^M}{d\tau_R} > 0$.

[13]Because noise terms are independent across firms in the model, information about other firms affects i's valuation only through their collective influence over $\overline{\lambda} \equiv \overline{\lambda}(\overline{F})$.

The result highlight the point that the optimal climate disclosure depends on the quality of financial reporting. Given the endogenous relationship, the proposition predicts stricter (more precise) climate disclosures in countries that historically feature high quality financial reports. This result adds to Christensen et al. (2021) who point out that institutional arrangements impose constraints on the mandate of climate disclosure and noted "intricate complementarities among the many institutions in a market or country." In fact, if a country has an overall opaque financial information environment, this model predicts that mandating strict climate disclosure has the risk of inducing firms to sacrifice too much financial returns in exchange for favorable climate performance.

7 Extensions and Discussions

7.1 Adding an investment with positive ESG consequences

Investment studied in the main model imposes negative ESG consequences, such as emissions. This subsection adds a "green" investment that reduces emissions. 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 $\frac{c^2}{2}$. I augment firm profit $v(k)$ in (1) by incorporating the cost of carbon capturing $\frac{c^2}{2}$:

$$v(k, c) = \lambda k - \frac{k^2}{2} - \frac{c^2}{2} + \psi, \tag{18}$$

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

$$F(k, c) = f(k) - g(c) + \phi. \tag{19}$$

A main message in the single-firm analysis (i.e., Sections 3-5) is that ESG disclosure, $D = F + \xi$, is critical in ensuring that the firm makes investment in accordance with the investors pro-ESG tastes. Further, stronger tastes for ESG do not make more precise disclosure desirable.

Both results hold after introducing the green investment, c. We know from (7) that the efficient k^{FB} that pro-ESG investors would choose themselves is determined from $\lambda = k^{FB} + sf'(k^{FB})$. Similarly, the efficient carbon-reducing c^{FB} is determined by $c^{FB} = s\,g'(c^{FB})$, which equates the marginal cost of the investment to its marginal benefit in reducing emissions. It shows below that the optimal precision τ_ξ^* of ESG disclosure in Proposition 2 also incentivizes the firm to undertake the efficient carbon reducing investment c^{FB}. (Proof is given in the appendix.)

Observation 1: *The precision τ_ξ^* in Proposition 2 motivates the firm to choose k^{FB} and c^{FB}.*

Move to the large economy analyzed in Section 6, in which I model the externality of total emissions $\overline{F}$ in reducing firm productivity $\overline{\lambda}$, as in (13). The aggregated emissions is modified as $\overline{F} = \int_i F(k_i, c_i)di$ to incorporate the effect of carbon-reducing $g(c_i)$. One can use similar arguments in Section 6 to show that the socially optimal k^S and c^S maximize $\int_i [v_i(k,c) - sF_i(k,c)]\,di = \overline{\lambda}k - \frac{k^2}{2} - \frac{c^2}{2} - s\,[f(k) - g(c)]$. Substituting $\overline{F} = \int_j F(k,c)dj = f(k) - g(c)$ into $\overline{\lambda} \equiv \overline{\lambda}(\overline{F})$, we know k^S and c^S are obtained from $\overline{\lambda} = k^S + f'(k^S)\left(s + |\frac{d\overline{\lambda}}{d\overline{F}}|\,k^S\right)$ and $c^S = g'(c^S)\left(s + |\frac{d\overline{\lambda}}{d\overline{F}}|\,k^S\right)$, respectively.

As in the main model, a regulator can implement k^S and c^S in a decentralized economy by mandating the quality of climate disclosure, τ_ξ^M. We know from (9) that a firm chooses its emission-generating investment k according to $\lambda = k + \frac{\alpha_F(\tau_\xi)}{\alpha_v(\tau_\xi)}f'(k)$. Similarly, a firm chooses its carbon-reducing investment c according to $c^* = \frac{\alpha_F(\tau_\xi)}{\alpha_v(\tau_\xi)}g'(c)$. To implement k^S and c^S, the regulator needs to mandate the climate disclosure τ_ξ^M to ensure the following:

$$\frac{\alpha_F(\tau_\xi^M)}{\alpha_v(\tau_\xi^M)} = s + |\frac{d\overline{\lambda}}{d\overline{F}}|\,k^S. \tag{20}$$

The condition above motivate firms to internalize the negative (and positive) externalities of their emission-generating k (and emission-reducing c). In this case, the private cost of k and the private benefit of c equal their social counterparts.

Observation 2: *Mandating τ_ξ^M, which is determined by (20), motivates firms to choose the socially optimal k^S and c^S. The mandate is more precise than would be voluntarily provided.*

In both observations shown above, the fact that a single disclosure precision can motivate efficient k and c simultaneously is because the two investments are assumed to be separable. I are not claiming that the separable structure applies to all investments. All I am saying is that the mechanism in the paper is not unique to discouraging investments that are damaging to ESG, and the argument apply to promoting investments that have positive ESG consequences. The key tension underlying the mechanism is the tradeoff between maximizing profit and ESG performance. Here, carbon capturing is good for ESG but is costly to implement.

7.2 ESG tastes by other stakeholders

A premise of the paper is that certain stakeholders care about firm emissions. The focus on shareholders' social awareness is standard in models studying ESG investing, e.g., Pástor et al. (2021). This subsection presents an alternative setup in which shareholders only care about financial returns, and a firm's emissions prompt *other stakeholders*, such as customers, to take actions that negatively affects firm's financial value. In particular, suppose a firm's liquidation cash flow θ is

$$\theta = v(k) - s\,F(k). \tag{21}$$

The short-term profit $v(k)$ and emission $F(k)$ are defined in (1) and (2). As in the main model, the investors receive signals about $v(k)$, and learns about $F(k)$ from the reported emissions $D = F(k) + \xi$. One can think of $-s\,F(k)$ in (21) as the *transition risks* related to the long-term reduced market demand for carbon-intensive products, as considered by the SEC.[14] Assuming that transition risk is increasing in emission F in (21) is consistent with the SEC's view that a firm's GHG emissions "have become a commonly used metric to assess a registrant's exposure to such [transition] risks." The assumption is also consistent with Bolton and Kacperczyk (2023), who document that "a firm's exposure to carbon-transition risk is *proportional* to

[14] The SEC states that: "Transition risks would include, but are not limited to, increased costs attributable to climate-related changes in law or policy, reduced market demand for carbon-intensive products leading to decreased sales, prices, or profits for such products, ..., changes in consumer preferences or behavior, or changes in a registrant's behavior."

the level of its emissions. [emphasis added]"

The cash-flow formulation (21) offers an alternative setup/interpretation to the main model. Here, investors care only about the financial impact of emissions, and it is other stakeholders (e.g., customers) who take actions against a polluting firm. The transition risks $s\,F(k)$ in (21) – related to the customers' tastes against a polluting firm – play a similar role as the investors' ESG tastes in the main model. This can be seen by noting that the investors' demand for the polluting firm's equity is the same under both settings, and is specified in (4). It follows that all the results reported in the main model are preserved under the cash-flow formulation above.

8 Conclusion

This paper studies the role of ESG disclosure in transforming firm investment when its shareholders' preferences include both financial and ESG elements. The way I model ESG activities follows the view that corporate social responsibility is a delegated philanthropy (Tirole, 2017). The analysis shows that, as long as external investors do not perfectly observe firm investment, disclosing ESG performance is necessary in ensuring the firm makes investment in accordance with investors' tastes for ESG. I characterize the optimal precision of ESG disclosure that balances the financial and environmental implications of the investment.

While it is tempting to think that more ESG disclosures are desirable when shareholders care more about ESG, I show this intuition is incomplete because it overlooks the fact that a stronger taste for ESG changes how investors use their information. In particular, a stronger taste for ESG increases (decreases) the relevance of information about emissions (profit, respectively), and increases the risks investors face. These effects determine how intensively investors trade on their information, which, in turn, influences the design of ESG disclosure. The analysis cautions against the temptation to focus on regulating ESG disclosures to directly change firm behaviors. In particular, the fact that improving ESG disclosure can move investment towards efficient goals does not mean that one should improve the disclosure. A better approach seems to be to think of ESG disclosures as interventions used to iron out inefficiency that (taste-driven) 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.

The paper also adds to the ongoing policy debate regarding mandatory climate disclosure. I illustrate why a mandatory climate disclosure can be valuable. The argument exploits the free-rider problem underlying firms' efforts to reduce GHG emissions. I show that the free-rider problem underlying firms' climate-related investments extends to their disclosure incentives. As a result, there will be an under-provision of climate disclosure and over-pollution if disclosure is voluntary. Mandating a climate disclosure that is more precise than what firms would voluntarily provide can motivate self-interested firms to act on common interests in reducing emissions and avoid the tragedy of the commons. The result indicates that a regulator can leverage market forces and disclosure mandate to achieve a similar result as a Pigovian tax in motivating firms to internalize the externalities of climate-related investments.

One limitation of the model is that I am agnostic about how ESG disclosures affect other stakeholders such as employees and suppliers. 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 features ex ante identical firms and, hence, cannot address the potential shift of "dirty" activities from public companies to private sectors. Exploring how ESG disclosures influence this shift could be an interesting avenue for future research.

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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

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

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

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

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

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

and it verifies (4).

For $\mathcal{F}_i = \{p, y_i, R\}$ (i.e., without ESG disclosure), I 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

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

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, I 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 $\alpha_R = \gamma$, I 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), I rewrite the first-order condition characterizing $k^\emptyset$ as

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

from which I conclude $k^\emptyset = \lambda$. To complete the characterization of the equilibrium, I 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. ■

Proof of Lemma 2. The equilibrium for a given $\tau_\xi \geq 0$ is solved in three steps. I first solve for the linear pricing function, taking the market conjecture $\hat{k}$ as given. In the second step, I 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 $D = F + \xi$), I guess and verify the following linear pricing equilibrium:

$$p = \alpha_0 + \beta v + \gamma R - \alpha_F D - \alpha_\epsilon \epsilon, \tag{A.9}$$

The market price p is informationally equivalent to

$$m = \frac{p - \alpha_0 - \gamma R + \alpha_F D}{\beta} = v - \frac{\alpha_\epsilon}{\beta}\epsilon, \tag{A.10}$$

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:

$$\begin{bmatrix} v - sF \\ y_i \\ m \\ D \\ R \end{bmatrix} \sim N \left(\begin{bmatrix} \lambda\hat{k} - \frac{\hat{k}^2}{2} - sf(\hat{k}) \\ \lambda\hat{k} - \frac{\hat{k}^2}{2} \\ \lambda\hat{k} - \frac{\hat{k}^2}{2} \\ f(\hat{k}) \\ \lambda\hat{k} - \frac{\hat{k}^2}{2} \end{bmatrix}, \begin{bmatrix} \frac{1}{\tau_v} + \frac{s^2}{\tau_F} & \frac{1}{\tau_v} & \frac{1}{\tau_v} & -s\frac{1}{\tau_F} & \frac{1}{\tau_v} \\ \frac{1}{\tau_v} & \frac{1}{\tau_v} + \frac{1}{\tau_\eta} & \frac{1}{\tau_v} & 0 & \frac{1}{\tau_v} \\ \frac{1}{\tau_v} & \frac{1}{\tau_v} & \frac{1}{\tau_v} + \frac{\alpha_\epsilon^2}{\beta^2 \tau_\epsilon} & 0 & \frac{1}{\tau_v} \\ -s\frac{1}{\tau_F} & 0 & 0 & \frac{1}{\tau_F} + \frac{1}{\tau_\xi} & 0 \\ \frac{1}{\tau_v} & \frac{1}{\tau_v} & \frac{1}{\tau_v} & 0 & \frac{1}{\tau_v} + \frac{1}{\tau_R} \end{bmatrix} \right). \tag{A.11}$$

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, I 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 I characterize the linear price function by comparing the price coefficients in the market-clearing price p obtained above to those in (A.9).

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). I 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.9) and letting $\alpha_v = \beta + \gamma$ and $\alpha_R = \gamma$, I rewrite the price function as follows:

$$p = \alpha_0 + \alpha_v v + \alpha_R \zeta - \alpha_F F - \alpha_\epsilon \epsilon. \tag{A.12}$$

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

$$\frac{d\alpha_v}{d\hat{k}} = \frac{d\alpha_R}{d\hat{k}} = \frac{d\alpha_\epsilon}{d\hat{k}} = \frac{d\alpha_F}{d\hat{k}} = 0. \tag{A.13}$$

That is, the investors' conjecture $\hat{k}$ only affects the intercept α_0 in the price function (A.12) 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, I endogenize the investment. The firm takes market conjecture $\hat{k}$ and the price function (A.12) 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

$$\lambda = k^* + \frac{\alpha_F(\tau_\xi)}{\alpha_v(\tau_\xi)} f'(k^*). \tag{A.14}$$

Recall from (A.13) that $\frac{\alpha_F(\tau_\xi)}{\alpha_v(\tau_\xi)}$ is independent of $\hat{k}$. Therefore, one 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 $k^*(\tau_\xi)$, I 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 2. Comparing the first-order condition (A.14) to $\lambda = k^{FB} + sf'(k^{FB})$ in (7), I 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, I 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 3. 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 Lemma 3. The game is solved backwards. At $t = 2$, aggregated emissions $\overline{F} = \int_i F(k_i)di$ are known by aggregating the reported emissions from all firms, as in

$$\overline{F} = \int_i D_i di = \int_i [F(k_i) + \xi_i]\, di = \int_i F(k_i)di. \tag{A.15}$$

The last equality uses the fact that the reporting noise ξ_i is independent across firms and has a zero mean. It follows that $\overline{\lambda} \equiv \overline{\lambda}(\overline{F})$ is determined and known to the investors prior to trading. I argue that each firm's price function takes the form $p = \alpha_0 + \alpha_v v + \alpha_R \zeta - \alpha_F F - \alpha_\epsilon \epsilon$ shown in (A.12), and that the price coefficients are the same as those specified in Lemma 2 (after replacing the parameter λ with $\overline{\lambda}$.) To see this, I examine a representative investor's demand for firm i:

$$q_i = \frac{\mathbb{E}\left(v_i - sF_i|\mathcal{F}\right) - p_i}{\rho\, \mathrm{var}\left(v_i - sF_i|\mathcal{F}\right)},$$

where $v_i = \overline{\lambda}k_i + \frac{k_i^2}{2} + \psi_i$ and $F_i = f(k_i) + \phi_i$ are firm i's profits and emissions, p_i is its price, and $\mathcal{F}$ is the representative investor's information set that includes her private signals and public reports from all firms. Because all noise terms are independent across firms, firm j's reports has no value in updating firm i's profits v_i or emissions F_i. It follows that information about other firms (including their investment choices) affects i's demand function only through their collective influence over $\overline{\lambda} \equiv \overline{\lambda}(\overline{F})$. Because $\overline{\lambda}$ is a known constant at the time of trading (see (A.15)), the price function is characterized as in the proof of Lemma 2.

At $t = 1$, firm i takes the price function (particularly, price coefficients) as given and chooses k_i to maximize its expected price, i.e., $\max_{k_i} \mathbb{E}[p|\hat{k}_i, k_i] = \alpha_0(\hat{k}_i) + \alpha_v E[v|k_i] - \alpha_F E[F|k_i]$. The first-order condition is

$$\lambda = k_i + f'(k_i)\frac{\alpha_F(\tau_\xi^i, s)}{\alpha_v(\tau_\xi^i, s)}, \tag{A.16}$$

and the notation $\frac{\alpha_F(\tau_\xi^i,s)}{\alpha_v(\tau_\xi^i,s)}$ emphasizes its dependence on s and firm i's disclosure precision τ_ξ^i.

At $t = 0$, the firm chooses τ_ϵ^i to maximize its expected price, knowing that τ_ϵ^i influences the investment k_i it will choose at $t = 1$ as in (A.16). One can examine the price function (A.12) and verify that firm i's expected price satisfies

$$E[p_i] = E[v(k_i) - s\,F(k_i)] = \overline{\lambda}k_i - \frac{k_i^2}{2} - s\,f(k_i). \tag{A.17}$$

It is easy to see that $E[p_i]$ is maximized if k_i satisfies $\overline{\lambda} = k_i + sf'(k_i)$. When choosing τ_ξ^i at $t = 0$, firm i takes *other* firms' investment choices and, hence, $\overline{\lambda} = \overline{\lambda}(\int_j F(k_j)dj)$ as given. Recall from Proposition 2 that setting $\tau_\xi^i = \tau_\xi^*$ ensures $\frac{\alpha_F}{\alpha_v} = s$, which, in turn, transforms the first-order condition (A.16) that characterizes firm i's investment k_i into $\overline{\lambda} = k_i + sf'(k_i)$. As argued above, an investment k_i satisfying $\overline{\lambda} = k_i + sf'(k_i)$ maximizes $E[p_i]$. This proves the optimality of $\tau_\xi^i = \tau_\xi^*$.

It remains to characterize the symmetric equilibrium investment k^V. As argued above, firm i takes other firms' investment k_j (hence, $\overline{\lambda} = \overline{\lambda}(\int_j F(k_j)dj))$ as given, and chooses τ_ξ^i at $t = 0$ and k_i at $t = 1$ so that $\overline{\lambda} = k_i + sf'(k_i)$. In a symmetric equilibrium, I drop the firm-subscript i and obtain $\overline{\lambda} = \overline{\lambda}(f(k))$. The symmetric equilibrium k^V is the unique solution to

$$\overline{\lambda}\left(f(k^V)\right) = k^V + s \times f'(k^V). \tag{A.18}$$

There is at most one k^V satisfying (A.18) because its right-hand side is increasing in k^V and its left-hand side is decreasing in k^V. The existence of a solution is guaranteed because the right-hand side of (A.18) is less than (and greater than) its left-hand side at $k = 0$ (and as $k \to \infty$, respectively.) Collecting the conditions completes the proof. ■

Proof of Proposition 4. Consider a benchmark in which a conglomerate owned all firms and picked an investment k for them. Given the investment choice, $\int_i [v_i(k) - sF_i(k)]\,di = \overline{\lambda}k - \frac{k^2}{2} - sf(k)$ is a constant because the idiosyncratic noises in v_i and F_i are integrated away by the laws of large numbers. The socially optimal k^S maximizes the aggregated $\overline{\lambda}(\overline{F})k - \frac{k^2}{2} - sf(k)$. Substituting $\overline{F} = \int_j F(k)dj = f(k)$ into $\overline{\lambda}(\overline{F})$, one obtain the first-order condition that characterizes k^S as follows (recall $\frac{d\overline{\lambda}}{d\overline{F}} < 0$):

$$\overline{\lambda}\left(f(k^S)\right) = k^S + s\, f'(k^S) + |\frac{d\overline{\lambda}}{d\overline{F}}|\, f'(k^S)\, k^S. \tag{A.19}$$

Consider the mandatory disclosure regime in which a regulator chooses a disclosure requirement τ_ξ^M at $t = 0$, and each firm chooses its own investment at $t = 1$. It is shown in (A.16) that the investment chosen by an individual firm i at $t = 1$ satisfies $\lambda = k_i + f'(k_i)\frac{\alpha_F}{\alpha_v}$. The regulator can implement k^S as a symmetric equilibrium via mandating τ_ξ^M if k^S satisfies the firm's first-order condition. That is,

$$\overline{\lambda}\left(f(k^S)\right) = k^S + \frac{\alpha_F\left(\tau_\xi^M, s\right)}{\alpha_v\left(\tau_\xi^M, s\right)} f'(k^S). \tag{A.20}$$

The price coefficients α_F and α_v (determined at $t = 2$) are the same as in the voluntary disclosure regime analyzed at the beginning of Lemma 3, after replacing τ_ξ^V with τ_ξ^M.

Implementing k^S as a symmetric equilibrium requires that the right-hand sides of (A.19) and (A.20) are the same. That is,

$$\frac{\alpha_F(\tau_\xi^M, s)}{\alpha_v(\tau_\xi^M, s)} - s = |\frac{d\overline{\lambda}}{d\overline{F}}| \times k^S. \tag{A.21}$$

One can verify that $\frac{\alpha_F}{\alpha_v} = 0$ when $\tau_\xi^M = 0$ and that $\frac{\alpha_F}{\alpha_v} = \left(1 + \frac{\tau_v}{\tau_\eta + \tau_p + \tau_R}\right) s$ when $\tau_\xi \to \infty$. It follows that the left-hand side of (A.21) is less than its right-hand side at $\tau_\xi^M = 0$. To ensure a $\tau_\xi^M > 0$ satisfying (A.21), a sufficient condition is to have its left-hand side greater than its right-hand side as $\tau_\xi \to \infty$, which can be stated equivalently as follows (rewriting $\frac{d\overline{\lambda}}{d\overline{F}}|_{k=k^S}$ as $\overline{\lambda}'\left(f(k^S)\right)$):

$$\frac{\tau_v\, s}{\tau_R + \tau_\eta + \tau_p} > |\overline{\lambda}'\left(f(k^S)\right)| \times k^S. \tag{A.22}$$

Next, I show $\tau_\xi^M > \tau_\xi^V$. It follows from (A.21) that $\frac{\alpha_F(\tau_\xi^M)}{\alpha_v(\tau_\xi^M)} > s$, and I drop the argument s in $\frac{\alpha_F(\tau_\xi^M, s)}{\alpha_v(\tau_\xi^M, s)}$ for brevity. Recall from Proposition 2 that $\tau_\xi^V = \tau_\xi^*$ is unique, and is chosen to ensure

$\frac{\alpha_F(\tau_\xi^V)}{\alpha_v(\tau_\xi^V)} = s$. Note that $\frac{\alpha_F(\tau_\xi)}{\alpha_v(\tau_\xi)}$ is increasing in the neighborhood of τ_ξ^*. Therefore, for small $\epsilon > 0$, we know $\frac{\alpha_F(\tau_\xi)}{\alpha_v(\tau_\xi)} < s$ for $\tau_\xi = \tau_\xi^V - \epsilon$ and $\frac{\alpha_F(\tau_\xi)}{\alpha_v(\tau_\xi)} > s$ for $\tau_\xi = \tau_\xi^V + \epsilon$. To prove $\tau_\xi^M > \tau_\xi^V$, suppose by contradiction that $\tau_\xi^M < \tau_\xi^V$ (for we know $\tau_\xi^M \neq \tau_\xi^V$). This means $\frac{\alpha_F(\tau_\xi)}{\alpha_v(\tau_\xi)} > s$ holds both at τ_ξ^M, which is less than τ_ξ^V by assumption, and at $\tau_\xi^V + \epsilon$. Because $\frac{\alpha_F(\tau_\xi)}{\alpha_v(\tau_\xi)} < s$ at $\tau_\xi = \tau_\xi^V - \epsilon$ for some arbitrarily small ϵ, it follows from continuity that there are at least two values of $\tau_\xi \in (\tau_\xi^M, \tau_\xi^V + \epsilon)$ satisfying $\frac{\alpha_F(\tau_\xi)}{\alpha_v(\tau_\xi)} = s$. However, this contradicts the fact that there exists a unique $\tau_\xi^V = \tau_\xi^*$ satisfying $\frac{\alpha_F(\tau_\xi^V)}{\alpha_v(\tau_\xi^V)} = s$, shown in Proposition 2.

It remains to verify the claim about stock valuation, $E[p] = E[v(k) - sF(k)] = \overline{\lambda}k - \frac{k^2}{2} - s\,f(k)$. Note from the discussion prior to (A.19) that k^S maximizes $\overline{\lambda}k - \frac{k^2}{2} - sf(k)$. The claim follows by noting that mandating τ_ξ^M induces the firms to choose k^S in equilibrium. ■

Proof of Proposition 5. I prove $\frac{d\tau_\xi^M}{d\tau_R} > 0$ here, and a similar argument applies for $\frac{d\tau_\xi^M}{d\tau_\eta} > 0$. Investigating (A.19) shows that the socially optimal k^S is independent of the quality of the earnings report τ_R. As τ_R increases, it follows from (A.20) that $\frac{\alpha_F}{\alpha_v}$ must hold as a constant because k^S is independent of τ_R. It is easy to verify that an increase in τ_R (i.e., a more precise earnings report) increases the price coefficient α_v. Therefore, α_F must also increase to maintain $\frac{\alpha_F}{\alpha_v}$ unchanged. Given $\alpha_F = s\frac{\tau_\xi^M}{\tau_\xi^M + \tau_F}$, we know that α_F is higher if and only if τ_ξ^M increases. This proves $\frac{d\tau_\xi^M}{d\tau_R} > 0$. ■

Proof of Observations 1 and 2. The proof follows similar steps in the proof of Proposition 2 (for the single firm analysis) and Proposition 4 (for the large economy with externalities). So, I only sketch the main steps of the argument. Given a precision $\tau_\xi \geq 0$, 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.12). 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.13) 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 firm's optimal k^* and c^* are

$$\lambda = k^* + \frac{\alpha_F(\tau_\xi)}{\alpha_v(\tau_\xi)} f'(k^*), \tag{A.23}$$

and

$$c^* = \frac{\alpha_F(\tau_\xi)}{\alpha_v(\tau_\xi)} g'(c). \tag{A.24}$$

We show in the text that k^{FB} and c^{FB} are determined from $\lambda = k^{FB} + sf'(k^{FB})$ and $c^{FB} = s\, g'(c^{FB})$. 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 2. This proves Observation 1.

Moving to the large economy, it is shown in the text that k^S and c^S are obtained from $\overline{\lambda} = k^S + f'(k^S)\left(s + |\frac{d\overline{\lambda}}{d\overline{F}}|\, k^S\right)$ and $c^S = g'(c^S)\left(s + |\frac{d\overline{\lambda}}{d\overline{F}}|\, k^S\right)$. Similar argument as in Lemma 3 suggests that, under voluntary disclosure, each firm chooses the same disclosure quality τ_ξ^* as in the single-firm setting. The equilibrium under voluntary disclosure has the firms invests too much in emission-generating k, and too little in carbon-reducing c.

A regulator can implement k^S and c^S in the decentralized economy by mandating τ_ξ^M if it satisfies $\frac{\alpha_F(\tau_\xi^M)}{\alpha_v(\tau_\xi^M)} = s + |\frac{d\overline{\lambda}}{d\overline{F}}|\, k^S$. In this case, the conditions (A.23) and (A.24) used to determine the firm's k^* and c^* coincide with the first-order conditions used to determine k^S and c^S. This proves Observation 2. ■

B Appendix B

In the main model, I have assumed that information about the firm's emissions comes solely from its ESG disclosure. Here, I assume that in addition to observing the ESG disclosure $D = F + \xi$, each investor i observes a private signal x_i about the firm's emissions F as follows:

$$x_i = F + \delta_i, \tag{B.1}$$

where $\delta_i \sim N(0, \tau_\delta^{-1})$ is independent of other variables in the model and across investors. To maintain tractability, I assume away private signals about profits v.[15]

Given the distribution of profit v and emissions F, one can verify that the linear price function is

$$p = \alpha_0 + \alpha_R R - \alpha_f F - \alpha_D D - \alpha_\epsilon \epsilon, \tag{B.2}$$

where $R = v + \zeta$ and $D = F + \xi$ are publicly reported earnings and emissions as defined in the main model. It shows in (9) that the first-order condition determining the firm's investment is

$$\lambda = k^* + \frac{\alpha_F(\tau_\xi)}{\alpha_v(\tau_\xi)} f'(k^*), \tag{B.3}$$

where $\alpha_F(\tau_\xi) = \alpha_f + \alpha_D$ incorporates the price impact of public and private signals about F. As in (11), the optimal ESG disclosure τ_ξ^* aligns the firm's perceived social tradeoff with that of the investors, i.e., $\frac{\alpha_F(\tau_\xi^*)}{\alpha_v(\tau_\xi^*)} = s$. The next result echoes Propositions 2 and 3 in the main model.

Proposition 6 *The optimal precision of ESG disclosure is* $\tau_\xi^* = \max\{0, \frac{\tau_F \tau_R}{\tau_v} - \tau_\delta \left(1 + \frac{r^2 s^2 \tau_v^2 \tau_\delta \tau_\epsilon}{(s^2 \tau_v + \tau_F)^2}\right)\}$. *A positive* τ_ξ^* *satisfies* $\frac{d\tau_\xi^*}{ds} < 0$ *if and only if* $s < \sqrt{\frac{\tau_F}{\tau_v}}$.

It is optimal to keep $\tau_\xi^* = 0$ if private signals about emissions are already precise enough, i.e., if τ_δ is sufficiently high. Recall that τ_ξ^* is chosen to obtain $\frac{\alpha_F(\tau_\xi^*)}{\alpha_v(\tau_\xi^*)} = s$, which can be rewritten

[15] While it is conceptually straightforward to incorporate private signals about both v and F, the price coefficients can only be solved numerically.

as follows:

$$s \times \frac{\frac{\tau_p^F+\tau_\delta+\tau_\xi}{\tau_p^F+\tau_\delta+\tau_\xi+\tau_F}}{\frac{\tau_R}{\tau_R+\tau_v}} = s, \tag{B.4}$$

where $\tau_p^F = (\frac{\alpha_f}{\alpha_\epsilon})^2\tau_\epsilon$ is the precision of price when used a signal about the emissions F.[16] For sufficiently large τ_δ, the left-hand side of (B.4) is higher than its right-hand side even without any ESG disclosure, i.e., $\tau_\xi = 0$. In this case, pricing of investors' private signals about emissions already makes the firm's perceived social cost of investment higher than that of the investors, and setting a positive τ_ξ^* will only make it worse.

The reminder of the Appendix focuses on the case with $\tau_\xi^* > 0$. To understand the condition for $\frac{d\tau_\xi^*}{ds} < 0$ in the proposition, rewrite the equality (B.4) as $G(\tau_\xi^*, s) \equiv \frac{\alpha_F(\tau_\xi^*,s)}{\alpha_v(\tau_\xi^*,s)} - s$. One can apply the implicit function theorem to $G(\tau_\xi^*, s) = 0$ and obtain $\frac{d\tau_\xi^*}{ds} = -\frac{\partial G/\partial s}{\partial G/\partial \tau_\xi^*}$. Using the fact that $\partial G/\partial \tau_\xi^* > 0$, I show that

$$\begin{aligned}
\frac{d\tau_\xi^*}{ds} \propto -\partial G/\partial s \quad &= \quad -\left[\frac{\frac{\tau_p^F+\tau_\delta+\tau_\xi^*}{\tau_p^F+\tau_\delta+\tau_\xi^*+\tau_F}}{\frac{\tau_R}{\tau_R+\tau_v}} + s\frac{d}{ds}\left(\frac{\frac{\tau_p^F+\tau_\delta+\tau_\xi^*}{\tau_p^F+\tau_\delta+\tau_\xi^*+\tau_F}}{\frac{\tau_R}{\tau_R+\tau_v}}\right) - 1\right] \\
&= \quad -s\frac{d}{ds}\left(\frac{\frac{\tau_p^F+\tau_\delta+\tau_\xi^*}{\tau_p^F+\tau_\delta+\tau_\xi^*+\tau_F}}{\frac{\tau_R}{\tau_R+\tau_v}}\right) \\
&\propto \quad -\frac{d\tau_p^F}{ds}.
\end{aligned} \tag{B.5}$$

The second equality uses the fact that $\tau_\xi^* > 0$ is chosen so that $\frac{\frac{\tau_p^F+\tau_\delta+\tau_\xi^*}{\tau_p^F+\tau_\delta+\tau_\xi^*+\tau_F}}{\frac{\tau_R}{\tau_R+\tau_v}} = 1$, as in (B.4).

It follows from (B.5) that $\frac{d\tau_\xi^*}{ds} < 0$ if and only if $\frac{d\tau_p^F}{ds} > 0$ holds at the optimal τ_ξ^*, i.e., if a higher s changes how investors use their information so that price contains more information about F. As discussed in the main model, an increase in the tastes s for ESG changes how investors use their information in two way. First, a higher s increases (decreases) the relevance of information about emissions (profits, respectively) in an investor's portfolio choice. Second,

[16] It follows (B.2) that observing p is informationally equivalent to $\frac{p-\alpha_0-\alpha_R R+\alpha_D D}{\alpha_f} = -F - \frac{\alpha_\epsilon}{\alpha_f}\epsilon$, which is a signal of F with a precision $\tau_p^F = (\frac{\alpha_f}{\alpha_\epsilon})^2\tau_\epsilon$.

a higher s increases the risks investors face by increasing $\mathrm{var}(v - sF|\mathcal{F})$. The two effects impose opposite effects on how intensively investors trade on their private signals about emissions: the increasing relevance motivates more intensive trading while the higher risk discourages trading. At the optimal τ_ξ^*, the relevance effect dominates its risk effect if and only if $s < \sqrt{\frac{\tau_F}{\tau_v}}$, results in more intensive trading on private signals of F and, hence, $\frac{d\tau_p^F}{ds} > 0$. Because of its role in elevating τ_p^F, a higher s increases the firm's perceived social cost of investment (i.e., the left-hand side of (B.4)) faster than the investors' social tradeoff on the right-hand side. The optimal τ_ξ^* therefore decreases to restore the induced corporate social tradeoff to the level justified by the investors' social tradeoff s.

Incorporating private signals about the firm's emissions does not affect the analysis in Section 6 of the main model, in which I study "the tragedy of the commons." There is essentially no change to the arguments other than replacing the closed-form expression of τ_ξ^* that ensures $\frac{\alpha_F(\tau_\xi^*)}{\alpha_v(\tau_\xi^*)} = s$ with the expression shown in Proposition 6 in this appendix.

Proof of Results in Appendix B

Proof of Proposition 6. I guess and verify that the linear price function is

$$p = \alpha_0 + \alpha_R R - \alpha_f F - \alpha_D D - \alpha_\epsilon \epsilon. \tag{B.6}$$

The non-negative price coefficients can depend on the conjectured $\hat{k}$ along with other parameters in the model. It follows from the market-clearing condition, $\int_i \frac{\mathbb{E}(v - sF|\mathcal{F}_i) - p}{\rho\,\mathrm{var}(v - sF|\mathcal{F}_i)}\, di = \epsilon$, that the price function can be expressed as $p = \int_i \mathbb{E}\left(v - sF|\mathcal{F}_i\right)\, d_i - \rho \mathrm{var}\left(v - sF|\mathcal{F}_i\right)\epsilon$, where $\mathcal{F}_i = \{p, R, D, x_i\}$ is investor i's information set. Note that observing price p is informationally equivalent to observing $\frac{p - \alpha_0 - \alpha_R R + \alpha_D D}{\alpha_f} = -F - \frac{\alpha_\epsilon}{\alpha_f}\epsilon$, which is a signal of F with a precision

$$\tau_p^F = \left(\frac{\alpha_f}{\alpha_\epsilon}\right)^2 \tau_\epsilon.$$

Denote by $\hat{\mu}_v \equiv \lambda\hat{k} - \frac{\hat{k}^2}{2}$ and $\hat{\mu}_F \equiv f(\hat{k})$ the prior mean of firm profit and emissions as a function of the investors' conjectured $\hat{k}$. One can follow similar steps in the proof of Lemma 2 to calculate $\mathbb{E}\left(v - sF|\mathcal{F}_i\right)$ and $\mathrm{var}\left(v - sF|\mathcal{F}_i\right)$ and obtain the following:

$$\begin{aligned} p = \quad & \frac{(\tau_p^F + \tau_\delta + \tau_\xi + \tau_F)\tau_v\hat{\mu}_v - s(\tau_R + \tau_v)\tau_F\hat{\mu}_F}{(\tau_R + \tau_v)(\tau_p^F + \tau_\delta + \tau_\xi + \tau_F)} + \frac{\tau_R}{\tau_R + \tau_v}R \\ & - s\frac{\tau_p^F + \tau_\delta}{\tau_p^F + \tau_\delta + \tau_\xi + \tau_F}F - s\frac{\tau_\xi}{\tau_p^F + \tau_\delta + \tau_\xi + \tau_F}D \\ & - \left[\frac{s\frac{\alpha_f}{\alpha_\epsilon}\tau_\epsilon}{\tau_p^F + \tau_\delta + \tau_\xi + \tau_F} + \rho\frac{\tau_p^F + \tau_\delta + \tau_\xi + \tau_F + s^2(\tau_R + \tau_v)}{(\tau_R + \tau_v)(\tau_p^F + \tau_\delta + \tau_\xi + \tau_F)}\right]\epsilon. \end{aligned} \tag{B.7}$$

Comparing (B.6) and (B.7) and substituting $\tau_p^F = (\frac{\alpha_f}{\alpha_\epsilon})^2\tau_\epsilon$, I characterize the price coefficients recursively as follows:

$$\begin{aligned} \alpha_f &= s + \frac{\alpha_0 - \frac{\hat{\mu}_v\tau_v}{\tau_v + \tau_R}}{\hat{\mu}_F} \times \frac{\tau_F + \tau_\xi}{\tau_F}, \quad \alpha_\epsilon = \sqrt{\frac{\alpha_f^2\tau_\epsilon(s - \alpha_f)}{\alpha_f(\tau_F + \tau_\delta + \tau_\xi) - s\tau_\delta}}, \\ \alpha_D &= s\frac{\tau_\xi}{(\frac{\alpha_f}{\alpha_\epsilon})^2\tau_\epsilon + \tau_\delta + \tau_\xi + \tau_F}, \quad \alpha_R = \frac{\tau_R}{\tau_R + \tau_v}, \end{aligned}$$

and α_0 is the unique real root of a cubic polynomial whose expression is omitted for brevity. Tedious algebra verifies $\frac{d\alpha_f}{d\hat{\mu}_F} = \frac{d\alpha_f}{d\hat{\mu}_v} = 0$ after substituting α_0.

The optimal τ_ξ^* is chosen such that $\frac{\alpha_F(\tau_\xi^*)}{\alpha_v(\tau_\xi^*)} = s$, where $\alpha_F = \alpha_f + \alpha_D$. Using the price coefficients shown above, one can solve

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

where $r = \frac{1}{\rho}$ is the inverse of the investors' risk-aversion. Adding the condition $\tau_\xi^* \geq 0$ verifies the statement in Proposition 6. Straightforward algebra shows

$$\frac{d\tau_\xi^*}{ds} < 0 \text{ if and only if } s < \sqrt{\frac{\tau_F}{\tau_v}},$$

which completes the proof. ■