Financing and the Green Paradox

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Abstract

We study the investment decisions of polluting firms in response to climate regulation risks. We build a model of firm financing and investment that predicts higher investment prior to a regulatory shock for firms more exposed to the shock, and higher borrowing costs after the regulatory shock. In our empirical analysis, using the Paris Climate Accord as a shock to future climate regulation, we find evidence consistent with the model. High-emissions intensity firms issue shorter-maturity bonds post Paris but do not see a decrease in yields, experience a drop in capital expenditures and investment rates, and see an increase in pollution rates. Our findings show that high-emissions intensity firms that expect financing frictions to intensify under climate regulation shocks can exhibit behavior consistent with a "green paradox," where polluting firms increase ex ante investment in the expectation of future climate regulation. We discuss the possibility of multiple equilibria and what it suggests about how firms respond to the threat of regulation.

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1 Introduction

The green paradox refers to increases in emissions due to actions that fossil fuel producers take in anticipation of a policy intervention aimed at reducing the future rents from these resources (Sinclair, 1992; Sinn, 2008). This paper studies the corporate bond issuance and investment decisions of polluting firms ahead of a shock to the saliency of climate risks and of increased future regulation. We develop a model of firm investment and financing where firms behave according to the green paradox and test its predictions in our empirical analysis. The model reconciles the evidence on financing decisions from the corporate bond market with observed investment and emissions decisions.

We model a firm that can take an investment option at a cost and needs financing for it. The investment is sensitive to (climate) regulation: the period the firm is deciding over the investment option coincides with the possibility of a regulatory shock on emissions that increases the project's operating costs. The firm can contribute financing toward the cost of the project at the time of taking the option or prior to it. If the borrowing rate is the same prior to the option exercise and at the time of the option exercise, the firm does not borrow earlier, because the option may never materialize and all of the early investment would have been for nought. However, if the regulatory shock increases the expected financing cost for the polluting firm, then the higher future cost creates an incentive to invest earlier. By investing earlier the firm benefits from cost savings as more of the financing of the cost of the investment is done at the lower rate.

The model delivers several predictions. First, the model predicts that a higher probability of climate regulation affecting the firm leads the firm to borrow and invest more earlier on, akin to the green paradox. Importantly, this result only applies if borrowing costs are contingent on the passing of the regulation. If instead borrowing costs are higher in the future independently of whether the regulation shock realizes, then the firm will still want to do some early investment, but will do *less* of it if the probability of climate regulation increases. Second, the earlier investment by the firm is associated with a higher probability of completing the investment project, and with more pollution. Third, if the regulatory event carries increased costs to the firm, then the firm faces higher borrowing costs in that state of nature.

When we introduce a regulatory body to the model, we show that the regulation equilibrium may exhibit multiple equilibria. In the spirit of Glazer and McMillan (1992) and others, the regulatory body is modeled to increase the probability of regulation when it sees higher investment earlier on by polluting firms. This threat coupled with the green paradox result can produce multiple equilibria: an equilibrium with low risk of regulation and low investment earlier on and an equilibrium with high risk of regulation and high investment earlier on. In the high investment equilibrium, the industry's expectation of the likelihood of the regulator's action drives investment up by polluting firms (i.e., the model's green paradox effect), and the increased investment leads to a higher probability of regulation, thus validating those expectations. An immediate consequence of the multiplicity of equilibrium is that changes in expectations can drive the industry to the high-pollution equilibrium. This model prediction can explain why the Paris Accord appears to have impacted firms (see below), whereas other United Nations Conference of the Parties did not. It can also explain the differential investment patterns across private and public US firms (e.g. Duchin, Gao, and Xu 2022) subject to different sets of regulatory bodies. For example, the SEC's new rules to standardize climate-related disclosures apply only to public companies. Second, the very actions of the regulator aimed at curbing firm investment in polluting technologies can be counterproductive. At the same time, and because of the symmetry of our results, a shift in policy that may signal a reduced likelihood of regulation leads to less early investment by polluting firms.

To empirically analyze how the risk of climate regulation affects financing and investment decisions, we consider the 2015 Paris Climate Accord as a shock to future regulatory risk (Ilhan, Sautner, and Vilkov, 2021; Bolton and Kacperczyk, 2021, 2023; Seltzer, Starks, and Zhu, 2024).[1] We estimate difference-in-difference equations describing financing, investment and emissions pre- and post-Paris Accord. We use two variables to indicate treatment: a continuous variable equal to the lagged value of firm GHG-emissions intensity and an indicator variable equal to 1 if the lagged value of firm emissions intensity is above the sample median.

We focus our analysis of firm financing decisions to the corporate bond market because it can capture two unmodeled dimensions that are of interest in our analysis. While our model emphasizes the increased bankruptcy cost associated with regulation as the incentive for firms to invest earlier, there are two additional reasons why the cost of financing in the bond market may increase post regulation. First, the bond market is a natural way to segment investors by investor horizon (Vayanos and Vila, 2021) and recent evidence suggests that there is a segment of the investor population that has longer-term investment horizon and non-pecuniary preferences toward the

[1]The Paris Climate Accord is an international treaty on climate change whose signatories committed to tight climate policy objectives. Before Paris, the Kyoto Protocol (1997) was the first-ever international commitment to reducing greenhouse gas emissions. Because it called for penalties for noncomplying countries, the Kyoto Protocol required Congress approval and was never implemented in the US. The US signed the Copenhagen Accord of 2009, but this Accord was a non-legally binding, political accord.

environment, social and governance (ESG) performance of firms (e.g. Starks, Venkat, and Zhu (2017)). The Paris Accord may induce a shift of these investors to less polluting firms, increasing the cost of borrowing to more polluting firms particularly at longer maturities. Second, cash flows of bonds of longer maturity may be more sensitive to the uncertainty of future regulation. This added sensitivity may reflect in an higher borrowing cost for longer term bonds that forces polluting firms to consider shorter term debt. Empirically, the corporate bond market data allow us to study investment and financing of public and private companies and prior evidence has shown that private firms have high GHG emissions intensity (Ivanov, Kruttli, and Watugala, 2024).

We use data on facility-level greenhouse gas emissions from the US Environmental Protection Agency (EPA) and combine these data with corporate bond data from Mergent and balance sheet data from Capital IQ. The EPA data have detailed information on a facility's parent companies, their names, addresses, and ownership stakes in a given year, which we use to assign emissions levels to parent companies. We aggregate bond issues by the same firm in a given year to a single observation. Our data range from 2010 to 2020, with the merged EPA and Capital IQ sample, and merged EPA, Capital IQ, and Mergent sample comprising about 3,000 firm-year observations each.

We first consider how bond characteristics, offering yield, maturity and amount vary with firm emissions before and after the Paris Accord. We find that firms with higher GHG-emissions intensity offer bonds with shorter maturity in the post Paris period, controlling for common firm determinants. For the firms with above median GHG-emissions intensity, the offering maturity of new corporate debt issues drops by about 1.7 years on average. This result is consistent with the finding in Seltzer, Starks, and Zhu (2024) regarding insurance companies' behavior around the Paris Accord.

We do not find any statistically significant effect on offering amounts, or on maturity-weighted yields. One interpretation of the result on yields is that firms adjust to an upward shift of their yield curve post Paris (see Seltzer, Starks, and Zhu 2024 and others for additional evidence of tightening of financing costs for emissions inefficient firms post Paris) by borrowing more short term, which typically carries lower yields. Arguably, with an upward sloped yield curve, they would be paying higher yields had they continued borrowing at similar maturities as before.

We then analyze whether a firm's emissions intensity has a corresponding effect in its investment policy, as predicted by the model, by studying changes in firm capital expenditures (CAPEX) in the period following the passage of the Paris Accord. We find that the ratio of CAPEX to assets is lower for high-emissionss intensity firms in the post-period. The effect we find is sizable. For the firms with above median emissions intensity, the investment rate is 1.1 percentage point smaller than for other firms, all else equal, in the post-Paris period. When we repeat the regressions using the level of CAPEX as the outcome, we again find a significant decrease in CAPEX for high-emissions intensity firms in the post-period.

Finally, we report results on changes to firm emissions in the post-Paris period. Recall that the model predicts that by investing more earlier, the more emissions inefficient firms have a greater likelihood of completing the investment and hence of polluting if the regulatory shock materializes. We find that firms with high-emissions intensity tend to have relatively higher emissions intensity in years subsequent to the Paris Accord.

Relative to the literature on the green paradox hypothesis, we are the first to show firm investment and emissions effects. Norman and Schlenker (2024) shows that oil prices in futures markets decreased with increases in the daily change in the prediction market's expectations that the Waxman-Markey bill would pass, a bill aimed at promoting investments in renewable energy sources and reducing carbon emissions. Lemoine (2017) finds that the U.S. Senate breakdown in negotiations of the Waxman-Markey bill lead to an increase in coal futures prices and in coal storage. These papers do not study the firm financing channel and firm emissions. Sinn (2015) argues that the failure of policies to curb CO2 emissions and to generate a significant increase in carbon prices is itself evidence of the green paradox. Jensen, Mohlin, Pittel, and Sterner (2015) study within the context of a model of the green paradox the effect that several factors may firm financing.

The next section offers a brief review of the related literature. Section 3 presents the model and its main predictions. Section 4 discusses the data sources and the empirical strategy and Section 5 presents the results. Section 6 concludes.

2 Related literature

Seltzer, Starks, and Zhu (2024) find that after the Paris Accord credit ratings decrease and corporate bond yields on existing debt increase for high-emissions public firms (for the loan market see Ehlers, Packer, and de Greiff 2022), and that insurance companies (mutual funds) reduce (increase) their exposure to high-emissions firms. Also using the Paris Accord as a shock to the risk of regulation, Cao, Li, Zhan, Zhang, and Zhou (2023) find that liquidity deteriorates in bonds of high carbon-intensive public firms post-Paris. Several papers find changes to firm risk in the public equity and options markets for high emissions firms in the post-Paris period. Seltzer, Starks, and Zhu (2024) find evidence of increased asset volatility which they back out using equity values pre- and post-Paris periods. Ilhan, Sautner, and Vilkov (2021) find that carbon tail risk is priced in stock options and that it increases after Paris for firms with carbon-intense business models. Bolton and Kacperczyk (2021) find a carbon risk premium in the cross section of U.S. stocks that also increases post Paris. Our paper provides further evidence on the effects of the Paris Accord on firm-level investment and emissions policies.

Beyene, De Greiff, Delis, and Ongena (2021) focus on a cross-country sample of fossil fuel firms and find those facing higher climate risk, using a climate change policy index, pay higher bond spreads but not higher syndicated loan spreads. Ivanov, Kruttli, and Watugala (2024) find that the passage of climate-related policies in Congress is associated with shorter loan maturities and higher loan interest rates for treated firms. Korganbekova (2023) finds positive spillovers across facilities in different states owned by the same firm following state-level climate regulation. Kacperczyk and Peydro (2022) find that banks with carbon commitments restrict loan supply to carbon intensive industries.

Bellon and Boualam (2024) argue that climate regulation risk makes dirty technologies more attractive to distressed firms, akin to a risk-shifting argument. Gupta, Kopytov, and Starmans (2024) show that the anticipation of the arrival of an activist with pro-social preferences may adversely contribute to a high-emissions status quo of the firm. Huang and Kopytov (2024) propose that regulations can substitute for the value of investors with pro-social preferences discouraging the adoption of green technologies by polluting firms. van der Ploeg and Withagen (2012) discuss welfare implications of backstops, renewable resources that substitute perfectly for fossil fuels, and when a green paradox exists depending on the costs associated with the backstop technology. Acharya, Giglio, Pastore, Stroebel, and Tan (2024) study climate risk that arises from the arrival of breakthrough technologies in the renewable energy sector and from taxes on carbon emissions and restrictions on drilling. Engle (2024) suggests that the risk of stranded assets can lead polluting firms to underinvest, reducing the overall supply of fossil fuels. Acemoglu, Akcigit, Hanley, and Kerr (2016) study taxation and technology adoption when there is climate-related transition risk and the dirty technology is more advanced. Landeri and Rampini (2023) study the adoption of clean technologies when firms are heterogeneously financially constrained. In Chen (2023), when investors have greater preference for ESG, the firm may decrease ESG investments if it cannot disclose credibly its ESG policies, and investors discount firm statements of being green. Piccolo, Schneemeier, and Bisceglia (2022) argue that concentration of ESG-oriented investors on a small set of green firms may discourage green investments by excluded firms.

3 A model of financing and investment and the green paradox

Consider the investment and borrowing decisions of a firm that faces the prospect of climate-related regulatory risk. There are three periods indexed by $0, 1, 2$. At time 1, the firm has an investment option (e.g. to drill oil from a new well, or build a new factory that uses gas-powered heating) that requires an investment of I. The investment pays out an operating profit of $\tilde{\pi}$, with continuous cdf $F(\tilde{\pi})$, at time 2. Also at time 1, there is a shock to climate regulation; the firm's probability of being affected by the shock is given by λ. This shock affects the operating profit from the investment opportunity reducing it by the constant κ. We view κ as the cost that results from having to adapt the investment opportunity to meet the new regulations, which includes any pollution-abatement actions by the firm, or carbon credits that need to be purchased.[2]

At time $t = 0$, the firm can borrow an amount $I_0 \leq I$. The borrowed amount I_0 is used to partially fund the investment needed at $t = 1$ to exercise the option. If the option is taken at time $t = 1$, then the additional borrowing of $I_1 = I - I_0 \geq 0$ is needed to undertake the investment. There is a convex cost to early investment of $\psi I_0^2/2$. This non-pecuniary cost is motivated by the reputational considerations that may arise from an empire-building motive or the lack of commitment not to abscond with the money. This cost is introduced to ensure an interior solution.

We assume that the firm can issue one-period bonds at the gross interest rate R in both periods 0 and 1, unless the regulatory risk materializes in which case the borrowing cost goes up to R_λ. For now, we take R_λ to be exogenous. Below, we show that $R_\lambda > R$, where the gap between the two is driven by κ and the existence of bankruptcy costs. For simplicity, the firm's rate of time preference is set to zero.

The firm's maximizing problem at time 0 is

$$\begin{aligned}\max_{0\leq I_0\leq I} &= (1-\lambda)E\left[\max_{I_1\in\{I-I_0,0\}}(\tilde{\pi}-RI_1,0)\right] \\ &+ \lambda E\left[\max_{I_1\in\{I-I_0,0\}}(\tilde{\pi}-\kappa-R_\lambda I_1,0)\right]-RI_0-\frac{\psi}{2}I_0^2. \qquad (1)\end{aligned}$$

[2]The effects of regulation do not have to come through the supply side via κ. Regulation that affects the firm's demand, captured by a reduction in the mean of π, is isomorphic in our model. Also, scaling the cost by the investment size does not change the results.

In the regulation state, the investment option is less valuable for two reasons, the abatement cost κ and the higher financing cost R_λ. Rewrite the problem as

$$\begin{aligned}\max_{0\le I_0\le I} &= (1-\lambda)\int_{R(I-I_0)}^{\infty}(\tilde{\pi}-R(I-I_0))\,dF(\tilde{\pi})\\ &+ \lambda\int_{\kappa+R_\lambda(I-I_0)}^{\infty}(\tilde{\pi}-\kappa-R_\lambda(I-I_0))\,dF(\tilde{\pi})-RI_0-\frac{\psi}{2}I_0^2.\end{aligned}$$

The first order condition with respect to I_0 yields:

$$(1-\lambda)\,[1-F(R(I-I_0))]\,R+\lambda\,[1-F(\kappa+R_\lambda(I-I_0))]\,R_\lambda-R-\psi I_0\le 0. \qquad (2)$$

The optimal choice of I_0 equates the marginal borrowing cost at time 0, R, plus the cost of investing early, ψI_0, to the marginal benefit at time 1. The marginal benefit at time 1 is the cost savings from having invested earlier: these are the weighted average of R times the expected option exercise $(1-F(R(I-I_0))$ if there is no regulation, and R_λ times the expected option exercise $(1-F(\kappa+R_\lambda(I-I_0))$ if there is regulation. The cost savings occur only if there is a regulatory shock and the option is exercised, so naturally, $I_0^*=0$ when $\lambda=0$.

If the marginal benefit of early investing evaluated at $I_0=0$ is larger than R (thus guaranteeing $I_0^*>0$), and the marginal benefit of early investing evaluated at $I_0=I$ is below $R+\psi I$ (thus guaranteeing $I_0^*<I$), then by continuity the problem admits at least one interior maximum. The later condition is easy to satisfy by appropriately choosing a high value of ψ, all else equal. For the former condition, it would seem that picking a high enough value of R_λ would do the trick. However, in the model, while a high R_λ increases the cost savings if the project is undertaken, it also reduces the

likelihood of undertaking the project and hence the expected cost savings. It turns out that if the mean of operating profits is high enough, the second effect is attenuated and the problem admits an interior maximum. The following proposition gives sufficient conditions for an interior maximum for a specific functional form for F. All proofs can be found in Appendix A.

Proposition 1. *Let F be the cumulative normal distribution, μ_π and σ_π the mean and standard deviation of operating profits, respectively, and let $\mu_\pi = 1.96\sigma_\pi + \kappa + R_\lambda I$. There is an interior maximum if*

$$\frac{0.0256}{\lambda} < \frac{R_\lambda - R}{R} < \frac{\psi I}{R\lambda}. \tag{3}$$

The proposition gives sufficient conditions for an interior maximum in the form of upper and lower bounds to R_λ. The critical feature of these conditions is that as R_λ increases to meet the lower bound constraint, μ_π also must increase. The agency cost, ψ is needed to generate an interior optimum. If R_λ is sufficiently large relative to R, a high enough probability of exercising the option conditional on the regulatory shock occurring generates savings that will make the firm take the corner solution of investing all at time 0. The proposition shows that ψ can be used to construct an upper bound to R_λ for the problem to admit an interior maximum.

3.1 Model predictions

We highlight model properties related to variation in λ, the firm's probability of being affected by the regulatory shock.[3] Our main result is that a firm facing higher regulatory risk at time 1 (i.e., higher λ), invests relatively more at time 0, $dI_0^*/d\lambda > 0$. To see the intuition for this result note that in the state of the world where the regulatory shock occurs the likelihood of exercising the option is lower because of κ and the higher borrowing cost, i.e., $\kappa + R_\lambda(I - I_0) > R(I - I_0)$. Thus, a firm that faces a higher λ has a lower overall probability of exercising the investment option, which discourages early investment. However, the state where there is regulatory risk is also the state of cost savings, and an increase in λ increases the likelihood of cost savings and encourages early investment. At the optimum, under the conditions that guarantee an interior solution, the second effect dominates and I_0^* increases with λ.

Importantly this result is not due to having higher borrowing rates unconditionally in period 1: if at time 1 the cost of borrowing is R_λ across all states, then a higher λ puts more weight on the state of the world where the probability of exercising the option is lower and the marginal benefit of investing earlier declines, leading to lower I_0^*. In this sense, the result has the flavor of the 'green paradox' (Sinn, 2008): the higher cost faced by the firm in the state where regulatory risk occurs generates an incentive to invest early in the potentially polluting technology, which itself counteracts the efforts of the regulation.

A consequence of higher early investment for a firm with higher regulatory risk (i.e.,

[3] Empirically, we shall think of λ has having a firm-specific component related to the exposure that firms have to regulation through their past policy decisions and technology choices, and an aggregate component related to the probability of new regulation. In the model, we make no distinction on which of the two is driving changes in λ.

higher λ) is that the firm also has a higher probability of exercising the option at time 1. Hence, firms with higher regulatory risk are more likely to see increases in pollution. The next proposition collects these results.

Proposition 2. *At an interior maximum, a firm with higher λ:*

- *invests relatively more (less) in the period prior to (after) the regulatory shock;*
- *experiences a larger increase in pollution in the period after the regulatory shock.*

The model offers an additional prediction on abatement technologies via the cost parameter κ. A firm with better abatement technology (i.e., lower κ) invests more earlier on, that is $dI_0^*/d\kappa < 0$. Intuitively, the marginal benefit of early investment increases with a lower κ, all else equal: the probability of exercising the option in the state of increased climate regulation increases, thus increasing the expected cost savings from early investing.

3.2 Cost of financing in the event of a regulatory shock

In this section, we endogenize the value of R_λ. We argue that one reason for a higher interest rate when the regulatory event occurs at time 1 is intrinsically linked to the regulatory event through a higher probability of bankruptcy. We continue to assume an exogenous interest rate R when borrowing at time $t = 0$ or in time $t = 1$ if the regulation shock does not materialize.[4] The introduction discusses other reasons why $R_\lambda > R$.

[4] It is possible to extend the model to endogenize R. Naturally, an endogenous R at time 0 incorporates some premium for losses when the regulation shock hits. However, as R is a weighted average of future payouts to lenders, if lenders have less to lose when the regulation shock does not materialize, then a gap will exist between R_λ and R in equilibrium.

Upon the regulatory event, the firm pays a random abatement cost $\tilde{\kappa}$ with cdf $G(\tilde{\kappa})$. The realization of the random variable $\tilde{\kappa}$ occurs after the decision to invest I_1 at time 1. The expected time 1 payout for the firm in the event of regulation is

$$E_{\tilde{\pi}}\left[\max_{I_1\in\{I-I_0,0\}}\left[E_{\tilde{\kappa}}\max_{eqty,noeqty}\left(\tilde{\pi}-\tilde{\kappa}-R_\lambda I_1,0\right),0\right]\right], \tag{4}$$

where *eqty* and *noeqty* identify states of the world where equity holders are paid. If the option is undertaken, but the cost ends up larger than $\pi - R_\lambda I_1$ (which occurs with probability $1 - G\left(\pi - R_\lambda I_1\right)$), then equity holders get zero and lenders get only a fraction of their investment, or possibly nothing if the cost is high enough.

We assume lenders are risk neutral. Lenders break even on average across realizations of $\tilde{\pi}$, assuming a borrowed amount of $I_1 = I$. The interest rate R_λ solves:

$$RI = \int G\left(\tilde{\pi}-R_\lambda I\right)dF(\tilde{\pi})R_\lambda I + (1-\alpha)\int\int_{\tilde{\pi}-R_\lambda I}^{\tilde{\pi}}(\tilde{\pi}-\tilde{\kappa})dG(\tilde{\kappa})dF(\tilde{\pi}), \tag{5}$$

where $\alpha > 0$ is a proportional bankruptcy cost. Note that R_λ does not actually depend on the value of λ, contrary to what the subscript might suggest. The subscript merely indicates the states of the world where the cost of borrowing R_λ applies.

The first term on the right-hand side of equation (5) describes the full repayment to lenders when $\tilde{\kappa} < \tilde{\pi} - R_\lambda I$. The second term on the right-hand side of equation (5) shows that for intermediate values of the cost, $\tilde{\pi} - R_\lambda I < \tilde{\kappa} < \tilde{\pi}$, lenders get a decreasing amount $\tilde{\pi} - \tilde{\kappa}$. The bankruptcy cost α is paid to recover a payout when the firm is in distress. Finally, for values $\tilde{\kappa} > \tilde{\pi}$, lenders get zero.

Because $\int_{\tilde{\pi}-R_\lambda I}^{\tilde{\pi}}(\tilde{\pi}-\tilde{\kappa})dG(\tilde{\kappa}) < \left[G(\tilde{\pi}) - G\left(\tilde{\pi}-R_\lambda I\right)\right]R_\lambda I$, then $R < \int G(\tilde{\pi})dF(\tilde{\pi})R_\lambda \leq R_\lambda$. The bankruptcy cost α increases this gap. The result that $R_\lambda > R$ is the critical assumption we had made earlier on and that comes through in the model with a higher probability of default in the event of the regulatory shock.[5] The increased risk of bankruptcy in the event the regulatory risk is realized gives rise to the proposition:

Proposition 3. *A firm exposed to regulatory risk (i.e., with $\lambda > 0$) has higher interest rate at time 1 in the state of the world where the regulatory shock is realized compared to the interest rate it faces absent the regulatory shock.*

3.3 Equilibrium regulation

We introduce a regulator that determines the probability of the regulatory shock based on the level of investment made by the firms in the industry at time 0. We are motivated by the notion that regulators often use the threat of regulation to affect firm behavior (for early work see Glazer and McMillan 1992, and Erfle and McMillan 1990). Let m be the measure of firms in the industry and for simplicity let firms be ex ante identical so that mI_0 is the industry's investment at time 0. We model regulation as a binary random variable whose probability distribution, $\Lambda\left(mI_0\right)$, is an increasing function of industry early investment in the polluting technology. The regulator takes aggregate investment as exogenous.

Firms have beliefs about future regulation, λ, and make investment decisions as a function of these beliefs, $I_0^*(\lambda)$, as discussed above. Firms know that Λ is a function

[5] An alternative to close the model is to assume that lenders break even for every π and $I_1 > 0$. In this case lenders are paid a rate of return that equals R on average

$$RI_1 = G\left(\pi - R_\lambda I_1\right) R_\lambda I_1 + (1-\alpha)\int_{\pi - R_\lambda I_1}^{\pi} (\pi - \tilde{\kappa})dG(\tilde{\kappa}). \tag{6}$$

The interest rate R_λ that solves this equation is contingent on the realization of π and I_1 since the shareholder makes the investment decision knowing how much investment is still needed and what π is. Here, too, it can be shown that $R_\lambda > R$.

of aggregate investment, but they are atomistic and view the equilibrium aggregate investment and hence the probability of regulation as exogenous. In a rational expectations equilibrium (λ^*, I_0^*) firms correctly anticipate the regulator's probabilistic action λ^* and choose early investment accordingly $I_0^*(\lambda^*)$, and regulator's action $\Lambda\left(mI_0^*\right)$ is consistent with firms' investment decisions. That is, the equilibrium λ^* is a fixed point: $\lambda^* = \Lambda\left(mI_0^*(\lambda^*)\right)$. Figure 1 illustrates the regulation equilibrium. The solid line depicts the function $mI_0^*(.)$ (plotted on the y-axis) against values of λ. There is no investment at time 0 for low enough λ (as shown in the discussion preceding Proposition 2), after which I_0^* increases with λ. The dashed line depicts the function $\Lambda\left(.\right)$ (plotted on the x-axis) against values of I_0 (plotted on the y-axis). Points where the two curves intersect are equilibrium points.

[Insert Figure 1 here]

Depending on the curvatures of the $\Lambda(.)$ and $I_0^*(.)$, there can be multiple equilibria as the figure illustrates: an equilibrium with high regulatory risk and high investment at time 0, and an equilibrium with low regulatory risk and low investment at time 0. There are three reasons for the possibility of multiple equilibria in the model. First, firms take the probability of regulation as given, which leads to an externality. Firms do not incorporate the fact that as each of them invests more, the regulator increases the probability of the regulatory shock. Second, in our model, the benefit of investing early (through the borrowing-cost savings) accrues because of the possibility of future regulation, a feature that is absent in models of the threat of regulation and that is the source of the green paradox result in the model. This feature is what gives the positive slope of the aggregate investment curve and is the main reason for the multiplicity of equilibria. Third, in the illustrated equilibrium, the regulatory function $\Lambda(.)$ penalizes industry investment sufficiently aggressively in order to intersect with $I_0^*(.)$.

With multiple equilibria the risk of regulation can be self fulfilling: if firms anticipate high regulatory risk (i.e., a high λ), then it is advantageous for each of the firms to invest more at time 0. In other words, the industry's expectation of the likelihood of the regulator's action leads to increased investment, which then validates the original expectations. This gives rise to a complementarity between the likelihood of regulation and polluting-technology adoption. This result contrasts with that in Biais and Landier (2022) where there is also multiple equilibria. In Biais and Landier (2022), there is a "pessimistic" equilibrium where investors expect no emissions cap and hence do not invest in the green technology. In their setting, there is a complementarity between regulation and green-technology adoption. The reason is that the adoption of the clean technology carries positive spillovers that decrease the cost of emissions reduction in the aggregate, and makes the government more willing to implement emissions caps.

The first prediction from the self-fulfilling nature of the equilibria is that the green paradox may manifest itself in some industries but not others, or to different degrees for different groups of firms, subject to different regulatory bodies, and exposed to different public pressure. This result may explain the differential behavior in terms of emissions by private and public firms found in Duchin, Gao, and Xu (2022) and Im (2023). Second, the existence of multiple equilibria suggests that the (threat of) regulatory action can be counterproductive, though not because the regulator is subject to the efforts of powerful lobbies in the way discussed in Stigler (1971) and Peltzman (1976). However, the symmetric nature of our predictions yields that changes in policy stance that suggest less future regulation, can result in less pollution.

3.4 Discussion

The paper's main result is that early investment in the polluting technology increases with the probability of climate regulation. As indicated above, this result relies on firms' facing a higher cost of financing only in the state where regulation occurs. It is worthwhile investigating what would be required to have higher borrowing rates unconditionally in period 1. First, aggregate conditions could be such that everyone expects higher borrowing rates in the future. This setting is possible though not the most interesting for us. Second, firms may feel threatened today of increased costs in the future unconditionally because the capital market decides to penalize them even if the regulatory shock does not occur. In this case, an increase in λ reduces early investment. The actions of regulator and financiers would be complementary in this case in bringing down investment in polluting technologies.

We assume that investment requires external financing. If no external financing is needed, and shareholders' required rate of return is constant over time, then it would not be optimal to invest early. There is no benefit to committing resources early to an investment option that realizes in the future and that can be fully funded at that point. This makes explicit that the hypothesis developed in this paper relies on firm exposure to financial markets, in particular to investor responses to the risk of bankruptcy when climate regulation is implemented.

We model only a high-pollution investment option for the firm, but it is reasonable to assume in some instances that firms have investment options with cleaner technology. One relevant theoretical trade-off is that the cleaner technology does not require any technological abatement if climate-related regulation is imposed, but not taking the high-pollution option can result in a loss of firm value. The loss of value can come from stranded (polluting) assets, especially if these assets become obsolete, or from having to dispense with a low-marginal cost technology. Empirically, enlarging the set of firm responses to regulation uncertainty can result in a weakening of the mechanism we hypothesize, in which case we would be unlikely to find any evidence in favor of the green paradox.

4 Empirical methodology

4.1 Data

The empirical analysis uses data from multiple sources. We obtain the sample of U.S. corporate bond issuances from 2010-2020 from Mergent Fixed Income Securities Database (FISD) using standard processing based on Adrian, Boyarchenko, and Shachar (2017) and others. We aggregate bond issues by the same firm in a given year to a single observation. We obtain balance sheet data of U.S. public and private firms from S&P Capital IQ. Capital IQ collates data on private firms through publicly available disclosures, for example, private and public firms face SEC disclosure requirements when issuing publicly traded debt like corporate bonds. We merge Mergent FISD and Capital IQ data based on bond issuer-level CUSIP. The matched data are aggregated to the parent level to ensure a Mergent parent corresponds to an ultimate parent firm in Capital IQ. We use 2-digit SIC industry codes to filter out firms in financial (60-67), government (91-97) and "nonclassifiable" (99) industries.

The emissions data measured in CO2 equivalents (CO2e) are from the U.S. Environmental Protection Agency (EPA). Starting in 2010, the EPA requires that each production facility with more than 25,000 metric tons of CO2e emissions per year reports their emissions. This regulation covers carbon dioxide, methane, nitrous oxide, and fluorinated GHGs. These data are publicly available (https://www.epa.gov/ghgreporting), cover a wide range of industries, account for a substantial share of total U.S. emissions, and have been used in other studies (e.g., Shive and Forster (2020); Bartram, Hou, and Kim (2022); Ivanov, Kruttli, and Watugala (2024)). Firms are required to report direct and indirect GHG emissions. Direct CO2e emissions are those emitted from the facility itself, for example, through the combustion of fossil fuels by boilers and furnaces and emissions from industrial processes. Indirect emissions are the emissions from materials sold by the facility and combusted elsewhere.

The EPA data have detailed information on a facility's parent companies, their names, addresses, and ownership stakes in a given year. We match parent firms in the EPA data to parent firms in the Capital IQ and Mergent datasets, respectively, using the name and ZIP code of the parent company of each GHG-emitting facility. We first conduct a fuzzy name match and then verify each potential match manually. We use ownership stakes data to assign emissions levels of facilities to parent companies. In Figure 2, we show the county-level distribution of high GHG-emitting facilities as of 2015 for EPA facilities that are mapped to Capital IQ firms. In the figure, we sum up the GHG emissions of all facilities in a given county. Emissions are geographically dispersed across the U.S. Emissions are aggregated to parent level for the empirical analysis.

The summary statistics for the variables used in our empirical analysis are reported in Table 1 Panels A (EPA sample) and B (Mergent sample). We reproduce descriptive stats for balance sheet information under both samples. There are many firms with emissions data but no Capital IQ data (see panel A), whereas there is Capital IQ data for almost all firms in the Mergent data (see panel B). Table B.1 in Appendix B presents the variable definitions.

We take the log of emissions and of emissions intensity (emissions divided by revenues). This reduces the skewness of the two variables and the resulting means (medians) are 11.0 and 5.6 (11.2 and 5.9), respectively. For the capital expenditures, we also either take the log of the variable or divide by the firm's assets. The average (median) value of capital expenditures to assets of a firm in our sample is 7.1% (5.1%). The additional balance sheet variables debt, net property plant and equipment, and cash are also divided by the respective firm's assets. For the Mergent sample, shown in Table 1 Panel B, we have data on the total offering amount, yields, and time-to-maturity (TTM) of the issued bonds. Further, we have the same balance sheet variables as in Panel A.

4.2 Regression specification

We analyze the effects of a shock to climate regulation risk using the following panel regression specification:

$$\begin{aligned} y_{i,t} = &\beta_0 EmissionsIntensity_{i,t-1} + \beta_1 EmissionsIntensity_{i,t-1} \times PostParis_t \\ &+ \gamma Z_{i,t-1} + \theta_t + \nu_i + \epsilon_{i,t}, \end{aligned} \tag{7}$$

where i denotes the firm and t the current year. The sample period is from 2010 to 2020. We estimate multiple empirical specifications, where the dependent variables of interest, $y_{i,t}$, are bond market variables—offering amount of corporate bonds issued by the firm, time-to-maturity of the issued bonds, and offering yield—firm emissions intensities and changes in emissions, and firm annual capital expenditures and investment rate, or capital expenditures normalized by assets. The main independent variables are the dummy variable $PostParis_t$ that captures the period following the Climate Paris Accord, 2016 through 2020, the lagged value of emissions intensity (or a dummy that classifies firms above median emissions intensity), and the interaction between the two.

The specification in equation (7) allows us to test the model predictions implied by Propositions 2 and 3 regarding λ. Empirically, we let the firm's probability of being affected by the regulatory event, λ, depend on the firm's exposure to future regulation, which we proxy by its emissions intensity, and on the aggregate probability of additional regulation, which we proxy with $PostParis_t$. Thus, we capture λ in the data via the interaction $EmissionsIntensity_{i,t-1} \times PostParis_t$. The reasoning is that the Paris Accord delivered country-wide commitments to act to keep global warming at most at 2 degrees Celsius above pre-industrial temperatures. These commitments and the regulatory changes that they entail are likely to impact more acutely more polluting firms.

We also control for lagged firm-level variables, $Z_{i,t-1}$, which capture observed variation at the firm level of determinants of spreads and investment policy. Specifications include firm fixed effects and time fixed effects to control for unobserved time-invariant and firm characteristics. Except for the regressions using the Mergent cdata, where there are significantly fewer observations, the rest of the regressions also consider industry times year fixed effects as a way to account for industry-wide shocks that affect firm decisions. Controlling for industry times year fixed effects may be more or less important depending on whether the assignment of the control group across industries is more or less random. Any lower order terms (e.g., $PostParis_t$ by itself) that are not shown are absorbed by the fixed effects. The standard errors are clustered at the firm level.

Proposition 3 predicts borrowing frictions tighten following climate regulation. We thus hypothesize that the coefficient on the interaction term $EmissionsIntensity_{i,t-1} \times PostParis_t$ is positive for the dependent variable offering yield and negative for time to maturity. Proposition 2 predicts that investment is relatively lower to more polluting firms following the regulatory shock, which we test with the hypothesis of a negative coefficient on the interaction term $EmissionsIntensity_{i,t-1} \times PostParis_t$ when the dependent variable is the log of capital expenditures or capital expenditures to assets. Proposition 2 also predicts that emissions increase following the regulatory shock. We therefore hypothesize a positive sign on the coefficient on the interaction $EmissionsIntensity_{i,t-1} \times PostParis_t$ when the dependent variable is either log emissions or changes in log emissions.

We capture firms' exposure to future regulation (a component of λ) through their emissions intensity. We are motivated by evidence that in some industries institutional investors base their exclusionary screening on emissions intensity. In addition, the 2010 Waxman-Markey bill, the only climate bill to ever pass one of the houses of Congress, selected firms to be included using energy intensity (a normalized measure of scope 2 emissions). Also, if emissions intensity is a technology feature (with some technologies being more polluting than others) then targeting with regulation technologies (and industries) that generate high revenues and have high emissions intensity is likely to yield the greatest benefit in emissions reduction.

5 Results

This section displays the results when empirically testing the model-implied hypotheses discussed in Section 3. We center this empirical analysis around the Paris Agreement and examine its impact on corporate decisions along multiple dimensions.

5.1 Corporate bond issuance

Table 2 shows results from estimating the regression specification in equation (7) when the dependent variable is one of four bond market variables, annual amount offered, average offered yield weighed by issued amount, average offered yield weighed by maturity, and average time to maturity weighed by amount issued. For each dependent variable we present two regressions, each with a different metric for emissions, a continuous proxy, the logarithm of emissions to revenue, and a discrete proxy, a dummy that takes the value of one when a firm's emissions are above median emission intensity that year. All regressions include the following control variables: firm size (the logarithm of assets), leverage (debt to assets ratio), fraction of tangible assets (property plant and equipment to assets), fraction of liquid assets (cash to assets), CAPEX to asset, and firm and year fixed effects.

In columns (1) and (2), the dependent variable is the offering amount. The coefficient on the logarithm of Emissions/Revenue is positive but statistically insignificant. Same applies to the coefficient on the dummy High Emissions/Revenue. The interactions with $PostParis$ are also insignificant suggesting that firms with higher emissions intensity do not issue larger corporate bond notional amounts relative to firms that are less emissions inefficient, before or after the Paris Accord. In columns (3) and (4), the dependent variable is the average offering yield weighed by issued amount, and in columns (5) and (6), the dependent variable is the average offering yield weighed by time to maturity. We make this distinction because firms that shift to lower maturity bonds may benefit from lower yields due to the (generally positive) slope of the yield curve (e.g., a firm that issues two bonds with two years apart in offered maturity and shifts to lower maturities puts greater weight on the longer maturity bond). In fact, column (3) shows that more emissions inefficient firms experienced lower yields in the post Paris period of our sample, but this effect disappears when we weigh offered yields by the offered bonds' time to maturity. Lastly, columns (7) and (8) show results for time to maturity. The coefficient on lagged logarithm of Emissions/Revenue is positive but insignificant. The coefficient of emissions intensity interacted with $PostParis$ is negative and significant at 1% level. The estimated coefficient suggests that an increase in firm emissions intensity by one standard deviation is associated with a decrease in bond maturity issuance of 1.33 years (-0.486×2.735 years). We find a quantitatively slightly larger result in column (8): in the post Paris period, a firm with above median emissions intensity issued bonds with 1.7 years shorter maturity than more emissions efficient firms. These decreases in maturity are economically significant, representing about 14% (16.6%) of sample mean (median) maturity (the average (median) maturity of offered bonds in our sample is 12.3 (10.2) years).

Overall, the results indicate that more inefficient firms offer bonds of shorter maturity following the Paris Accord consistent with a tightening of financing conditions as predicted in Proposition 3. We find no statistically significant change in offered yields in the post Paris period for the high polluters viz-a-viz the less polluting firms when weighing yields by maturity. One possible interpretation of this result is that firms adjusted to an upward parallel shift of their yield curve post Paris (see Seltzer, Starks, and Zhu 2024 and others for additional evidence of tightening of financing costs for emissions inefficient firms post Paris) by borrowing more short term. By weighing offered yields by maturity we control for this effect. Despite this shift in maturity, firms were not able to lower their overall issuance yield.

The control variables in these regressions offer what are usual results. Firms with higher leverage then to issue less and at higher yields and firms with more tangible assets (i.e., higher NPPE to assets) tend to issue larger amounts. Larger firms tend to pay lower yields but also borrow at shorter maturities.

5.2 Corporate investment

The empirical results on borrowing conditions suggest a tightening of financial conditions for emissions inefficient firms following the Paris climate regulatory shock. The decrease in issued maturities also suggests that firms funded fewer long term investments or that they funded these investments with short term debt, which may keep financing costs lower but adds refinancing risk. Proposition 2 suggests that with higher financing costs in the regulation state, firms with higher emissions intensity invest relatively more in the pre-Paris period and less in the post-Paris period.

Table 3 presents results from estimating the regression specifications in equation (7) with capital expenditures and capital expenditures to assets as the dependent variables. The right hand side variables are the same as those used in Table 2. The results indicate that high-emissions intensity firms invest more in the pre-Paris period, though none of the estimated coefficients are statistically significant (columns (4) through (6)). In the post-Paris period, firms that increase their emissions intensity see an associated reduction in their subsequent capital expenditures. The results are particularly strong for the regression specifications with firm and industry times year fixed effects. In column (5), firm-years with above median emissions intensity experience an investment rate in the following year that is 1.1% lower than firms that are less emissions inefficient in the post-Paris period. This effect corresponds to 14% (1.1/7.9) of the average investment rate in our sample. When the dependent variable is the change in log capital expenditures (columns (2) and (3)) the results are qualitatively similar with growth in CAPEX decreasing by roughly 10%. This result is in line with unconditional changes in aggregate investment for heavy emitters versus low emitters pre- and post-2015 found in Jagannathan, Meier, and Sokolovski (2025).

Regarding the control variables, larger firms tend to invest more in dollar terms, but have a lower investment rate, suggestive of decreasing returns to scale. Firms with higher Property Plant and Equipment in place also have lower investment and investment rates. More leveraged firms have lower investment, which could be an indication of many things, including possible debt overhang. Firms with more cash to assets have higher investment in our sample of issuing firms.

5.3 Emissions intensity

Table 4 presents the results with firm emissions intensity as the dependent variable. In columns (1) to (3), the treatment variable is lagged log emissions intensity and in columns (4) to (6) the treatment variable is the dummy for emissions intensity above the median of the sample. The control variables are the same as those used in Table 3, including firm and year fixed effects, and industry times year fixed effects.

In columns (1) to (3), we see that the past level of emissions intensity is associated with higher future values of the variable post-Paris. This result is consistent with Proposition 2 that predicts higher emissions following the shock to regulatory risk. Hartzmark and Shue (2023) show that an increase in borrowing costs for brown firms makes them pollute more, whereas a decrease in borrowing costs to green firms does not make them greener. Our finding that the prospect of climate regulation is associated with both higher borrowing costs and increased emissions intensity is in line with their findings, but reveals a distinct mechanism. According to the hypothesis we study, investment occurs in anticipation of higher borrowing costs and increased pollution is a reflection of this increased investment.

Of the control variables, we do not find that firm size affects the future level of emissions intensity. However, the share of property, plant, and equipment in total assets and the share of cash in assets are both positively related to emissions, suggesting that asset tangibility and asset liquidity are both linked to firm emissions.

5.4 Total debt and cash holdings

We study two more financial variables, total debt and corporate cash holdings. We expect that debt grows at a slower pace for high-pollution firms after the regulatory shock compared to low-pollution firms, consistent with the prediction from Proposition 3 of costlier financing after the regulatory shock. In addition, in the spirit of the argument of the model, a riskier regulatory environment post-Paris may motivate a precautionary reduction in debt and increase in cash holdings relative to total assets. The cash flow used to fund these changes in debt and cash may come from the investments made prior to the regulatory shock that start paying out or from the reduced investment post-Paris.

Table B.2 in Appendix B presents results for the growth rate of debt and cash and for the stock of debt to total assets and cash holdings to total assets. The regressions include lagged values of the following control variables: firm size (the logarithm of assets), leverage (debt-to-assets ratio), fraction of tangible assets (property plant and equipment to assets), fraction of liquid assets (cash to assets), and CAPEX to assets. The regressions include year, firm, or industry times year fixed effects.

The results in columns (3) and (7) suggest that cash holdings to assets increase post-Paris for the high polluting firms and debt to assets decrease consistent with the predictions above. In the regression that we saturate with firm and industry times year fixed effects, we no longer find significant effects–the coefficient on the interaction term is economically smaller only in the case of debt to assets–but the signs of the coefficient estimates remain the same.

6 Conclusion

We show how financing can interact with firm policies inducing firms to exhibit behavior consistent with a "green paradox," where polluting firms increase ex ante investment and eventually pollution in the expectation of future climate regulation. We develop a simple model of firm financing and investment that predicts higher investment prior to the regulatory shock and a worsening of credit terms after the regulatory shock for firms more exposed to the shock. In our empirical analysis, using the Paris Climate Accord as a shock to future climate regulation and transition risk, we find evidence consistent with the model. Firms with high emissions intensity issue shorter-maturity bonds post-Paris without any significant decrease in yields at issuance. Further, these high-emissions intensity firms decrease capital expenditures and investment rates after the Paris Climate Accord but see an increase in emissions intensity.

We allow for a regulatory decision maker in the model and consider the implications of a regulation equilibrium. We show that there can be multiple equilibria and the reason for the multiplicity of equilibria is tied directly to the existence of a green paradox. This is because the model predicts an increase in pollution when the regulatory state becomes more likely, and we assume that the regulator is more likely to initiate regulation if it observes increased investment by polluting firms. The multiplicity of equilibria suggests that changes in firms' expectation of regulation can trigger an escalade of investment by polluting firms. At the same time, the symmetry of the results in the model suggests that a reduction in the perception that climate regulation will occur can dramatically reduce investment by polluting firms. There are interesting attenuating forces to the multiplicity of equilibria. For example, if the early investments require growing the firm's labor force, then the regulator may feel less inclined to promote regulation that results in job loss. These predictions are worth further study.

Our findings show that high-emissions firms that expect financing frictions to intensify under future climate regulatory shocks may in fact initiate investments that eventually lead to increased pollution. As such, the green paradox hypothesis suggests that long periods where the threat of climate regulation remains high without the actual passage and implementation of binding regulation that puts a price on GHG emissions may have counterproductive effects. The model also suggests that these unintended effects of delay in regulation can be reversed if polluting firms' expected the capital market to penalize them independently of whether the regulator takes action, but it is yet unclear in the literature what financial trade-off are investors willing to accept to do so.

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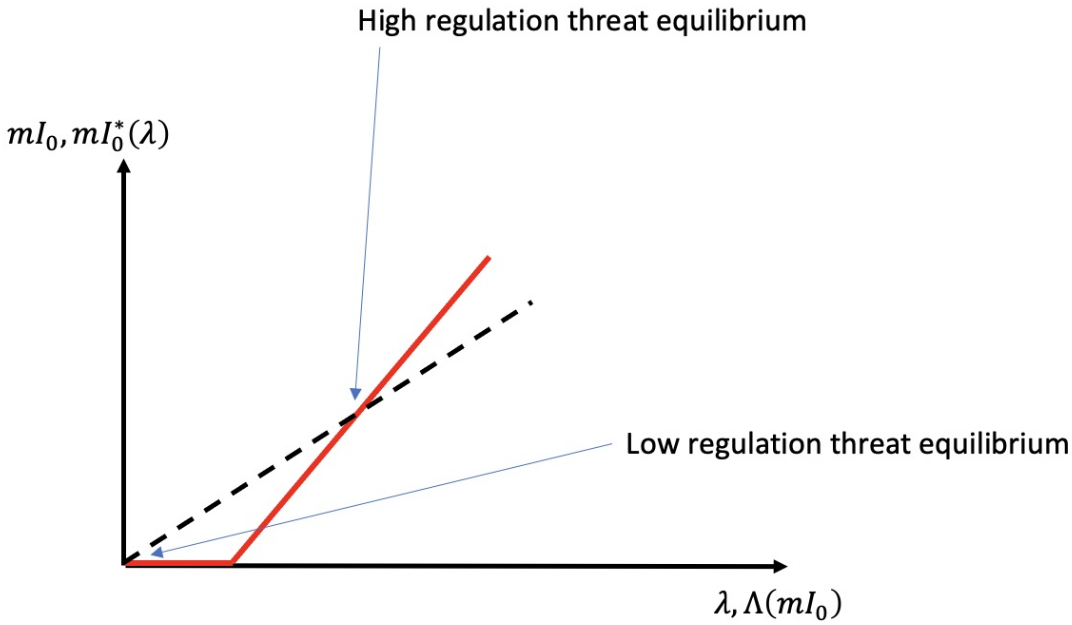

Figure 1: Equilibrium regulation levels and industry investment

The y-axis displays values for industry investment, $mI_0^*(\lambda)$, as a function of λ (solid line). The x-axis displays values of the regulatory function, $\Lambda(mI_0)$, as a function of mI_0 (dashed line). The points where the two curves intersect are equilibrium points.

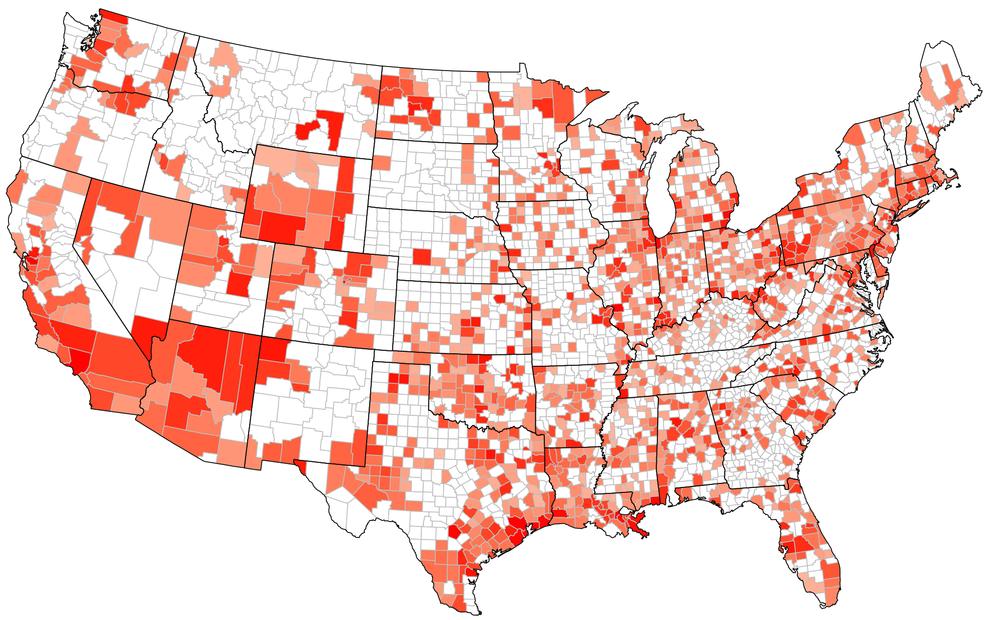

Figure 2: County-Level Emissions Based on EPA Facilities

This figure shows county-level emissions based on the EPA facilities located in a given county for public and private firms. Only facilities of EPA firms that are also in the Capital IQ data are included. The data illustrated in the figure are for 2015. Our analysis uses the time series.

Table 1: Summary Statistics

This table shows the summary statistics for the main variables used in the analysis. The data are annual from 2010 to 2020. Table B.1 presents all variable definitions. Panel A presents summary statistics for the sample of EPA firms. Panel B gives summary statistics for the sample of Mergent firms. The N column shows the number of observations used to calculate the statistics in a particular row. The last four columns show percentiles.

Panel A: Firm emissions and balance sheet information (EPA sample)

	N	Mean	Median	Stdev	25th	75th	10th	90th
$log(Emissions)$	35,337	10.959	11.217	3.458	10.277	12.592	7.771	14.464
$log(\frac{Emissions}{Revenue})$	2,993	5.552	5.935	2.511	3.67	7.654	1.899	8.662
$log(CAPEX)$	2,967	5.594	5.700	1.993	4.418	7.100	2.984	8.084
$\Delta log(CAPEX)$	2,937	0.029	0.037	0.537	-0.183	0.256	-0.527	0.563
$\frac{CAPEX}{Assets}$	2,954	0.071	0.051	0.069	0.030	0.082	0.018	0.142
$log(Assets)$	3,014	8.510	8.573	1.847	7.342	9.929	6.062	10.829
$\frac{Debt}{Assets}$	3,014	0.355	0.334	0.208	0.225	0.456	0.116	0.611
$\frac{NPPE}{Assets}$	3,008	0.506	0.526	0.244	0.306	0.717	0.152	0.813
$\frac{Cash}{Assets}$	2,980	0.06	0.037	0.068	0.011	0.086	0.003	0.149

Panel B: Bond offerings information (Mergent sample)

	N	Mean	Median	Stdev	25th	75th	10th	90th
log(Total Offering Amount)	1,155	14.044	13.976	1.079	13.122	14.809	12.663	15.554
Amount-Weighted Offering Yield (%)	1,068	4.484	4.121	1.891	3.189	5.267	2.521	6.884
Maturity-Weighted Offering Yield (%)	1,068	4.653	4.326	1.802	3.487	5.375	2.823	6.885
TTM (in Years)	1,155	12.301	10.167	6.788	7.848	15.419	6.097	21.952
$log(\frac{Emissions}{Revenue})$	1,155	5.246	5.670	2.735	2.895	7.607	1.265	8.603
$log(CAPEX)$	1,151	6.823	7.057	1.460	5.879	7.905	4.717	8.525
$\frac{CAPEX}{Assets}$	1,151	0.079	0.058	0.078	0.032	0.086	0.020	0.169
$log(Assets)$	1,150	9.660	9.844	1.422	8.729	10.680	7.604	11.323
$\frac{Debt}{Assets}$	1,150	0.354	0.334	0.169	0.250	0.436	0.171	0.546
$\frac{NPPE}{Assets}$	1,150	0.504	0.528	0.255	0.283	0.717	0.138	0.841
$\frac{Cash}{Assets}$	1,140	0.048	0.029	0.054	0.008	0.070	0.002	0.115

Table 2: Firm Corporate Bond Issuance - Post-Paris Agreement

This table presents results of the panel regression model given in equation (7). The data are annual from 2010 to 2020. The dependent variables are log(offering amount) in Columns (1) - (2), amount-weighted yield (in %) in Columns (3) - (4), maturity-weighted yield (in %) in Columns (5) - (6), and time to maturity in Columns (7) - (8). All specifications include year fixed effects and firm fixed effects. The standard errors are clustered at the firm level. t-statistics are shown below the corresponding coefficient estimates. The significance of the coefficient estimate is indicated by * for $p < 0.10$, ** for $p < 0.05$, and *** for $p < 0.01$.

	log(Total Offering Amount)		Amount-Weighted Offering Yield (%)		Maturity-Weighted Offering Yield (%)		TTM	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
$log(\frac{Emissions_{i,t-1}}{Revenue_{i,t-1}}) \times PostParis_t$	0.015		-0.059**		-0.036		-0.486***	
	0.846		-2.174		-1.353		-3.029	
$IsHighEOR_{i,t-1} \times PostParis_t$		0.134		-0.196		-0.076		-1.702*
		1.262		-1.235		-0.488		-1.892
$log(\frac{Emissions_{i,t-1}}{Revenue_{i,t-1}})$	0.031		0.074		0.058		0.023	
	0.490		1.217		0.917		0.076	
$IsHighEOR_{i,t-1}$		0.179		0.148		0.055		0.624
		1.284		0.761		0.287		0.782
$log(Assets)_{i,t-1}$	-0.021	-0.025	-0.157**	-0.172**	-0.176***	-0.190***	-0.461*	-0.383*
	-0.419	-0.577	-2.385	-2.558	-2.783	-2.972	-1.935	-1.802
$\frac{Debt_{i,t-1}}{Assets_{i,t-1}}$	-0.376	-0.334	0.869*	0.934*	0.739	0.800*	-0.194	-0.192
	-1.022	-0.940	1.708	1.933	1.515	1.734	-0.112	-0.115
$\frac{NPPE_{i,t-1}}{Assets_{i,t-1}}$	1.105***	1.054***	0.588	0.567	0.681	0.653	-0.081	-0.439
	2.799	2.728	0.803	0.757	0.970	0.912	-0.041	-0.218
$\frac{Cash_{i,t-1}}{Assets_{i,t-1}}$	0.698	0.640	-0.777	-0.852	-0.826	-0.892	-1.040	-1.136
	0.874	0.805	-0.572	-0.612	-0.623	-0.659	-0.264	-0.296
$\frac{CAPEX_{i,t-1}}{Assets_{i,t-1}}$	1.110	1.146	-3.791***	-3.794***	-3.910***	-3.875***	-3.001	-2.705
	1.402	1.429	-3.385	-3.355	-3.585	-3.533	-0.873	-0.806
Observations	1,140	1,142	1,054	1,056	1,054	1,056	1,140	1,142
Adjusted R^2	0.583	0.584	0.723	0.723	0.719	0.719	0.431	0.425
Year FE	Y	Y	Y	Y	Y	Y	Y	Y
Firm FE	Y	Y	Y	Y	Y	Y	Y	Y

Table 3: Firm Capital Expenditure - Post-Paris Agreement

This table presents results of the panel regression model given in equation (7). The data are annual from 2010 to 2020. The dependent variables are $\Delta log(CAPEX_{i,t})$ in Columns (1) - (3), and $\frac{CAPEX_{i,t}}{Assets_{i,t}}$ in Columns (4) - (6). The specifications include a combination of year, industry, firm, and industry-year fixed effects as indicated. The standard errors are clustered at the firm level. t-statistics are shown below the corresponding coefficient estimates. The significance of the coefficient estimate is indicated by * for $p < 0.10$, ** for $p < 0.05$, and *** for $p < 0.01$.

	$\Delta log(CAPEX_{i,t})$			$\frac{CAPEX_{i,t}}{Assets_{i,t}}$		
	(1)	(2)	(3)	(4)	(5)	(6)
$IsHighEOR_{i,t-1} \times PostParis_t$	-0.032	-0.093**	-0.126**	-0.004	-0.011***	-0.010**
	-0.910	-2.198	-2.382	-1.494	-3.375	-2.340
$IsHighEOR_{i,t-1}$	-0.003	-0.027	0.015	0.002	0.006	0.008
	-0.081	-0.414	0.238	0.708	1.060	1.491
$log(Assets)_{i,t-1}$	-0.024***	-0.287***	-0.320***	-0.001*	-0.007	-0.011***
	-3.813	-4.575	-6.096	-1.650	-1.466	-2.762
$\frac{Debt_{i,t-1}}{Assets_{i,t-1}}$	-0.212**	-0.595***	-0.442***	-0.016***	-0.069***	-0.056***
	-2.431	-3.995	-2.839	-3.253	-4.232	-3.490
$\frac{NPPE_{i,t-1}}{Assets_{i,t-1}}$	-0.064	-1.342***	-1.311***	0.011	-0.106***	-0.112***
	-0.718	-5.312	-5.194	1.435	-5.202	-5.218
$\frac{Cash_{i,t-1}}{Assets_{i,t-1}}$	0.987***	1.076***	1.096***	0.073***	0.077***	0.084***
	4.213	3.646	3.645	3.600	3.180	3.453
$\frac{CAPEX_{i,t-1}}{Assets_{i,t-1}}$	-2.265***	-4.243***	-4.784***	0.639***	0.385***	0.328***
	-7.112	-10.069	-12.492	24.674	9.100	6.534
Observations	2,567	2,567	2,567	2,569	2,569	2,569
Adjusted R^2	0.138	0.236	0.295	0.691	0.750	0.765
Year FE	Y	Y	N	Y	Y	N
Industry FE	Y	N	N	Y	N	N
Firm FE	N	Y	Y	N	Y	Y
Industry × Year FE	N	N	Y	N	N	Y

Table 4: Firm Greenhouse Gas Emissions

This table presents results of the panel regression model given in equation (7). The data are annual from 2010 to 2020. The dependent variable is $log(\frac{Emissions_{i,t}}{Revenue_{i,t}})$. The specifications include a combination of year, industry, firm, and industry-year fixed effects as indicated. The standard errors are clustered at the firm level. t-statistics are shown below the corresponding coefficient estimates. The significance of the coefficient estimate is indicated by * for $p < 0.10$, ** for $p < 0.05$, and *** for $p < 0.01$.

	(1)	(2)	(3)	(4)	(5)	(6)
$log(\frac{Emissions_{i,t-1}}{Revenue_{i,t-1}}) \times PostParis_t$	0.028***	0.017**	0.034*			
	3.351	2.033	1.723			
$log(\frac{Emissions_{i,t-1}}{Revenue_{i,t-1}})$	0.880***	0.470***	0.428***			
	45.043	9.599	7.513			
$IsHighEOR_{i,t-1} \times PostParis_t$				0.316***	0.177***	0.231**
				3.095	2.908	2.088
$IsHighEOR_{i,t-1}$				2.210***	0.689***	0.568***
				14.437	4.245	3.711
$log(Assets)_{i,t-1}$	-0.000	-0.017	0.016	-0.125***	-0.094	-0.055
	-0.012	-0.338	0.313	-3.554	-1.246	-0.794
$\frac{Debt_{i,t-1}}{Assets_{i,t-1}}$	-0.004	-0.287**	-0.240*	0.134	-0.305**	-0.290**
	-0.056	-2.278	-1.906	0.549	-2.205	-2.061
$\frac{NPPE_{i,t-1}}{Assets_{i,t-1}}$	0.677***	0.702***	0.699**	2.200***	0.670**	0.640**
	5.565	2.652	2.402	5.779	2.136	2.005
$\frac{Cash_{i,t-1}}{Assets_{i,t-1}}$	0.211	0.709**	0.998***	0.912	0.765**	0.941**
	0.847	2.246	2.789	1.302	2.043	2.298
$\frac{CAPEX_{i,t-1}}{Assets_{i,t-1}}$	-0.054	-0.077	-0.024	-0.308	-0.123	-0.060
	-0.206	-0.213	-0.063	-0.384	-0.295	-0.136
Observations	2,562	2,562	2,562	2,564	2,564	2,564
Adjusted R^2	0.946	0.958	0.959	0.815	0.948	0.950
Year FE	Y	Y	N	Y	Y	N
Industry FE	Y	N	N	Y	N	N
Firm FE	N	Y	Y	N	Y	Y
Industry × Year FE	N	N	Y	N	N	Y

Appendix

A Proofs

In this appendix we offer proofs for the various propositions in the paper.

Proof of Proposition 1. To obtain a sufficient condition for $I_0^* > 0$, the marginal benefit evaluated at $I_0 = 0$ must be larger than R:

$$(1-\lambda)\left[1-F(RI)\right]R + \lambda\left[1-F(\kappa+R_\lambda I)\right]R_\lambda > R. \tag{A.1}$$

With $\mu_\pi = 1.96\sigma_\pi + \kappa + R_\lambda I$, $F(\kappa + R_\lambda I) = 0.025 > F(RI)$. Hence,

$$(1-\lambda)\left[1-F(RI)\right]R + \lambda\left[1-F(\kappa+R_\lambda I)\right]R_\lambda > (1-\lambda)0.975R + \lambda 0.975R_\lambda. \tag{A.2}$$

Thus, inequality (A.1) holds provided $(1-\lambda)0.975R + \lambda 0.975R_\lambda > R$, which results in the left inequality in (3). To obtain a sufficient condition for $I_0^* < I$, the marginal benefit evaluated at $I_0 = I$ must be smaller than $R + \psi I$:

$$(1-\lambda)\left[1-F(0)\right]R + \lambda\left[1-F(\kappa)\right]R_\lambda < R + \psi I. \tag{A.3}$$

Notice that

$$(1-\lambda)\left[1-F(0)\right]R + \lambda\left[1-F(\kappa)\right]R_\lambda < (1-\lambda)R + \lambda R_\lambda. \tag{A.4}$$

The right inequality in (3) holds if and only if $(1-\lambda)R + \lambda R_\lambda < R + \psi I$, and thus guarantees inequality (A.3).

The second-order condition for a maximum is satisfied the first time the marginal benefit curve intersects the marginal cost curve since, by intersecting from above, it implies that the slope of the marginal benefit curve is smaller than the slope of the marginal cost curve. Other maxima may exist.

□

Proof of Proposition 2. Denote the left-hand side of (2) by $g(I_0, \lambda)$. Then,

$$\frac{dI_0^*}{d\lambda} = -\frac{-\left[1 - F(R(I - I_0))\right] R + \left[1 - F(\kappa + R_\lambda(I - I_0))\right] R_\lambda}{(1-\lambda) f(R(I - I_0))R^2 + \lambda f(\kappa + R_\lambda(I - I_0))R_\lambda^2 - \psi} \tag{A.5}$$

where f is the density function of operating profits. The denominator is negative as required in a maximum. To show that the numerator is positive, note that at the optimum, $g(I_0^*, \lambda) = 0$, and rewrite to get

$$-\left[1 - F(R(I - I_0))\right] R + \left[1 - F(\kappa + R_\lambda(I - I_0))\right] R_\lambda = \frac{F(R(I - I_0))R + \psi I_0}{\lambda} > 0. \tag{A.6}$$

With increased early investment, the probability of exercising the investment option at $t = 1$ is higher. □

B Additional tables

Table B.1: Variable Definitions

This table presents definitions of the main variables. The first column gives the variable name. The second column includes a short description. The last column gives the reference to the raw data source. Detailed descriptions and summary statistics of these variables are in Section 4.

Variable	Description	Source
log(Total Offering Amount)	Natural log of total notional amount of all bonds issued by a parent firm in a year	Mergent FISD
Amount-Weighted Offering Yield (%)	Average offering yield weighted by the offering amount of the bonds issued by a parent firm in a year	Mergent FISD
Maturity-Weighted Offering Yield (%)	Average offering yield weighted by the time-to-maturity of the bonds issued by a parent firm in a year	Mergent FISD
TTM	Average time-to-maturity (in years) weighted by the offering amount of the bonds issued by a parent firm in a year	Mergent FISD
$log(\frac{Emissions_{i,t}}{Revenue_{i,t}})$	Natural log of emissions over revenue (i.e., emission intensity)	EPA, S&P Capital IQ
$\Delta log(\frac{Emissions_{i,t}}{Revenue_{i,t}})$	Change in the natural logarithm of emissions to revenue	EPA, S&P Capital IQ
$\Delta log(Emissions_{i,t})$	Change in the natural log of emissions level	EPA
$IsHighEOR_{i,t}$	Indicator variable that takes value one if the firm-year emissions to revenue are above the sample median of emissions to revenue	EPA, S&P Capital IQ
$log(CAPEX_{i,t})$	Natural logarithm of firm capital expenditures	S&P Capital IQ
$\frac{CAPEX_{i,t}}{Assets_{i,t}}$	Ratio of firm capital expenditures to total assets	S&P Capital IQ
$log(Assets_{i,t})$	Natural logarithm of firm total assets.	S&P Capital IQ
$\frac{Debt_{i,t}}{Assets_{i,t}}$	Ratio of firm total debt to total assets	S&P Capital IQ
$\frac{NPPE_{i,t}}{Assets_{i,t}}$	Ratio of firm net property plant and equipment to total assets. A measure of asset tangibility (Lemmon, Roberts, and Zender, 2008).	S&P Capital IQ
$\frac{Cash_{i,t}}{Assets_{i,t}}$	Ratio of firm cash to total assets	S&P Capital IQ
PostParis$_t$	Indicator variable that equals one if the year is after the passage of the Paris Accords	

Table B.2: Firm Cash and Debt - Post Paris

This table presents results of the panel regression model given in equation (7). The data are annual from 2010 to 2020. The dependent variables are $\Delta log(Cash_{i,t})$ in Columns (1) - (2), $\frac{Cash_{i,t}}{Assets_{i,t}}$ in Columns (3) - (4), $\Delta log(Debt_{i,t})$ in Columns (5) - (6), and $\frac{Debt_{i,t}}{Assets_{i,t}}$ in Columns (7) - (8). The specifications include a combination of year, industry, firm, and industry-year fixed effects as indicated. The standard errors are clustered at the firm level. t-statistics are shown below the corresponding coefficient estimates. The significance of the coefficient estimate is indicated by * for $p < 0.10$, ** for $p < 0.05$, and *** for $p < 0.01$.

	$\Delta log(Cash_{i,t})$		$\frac{Cash_{i,t}}{Assets_{i,t}}$		$\Delta log(Debt_{i,t})$		$\frac{Debt_{i,t}}{Assets_{i,t}}$	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
$IsHighEOR_{i,t-1} \times PostParis_t$	0.112	0.100	0.008**	0.009	-0.082*	-0.044	-0.019**	-0.007
	1.419	0.710	2.141	1.576	-1.943	-0.747	-2.349	-0.555
$IsHighEOR_{i,t-1}$	-0.100	-0.069	-0.004	-0.003	0.033	0.009	0.020*	0.015
	-0.787	-0.489	-0.740	-0.614	0.559	0.139	1.806	1.341
$log(Assets)_{i,t-1}$	-0.408***	-0.413***	-0.020***	-0.021***	-0.168***	-0.198***	0.025**	0.019
	-4.764	-4.324	-4.830	-4.857	-2.709	-3.163	2.128	1.575
$\frac{Debt_{i,t-1}}{Assets_{i,t-1}}$	-0.046	-0.192	-0.014	-0.023	-1.555***	-1.513***	0.541***	0.542***
	-0.156	-0.629	-0.955	-1.451	-8.795	-9.044	15.125	16.895
$\frac{NPPE_{i,t-1}}{Assets_{i,t-1}}$	-0.211	-0.150	-0.052**	-0.050**	0.433*	0.444**	0.114***	0.102**
	-0.491	-0.332	-2.366	-2.149	1.901	1.998	2.851	2.427
$\frac{Cash_{i,t-1}}{Assets_{i,t-1}}$	-9.334***	-9.555***	0.252***	0.264***	0.926*	0.683*	-0.042	-0.084
	-11.934	-11.581	5.482	5.445	1.842	1.853	-0.560	-1.223
$\frac{CAPEX_{i,t-1}}{Assets_{i,t-1}}$	1.115*	0.890	-0.017	-0.032	1.419***	1.244***	-0.097	-0.108
	1.849	1.376	-0.550	-1.118	4.130	3.407	-1.016	-1.083
Observations	2,564	2,564	2,564	2,564	2,506	2,506	2,571	2,571
Adjusted R^2	0.069	0.043	0.667	0.676	0.157	0.234	0.852	0.861
Year FE	Y	N	Y	N	Y	N	Y	N
Firm FE	Y	Y	Y	Y	Y	Y	Y	Y
Industry × Year FE	N	Y	N	Y	N	Y	N	Y