Climate conscious investors, carbon disclosures, and efficiency*

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This version: June 2024 – Preliminary

Abstract

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JEL Classification: G31, G38, Q52, Q58
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*We thank Rafael Repullo, Guillermo Caruana, Gerard Llobet, and Anatoli Segura for insightful comments and suggestions. Vedant Agarwal acknowledges financial support from Grant PRE2021-099907, funded by MCIN/AEI/ 10.13039/501100011033 and by "ESF +", the Maria de Maeztu Unit of Excellence CEMFI MDM-2016-0684, funded by MCIN/AEI/10.13039/501100011033, and CEMFI. Javier Suarez acknowledges support from Spanish government grant PID2022-142998NB-I00.

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Abstract

We analyze whether carbon disclosures can substitute for carbon emission taxation when emissions generate negative externalities. In our setup, climate conscious investors adjust their funding terms based on their beliefs about firms' carbon intensities, which firms can choose to disclose at a cost. In equilibrium, the least carbon-intensive firms disclose and are financed at terms based on their carbon intensity, while non-disclosing firms are financed at more expensive pooling terms. Encouraging disclosures reduces investment and therefore emissions by non-disclosing firms, but may increase investment and emissions by newly disclosing firms, overall having ambiguous effects on total emissions and social welfare.

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1 Introduction

Economic theory suggests that suitably designed carbon taxes would be the most effective way of regulating the negative externalities associated with carbon emissions. However, the impression that current carbon taxes are not enough to control the externalities prompted many commentators to call for policy action on related fronts. This included imposing climate-related disclosure requirements on potential emitters, most notably firms. The argument is that carbon disclosures might support a more explicit and discriminatory pricing of carbon by investors (Bolton et al., 2020).[1] This can occur through two complementary channels. First, disclosures would improve the capacity of investors driven by strict financial rewards to assess the private value implications of forthcoming transition costs (including carbon taxes not yet in place and the costs of not-yet-started technological adaptations). Second, disclosures might allow altruistic or socially responsible investors who also care about external costs imposed on climate or the environment to influence asset prices or firm policies in a way that leads to a better internalization of the externalities (as in the seminal contribution of Heinkel, Kraus, and Zechner, 2001). Through any of these channels, carbon disclosures may allow the least carbon intensive firms to attract funding and to finance investment opportunities at better terms than the more carbon intensive firms. This is consistent with the positive association between stock returns and carbon emissions documented by Bolton and Kacperczyk (2021a), among other, which can be interpreted as evidence that emissions increase the cost of capital.[2]

In this paper we analyze the impact of climate disclosures on firms endowed with technologies that differ in carbon intensity. Disclosures are costly but allow investors to charge a cost of capital based on the emission intensity of each disclosing firm. Relative to an equilibrium based on totally voluntary choices between disclosing or not, what are the effects of encouraging disclosures? How do disclosure policies affect the allocation of investment across firms as well as the level of aggregate carbon emissions and its distribution across firms? Can higher disclosures improve efficiency and especially so when carbon taxes are not

[1] Accounting standards are evolving in the direction of requesting firms to provide estimates of their carbon emissions and other relevant impacts on the environment. In the financial sector, the initiative was led by the Financial Stability Board's Task Force on Climate-Related Financial Disclosures (TCFD) and its influential 2017 report. In late 2023 the TCFD passed the ball to the accounting standard setters of the IFRS Foundation. On-going climate disclosure initiatives in Europe are described in European Central Bank (2023). For a survey of the accounting literature on carbon accounting, see He et al. (2020).

[2] In contrast, Atilgan et al. (2023) dispute this interpretation and attribute the evidence to positive stock price reactions to unexpected earnings shocks. However, aligned by the standard interpretation, the survey data examined by Gormsen, Huber and Oh (2023) suggests that green investment is associated with a significantly lower perceived cost of capital.

set at the socially efficient level?

To address these questions, we develop a model in which heterogeneous firms have private information about the emission intensity of their technologies. Their investments are funded by *climate conscious* investors who partially internalize the present or future social costs of carbon emissions and adjust the terms of funding (cost of capital) for each firm according to their beliefs about its emission intensity. Climate consciousness can be interpreted as a reflection of investors' awareness about the future financial implications of emissions (transitional costs), as a reflection of impure altruism (*a la* Andreoni, 1990) that leads them to better internalize genuine environmental externalities, or as a combination of both.

In the model, firms can credibly reveal their emission intensity to outsiders by paying a disclosure cost.[3] In the game of voluntary carbon disclosures, firms with relatively lower emission intensity face a basic trade-off: disclosing is costly but allows them to finance investments at a cost of capital that reflects their true emission-intensity type, taking them out of the pool of non-disclosing firms. When financing the non-disclosing firms, investors rationally assign a cost of capital based on the anticipated composition of emission intensity within such a pool. In the equilibrium of this game, only the firms with emission intensity below an endogenous disclosure threshold disclose. Among non-disclosing firms, the relatively less carbon emitters cross-subsidize the relatively higher emitters, and for the marginal non-disclosing firm the cost of the cross-subsidies (that is, being financed at the pooling terms rather than those that would correspond to its true type) equals the cost of disclosure.[4]

In the analysis of the model, we first look at the laissez faire equilibrium without emission taxes and with investors who only partially internalize the social cost of emissions. This equilibrium provides a useful benchmark to assess the implications of policy interventions on firms' disclosure decisions. Then we analyze the equilibrium with emission taxes and characterize the constrained efficient allocation that can be reached by optimally setting both taxes (or subsidies) on disclosure and taxes on (disclosed or, otherwise, estimated) carbon emissions.[5]

[3]Bolton and Kacperczyk (2021b) report that only 12% of firms in their large global sample of publicly listed companies disclose carbon emissions, suggesting that the underlying disclosure costs are high. They also provide an excellent discussion of the potential direct and indirect costs associated with carbon disclosures.

[4]Disclosure costs play an important role in sustaining this equilibrium. If disclosure were not costly, the classical unraveling results of Stiglitz (1975), Ross (1979), Grossman (1981) and Milgrom (1981) would extrapolate to our setup, implying that all firms would disclose. Classical models of costly voluntary disclosures include Jovanovic (1982) in a product market context and Verrecchia (1983) in a financial context.

[5]In our analysis, the tax authorities are assumed to have the same information as investors, meaning that they can make the taxes a function of the true emission intensities for disclosing firms but not for the pool of non-disclosing firms. For the latter, the tax must be based on authorties' beliefs about the emission intensities of the non-disclosing firms.

Core results on disclosure interventions In the equilibrium with voluntary disclosure, the disclosure threshold can be increased (decreased) by the policymakers by means of a subsidy (tax) on the disclosure cost. However, in the scenario without emission taxes, the desirability of increasing the disclosure threshold is unclear. If more firms are induced to disclose, the investment and emissions of already previously disclosing firms do not change, and those of non-disclosing firms (for which the perceived emission intensity increases) go down. However, newly disclosing firms invest and emit more because the disclosure improves investors' perceptions about their emission intensity and, hence, reduces their cost of capital.

Even without taking the increase in total disclosure costs into account, the rise in investment and emissions by newly disclsoing firms generates additional uninternalized costs that may offset the efficiency increasing effects obtained from the reduction in investment and emissions amongst the pool of non-disclosing firms. Confirming the ambiguity of the net aggregate results, we provide examples in which higher disclosures lead to higher overall emissions and lower welfare, as well as examples with the opposite net effects. These results suggest that the emission-reducing and welfare-enhancing effects of promoting carbon disclosures are not warranted.

Strikingly enough, when investors fully internalize the social cost of emissions (either because they are fully climate conscious or because of Pigouvian carbon taxation), disclosures are always socially excessive. This finding extends to our setting the classical result of Jovanovic (1982) in a product market setup where firms can disclose the quality of their product at a cost (thus affecting consumers' willingness to pay for it). As in other adverse selection setups, when the marginal firms decides to exit the pool of non-disclosing firms, it assesses the value of staying in the pool based on the average type that investors would attribute to it in the pool, rather than its true (less emitting) type, which is what a social planner would take into account to fix the constrained-efficient disclosure threshold. Thus, once emission externalities are already dealt with, firms' private incentives to disclose are unambiguously excessive, and reaching constrained efficiency would require taxing (rather than promoting) disclosures.

Our conclusions on the potential counterproductive effects of encouraging climate disclosure, including the result that constrained-efficient carbon taxation should optimally be accompanied with a tax on disclosures, can be seen as a call for caution against the view that promoting carbon disclosures per se provides a substitute, even if partial and imperfect, for carbon taxation. From the eyes of our model, not necessarily so. However, our caveats on disclosure policies can be qualified on the basis of a number of conceptual and practical considerations not fully accounted for in our analysis. We believe that the most relevant one is that the exercise of both investors' consciousness and carbon taxation may require the availability of verifiable measures of emission intensity to start with. In our setup, investors and tax authorities are able to impose suitable financing terms and taxes to the pool of non-disclosing firms on the basis of rational expectations (that is, Bayesian estimates of their emission intensity combined with the observable levels of investment/activity of each firm). However, behavioral and governance frictions may prevent investors from fully disciplining firms whose emission intensity is not observed.[6] Similarly, carbon taxation might be legally challenged if not based on objective measures of emission intensity. Extending the analysis to accommodate these frictions would reinforce the case for emission disclosures.

Another consideration favoring disclosures would be the provision of incentives to adopt technological improvements (or emission abatement measures) that reduce emission intensity. Under our formulation, non-disclosing firms would lack incentives to adopt any unobservable improvement which is not large enough to allow them to exit the non-disclosing pool, since neither investors nor tax authorities would acknowledge the improvement when setting their financing terms and taxes.[7] Disclosures would enhance the solution of this incentive problem. The presence of externalities that could be avoided with the induced technological improvements might justify promoting disclosures above and beyond what a voluntary disclosure equilibrium would entail.

With these considerations in mind, our results can be seen as a benchmark case that, suitably extended, might allow a (necessarily quantitative) evaluation of the net efficiency gains associated with policies that encourage or require carbon disclosures. From a positive perspective, as it stands, our analysis provides insights on the rich cross-sectional and aggregate implications for investment, emissions, and economic efficiency of changing the cost of climate disclosures, the degree of investors' climate consciousness, and carbon taxes, and thus can contribute to interpret and understand existing and future empirical results on these topics.

Additional results on the effects of climate consciousness In the laissez faire equilibrium (or, more generally, under insufficient emission taxes), the effects of an increase in investors' climate consciousness are also nuanced. As one would expect, if investors internalize the social cost of emissions at a larger degree, they assign a larger cost of capital per

[6] The absence of credible disclosures may make firms emission not "salient" enough to be taken into consideration, or may prevent the effective delegation of carbon pricing to intermediaries, which might collude with the firms in attributing them an unduly small emission intensity (a form of "greenwashing").

[7] This is so unless the improvement can be separately disclosed (without having to disclose the benchmark emission intensity) so as to get the corresponding credit from investors or tax authorities.

unit of perceived implied emissions. Ceteris paribus, this reduces firms' investment and the emissions conditional on any perceived emission intensity. However, depending on parameters (including the sensitivity of the investment scale to the cost of capital), the disclosure threshold can increase or decrease. In the first scenario, when more firms disclose (which is the case when investment is not highly sensitive to the cost of capital), the estimated average emission intensity of the pool of non-disclosing firms increases, reinforcing the fall in investment and emissions among these firms. However, the newly disclosing firms may invest and emit more than previously in the pool, potentially offsetting the emission-reduction effects obtained across all other firms. In the second scenario, when the increase in climate consciousness leads less firms to disclose (which is the case when investment is highly sensitive to the cost of capital), cross-subsidization within the pool of non-disclosing firms increases. Then disclosing firms as well as firms joining the non-disclosing pool will invest and emit less than with less climate-conscious investors, but the rest of the non-disclosing firms might experience reductions in the cost of capital and end up investing and emitting more.

Therefore, under either possible scenario (regarding the shift in the disclosure threshold), an increase in climate consciousness does not induce reductions in emissions across all firm types and should be expected to have rich cross-sectional implications. The final net effects on aggregate emissions and social welfare might be heterogenous (in principle, even in terms of sign) across industries in a given economy, and across economies with different industry structures (depending on technological parameters as well as the density of firms across emission intensities).[8]

Related literature This paper contributes to a growing literature at the intersection of finance and climate change, as well as the literature that more generally considers the influence of environmental, social, and governance (ESG) issues on economic activity. Specifically, our paper is related to theoretical contributions that explore the role of socially responsible investors in affecting firms' investment decisions and their impact on the environment. Following the path inaugurated by Heinkel, Kraus, and Zechner (2001), several papers develop asset pricing models in which at least some investors make portfolio decisions under social responsibility considerations about the environment, affecting the allocation of investment across more and less socially damaging technologies. For example, Pástor, Stambaugh, and Taylor (2021) consider a setup in which investors have preferences that include non-pecuniary benefits (costs) from the investment in green (brown) assets, and the resulting equilibrium

[8]However, in all the numerical examples that we have explored, a higher investor climate consciousness leads to lower aggregate emissions and an increase in welfare.

expected returns imply lowering the cost capital for additional real investment by green compared to brown firms. Gollier and Pouget (2022) consider the interaction between investors' portfolio choices in a prior stage and the later adoption of technological decisions by voting at the general assembly. Oehmke and Opp (2023) identify a channel through which socially responsible investment funds can achieve impact on climate-related outcomes (firms' choice between clean and dirty technologies) even when funding from profit-seeking investors is in perfectly elastic supply.[9] These recent papers contain excellent reviews of prior contributions to this literature. We borrow from this literature the interpretation that (some) investors may internalize climate externalities and induce changes in the allocation of capital across firms or technologies, but we abstract from modeling the portfolio decisions, asset pricing or governance mechanisms through which such an influence occurs.

In our analysis, we directly assume an implication of the theoretical literature: that the presence of climate conscious investors makes firms' cost of capital a function of investors' beliefs about firms' emission intensity. This assumption is also consistent with empirical studies showing a positive association between carbon emissions and stock returns (El Ghoul et al., 2011; Chava, 2014; Bolton and Kacperczyk, 2021a) as well as a positive correlation between those asset pricing effects and the presence of environmentally conscious investors (Gormsen, Huber and Oh, 2023). There is also evidence that sustainability concerns affect the pricing of bonds (Diaz and Escribano, 2021), the returns demanded by venture capital investors (Barber, Morse and Yasuda, 2021), and the availability and terms of bank lending (Kacpercyk and Peydro, 2022).[10]

Differently from other analytical contributions in the field, we consider the case in which emission intensity is not observable to investors without disclosures, and study firms' incentives to disclose, policy interventions on disclosure, and the implications for the overall allocation of capital across firms, carbon emissions and welfare, with and without carbon taxation. To the best of our knowledge, we are first to consider a theoretical model in which endogenous equilibrium decisions on climate-related disclosures interact with the firms' cost of capital and their equilibrium levels of investment and emissions. The endogenous disclosure part of our analysis is related to references in information economics, including Stiglitz (1975), Ross (1979), Grossman (1981) and Milgrom (1981), which obtained the classical

[9]Specifically, firms face financial constraints due to moral hazard and resposible investors base their impact on relaxing those constraints (at a cost in terms of their financial returns) if firms make the "right" technological choice.

[10]However, Berk and van Binsbergen (2022) argue that the effects of socially responsible investors on the cost of capital are not big enough to have a material impact on firms' investment and that having such an impact may require the proactive involvement of the investors in management decisions.

unraveling result (whereby all types end up disclosing) when disclosure costs are zero. Jovanovic (1982) added to this literature by considering costly voluntary disclosures (about product quality) in a product market context, finding that the unregulated equilibrium may involve an excessive level of disclosure due to adverse selection externalities. The same qualitative insight appears in Verrecchia (1983) in a context of costly financial reporting relevant for asset pricing. The implication of these results is that justifying the social desirability of encouraging disclosures above the level that would emerge in an unregulated equilibrium requires more than just asymmetric information between firms and investors. The extra ingredient may generally be some positive externality associated with the aggregate transparency attained in equilibrium. Admati and Pfleiderer (2000) explore a context in which those externalities come from the fact that firm values are correlated (and hence information disclosed by one firm can help valuing another firm). They show, however, that even in such a context inducing firms to improve the precision of their disclosures is not always welfare improving. Conceptually, our results advising against unconditionally considering carbon disclosure interventions desirable even in the presence of unaddressed carbon externalities resemble these findings but we obtain this conclusion in a very different setting.

The cross-sectional implications of our equilibrium with voluntary disclosures are broadly consistent with papers documenting differences between disclosing and non-disclosing firms. This includes the findings in Matsumura, Prakash and Vera-Muñoz (2014), who study voluntary carbon disclosures by S&P 500 companies and find that the median market value of disclosing firms is higher than that of comparable non-disclosing firms. The results in Kleimeier and Viehs (2018), who show that firms which choose to voluntarily reveal their carbon emissions pay lower spreads on their bank loans, and Bolton and Kacperczyk (2021b), who find that firms voluntary disclosing their carbon emissions face a lower cost of capital, are also consistent with the assortative properties of our equilibrium with voluntary disclosures.

Finally, for its normative contents, this paper complements other studies that address normative questions in environments in which negative externalities from carbon emissions coexist with other frictions. For example, Döttling and Rola-Janicka (2022) consider constrained-efficient carbon taxation in a context in which limits to cash flow pledgeability may push firms into inefficient liquidation when their financial constraints bind. Biais and Landier (2022) highlight a complementarity between environmental policies (emissions caps) and private green investment. Oehmke and Opp (2022) discuss the limitations of bank capital requirements as a tool to address externalities caused by carbon emissions while still serving their main role in preserving financial stability, thus highlighting, as in our paper, the difficulty to subsume proper carbon taxation with other policy tools. Piatti, Shapiro, and Wang

(2023) consider the impact of portfolio choices by environmentally conscious investors on firms' provision of a public good (e.g. emission reductions), and show that green subsidies may dominate the government provision of the public good in this context.

Outline of the paper The rest of the paper is organized as follows. Section 2 describes the model. Section 3 characterizes the competitive equilibrium with voluntary disclosures and analyzes the effects and desirability of promoting disclosures in the absence of carbon taxes. In Section 4 we characterize the constrained efficient allocation that can be attained by simultaneously controlling a tax or subsidy on disclosure and a tax on perceived carbon emissions, and obtain the result that even under efficient carbon taxation unregulated disclosures would be excessive. In Section 5 we discuss potential variations of the baseline setup in which our caveats on the potential negative effects of promoting disclosures would be further qualified. Section 6 contains concluding remarks.

2 The Model

Consider a two-date economy ($t = 0, 1$) with universal risk-neutrality in which the risk-free rate is normalized to zero. The economy is populated by a measure-one continuum of firms indexed by $i \in [0, 1]$. Each firm is owned and managed by a penniless entrepreneur. The firms differ in a parameter θ which characterizes the *emission intensity* of their investments. θ follows a continuous distribution with positive density $g(\theta)$ and cumulative distribution function $G(\theta)$ over the interval $[0, 1]$. We denote emission-intensity of firm i as θ_i. Each firm's type θ_i is privately and costlessly observable to the entrepreneur at $t = 0$, and to the outsiders only if the entrepreneur decides to disclose it ($x_i = 1$) at a cost ϕ. When θ_i is not disclosed ($x_i = 0$), outsiders form Bayesian beliefs about it based on the structure and observable actions of the underlying voluntary disclosure game.

Technologies Firms have access to investment opportunities at $t = 0$ whereby investment at scale k generates positive cash flows of $f(k)$ at $t = 1$, where $f(\cdot)$ satisfies the Inada conditions. The investments undertaken by firms are environmentally relevant in that they generate emissions that contribute to climate change and, thus, negative externalities. In particular, we assume that for every unit of investment by firm i, the resulting externality has a social cost $\psi\theta_i$, where $\psi > 0$ can be thought of as the assessed pecuniary value of the social damage caused by a unit of emissions. Therefore, under our formulation all firms generate similar cash-flows for a given scale of investment k, but those with a lower θ_i (the more climate-friendly firms) do so at a lower cost in terms of climate-related externalities.

Preferences We assume that the entrepreneurs who own the firms are purely motivated by financial incentives, i.e., they care only about (net) expected cash flows. However, to finance their firms, they need to raise funding from outside investors who are perfectly competitive and partially climate conscious. Specifically, in contrast to the entrepreneurs, investors partially internalize the externalities resulting from the activities that they finance and include a part of the social cost of the relevant emissions in their assessment of the cost of the investment (adding to the private opportunity cost of their funds). This means that if asked to finance k_i units of investment by a firm of known type θ_i, they would demand a repayment of at least $(1+\gamma\theta_i)k_i$ at $t=1$, where $\gamma<\psi$ is the part of the social externalities that they internalize. Thus, investors' utility of providing funds to firm i can be described as

$$u_i^I = b_i - (1+\gamma\theta_i)k_i, \tag{1}$$

where b_i is the repayment received from firm i at $t=1$ in exchange for the funds k_i at $t=0$. When investors are uncertain about the value of θ_i, they care about the expected value of u_i computed according to their Bayesian beliefs about θ_i.

Emission taxes The firm is subject to emission taxes that impose an effective tax rate τ_i per unit of investment k_i that, as further specified below, may depend directly on θ_i (for disclosing firms) or on authorities' Bayesian belief about the underlying θ_i (for non-disclosing firms). Thus, the utility of the entrepreneur who owns firm i can be expressed as

$$u_i^E = f(k_i) - \phi x_i - b_i - \tau_i k_i. \tag{2}$$

Firms' private and social value Combining (1) and (2), the total private value of firm i can be expressed as

$$v_i = u_i^E + u_i^I = f(k_i) - \phi x_i - (1+\gamma\theta_i)k_i - \tau_i k_i. \tag{3}$$

In contrast, the social value (or net welfare) that firm i generates after taking fully into account the externalities due to its emissions, is

$$w_i = f(k_i) - \phi x_i - (k_i + \psi\theta_i)k_i. \tag{4}$$

To explain this expression, notice that the part of the cost of emissions internalised by investors in u_i^I is comprised in the term $\psi\theta_i k_i$ and hence does not need to appear separately, while the carbon taxes subtracted in u_i^E entail a redistribution of value from entrepreneurs to the tax authority and, hence, do not need to appear in w_i either.

Total welfare and total emissions Total social welfare is just the sum of w_i across all firms:

$$W = \int_0^1 w_i di = \int_0^1 \left[f(k_i) - \phi x_i - (1 + \psi\theta_i)k_i \right] di, \tag{5}$$

and the total emissions generated by all firms are

$$\Sigma = \int_0^1 \theta_i k_i di. \tag{6}$$

3 Equilibrium without emission taxes

In this section, we begin by characterizing the laissez faire equilibrium of the disclosure and investment game defined by our setup in the absence of carbon taxes ($\tau_i = 0$ for all i). After establishing the conditions for the existence of an equilibrium in which only a subset of firms disclose their emission intensities, we analyze the extent to which a social planner may induce welfare gains by encouraging more firms to disclose. We also analyze the impact of investors' climate consciousness on equilibrium outcomes.

3.1 Laissez faire

The objective of each entrepreneur i is to choose a financing arrangement —consisting of a disclosure choice $x_i \in \{0, 1\}$, a scale of investment k_i, and a promised repayment to investors b_i— that maximizes her utility u_i^E subject to investors' participation constraint. Investors in turn evaluate whether the terms of financing implied by the entrepreneur's choice of $\{x_i, k_i, b_i\}$ are acceptable to them, taking into the account their beliefs about θ_i based on such a choice, so their particpation constraint is $\mathbb{E}(u_i^I \mid x_i, k_i, b_i) \geq 0$.

Clearly, belief formation is trivial when θ_i is disclosed (i.e., $x_i = 1$). Therefore, *conditional on* $x_i = 1$, the problem of entrepreneurs is

$$\max_{k_i, b_i} \; f(k_i) - b_i - \phi \tag{7}$$

$$\text{s.t.} \;\; b_i - (1 + \gamma\theta_i)k_i \geq 0. \tag{8}$$

In contrast, when θ_i is not disclosed (i.e., $x_i = 0$), investors' beliefs about θ_i could in principle be affected by the entrepreneur's choice of $\{k_i, b_i\}$. However, we will focus attention on the simple and intuitive equilibria in which the choices $\{k_i, b_i\}$ are *uninformative* about θ_i (conditional on $x_i = 0$). In other words, we consider the cases in which non-disclosing entrepreneurs follow pooling strategies and investors compute $\mathbb{E}(u_i^I \mid x_i, k_i, b_i)$, where u_i^I is linear in θ_i, by attributing a common conditional expected emission intensity

$\hat{\theta} = \mathbb{E}(\theta_i \mid x_i = 0)$ to all non-disclosing firms. In this case, the problem of entrepreneurs *conditional on* $x_i = 0$ is

$$\max_{k_i, b_i} \; f(k_i) - b_i \tag{9}$$

$$\text{s.t.} \;\; b_i - (1 + \gamma\hat{\theta})k_i \geq 0, \tag{10}$$

which analogous to that under disclosure except because $\hat{\theta}$ replaces θ_i in investors' participation constraint.

In this setup, we will conjecture and verify the existence of a *Bayesian equilibrium* in which there is some $\bar{\theta} \in [0, 1)$ such that:

C1 Firms with $\theta_i \leq \bar{\theta}$ optimally choose $x_i = 1$, while those with $\theta_i > \bar{\theta}$ optimally choose $x_i = 0$.

C2 Firms choosing $x_i = 1$ solve the program in (7)-(8), while firms choosing $x_i = 0$ solve the program in (9)-(10).

C3 Investors form their beliefs using Bayes' rule and, thus, set

$$\hat{\theta} = \mathbb{E}(\theta \mid \theta \geq \bar{\theta}) = \frac{1}{1 - G(\bar{\theta})} \int_{\bar{\theta}}^{1} \theta g(\theta) d\theta. \tag{11}$$

The conjectured equilibrium is characterized by (i) solving the problem determining $\{k_i, b_i\}$ for entrepreneurs choosing $x_i = 1$, (ii) solving the problem determining $\{k_i, b_i\}$ for entrepreneurs choosing $x_i = 0$ under the assumption implied by C3, and (iii) determining the threshold $\bar{\theta}$ consistent with optimal choices of entrepreneurs as per C1.

Because the objective functions in (7) and (9) are decreasing in b_i, the participation constraint of investors must be binding in any solution to the problems of disclosing or non-disclosing entrepreneurs. Then, substituting the binding constraint in the objective function of an entrepreneur choosing $x_i = 1$ and solving for k_i yields the following first order condition

$$f'(k_i) = 1 + \gamma\theta_i, \tag{12}$$

which implicitly defines the optimal scale of investment by a disclosing firm as a function of θ_i. Similarly, solving the problem of an entrepreneur choosing $x_i = 0$ yields

$$f'(k_i) = 1 + \gamma\hat{\theta}, \tag{13}$$

which implicitly defines a common investment level $\hat{k}$ for all non-disclosing firms.

Firms' investment scales in this setup can then be compactly described as

$$k_i = \begin{cases} k(\theta_i), & \text{if } x_i = 1, \\ k(\hat{\theta}), & \text{if } x_i = 0, \end{cases} \tag{14}$$

where

$$k(\theta) = (f')^{-1}(1 + \gamma\theta) \tag{15}$$

and $(f')^{-1}(\cdot)$ denotes the inverse of $f'(\cdot)$, which exists because $f'(\cdot)$ is monotonically decreasing. Moreover, the concavity of the return function implies that $k(\cdot)$ is decreasing in θ and γ, by the implicit function theorem. Building on this notation, we can represent entrepreneurs' equilibrium utility (which, in equilibrium equals firms' private values) as

$$v_i = \begin{cases} v(\theta_i) - \phi, & \text{if } x_i = 1, \\ v(\hat{\theta}), & \text{if } x_i = 0, \end{cases} \tag{16}$$

where

$$v(\theta) = f(k(\theta)) - (1 + \gamma\theta)k(\theta). \tag{17}$$

Finally, to characterize firms' optimal disclosure decisions, denote by $\bar{\theta}$ the threshold emission intensity that satisfies the indifference condition

$$v(\bar{\theta}) - \phi = v(\mathbb{E}(\theta \mid \theta \geq \bar{\theta})), \tag{18}$$

if it exists. Notice that

$$v'(\theta) = [f'(k(\theta)) - (1 + \gamma\theta)]k'(\theta) - \gamma k(\theta) = -\gamma k(\theta) < 0, \tag{19}$$

where the term in square brackets in the first equality is 0 by the envelope theorem: Therefore, $v(\cdot)$ is decreasing in θ, which implies that if there is a threshold $\bar{\theta} \in [0, 1]$ that satisfies (18), then an entrepreneur obtains greater profits under $x_i = 1$ than under $x_i = 0$ if and only if $\theta_i \leq \bar{\theta}$, and condition C1 holds.

The condition in (18) determines the disclosure threshold $\bar{\theta}$ as the emission intensity that makes the corresponding entrepreneur is indifferent between disclosing and not. Intuitively, disclosing has a cost ϕ but allows entrepreneurs of less emission-intensive ($\theta < \bar{\theta}$) firms to undertake investments at a lower cost of capital than if they were individually joining the pool of non-disclosing firms (and hence perceived to have an average emission intensity $\hat{\theta} > \bar{\theta}$). Among the non-disclosing firms, the ones with relatively lower emission intensities prefer paying a larger cost of funds than the cost of disclosure, while the firms with relatively higher emission intensities additionally benefit from not been distinguished as high θ firms within the pool.

The following assumption provides a sufficient condition to ensure that the least emission-intensive firms (those with $\theta_i = 0$) find it optimal to disclose:

Assumption 1

$$\phi < v(0) - v\left(\mathbb{E}\left(\theta \mid \theta \geq 0\right)\right). \tag{20}$$

Essentially, (20) imposes that the disclosure cost is not too large and take us to the following result:

Proposition 1 *Under Assumption 1, there exists at least one $\bar{\theta} \in (0,1)$ that satisfies (18). Moreover, any odd-ranked $\bar{\theta} \in (0,1)$ satisfying (18) is strictly decreasing in the disclosure cost ϕ.*

All proofs appear in the Appendix. For the ease of exposition, we will henceforth assume that the solution to (18) is unique and refer to it as *the* disclosure threshold $\bar{\theta}$.[11]

Before moving forward, we can establish, as a direct implication of the comparative statics result in Proposition 1, that taxing or subsidizing the disclosure cost ϕ allows to reduce or increase, respectively, the equilibrium value of $\bar{\theta}$.

Corollary 1 *The disclosure threshold $\bar{\theta}$ can be decreased (increased) with a tax (subsidy) on the disclosure cost ϕ.*

3.2 Intervention on the disclosure threshold

In this section, we analyze whether a social planner would have incentives to intervene on the disclosure threshold $\bar{\theta}$. More specifically, we explore the potential welfare gains from (marginally) increasing the level of disclosures achieved in the competitive equilibrium without emission taxes.

Increasing $\bar{\theta}$ (which can be achieved by subsidizing the disclosure cost ϕ as proven above) induces changes in several elements of the equilibrium, including the total disclosure costs, the investment undertaken by the (marginal) firms that switch from not disclosing to disclosing, investors' expectations on the average emission intensity of the non-disclosing firms, $\hat{\theta}$, and consequently the investment undertaken by the non-disclosing firms. Formally, the

[11] If (18) has multiple solutions in $\bar{\theta}$, the equilibria associated with all the odd-ranked solutions would share the same qualitative properties (e.g., comparative statics) that we attribute to our unique disclosure threshold.

contribution of each of these changes to the overall variation in welfare can by found by computing the total derivative $dW/d\bar{\theta}$.[12]

Based on (5) and prior notation, the value of welfare in the competitive equilibrium is

$$W = \int_0^{\bar{\theta}} [f(k(\theta)) - (1+\psi\theta)k(\theta) - \phi]\, g(\theta) d\theta + \int_{\bar{\theta}}^1 \left[f(k(\hat{\theta})) - (1+\psi\theta)k(\hat{\theta})\right] g(\theta) d\theta. \tag{21}$$

Using Leibniz's rule, the marginal effect of a change in $\bar{\theta}$ on W can be expressed as

$$\frac{dW}{d\bar{\theta}} = \{\left[f(k(\bar{\theta})) - (1+\psi\bar{\theta})k(\bar{\theta}) - \phi\right] - \left[f(k(\hat{\theta})) - (1+\psi\bar{\theta})k(\hat{\theta})\right]\} g(\bar{\theta}) + \left\{\int_{\bar{\theta}}^1 \left[f'(k(\hat{\theta})) - (1+\psi\theta)\right] g(\theta) d\theta\right\} k'(\hat{\theta}) \frac{d\hat{\theta}}{d\bar{\theta}}, \tag{22}$$

where we have used $d\hat{\theta}/d\bar{\theta} = (\hat{\theta} - \bar{\theta})g(\bar{\theta})/(1 - G(\bar{\theta}))$ to simplify the expression. This expression decomposes the total welfare effect into two parts:

(i) The *direct effect* (the first term of (22)) can be formally expressed as $\partial W/\partial\bar{\theta}$ and comes from the change in the net social value generated by the firms with the threshold emission intensity $\bar{\theta}$, which will invest at a higher scale after existing the non-disclosing pool.

(ii) The *indirect effect* (the second term of (22)) comes from the decline in the investment of all remaining non-disclosing firms, which after being perceived to belong to a *worse* pool, face worse financing conditions.[13]

We next analyze each of these effects separately.

The direct effect The direct effect can be simplified by taking into account the indifference condition in (18), which implies

$$f(k(\bar{\theta})) - (1+\gamma\bar{\theta})k(\bar{\theta}) - \phi = f(k(\hat{\theta})) - (1+\gamma\hat{\theta})k(\hat{\theta}). \tag{23}$$

Using (23) to substitute for $f(k(\bar{\theta})) - f(k(\hat{\theta})) - \phi$ in the first term of (22) yields:

$$\frac{\partial W}{\partial\bar{\theta}} = [-(\psi - \gamma)\bar{\theta}k(\bar{\theta}) + (\psi\bar{\theta} - \gamma\hat{\theta})k(\hat{\theta})]g(\bar{\theta}), \tag{24}$$

[12] If $\bar{\theta}$ is increased by means of a subsidy, the amount of the subsidy involves in principle a mere redistribution from the intervening authorities to the subsidised disclosing firms and does not affect our utilitarian measure of welfare. However, if the subsidy had to funded with distortionary taxes or at the costs of sacrificing the provision of some public good, the corresponding (opportunity) cost should be subtracted from the variation in W to evaluate the net social gains from the intervention.

[13] Note that an increase in disclosure at the margin does not affect the investmet and welfare contribution of the already disclosing firms.

where the first term reflects the part of social cost of the emissions generated by the (new) marginal disclosing firms that investors do not internalize (thus the term $\psi - \gamma$ multiplying its emissions). The second term is, with the opposite sign, the analogous uninternalized part of the social cost that would be incurred if the marginally disclosing firms remained in the pool of non-disclosing firms. It is possible to show that the combination of these two terms makes the expression in square brackets in (24) negative for all $\bar{\theta} \in [0, 1)$. This can be proven by contradiction. Assume, on the contrary, that $\partial W / \partial \bar{\theta} > 0$. This would imply having

$$\frac{\psi\bar{\theta} - \gamma\hat{\theta}}{(\psi - \gamma)\bar{\theta}} > \frac{k(\bar{\theta})}{k(\hat{\theta})}. \tag{25}$$

Since $k(\bar{\theta}) > k(\hat{\theta})$, (25) implies

$$\frac{\psi\bar{\theta} - \gamma\hat{\theta}}{(\psi - \gamma)\bar{\theta}} > 1, \tag{26}$$

which can only hold if $\bar{\theta} > \hat{\theta}$, which is false. Therefore, we can conclude that the direct welfare effect of increasing the disclosure threshold $\bar{\theta}$ is always negative.

The negative sign of the direct effect comes from two reinforcing channels. One operates under $\gamma < \psi$, as we assume, and is explained by the implication that the newly disclosing firms face a lower cost of capital, invest at a higher scale, and thus produce more of the non-fully internalized emission externalities. The other channel is more intriguing and operates even under $\gamma = \psi$. It is based on the same logic that makes the voluntary incentives to disclose excessively high in the classical product market setup of Jovanovic (1982). Its nature can be clearly seen by evaluating (24) under $\gamma = \psi$:

$$\frac{\partial W}{\partial \bar{\theta}}_{|\gamma=\psi} = -\psi(\hat{\theta} - \bar{\theta})k(\hat{\theta})g(\bar{\theta}) < 0. \tag{27}$$

This expression reflects the discrepancy between the social value and the private value that are at stake (under $\gamma = \psi$) when the marginal disclosing firms decide to disclose and, hence, to leave the pool of non-disclosing firms. From the private perspective, each of this firms if remaining in the pool would be paying a funding cost $-\psi\hat{\theta}k(\hat{\theta})$ related to investors' assessment of its emissions (using the pooling belief $\hat{\theta}$ about their emission intensity); in contrast, from a social perspective, the social cost of the emissions of one of the marginal firms if remaining in the pool is just $-\psi\bar{\theta}k(\hat{\theta})$ (which uses the true emission intensity $\bar{\theta}$ of a marginal firm). The difference between these costs pushes firms' marginal incentives to disclose above what would be socially optimal.

The indirect effect The indirect effect of increasing $\bar{\theta}$ can be written as

$$\frac{\partial W}{\partial \hat{\theta}}\frac{d\hat{\theta}}{d\bar{\theta}} = [\int_{\hat{\theta}}^{1}(\gamma\hat{\theta} - \psi\theta)g(\theta)d\theta]k'(\hat{\theta})\frac{d\hat{\theta}}{d\bar{\theta}} = (\psi - \gamma)\hat{\theta}[1 - G(\bar{\theta})]k'(\hat{\theta})\frac{d\hat{\theta}}{d\bar{\theta}}$$
$$= -(\psi - \gamma)\hat{\theta}k'(\hat{\theta})(\hat{\theta} - \bar{\theta})g(\bar{\theta}), \tag{28}$$

where in the first equality we use the first order condition for the equilibrium choice of $k(\hat{\theta})$, in the second we compute the integral, and in the third we substitute $d\hat{\theta}/d\bar{\theta} = \frac{g(\bar{\theta})}{1-G(\bar{\theta})}(\hat{\theta} - \bar{\theta})$ after taking the corresponding derivative in (11). Since $\psi > \gamma$, $\hat{\theta} > \bar{\theta}$, and $k'(\hat{\theta}) < 0$, the indirect effect is positive for all $\bar{\theta} \in (0, 1)$. The intuition for this is straightforward. Increasing the disclosure threshold $\bar{\theta}$ worsens the composition of the pool of non-disclosing firms, reduces the cross-subsidies (from firms with $\theta_i \in (\bar{\theta}, \hat{\theta}]$ to firms with $\theta_i \in (\hat{\theta}, 1]$), and leads firms in the pool to reduce their investment level, implying a reduction in the externalities that they cause. *Ceteris paribus*, the greater the non-internalized social cost of emissions, $\psi - \gamma$, the higher the indirect welfare gains from incentivizing disclosure.

Either effect may dominate Since the direct and the indirect effects captured by each of the expressions discussed above have opposite signs, the sign of the overall welfare effect of a marginal change in the disclosure threshold $\bar{\theta}$ is analytically ambiguous. The numerical examples discussed in this section show that, depending on parameters, one effect or the other may dominate, determining the sin of the overall effect. So, in the world without optimal emission taxes, it is not generally true that inducing more disclosures leads to higher welfare.

For the numerical examples shown below we assume $f(k) = k^{\alpha}$, θ be uniformly distributed over the $[0, 1]$ interval, and $\psi = 1$. In Figure 1, we compare the equilibrium disclosure threshold with the threshold that the social planner would choose in three scenarios that differ in the sensitivity of investment to the cost of capital as determined by the parameter $\alpha \in \{0.3, 0.6, 0.9\}$. The left panels compare the two thresholds for values of the climate consciousness parameter γ in the interval $[0.1, 0.6]$. We fix the disclosure cost ϕ such that in equilibrium $\bar{\theta} = 0.25$ (one quarter of the firms disclose) when $\gamma = 0.1$. The right panels fix $\gamma = 0.2$ and compare the two thresholds for a range of values of ϕ. The disclosure cost ϕ is reported as a proportion of the investment $k(0)$ of the least emission-intensive firms ($\theta = 0$) under disclosure.

These numerical examples confirm that when emissions are not optimally priced and disclosures are costly, the social planner may not in general desire higher disclosures than what is attained in the competitive equilibrium. In the examples where the returns to scale parameter α is not very large (panels in the first two rows of Figure 3), the social planner

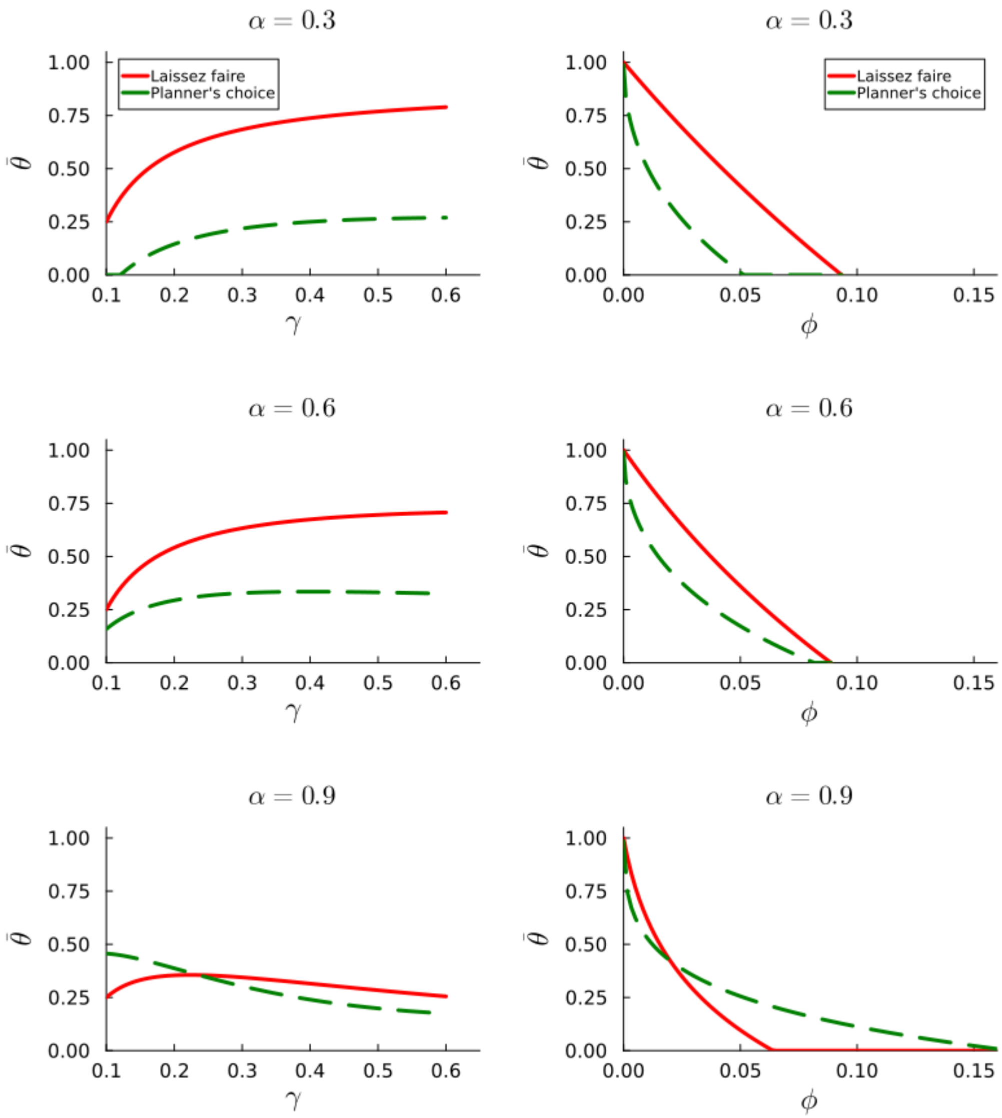

Figure 1: Intervening on disclosures under moderate emission externalities. This figure compares the laissez faire disclosure threshold (solid red lines) with the socially optimal disclosure threshold (dashed green lines) under moderate emission externalities. We assume $f(k) = k^\alpha$ with $\alpha \in \{0.3, 0.6, 0.9\}$, $\psi = 1$, and $\theta \sim U_{[0,1]}$. In the left panels, the cost of disclosure ϕ is set such that in equilibrium $\bar{\theta} = 0.25$ when $\gamma = 0.1$. In the right panels, we fix $\gamma = 0.2$ and ϕ is reported as a proportion of the investment undertaken by the least emission intensive firm under disclosure $(k(0))$ and the corresponding value of α.

would prefer a lower disclosure threshold than in the laissez faire equilibrium, and only when this parameter is large enough (the panels in the last row), increasing the disclosure threshold carries a net social welfare gain, but only when investors' climate consciousness is relatively low (left panel) and/or the cost of disclosure is relatively high (right panel).

Figure 2 shows that the results regarding the convenience or not of intervening on the disclosure threshold depend on the size of the emission externalities that investors do not internalize. The figure reproduces the analysis in Figure 1 under a higher value of the externality parameter ψ now fixed equal to 3 (rather than 1).[14] In this case, the optimality of increasing the disclosure threshold above its value in the laissez equilibrium emerges also under the more moderate values of the returns to scale parameter α. As in Figure 1, the case for increasing the disclosure threshold emerges for relatively low levels of investors' climate consciousness γ (left panels) and/or relatively high values of the disclosure cost ϕ.

Disentangling the drivers of the results The differences between the socially optimal disclosure threshold and the laissez faire disclosure threshold can be driven by several considerations including the planner's desire for saving on disclosure costs or reducing the social cost of emissions. Further insights on the role of each of these considerations can be gained by decomposing social welfare (and its variation when changing $\bar{\theta}$) in three components: (i) investment returns net of the financial cost of the investment ($f(k_i) - k_i$ for each firm i, labelled "narrow investment returns" in the figures below), (ii) disclosure costs (ϕx_i for each i), and (iii) the social cost of emissions ($\psi \theta_i k_i$ for each i). While the effect of an increase in $\bar{\theta}$ on the total disclosure cost is immediate, the effect on total emissions is less obvious since, as already noted, the newly disclosing firms operate at a higher scale and emit more, while the non-disclosing firms operate at a lower scale and emit less.

Based on this breakdown of the effects, Figures 3 and 4 analyze the drivers of the results shown in the Figures 1 and 2, respectively. They show that, in all cases where in Figures 1 and 3 the socially optimal disclosure threshold exceeds the one in laissez-faire, the gains from doing so come from the reduction in emissions (achieved in this case within the pool of non-disclosing firms, to investors impose a higher cost of capital by rationally anticipating the higher average emission intensity of the pool). In contrast, in most (but not all) cases where the planner prefers a lower disclosure threshold, the gains come mainly from saving on disclosure costs. However, there are parameter values for which lowering the disclosure threshold allows the planner both to save on disclosure costs and to reduce emissions (in this

[14] This value implies that a firm with the average emission intensity in our examples ($\theta = 0.5$) would generate negative externalities equal to 1.5 times the size of its investment scale.

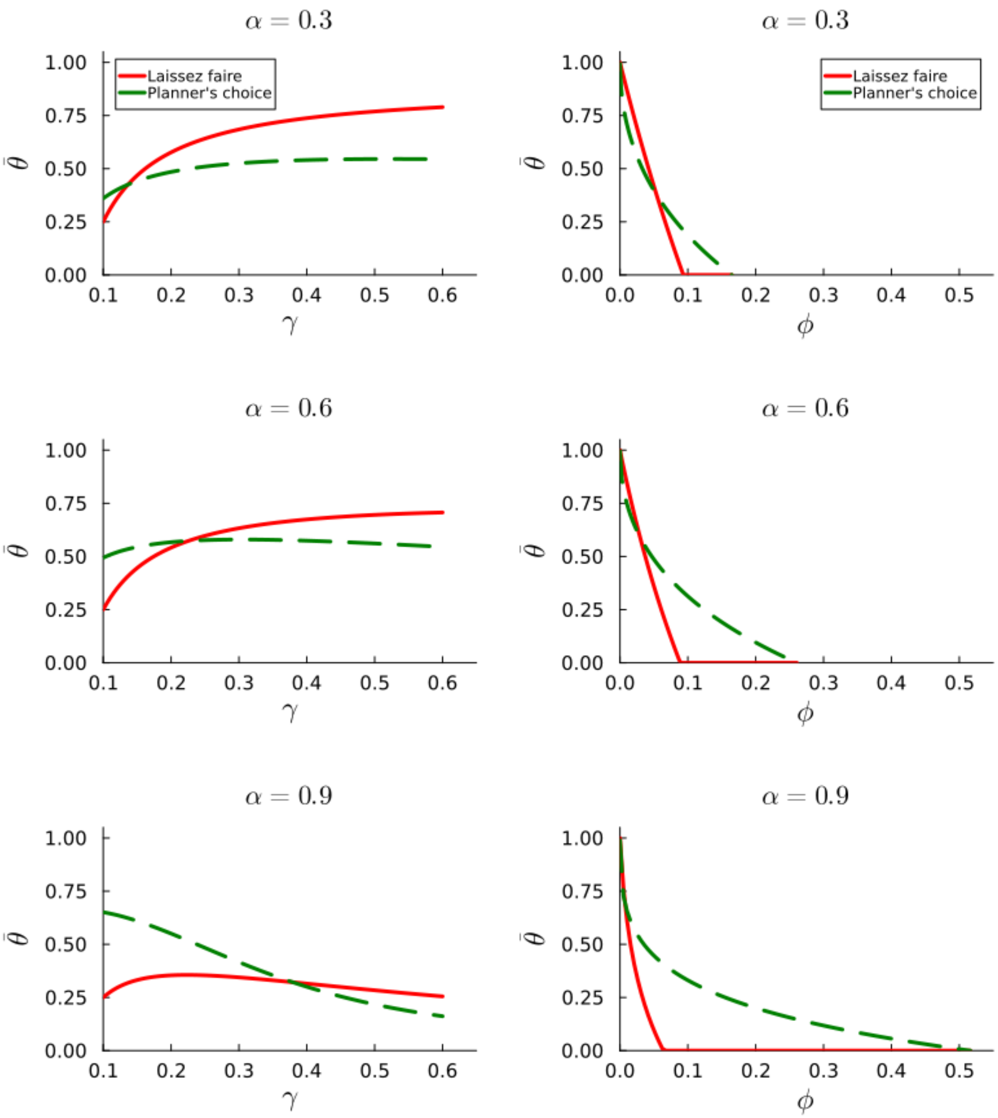

Figure 2: Intervening on disclosures under large emission externalities. This figure compares the laissez faire disclosure threshold (solid red lines) with the socially optimal disclosure threshold (dashed green lines) under higher emission externalities. We assume $f(k) = k^\alpha$ with $\alpha \in \{0.3, 0.6, 0.9\}$, $\psi = 3$, and $\theta \sim U_{[0,1]}$. In the left panels, the cost of disclosure ϕ is set such that in equilibrium $\bar{\theta} = 0.25$ when $\gamma = 0.1$. In the right panels, we fix $\gamma = 0.2$ and ϕ is reported as a proportion of the investment undertaken by the least emission intensive firm under disclosure $(k(0))$ and the corresponding value of α.

case thanks to the lower investment undertaken by the firms that switch from disclosing to not disclosing).

Each panel in Figure 3 plots the variation in the components (i), (ii), and (iii) mentioned above that would follow from adopting the disclosure threshold that maximizes total welfare W (the "planners' choice" described by the dashed green lines in corresponding panel of Figure 1) instead of the laissez faire threshold (depicted by the solid red lines in Figure 1). The variations in each component are normalized by (and hence reported as a proportion of) the total investment in the laissez-faire equilibrium reached under the corresponding parameter values. For the range of parameters over which the planners' choice in Figure 1 *exceeds* the laissez faire choice, the reported values have been *highlighted with thicker lines* in order to minimize the need to navigate between Figures 1 and 3.

In the cases in the first two rows ($\alpha = 0.3$, 0.6) of Figure 3, saving on disclosure costs is the main rationale for the social planner to prefer lower disclosure thresholds; narrow investment returns also increase by just by a tiny amount; the intervention on the disclosure threshold in these cases comes at the cost of higher emissions. In the case with $\alpha = 0.9$, where changes in the cost of capital have a larger impact on investment levels, there are parameter values (low values of investors' climate consciousness γ in the left panel or large values of the disclosure cost ϕ in the right panel) for which it is optimal for the social planner to induce higher disclosures since the gains from the reduction in emissions are large enough to offset the increase in disclosure costs.

Figure 4 plots the analogous breakdown of the welfare gains associated with the interventions on $\bar{\theta}$ that would be optimal in the scenarios depicted in Figure 2, where the externality parameter ψ was set to be higher. In this case, reducing emissions emerges as a rationale for intervention also under the more moderate values of the returns to scale parameter α. As in Figure 3, for all parameters where the socially optimal disclosure threshold exceeds the one in laissez-faire, the mains gains come from reducing emissions (and disclosure costs are the main cost, while the differences in narrow investment returns are tiny).

3.3 The effects of changes in investors' climate consciousness

This section explores the effects on equilibrium outcomes of changes in investors' climate consciousness parameter γ. As anticipated in prior sections, this parameter can be related to the presence of socially responsible investors with some degree of (impure) altruism that makes them internalize some of the social costs of the emissions generated by the investments that they finance. Alternatively (and perhaps complementarily), it can also be related to investors' concern about future financial costs (or risks) associated with firms' emissions,

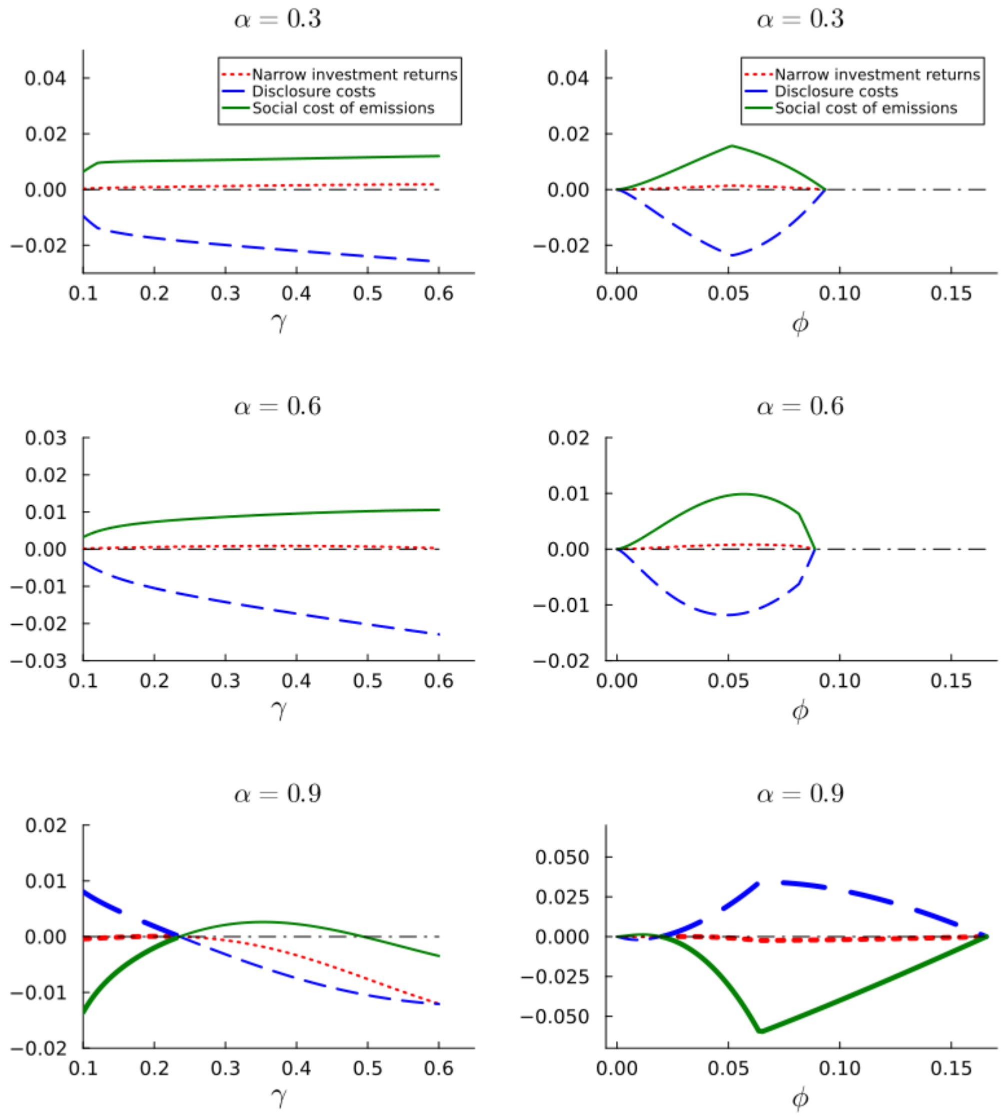

Figure 3: Disentangling the source of welfare gains under moderate emission externalities. Breakdown of the variation in welfare attained by adopting the "planner choice" disclosure threshold (dashed green lines in Figure 1) instead of the "laissez faire" choice (solid red lines in Figure 1). The variations in each component are measured as a proportion of the total investment in the laissez-faire equilibrium reached under the corresponding parameter values. We assume $f(k) = k^{\alpha}$ with $\alpha \in \{0.3, 0.6, 0.9\}$, $\psi = 1$, and $\theta \sim U_{[0,1]}$. In the left panels, the cost of disclosure ϕ is set such that in equilibrium $\bar{\theta} = 0.25$ when $\gamma = 0.1$. In the right panels, we fix $\gamma = 0.2$ and ϕ is reported as a proportion of the investment undertaken by the least emission intensive firm under disclosure ($k(0)$) and the corresponding value of α. For the range of parameters over which the planners' choice in Figure 1 *exceeds* the laissez faire choice, the reported values have been *highlighted with thicker lines.*

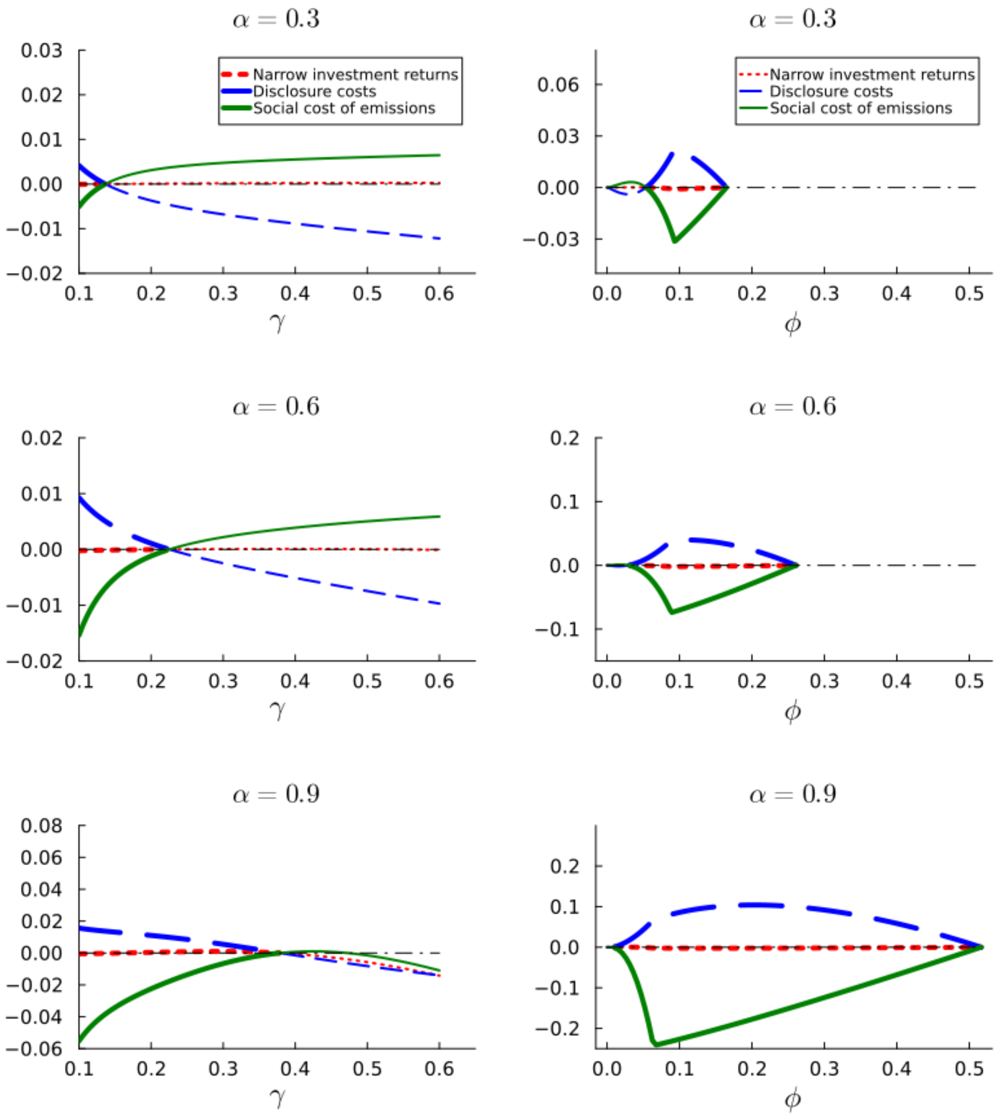

Figure 4: Disentangling the source of welfare gains under large emission externalities. Breakdown of the variation in welfare attained by adopting the "planner choice" disclosure threshold (dashed green lines in Figure 2) instead of the "laissez faire" choice (solid red lines in Figure 2). The variations in each component are measured as a proportion of the total investment in the laissez-faire equilibrium reached under the corresponding parameter values. We assume $f(k) = k^\alpha$ with $\alpha \in \{0.3, 0.6, 0.9\}$, $\psi = 3$, and $\theta \sim U_{[0,1]}$. In the left panels, the cost of disclosure ϕ is set such that in equilibrium $\bar{\theta} = 0.25$ when $\gamma = 0.1$. In the right panels, we fix $\gamma = 0.2$ and ϕ is reported as a proportion of the investment undertaken by the least emission intensive firm under disclosure ($k(0)$) and the corresponding value of α. For the range of parameters over which the planners' choice in Figure 2 *exceeds* the laissez faire choice, the reported values have been *highlighted with thicker lines.*

including those implied by the transition to a de-carbonized economy.

In scenarios with observable emission intensities, zero disclosure costs or compulsory disclosure, the implications of increasing γ would be trivial. By inducing an increase in the cost of capital proportional to each firms' emission intensity θ, a rise in γ would reduce investment and emission for all firms (except those with $\theta = 0$) and more so the higher their emission intensity. To the extent that γ remains below the social cost of emissions ψ, these changes would better align privately optimal investment decisions to the socially optimal ones, so social welfare W would necessarily increase. These predictions are possibly close to the common wisdom view on the effects of rising investors' climate consciousness.[15]

In the scenario with costly voluntary disclosures, things are more complicated. Investors' climate consciousness can alter firms' incentives to disclose their emission intensity, so the effects on investment levels in that case will reflect a convolution of the above direct effects (conditional on either the disclosed θ or the average emission intensity $\hat{\theta}$ of non-disclosing firms) and the effects associated with the shift in the disclosure threshold $\bar{\theta}$ (akin to those extensively discussed in the previous subsection).

Effect on disclosure incentives Interestingly, the (local) dependency of the disclosure threshold $\bar{\theta}$ with respect to γ is not generally unambiguously signed. The following result is a first step to show this:

Proposition 2 *The disclosure threshold $\bar{\theta}$ is (locally) strictly increasing in investors' climate consciousness γ if and only if*

$$\frac{\hat{\theta}}{\bar{\theta}} > \frac{k(\bar{\theta})}{k(\hat{\theta})}, \tag{29}$$

where $\hat{\theta} = \mathbb{E}(\theta \mid \theta \geq \bar{\theta})$.

This proposition states a necessary and sufficient condition under which the disclosure threshold $\bar{\theta}$ is (locally) increasing in investors' climate consciousness. Intuitively, the result means that a rise in γ increases disclosure if and only if the marginal disclosing firm is perceived to generate lower total emissions, $\bar{\theta}k(\bar{\theta})$, than the average firm in the pool of non-disclosing firms, $\hat{\theta}k(\hat{\theta})$. The condition holds if and only if the percentage difference in emissions per unit of investment, $\hat{\theta}/\bar{\theta} > 1$ (where per-unit emissions are obviously higher

[15] Our model adopts the simplifying partial equilibrium assumption that investors supply of funds is perfectly elastic at a baseline cost of capital (under $\theta = 0$) equal to the risk free rate (that we have further normalized to zero). In trivial extension of the model with an upward slopping supply of funds and an endogenous, market clearing risk free rate r, the increase in γ would induce further reallocation effects by inducing a decline in the equilibrium value of r (which would partly offset the direct impact of the rise in γ).

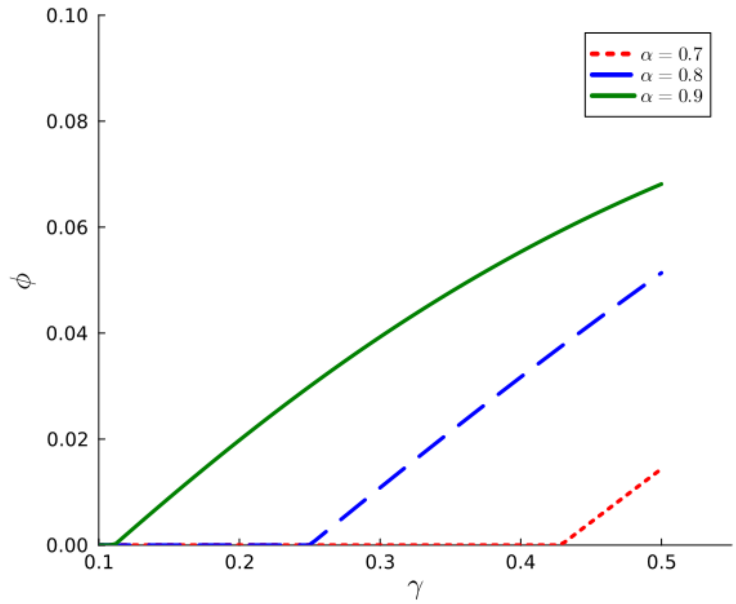

Figure 5: Frontier in (γ, ϕ) space above which the condition (29) holds. We assume $f(k) = k^{\alpha}$ with $\alpha \in \{0.7, 0.8, 0.9\}$, and $\theta \sim U_{[0,1]}$. The cost of disclosure ϕ is normalised and reported as a proportion of the investment $k(0)$ of the least emission-intensive firm ($\theta = 0$) under disclosure.

for firms in the pool than for the marginal firm $\bar{\theta}$) exceeds the percentage difference in equilibrium investment levels, $k(\bar{\theta})/k(\hat{\theta}) > 1$ (where investment is obviously higher for the marginal firm $\bar{\theta}$ than for the firms in the pool).

Numerical examples show that condition (29) may hold or not depending on the functional form of the return function $f(\cdot)$, the distribution of θ, and parameters. To illustrate this, consider the very tractable case in which the return function is $f(k) = k^{\alpha}$ with $\alpha \in (0, 1)$ and emission intensities θ are uniformly distributed on the interval $[0, 1]$. Figure 5 shows the frontier in (γ, ϕ) space above which (29) holds. We plot the frontier for three different values of the return to scale parameter, $\alpha \in \{0.7, 0.8, 0.9\}$, allowing the climate consciousness parameter γ to move between 0.1 and 0.5. To facilitate the interpretation, the disclosure cost ϕ is reported as a proportion of the investment $k(0)$ of the least emission-intensive firm ($\theta = 0$) under disclosure.

In these examples, condition (29) is more easily satisfied when α is smaller, that is, when investment is less responsive to changes in the cost of capital.[16] For a fixed α, the condition is more easily satisfied when the disclosure cost ϕ is smaller and investors' climate consciousness γ is larger.

[16] In fact, condition (29) is always satisfied when α is sufficiently small.

Effect on investment and emissions For given disclosure decisions, an increase in investors' climate consciousness γ would heterogeneously reduce the scale of investment across firms by increasing their cost of capital in proportion to their *perceived* emission intensity. However, as just discussed, an increase in γ also influences firms' incentives to disclose and does so in a nuanced manner, with a sign and intensity that depends on parameters. The effects of the change in the disclosure threshold $\bar{\theta}$ produce in turn further cross-sectional implications, along the lines discussed in Section 3.2. When putting all the relevant effects together, some firms will definitely emit less but other firms may end emitting more.

In what follows, we formally analyze the different effects that contribute to the change in overall emissions following a (marginal) increase in investors' climate consciousness γ. The overall emissions Σ in the competitive equilibrium can be expressed as

$$\Sigma = \int_0^{\bar{\theta}} \theta k(\theta) g(\theta) d\theta + \int_{\bar{\theta}}^1 \theta k(\hat{\theta}) g(\theta) d\theta = \int_0^{\bar{\theta}} \theta k(\theta) g(\theta) d\theta + (1 - G(\bar{\theta}))\hat{\theta} k(\hat{\theta}), \tag{30}$$

where in the second equality we use the definition of $\hat{\theta}$ to simplify the expression. Using Leibniz's rule, the marginal effect of a change in γ on Σ is given by

$$\begin{aligned}
\frac{d\Sigma}{d\gamma} &= \bar{\theta} k(\bar{\theta}) g(\bar{\theta}) \frac{d\bar{\theta}}{d\gamma} + \int_0^{\bar{\theta}} \theta \frac{\partial k(\theta)}{\partial \gamma} g(\theta) d\theta \\
&\quad - \bar{\theta} k(\hat{\theta}) g(\bar{\theta}) \frac{d\bar{\theta}}{d\gamma} + \left(\int_{\bar{\theta}}^1 \theta g(\theta) d\theta \right) \left(\frac{\partial k(\hat{\theta})}{\partial \gamma} + k'(\hat{\theta}) \frac{d\hat{\theta}}{d\bar{\theta}} \frac{d\bar{\theta}}{d\gamma} \right) \\
&= \bar{\theta}(k(\bar{\theta}) - k(\hat{\theta})) g(\bar{\theta}) \frac{d\bar{\theta}}{d\gamma} + \int_0^{\bar{\theta}} \theta \frac{\partial k(\theta)}{\partial \gamma} g(\theta) d\theta \\
&\quad + (1 - G(\bar{\theta}))\hat{\theta} \frac{\partial k(\hat{\theta})}{\partial \gamma} + k'(\hat{\theta})\hat{\theta}(\hat{\theta} - \bar{\theta}) g(\bar{\theta}) \frac{d\bar{\theta}}{d\gamma},
\end{aligned} \tag{31}$$

where in the second equality we again use the definition of $\hat{\theta}$ as well as $d\hat{\theta}/d\bar{\theta} = (\hat{\theta} - \bar{\theta}) g(\bar{\theta})/(1 - G(\bar{\theta}))$ to simplify the expression.

Rearranging, the effect of γ on total emissions can be decomposed into two parts. The first is the direct effect on investment (and therefore emissions) holding the disclosure threshold $\bar{\theta}$ fixed:

$$\frac{\partial \Sigma}{\partial \gamma} = \int_0^{\bar{\theta}} \theta \frac{\partial k(\theta)}{\partial \gamma} g(\theta) d\theta + (1 - G(\bar{\theta}))\hat{\theta} \frac{\partial k(\hat{\theta})}{\partial \gamma}. \tag{32}$$

This effect is a weighted sum of the (heterogenous) reductions in emissions that would follow the decline in investment scale among both disclosing and non-disclosing firms. As one would expect, if investors internalize the social cost of emissions at a larger degree, they assign a larger cost of capital per unit of perceived implied emissions, thus reducing the investment and the emissions conditional on any perceived level of emissions.

The second part in (31) captures the indirect effect of γ on total emissions, which comes from the impact of γ on disclosure decisions, and is given by

$$\frac{\partial \Sigma}{\partial \bar{\theta}} \frac{d\bar{\theta}}{d\gamma} = \left[\bar{\theta}(k(\bar{\theta}) - k(\hat{\theta}))g(\bar{\theta}) + k'(\hat{\theta})(\hat{\theta} - \bar{\theta})g(\bar{\theta}) \right] \frac{d\bar{\theta}}{d\gamma}, \tag{33}$$

where the sign of $d\bar{\theta}/d\gamma$ depends on the condition established in Proposition 2. The expression in square brackets measures the marginal change in total emissions resulting from a marginal change in the disclosure threshold and contains terms already explored in Section 3.2 when analyzing the welfare impact of intervening on $\bar{\theta}$.

The first term within the square brackets accounts for positive impact on total emissions of the increase in investment scale that occurs when the marginal disclosing firm switches from not disclosing to disclosing. So this term contributes positively to the indirect effect if and only if the disclosure threshold increases with γ ($d\bar{\theta}/d\gamma > 0$). The second term in square brackets has a negative sign since $k'(\hat{\theta}) < 0$ and $\hat{\theta} > \bar{\theta}$ and reflects that if the disclosure threshold increases, firms remaining in the pool of non-disclosing firms will be perceived as higher emitters on average and, hence, their cost of capital will increase and their investment will fall. So this term contributes negatively to the indirect effect if and only if the disclosure threshold increases with γ ($d\bar{\theta}/d\gamma > 0$). But then, in general, each of the terms in (33) have opposite signs and, depending on parameters as well as the density of firms across emission intensities, one or the other might dominate.

If the indirect effect is negative, then it reinforces the direct effect, and overall greater climate consciousness implies lower total emissions. Otherwise, the indirect effect would offset, at least partly, the direct effect. In spite of this analytical ambiguity on the sign of the overall effect of γ on Σ, in all the numerical examples that we have explored, higher investor climate consciousness leads to lower overall emissions, as well as to an increase in social welfare W as defined in (5).[17]

For illustration, assuming as in prior examples $f(k) = k^{\alpha}$, $\psi = 1$, and a uniform distribution of θ on the interval $[0, 1]$, Figure 6 shows the effects of increasing γ from 0.1 to 0.9 on the equilibrium disclosure threshold $\bar{\theta}$, and the implied overall emissions . We consider three different values of $\alpha \in \{0.3, 0.6, 0.9\}$, and the disclosure cost ϕ is set such that in equilibrium $\bar{\theta} = 0.5$ when $\gamma = 0.5$. Emissions and welfare are reported as (proportional) differences relative to their level in the case with $\gamma = 0.1$. Our examples include cases in which the dis-

[17] It would be possible to formally compute $dW/d\gamma$ and decompose such a total effect on the direct and indirect effects, as in the analysis of $d\Sigma/d\gamma$, but we omit this for brevity. Notice that in the analysis of policy interventions on the disclosure threshold in Section 3.2, we explicitly discussed the components and generally ambiguous sign of $dW/d\bar{\theta}$, which is just one of the elements in $dW/d\gamma = \partial W/\partial\gamma + (dW/d\bar{\theta})(d\bar{\theta}/d\gamma)$, where $\partial W/\partial\gamma > 0$ and the sign of $d\bar{\theta}/d\gamma$ is ambiguous as shown in Proposition 2.

closure threshold increases in investors' climate consciousness γ (the dashed blue and dotted red lines for sufficiently large values of γ) as well as cases in which it decreases in γ (the solid green line for sufficiently large values of γ). In all of them, however, emissions Σ decrease and welfare W increases when γ increases (approaching the full internalization level ψ from below).

4 Equilibrium with emission taxes

In this section, we begin by characterizing a competitive equilibrium with voluntary disclosures by firms in the presence of emission taxes and a possible subsidy or tax on disclosure. Then, we derive the *constrained efficient allocation* by determining the social planner's optimal joint choice of emission taxes and a disclosure tax or subsidy. We will show that, in our setup, under the optimal emission taxes, a tax on disclosure would be needed to avoid firms' generally excessive incentive to disclose.

4.1 Characterizing an equilibrium with taxes

Consider a voluntary disclosure regime in which each entrepreneur faces a tax τ_i on the investment level k_i undertaken by her firm as well as a common tax $T \geq 0$ or subsidy $T < 0$ on the choice to disclose ($x_i = 1$). Assume also that authorities fix τ_i based on their beliefs about the emissions per unit of investment, θ_i, that the firm generates, and that they have the same information about θ_i as investors. The definition and characterization of equilibrium in this setup can closely follow the notation and analysis in Section 3.1. Thus, for brevity, we only spell out the elements that highlight the key differences with respect to the laissez faire equilibrium.

As before, we focus on equilibria in which non-disclosing firms pool at common (uninformative) choices of k_i and investors and, now, tax authorities rationally attribute to all of them a common conditional distribution of θ_i and, hence, a common conditional expected emission intensity $\mathbb{E}(\theta_i \mid x_i = 0)$. Given this informational constraints, tax authorities set emission tax schedules (describing tax rates per unit of investment) of the form

$$\tau_i = \begin{cases} \tau(\theta_i), & \text{if } x_i = 1, \\ \hat{\tau}, & \text{if } x_i = 0, \end{cases} \tag{34}$$

where $\tau(\theta_i)$ can be suitably contingent on the disclosed θ_i, while $\hat{\tau}$ must be common to all non-disclosing firms.

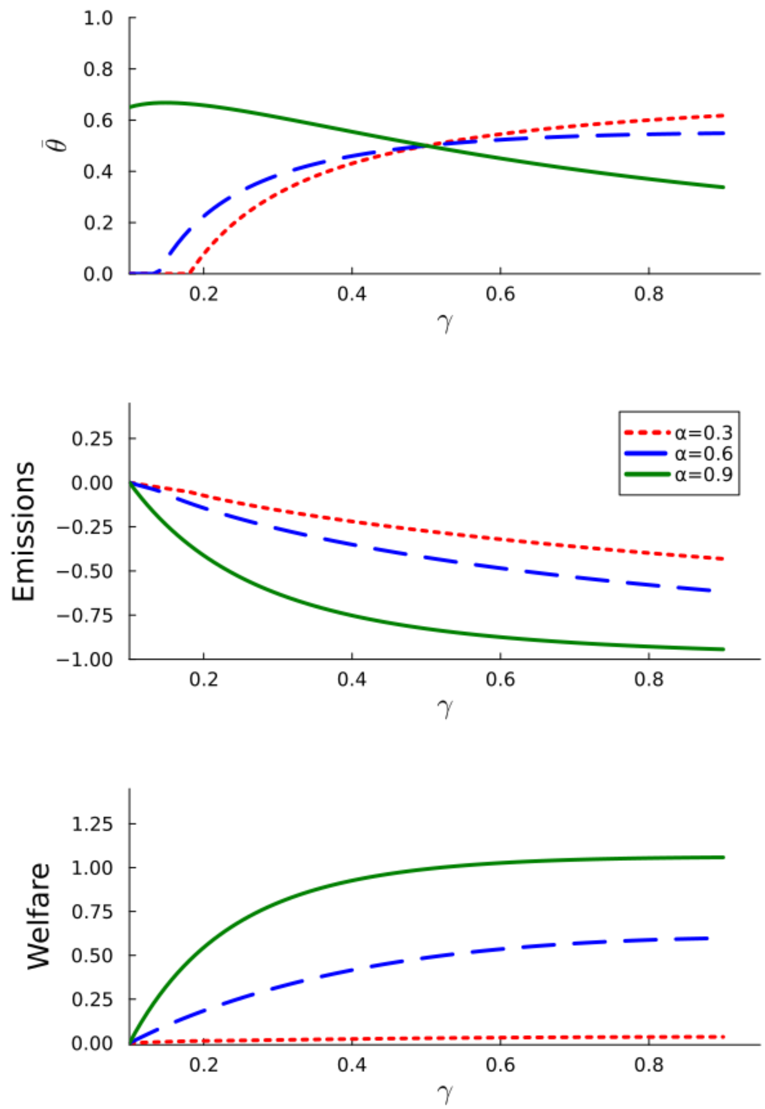

Figure 6: Effects of increasing investors' climate consciousness. We assume $f(k) = k^{\alpha}$ with $\alpha \in \{0.3, 0.6, 0.9\}, \psi = 1$, and $\theta \sim U_{[0,1]}$. The cost of disclosure ϕ is set such that in equilibrium $\bar{\theta} = 0.5$ when $\gamma = 0.5$. Emissions and welfare are reported as changes relative to the case when $\gamma = 0.1$.

Conditional on their disclosure decision, the problem solved by firms in the equilibrium with emission taxes is:

$$\max_{k_i,b_i} \; f(k_i) - (\phi + T)x_i - \tau_i k_i - b_i \tag{35}$$

$$\text{s.t. } b_i - (1 + \gamma\mathbb{E}(\theta_i \mid x_i))k_i \geq 0, \tag{36}$$

so that entrepreneurs maximize expected profits net of taxes subject to investors' participation constraint. Since the objective function is decreasing in the repayment b_i, this constraint is always binding. Then, using it to substitute for b_i in the objective function, the first order condition for an interior maximum in k_i becomes

$$f'(k_i) = 1 + \gamma\mathbb{E}(\theta_i \mid x_i) + \tau_i, \tag{37}$$

which implicitly defines each firm's optimal scale of investment given x_i as a function of investors' expectation about θ_i and the applicable tax rate τ_i.

To make the expressions more compact, denote $\mathbb{E}(\theta_i \mid x_i = 0)$ by $\hat{\theta}^{\tau}$ and the pooling tax rate $\hat{\tau}$ by $\tau(\hat{\theta}^{\tau})$.[18] Then firms' investment decisions and private value in the equilibrium with taxes can be described as

$$k_i^{\tau} = \begin{cases} k^{\tau}(\theta_i), & \text{if } x_i = 1, \\ k^{\tau}(\hat{\theta}^{\tau}), & \text{if } x_i = 0, \end{cases} \tag{38}$$

and

$$v_i^{\tau} = \begin{cases} v^{\tau}(\theta_i) - (\phi + T), & \text{if } x_i = 1, \\ v^{\tau}(\hat{\theta}^{\tau}), & \text{if } x_i = 0, \end{cases} \tag{39}$$

respectively, where

$$k^{\tau}(\theta) = (f')^{-1}(1 + \gamma\theta + \tau(\theta)), \tag{40}$$

and

$$v^{\tau}(\theta) = f(k^{\tau}(\theta)) - (1 + \gamma\theta + \tau(\theta))k^{\tau}(\theta). \tag{41}$$

Assuming that the tax schedule $\tau(\theta)$ is non-decreasing in its argument (which is a very mild condition in this setup), it is immediate to see that both the investment function $k^{\tau}(\theta)$ and the value function $v^{\tau}(\theta)$ are decreasing in θ, thus resembling equivalent qualitative properties of these functions in the absence of taxes. Additionally, notice that a ceteris paribus change in the tax rate $\tau(\theta)$ has the same qualitative impact on $k^{\tau}(\theta)$ and $v^{\tau}(\theta)$ as θ. So imposing a higher emission tax $\tau(\theta)$ on a firm disclosing type θ (or a higher common tax $\hat{\tau}$ on a firm not

[18] Result below will confirm that $\hat{\theta}^{\tau}$ does not belong to the range of values of θ_i for which firms choose $d_i = 1$, so that extending the definition of $\tau(\theta)$ to this value of θ entails no notational conflict with respect to (34).

disclosing its type) will reduce its investment (as well as the private value of the firm). Thus, authorities can aim to control the investment levels $k^\tau(\theta_i)$ for disclosing firms and $k^\tau(\hat{\theta}^\tau)$ for non-disclosing firms through a suitable choice of the tax schedule in (34).

Turning to the disclosure decision, we can define an interior Bayesian equilibrium with taxes characterized by a disclosure threshold $\bar{\theta}^\tau \in (0,1)$ which satisfies analogous conditions to C1-C3 for the equilibrium without taxes. Akin to what we have in (18), the equilibrium threshold $\bar{\theta}^\tau$ below which firms disclose, if it exists, should satisfy the indifference condition

$$v^\tau(\bar{\theta}^\tau) - (\phi + T) = v^\tau(\mathbb{E}(\theta \mid \theta \geq \bar{\theta}^\tau)), \tag{42}$$

since we would have $\hat{\theta}^\tau = \mathbb{E}(\theta \mid \theta \geq \bar{\theta}^\tau)$. Analogously to Assumption 1, the following condition guarantees the existence of an interior equilibrium with taxes:

$$\phi + T < v^\tau(0) - v^\tau(\mathbb{E}(\theta \mid \theta > 0)). \tag{43}$$

As in the analysis of the equilibrium without taxes, for the ease of exposition, we assume that (42) has a unique solution. Like in Proposition 1 for the equilibrium without taxes, the disclosure threshold in the interior equilibrium with taxes satisfies $d\bar{\theta}^\tau/d\phi < 0$ and, hence, also $d\bar{\theta}^\tau/dT < 0$. So authorities could indirectly decrease (increase) the disclosure threshold by increasing (decreasing) the tax on the choice of $x_i = 1$.

4.2 Constrained efficient allocation

Consider the problem of a social planner who can choose the tax rate schedule $\tau(\theta)$ for disclosing firms, the tax rate $\hat{\tau}$ for non-disclosing firms, and the tax (or subsidy) on disclosure T. The planner's welfare maximizing choice of the triple $(\tau^*(\theta), \hat{\tau}^*, T^*)$ determines the investment undertaken by disclosing and non-disclosing firms and the disclosure decisions of the implied *constrained efficient allocation,* $(\bar{\theta}^*, k^*(\theta), k^*(\hat{\theta}^*))$, where $\bar{\theta}^*$ is the disclosure threshold, $\hat{\theta}^*$ is the average emission intensity of the non-disclosing firms, $k^*(\theta)$ describes the θ-contingent investment level of disclosing firms, and $k^*(\hat{\theta}^*)$ is the common investment level of non-disclosing firms in the equilibrium induced by $(\tau^*(\theta), \hat{\tau}^*, T^*)$.

Formally, the welfare maximizing triple $(\tau^*(\theta), \hat{\tau}^*, T^*)$ satisfies

$$\begin{aligned}(\tau^*(\theta), \hat{\tau}^*, T^*) = \arg\max_{(\tau(\theta),\hat{\tau},T)} &\int_0^{\bar{\theta}^\tau} \left[f(k^\tau(\theta)) - (1+\psi\theta)k^\tau(\theta) - \phi\right] g(\theta)d\theta \\ &+ \int_{\bar{\theta}^\tau}^1 \left[f(k^\tau(\hat{\theta}^\tau)) - (1+\psi\theta)k^\tau(\hat{\theta}^\tau)\right] g(\theta)d\theta, \end{aligned} \tag{44}$$

where $\bar{\theta}^{\tau}$, $\hat{\theta}^{\tau}$, and $k^{\tau}(\theta)$ are the objects that describe the disclosure threshold, the mean emission intensity of the non-disclosing firms, and investment levels, respectively, in the equilibrium with taxes induced by each triple $(\tau(\theta), \hat{\tau}, T)$.

Assuming that the problem in (44) has an interior solution in $\bar{\theta}^*$ (which we can verify to be the case for strictly positive but not too large values of the disclosure cost ϕ), the following proposition characterizes the optimal taxes and the condition that implicitly defines the optimal disclosure threshold.[19]

Proposition 3 *The constrained efficient allocation can be attained as an equilibrium with taxes by setting emission taxes*

$$\tau^*(\theta) = (\psi - \gamma)\theta \tag{45}$$

for disclosing firms, and

$$\hat{\tau}^* = \tau^*(\hat{\theta}^*) = (\psi - \gamma)\hat{\theta}^* \tag{46}$$

for non-disclosing firms, and a tax on disclosure

$$T^* = \psi(\hat{\theta}^* - \bar{\theta}^*)k^*(\hat{\theta}^*). \tag{47}$$

Moreover, the (interior) socially optimal disclosure threshold $\bar{\theta}^*$ satisfies

$$\mathcal{D}(\bar{\theta}^*) = \phi,$$

where

$$\mathcal{D}(\bar{\theta}) = [f(k^*(\bar{\theta})) - (1 + \psi\bar{\theta})k^*(\bar{\theta})] - [f(k^*(\hat{\theta})) - (1 + \psi\bar{\theta})k^*(\hat{\theta})], \tag{48}$$

with $\hat{\theta} = \mathbb{E}(\theta \mid \theta \geq \bar{\theta})$, measures the social benefit of disclosure for a generic marginal disclosing firm $\bar{\theta}$ and is strictly positive for all $\bar{\theta} \in [0, 1)$.

The proposition states that constrained efficiency can be achieved by setting emission taxes that account for investors' non-internalized part of the emission externalities. Besides, the constrained efficient disclosure threshold $\bar{\theta}^*$, if interior, can be found following an elementary (social) cost-benefit calculation: by equating the cost of disclosure ϕ to the social benefit of disclosing θ for the marginal disclosing type $\bar{\theta}$ (which comes from the efficiency gain associated with choosing its investment level on the basis of its true θ rather than the imputed $\hat{\theta}^{\tau}$). Since the latter is always positive for $\bar{\theta}^{\tau} \in [0, 1)$ but becomes zero when $\bar{\theta}^{\tau} = 1$,

[19]The condition is a necessary condition for the optimality of $\bar{\theta}^*$. In case, several values of $\bar{\theta}$ satisfy that condition, $\bar{\theta}^*$ would be the one that, together with the corresponding values of $\tau^*(\theta)$, $\hat{\tau}^*$, and T^* imply the largest welfare.

full disclosure is optimal if and only if the disclosure cost ϕ is zero.[20] Moreover, the constrained efficient allocation will indeed involve an interior $\bar{\theta}^*$ (as assumed in the proposition) if ϕ is strictly positive but not too large. Instead, for sufficiently large values of ϕ, inducing no disclosures ($\bar{\theta}^* = 0$) would be optimal.

Interestingly, as anticipated when discussing the laissez-faire equilibrium in the limit case with $\gamma = \psi$, once emission taxes take care of the emission externalities, firms' private incentives to disclose are excessive. Thus, when the disclosure cost ϕ is strictly positive but not too large so that $\bar{\theta}^*$ is interior, inducing the constrained efficient allocation requires not only positive emission taxes but also a positive tax on disclosure $T^* > 0$. The intuition for this result is that, without such a tax, the private gains from disclosing of the marginal disclosing firm $\bar{\theta}^*$ would exceed the social benefit captured by $\mathcal{D}(\bar{\theta}^*)$. This can be formally seen by comparing the elements in the social indifference condition $\mathcal{D}(\bar{\theta}^*) = \phi$ with those in the private indifference condition (42) of the equilibrium with taxes. In the private calculations of firm value under no disclosure, the marginal firm takes into account that both its investment level and the cost of its capital are determined by the average type $\hat{\theta}^*$ of the non-disclosing firms (which is what investors take into account when pricing their funds). In contrast, in the relevant social calculations, the social cost of the investment undertaken by the marginal type if remaining in the pool of non-disclosing firms is computed under its true type $\bar{\theta}^*$. Having $\hat{\theta}^* > \bar{\theta}^*$ implies the need to impose a strictly positive tax T^* that offsets the (otherwise positive) difference between the private and the social cost of capital under no disclosure.

Numerical examples In Figure 7 we compare the constrained efficient disclosure threshold $\bar{\theta}^*$ with the ones that characterize (i) the laissez faire equilibrium, (ii) the equilibrium with Pigouvian emission taxes but no intervention on the disclosure threshold, and (iii) the equilibrium without emission taxes in which the social planner chooses the disclosure threshold. As before, we assume $f(k) = k^\alpha$ with $\alpha \in \{0.3, 0.6, 0.9\}$, a uniform distribution of θ over the interval $[0, 1]$, and $\psi = 1$. The examples correspond to the case with $\gamma = 0.2$. The disclosure cost ϕ is normalized and reported (on the horizontal axes of each panel) as a proportion of the investment $k(0)$ of the least emission-intensive firm ($\theta = 0$) under disclosure.

In all the depicted cases, $\bar{\theta}^*$ is very close to the disclosure threshold that the social planner would choose without emission taxes. In the cases with $\alpha = 0.3$ and $\alpha = 0.6$, all the unregulated disclosure thresholds are significantly higher than $\bar{\theta}^*$, except when the disclosure cost is close to zero. For both values of α, introducing Pigouvian emission taxes pushes the

[20] The positivity of $\mathcal{D}(\bar{\theta})$ is in contrast with what we found in the analysis of the laissez-faire equilibrium, where increasing $\bar{\theta}$ had two opposite-sign effects on welfare and the implied overall benefit of raising $\bar{\theta}$ could be negative.

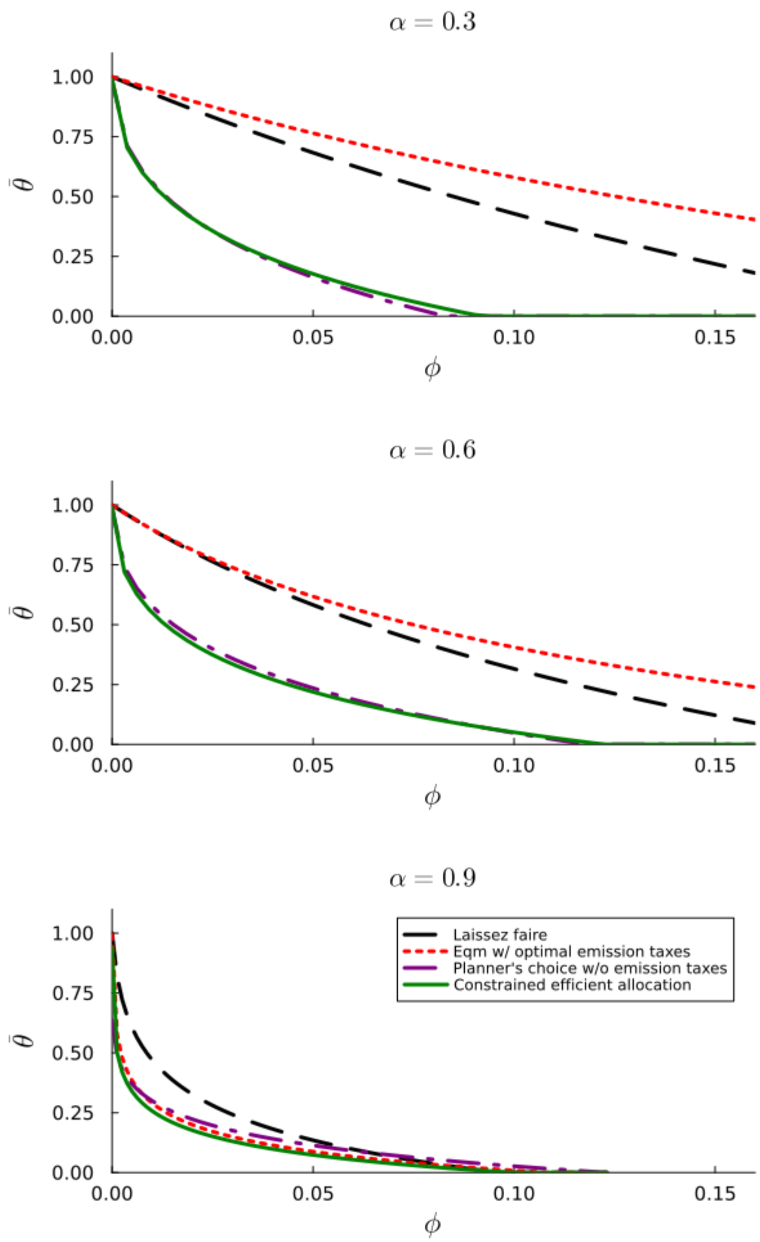

Figure 7: Comparing the disclosure threshold across regimes. This figure compares the constrained efficient disclosure threshold with the one in (i) the laissez faire equilibrium, (ii) the equilibrium with Pigouvian emission taxes but to intervention on the disclosure threshold, and (iii) the equilibrium without emssion taxes in which the social planner chooses the disclosure threshold. We assume $f(k) = k^{\alpha}$ with $\alpha \in \{0.3, 0.6, 0.9\}$, $\theta \sim U_{[0,1]}$, $\gamma = 0.2$, and $\psi = 1$. The disclosure cost ϕ is normalised and reported as a proportion of the investment $k(0)$ of the least emission-intensive firm ($\theta = 0$) under disclosure.

disclosure thresholds to even higher levels than in the laissez faire equilibrium. This last result is reversed in the case with $\alpha = 0.9$, where the difference $\bar{\theta}^*$ and the unintervened threshold with Pigouvian emission taxes is much smaller (while the laissez faire disclosure threshold is still significantly higher than $\bar{\theta}^*$).

5 Discussion of the results

This section will be further developed in the future. So far we just reproduce here the preliminary discussion already included in some paragraphs of the introduction.

The results obtained in previous sections suggest that when climate disclosures are costly, the emission-reducing and welfare-enhancing effects of promoting carbon disclosures are not warranted. Even when investors' climate consciousness and carbon taxes are insufficient to provide a full internalization of carbon related externalities, the welfare effect of promoting greater disclosures depends on technological parameters, investors' climate consciousness, carbon taxes, and the distribution of emission intensities across firms. Over wide ranges of parameters, unless the non-internalized external costs of emissions are huge, our numerical examples feature net negative effects from encouraging disclosures above and beyond the levels that characterize the voluntary disclosure equilibrium.

These caveats on disclosure policies, including the conclusion that constrained-efficient carbon taxation would have to be accompanied with a tax on disclosures can be qualified on the basis of a number of conceptual and practical considerations not fully accounted for in our analysis. The most relevant one is that, perhaps, the exercise of both investors' consciousness and carbon taxation require a verifiable measure of emission intensity. In out setup, investors and tax authorities are able to impose suitable financing terms and taxes to the pool of non-disclosing firms on the basis of rational expectations (that is, Bayesian estimates of their emission intensity combined with the observable levels of investment/activity of each firm). However, behavioral and governance frictions may prevent investors from fully disciplining firms whose emission intensity is not observed. For instance, the absence of credible disclosures may make firms emission not "salient" enough to be taken into consideration. The absence of disclosures might also prevent the effective delegation of carbon pricing to intermediaries, which might then collude with the firms in attributing them an unduly small emission intensity (a form of "green-washing"). Similarly, carbon taxation might face legal challenges if not based on objective measures of emission intensity.

Extending the analysis to accommodate these concerns would reinforce the case for emission disclosures. Another consideration favoring disclosures is the provision of incentives to adopt technological improvements (or emission abatement measures) that reduce emission intensity. Under our formulation, non-disclosing firms would lack incentives to adopt any small improvement that keeps them in the non-disclosing pool, since neither investors nor tax authorities would acknowledge the improvement when setting their financing terms and taxes.[21]

With these considerations in mind, our results can be seen as a benchmark case that, suitably extended, might allow a (necessarily quantitative) evaluation of the net efficiency gains associated with policies that encourage or require carbon disclosures. From a positive perspective, our analysis provides insights on the rich cross-sectional and aggregate implications for investment, emissions, and economic efficiency of changing the cost of climate disclosures, the degree of investors' climate consciousness, and carbon taxes, which can help placing existing and future empirical results in this field into perspective.

6 Concluding remarks

A key feature of today's investment environment is the evidence of a carbon premium on firms' financing opportunities, based on the information available about their climate-friendliness. The potential for market mechanisms to address the negative externalities contributing to climate change has raised the important question of whether firms should be mandated to disclose their carbon emissions.

To shed light on this question, we develop a simple model of firm investment with climate conscious investors who partly internalize the externalities associated with carbon emissions and informational frictions concerning the emission intensity of each firm. In our setup, emission intensities are, in principle, private information of each firm's financially motivated manager-owner who can credibly disclose it to outsiders by incurring a disclosure cost. In this setup, in a regime of voluntary disclosures, the least carbon-intensive firms opt for disclosure and receive better terms of financing, while the pool of non-disclosing firms are treated according to a common estimated average carbon intensity.

Our analysis reveals nuanced effects from interventions encouraging disclosures beyond the level achieved through voluntary disclosures. When more firms are induce to disclose, the remaining non-disclosing firms invest and emit less, but the newly disclosing firms invest and emit more. Given that investors only partly internalize the social cost of emissions, the increase in investment by newly disclosing firms is socially excessive. We find examples in

[21] This is so unless the improvement can be partially disclosed (and get the corresponding credit from investors or tax authorities) without having disclosed the benchmark emission intensity.

which this efficiency reducing effect outweighs the efficiency increasing effects obtained within the pool of non-disclosing firms.[22] Interestingly, when the emission externalities are fully internalized (e.g. because Pigouvian carbon taxation is in place), the disclosure threshold is always socially excessively high and reaching constrained efficiency would requires taxing disclosures. All in all, our analysis suggests the need to carefully assess policies regarding climate disclosures, without unconditionally assimilating them to a substitute for carbon taxation.

From a positive perspective, relative to analyses that abstract from disclosure decisions or treat them as either costless or exogenously given, our analysis yields novel predictions on the cross-sectional and aggregate effects of changes in investors' climate consciousness, carbon taxes, disclosure costs and disclosure policies on firms' emissions, investment, private value and social value, as well as on the determinants of their disclosure decisions.

[22] An increase in investors' climate consciousness, which has effects akin to raising carbon taxes in our model, could in principle also have those nuanced effects because it does not only modify investment levels across firms for given disclosure choices but can also have opposite indirect impacts via changes in equilibrium disclosure decisions. However, in all the numerical examples that we have explored, we always obtain reductions in overall emissions and improvements in welfare.

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Appendix: Proofs

Proof of Proposition 1 The indifference condition in (18) has a solution if and only if the function

$$h(z) = v(z) - v(\mathbb{E}(\theta \mid \theta \geq z)) \tag{49}$$

equals ϕ for at least one value of $z \in [0, 1]$. Under Assumption 1, $h(0) > \phi$, while $\mathbb{E}(\theta \mid \theta \geq 1) = 1$ implies $h(1) = 0$. Then, because $h(z)$ is a continuous function, it must equal ϕ for at least one value of z in the interval $(0, 1)$. On the other hand, a non-monotonically decreasing $h(z)$ might equal ϕ at an odd number of values in that interval. However, at the lowest, the highest and any other odd-ranked of those values of z we must have $h'(z) < 0$. This is illustrated in Figure A1.

[INSERT FIGURE A1 (TO BE DONE) ABOUT HERE]

Denoting by $\bar{\theta}$ the largest of the solutions to (18), the full differentiation of (18) with respect to $\bar{\theta}$ and ϕ implies $d\bar{\theta}/d\phi = 1/h'(\bar{\theta}) < 0$.■

Proof of Corollary 1 Follows directly from the last part of Proposition 1. When $h(z)$ as defined in (49) is monotonically decreasing, any threshold $\bar{\theta}$ can be attained as an equilibrium with voluntary disclosures by setting the unique tax $T > 0$ or subsidy $T < 0$ that satisfies the indifference condition $h(\bar{\theta}) = \phi + T$. If $h(z)$ is not monotonically decreasing, increasing (decreasing) the tax T can still be generically used to marginally decrease (increase) any odd-ranked solution $\bar{\theta}$ satisfying $h(\bar{\theta}) = \phi + T$, but perhaps not all values $\bar{\theta} \in [0, 1]$ can be implemented as a equilibrium.■

Proof of Proposition 2 Based on the definition of $h(\cdot)$ in the Proof of Proposition 1, equation (18) is equivalent to $h(\bar{\theta}) = \phi$. Fully differentiating this equation with respect to $\bar{\theta}$ and γ yields

$$h'(\bar{\theta})d\bar{\theta} + \frac{\partial h(\bar{\theta})}{\partial \gamma} d\gamma = 0. \tag{50}$$

From the definition of $h(z)$ and using the envelope theorem:

$$\begin{aligned} \frac{\partial h(\bar{\theta})}{\partial \gamma} &= \frac{\partial v(\bar{\theta})}{\partial \gamma} - \frac{\partial v(\mathbb{E}(\theta \mid \theta \geq \bar{\theta}))}{\partial \gamma} = \frac{\partial v(\bar{\theta})}{\partial \gamma} - \frac{\partial v(\hat{\theta}))}{\partial \gamma} \\ &= -\bar{\theta}k(\bar{\theta}) + \hat{\theta}k(\hat{\theta}). \end{aligned} \tag{51}$$

Thus we have

$$\frac{d\bar{\theta}}{d\gamma} = \frac{[\bar{\theta}k(\bar{\theta}) - \hat{\theta}k(\hat{\theta})]}{h'(\bar{\theta})}, \tag{52}$$

where we have already shown in Proposition 1 that $h'(\bar{\theta}) < 0$. Thus, $d\bar{\theta}/d\gamma$ is strictly positive if an only if the condition stated in (29) holds.■

Proof of Proposition 3 Since suitably choosing T would allow the social planner to have full indirect control on $\bar{\theta}$ (recall Corollary 1), the discussion of the problem in (44) can be simplified by restating it as one in which the social planner directly controls $\bar{\theta}^{\tau}$:

$$(\tau^*(\theta), \hat{\tau}^*, \bar{\theta}^*) = \arg \max_{(\tau(\theta), \hat{\tau}, \bar{\theta}^{\tau})} \int_0^{\bar{\theta}^{\tau}} \left[f(k^{\tau}(\theta)) - (1+\psi\theta)k^{\tau}(\theta) - \phi\right] g(\theta)d\theta$$
$$+ \int_{\bar{\theta}^{\tau}}^1 \left[f(k^{\tau}(\hat{\theta}^{\tau})) - (1+\psi\theta)k^{\tau}(\hat{\theta}^{\tau})\right] g(\theta)d\theta. \tag{53}$$

Applying the Leibniz rule and the chain rule, an interior solution to the restated problem should satisfy the following set of first order conditions

$$[f'(k^{\tau}(\theta)) - (1+\psi\theta)]\frac{\partial k^{\tau}(\theta)}{\partial \tau(\theta)} = 0, \tag{54}$$

for all $\theta \leq \bar{\theta}$,

$$\left\{\int_{\bar{\theta}^{\tau}}^1 [f'(k^{\tau}(\hat{\theta}^{\tau})) - (1+\psi\theta)]g(\theta)d\theta\right\} \frac{\partial k^{\tau}(\hat{\theta}^{\tau})}{\partial \hat{\tau}} = 0, \tag{55}$$

and

$$[\mathcal{D}(\bar{\theta}^{\tau}) - \phi]g(\bar{\theta}^{\tau}) + \left\{\int_{\bar{\theta}^{\tau}}^1 \left[f'(k^{\tau}(\hat{\theta}^{\tau})) - (1+\psi\theta)\right] g(\theta)d\theta\right\} k^{\tau\prime}(\hat{\theta}^{\tau})\frac{\partial \hat{\theta}^{\tau}}{\partial \bar{\theta}^{\tau}} = 0. \tag{56}$$

Notice that (54) is the necessary condition for the (point-wise) optimality of the taxes $\tau(\theta)$ imposed on disclosing firms, which takes into account that $\tau(\theta)$ impacts the objective function in (44) only through the investment level $k^{\tau}(\theta)$ of the disclosing firms of type θ. (55) is the necessary condition of the common tax imposed on non-disclosing firms, which takes into account that $\hat{\tau}$ affects the objective function only through the common investment level $k^{\tau}(\hat{\theta}^{\tau})$ of the non-disclosing firms. Finally, (56) is the necessary condition of the optimality of the (assumed to be interior) disclosure threshold $\bar{\theta}^{\tau}$. This condition, additionally to the direct impact of $\bar{\theta}^{\tau}$ on the objective function (the first term), takes into account the indirect effect channelled through the composition of the pool of non-disclosing firms (summarized by $\hat{\theta}^{\tau}$).

Since $\partial k^{\tau}(\theta)/\partial \tau(\theta) < 0$, (54) simplifies to

$$f'(k^{\tau}(\theta)) - (1+\psi\theta) = 0, \tag{57}$$

which using (37) to substitute for $f'(k^{\tau}(\theta))$ directly leads to the necessity of (45). Similarly, since $\partial k^{\tau}(\hat{\theta})/\partial \hat{\tau} < 0$, (55) simplifies to

$$\int_{\bar{\theta}^{\tau}}^1 [f'(k^{\tau}(\hat{\theta}^{\tau})) - (1+\psi\theta)]g(\theta)d\theta = (1 - G(\bar{\theta}^{\tau}))[f'(k^{\tau}(\hat{\theta}^{\tau})) - (1+\psi\hat{\theta}^{\tau})] = 0, \tag{58}$$

where the second equality uses the definition of $\hat{\theta}^{\tau}$ to simplify the first expression. From here, taking into account that $G(\bar{\theta}^{\tau}) < 1$ for any $\bar{\theta}^{\tau} < 1$ and using (37) to substitute for $f'(k^{\tau}(\hat{\theta}^{\tau}))$ directly leads to the necessity of (46).

The optimality condition for $k^{\tau}(\hat{\theta}^{\tau})$ given in (58) also implies that the indirect effect of $\bar{\theta}^{\tau}$ on W captured by the second term of (56) is zero when emission taxes are optimally set. So, (56) reduces to

$$\mathcal{D}(\bar{\theta}^{\tau}) = \phi, \tag{59}$$

whose solution in $\bar{\theta}^{\tau}$ is $\bar{\theta}^{*}$ as stated in the second part of the proposition.

To see that $\mathcal{D}(\bar{\theta}^{\tau})$ is positive, notice the first term in (48) can be thought of as a function $H(k)$ evaluated at $k^{*}(\bar{\theta}^{\tau})$, while the second term is the same function evaluated at $k^{*}(\hat{\theta}^{\tau})$. By definition, $k^{*}(\bar{\theta}^{\tau})$ maximizes $H(k)$ which is strictly concave, while for any $\bar{\theta} < 1$, we have $k^{*}(\hat{\theta}^{\tau}) < k^{*}(\bar{\theta}^{\tau})$, which does not maximize $H(k)$. Therefore, $\mathcal{D}(\bar{\theta}^{\tau}) > 0$ for all $\bar{\theta}^{\tau} \in [0,1)$, which intuitively captures the efficiency gains that can be achieved (in terms of allocation of investment across firms) when investors observe θ. Moreover, since $\bar{\theta}^{\tau} = 1$ implies $\hat{\theta}^{\tau} = 1$, we have $\mathcal{D}(1) = 0$, which for any strictly positive disclosure cost rules out the possibility of having $\bar{\theta}^{*} = 1$ and, together with $\mathcal{D}(\bar{\theta}^{\tau}) > 0$ for all $\bar{\theta}^{\tau} \in [0,1)$, also guarantees having $\bar{\theta}^{*} > 0$ for sufficiently small values of ϕ.

Finally, comparing (59) with (42) evaluated under $\tau(\theta) = \tau^{*}(\theta)$, $\hat{\tau} = \hat{\tau}^{*}$, $\bar{\theta}^{\tau} = \bar{\theta}^{*}$, and $\hat{\theta}^{\tau} = \hat{\theta}^{*}$, yields the need to set $T^{*} > 0$ as in (47) to induce $\bar{\theta}^{*}$ as the disclosure threshold in the equilibrium with taxes.■