Financing and the Green Paradox

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Abstract

We study firms' investment decisions in anticipation of higher financing costs under future climate regulation. The model predicts that high greenhouse-gas-emitting firms increase investment in polluting technology before regulation intended to curb emissions binds and, consequently, emit more ex post. Using the Paris Climate Accord and the Waxman-Markey cap-and-trade bill as quasi-exogenous shocks, we find that exposed firms increase investment prior to anticipated climate regulation. Exposed firms have higher emissions levels and intensity after the regulatory shock, consistent with a green paradox effect. We discuss the possibility of multiple equilibria and the implications for climate change regulation.

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1 Introduction

In recent decades, there have been widespread discussions and enactment of regulations aimed at curbing greenhouse gas (GHG) emissions around the world. A large literature has shown that enacted or anticipated climate change regulation can affect the cost of capital of high-emissions firms.[1] A natural question is how firms react to the threat of future climate regulation and associated increased financing costs. In this paper, we develop and test a model of firm investment and financing where the threat of future regulation has the unintended consequence of firms bringing forward investment in polluting technology before financing costs bind.

We model a firm that can take an investment option and needs financing for it. The investment is polluting (e.g., a cement or steel factory) and sensitive to climate regulation. The period the firm is deciding over the investment option coincides with the possibility of a regulatory shock that increases the project's operating costs due to a price or tax on emissions. The firm can invest in the project at the time of the regulatory shock or contribute investment toward the project prior to it. The project is financed through borrowing. When the firm decides to invest early, it finances this early investment through a loan that matures before the regulatory shock. If the borrowing rate is the same prior to the option exercise and at the time of the option exercise, the firm does not start the project and 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, a higher probability of climate regulation

[1] See, for example, Meng (2017); Bolton and Kacperczyk (2021, 2023); Ilhan, Sautner, and Vilkov (2021); Ivanov, Kruttli, and Watugala (2024); Seltzer, Starks, and Zhu (2025).

affecting the firm leads the firm to borrow and invest more earlier on. 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.[2] Second, the earlier investment by the firm is associated with a higher probability of completing the investment project, resulting in increased pollution. Third, firms with higher cash flow volatility are predicted to invest less earlier because of the higher option value, but this effect is attenuated when the probability of climate regulation increases. Overall, the model develops a novel mechanism that can lead to a "green paradox" through the financing channel, complementing the classical green paradox mechanism that arises through product price uncertainty (Sinclair, 1992; Sinn, 2008).

The prediction of a positive relation between the probability of future regulation and early investment has an additional implication for the success of regulation. We introduce a regulator in the model in the spirit of Glazer and McMillan (1992) and others: the regulator increases the probability of regulation when it sees higher investment earlier on by polluting firms. The regulation threat coupled with the green paradox result can produce multiple equilibria. An equilibrium with low risk of regulation and low early investment and low pollution, and an equilibrium with high risk of regulation and high early investment and high pollution. In the high investment equilibrium, the industry's expectation of the likelihood of the regulator's action drives investment up by polluting firms through the cost of financing channel (i.e., the model's green paradox effect), and the increased investment leads to a higher probability of regulation, thus validating those expectations. A consequence of the multiplicity of equilibrium is that changes in expectations can drive the industry to the high-pollution equilibrium.[3]

[2]To derive analytical predictions, in the main analysis interest rates are exogenous. The appendix presents an extension with endogenous interest rates that is solved numerically.

[3]The model can explain the differential polluting technology investment patterns across private and public US firms (e.g. Duchin, Gao, and Xu 2025) subject to different sets of regulatory bodies. For example, if new

To empirically identify and analyze how changes in the probability of climate regulation affect investment decisions and pollution levels, we consider two of the main episodes in recent US history: the 2015 Paris Climate Accord (Ilhan, Sautner, and Vilkov, 2021; Bolton and Kacperczyk, 2021, 2023; Seltzer, Starks, and Zhu, 2025) and the 2009 Waxman-Markey cap-and-trade bill (Meng, 2017; Ivanov, Kruttli, and Watugala, 2024).[4]

The Paris Climate Accord is an international treaty on climate change whose signatories committed to tight climate policy objectives.[5] The US adopted the Paris Accord on December of 2015. We estimate difference-in-difference equations describing investment and emissions pre- and post-Paris Accord. To measure a firm's exposure to the Paris Accord, we compute the lagged value of GHG-emissions intensity based on data from the US Environmental Protection Agency (EPA). We use annual data on facility-level greenhouse gas emissions from the Greenhouse Gas Reporting Program (GHGRP) from 2010 to 2020. These 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 merge our emissions data with Capital IQ to obtain balance sheet information.

We first analyze firm investment policy for high and low emissions firms by studying changes in firm capital expenditures (CAPEX) from before to after the passage of the Paris Accord. Consistent with the model prediction, we find that the ratio of CAPEX to assets is higher (lower) for high-emissions intensity firms relative to low-emission firms in the pre-Paris (post-Paris) 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 in the post-Paris period versus the pre-period, all else equal. This economic magnitude is large

rules introduced to standardize climate-related disclosures apply only to public companies.

[4]See, for example, the climate change news index of Engle, Giglio, Kelly, Lee, and Stroebel (2020).

[5]The 1997 Kyoto Protocol 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.

in comparison with a mean and median investment rate of 6.9% and 5.2%, respectively, in our sample. When we repeat the regressions using the change in the level of CAPEX as the outcome, we again find a significant decrease in CAPEX for high-emissions intensity firms in the post-period of up to 12.6 percentage points compared to the control group. These results hold within industry-year and within firm after including industry interacted with time fixed effects and firm fixed effects, respectively.

Second, we find that the observed changes in investment post-Paris for high-emissions firms have a parallel effect on emissions. Consistent with the model prediction, we find that firms with high-emissions intensity tend to have relatively higher emissions levels and emissions intensity in years subsequent to the Paris Accord. In addition, the results on investment and emissions are stronger for firms with higher cash flow volatility, as predicted by the model.

We then use the near passage of the Waxman-Markey Bill as a second quasi-natural experiment to test the model predictions on investments. On the one hand, this setting has an advantage over the Paris Accord because of the tighter identification that it allows. On the other hand, it presents a disadvantage relative to the Paris Accord setting because the introduction of the bill predates the EPA's GHGRP that provides emissions data only from 2010 onwards. The bill was introduced in May 2009, and passed the House of Representatives on June 26, 2009. Using prediction market prices, Meng (2017) notes that there was an elevated probability of the bill passing through the end of 2009 until early 2010. The bill never reached a Senate vote and Senate Democrats eventually dropped the bill from the discussion in July 2010. The bill included a feature that discriminated within the set of high-emissions manufacturing firms in the US by giving free emission permits to qualifying firms with energy intensity above 5%. This discontinuity provides for a cleaner identification and avoids confounding effects that can arise, for example, from a focus on the oil and gas industry or a simple comparison of high and low emission firms. We find that manufacturing

firms below the threshold of 5% of energy intensity, the treated firms, exhibit an increase in investment in the first quarter of 2010, the quarter when the likelihood of the bill passing started to decline. The evidence suggests that treated firms increased investments while the likelihood of the bill passing was high. The evidence is also consistent with Ivanov, Kruttli, and Watugala (2024) who show that banks adjust the financing to treated firms after the bill passed the House, likely increasing firms' expectations of future tighter financing after the implementation of the regulation.

Our model, and the model extension we present in the appendix, emphasize the incentive for firms to invest earlier, because the increased probability of bankruptcy due to the climate regulation affects the cost of financing. However, higher external financing costs could come from sources other than an increase in the probability of bankruptcy. For example, bond investors segment themselves across bond maturities (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 environment, social and governance (ESG) performance of firms (e.g. Starks, Venkat, and Zhu (2025)). 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.

The next section offers a 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. The appendix contains the proofs to the main results and an extended model that endogenizes the cost of borrowing at different times and states of nature for the firm.

2 Related literature

A large literature investigates the Paris Accord and finds changes in the cost of capital for high-emission firms. We build on these findings by studying the investment and emission actions of firms when they anticipate changes in the cost of capital due to regulation. Seltzer, Starks, and Zhu (2025) 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 (2025) 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. 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, 2023) find a carbon risk premium in the cross section of US and international stocks that increases post Paris. These results together with estimates from Ladika, Pazaj, and Sautner (2025) that show how the Paris Accord was widely anticipated by firms provide empirical support for our model assumptions.

Further, prior papers analyze the Waxman-Markey legislation and its impact on the cost of capital. Meng (2017) finds that the probability of the Waxman-Markey cap-and-trade bill becoming law was priced in stocks of US manufacturing firms. Ivanov, Kruttli, and Watugala (2024) find that the passage of the Waxman-Markey legislation by the US House of Representatives is associated with shorter loan maturities and higher loan interest rates for firms more exposed to the cap-and-trade legislation. These results suggest that high-emission firms had likely anticipated additional increases in the cost of capital should the Waxman-Markey bill also pass the US Senate.

Relative to the prior literature on the green paradox hypothesis, we are the first to show how an increase in financing costs stemming from climate regulation can give rise to a green paradox effect. While the green paradox has been mainly studied as a supply side effect—fossil fuel extraction firms are concerned about future climate policy and extract fossil fuels more quickly—our financing cost mechanism applies to fossil fuel producing or consuming high-emission firms. 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. Lemoine (2017) finds that the US Senate breakdown in negotiations of the Waxman-Markey bill lead to an increase in coal futures prices and in coal storage. 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 several factors that affect the pace of fossil fuel extraction. van der Ploeg and Withagen (2012) discuss welfare implications of backstops—renewable resources that substitute perfectly for fossil fuels—and how such backstops can cause a faster extraction of fossil fuels. Acharya, Giglio, Pastore, Stroebel, Tan, and Yong (2025) study oil extraction that arises from the arrival of breakthrough technologies in the renewable energy sector and from taxes on carbon emissions and restrictions on drilling.

A growing literature of theoretical models study different aspects of the transition towards a low-emission economy. Bellon and Boualam (2024) argue that financial distress makes dirty technologies more attractive to distressed firms, akin to a risk-shifting argument. Lanteri and Rampini (2023) and Bustamante and Zucchi (2024) study the adoption of clean technologies when firms are heterogeneously financially constrained. Ramadorai and Zeni (2024) show that firms' beliefs about climate regulation affect their emissions abatement. 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. Other papers

focus on how the presence of green investors affects firms' decisions. Gupta, Kopytov, and Starmans (2025) 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 under climate regulation the shareholder composition of polluting firms can change and discourage the adoption of green technologies. 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. Bisceglia, Piccolo, and Schneemeier (2025) argue that concentration of ESG-oriented investors on a small set of green firms may discourage green investments by excluded firms. Similarly, in Goldstein, Kopytov, Shen, and Xiang (2024), the growth of green investors together with better ESG information quality can raise a firm's cost of capital. Oehmke and Opp (2025) study how a socially responsible fund can steer firms towards reducing externalities.

Several papers study how the presence of investors with green preferences independent of climate regulation can affect firms' business operations through the exit or voice channel (see, e.g., Broccardo, Hart, and Zingales (2022); Hong, Wang, and Yang (2023); Berk and van Binsbergen (2025); Hartzmark and Shue (2026)). The green paradox mechanism that we propose is distinct as it relies on anticipated increases in cost of capital due to future climate regulation and not the presence of green investors.

3 A model of financing and investment and the green paradox

This section offers a tractable model of investment and borrowing decisions of a firm that faces the prospect of climate-related regulatory risk. There are three periods indexed by $0, 1, 2$. The firm has an investment option that requires an investment of I. Once in op-

eration, the investment generates pollution, such as a cement or steel manufacturing plant. The investment pays out an operating profit of $\tilde{\pi}$, with continuous cumulative distribution function (cdf) $F(\tilde{\pi})$, at time 2. $\tilde{\pi}$ is observed at time 1. 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 greenhouse gas emission permits that need to be purchased.[6] For simplicity, the firm's rate of time preference is set to zero.

At time $t = 0$, the firm can borrow an amount $I_0 \leq I$ for one period. The borrowed amount I_0 is used to invest at $t = 0$ (e.g., start the construction of the cement or steel plant). If, after observing $\tilde{\pi}$, the firm takes the option at time $t = 1$, additional borrowing of $I_1 = I - I_0 \geq 0$ is needed to complete the investment. If, however, the option is not taken at $t = 1$, then there are no cash flows and for simplicity we assume the liquidation value of the early investment to be zero. There is a convex cost to early investment of $\psi I_0^2/2$.[7] This cost is introduced to ensure an interior solution, but it is not needed in the extended model in Appendix B.

We assume that the firm can issue one-period bonds at the gross interest rate R in both periods 0 and 1, unless the climate regulatory shock materializes in which case the borrowing cost goes up to $R_\lambda > R$. If the firm borrows I_0 at $t = 0$, the debt will mature before the potential climate regulation shock, and the lenders receive RI_0 at $t = 1$. In the main text, we assume these interest rates are exogenous, but in the extended model in the appendix

[6] 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.

[7] This non-pecuniary cost is motivated by the manager's reputational considerations. The manager might borrow early but the project is not completed because the $\tilde{\pi}$ realization at $t = 1$ is too low. The low realization of $\tilde{\pi}$ could be difficult for the lender to verify, and the lender might think that the manager did not have any real intentions to complete the project.

these rates are endogenously priced.[8] A timeline of the model is given in Figure 1.

The firm's maximization problem at time 0 is

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

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

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

The first order condition with respect to I_0 yields:

$$(1-\lambda)\left[1-F(R(I-I_0))\right]R+\lambda\left[1-F(\kappa+R_\lambda(I-I_0))\right]R_\lambda-R-\psi I_0\leq 0. \tag{2}$$

The optimal choice of I_0 is determined by the relative cost of investing early versus later. The relative cost of investing early is the difference between the marginal borrowing cost at time 0, $R+\psi I_0$, and the marginal borrowing cost at time 1. The marginal borrowing cost at time 1 is the weighted average of R times the probability of option exercise $(1-F(R(I-I_0))$ if there is no regulation, and R_λ times the probability of option exercise $(1-F(\kappa+R_\lambda(I-I_0))$ if there is regulation. The marginal borrowing cost at time 1 can be interpreted as the marginal benefit of investing early—the amount that the firm invests at time 0 it does not have to invest at time 1. When the relative cost of investing early is too high, say for example when $\lambda=0$, then $I_0^*=0$.

[8] Section 3.3 discusses an alternative interpretation where R and R_λ are considered internal hurdle rates.

The following proposition gives sufficient conditions for an interior maximum for a specific functional form for F, and assuming that the operating profit mean is sufficiently bigger than its volatility. 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 must also 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.[9] Our main result is that a firm facing higher regulatory exposure at time 1 (i.e., higher λ), invests relatively more at time 0, $dI_0^*/d\lambda > 0$. To

[9]Empirically, we think of λ as having a firm-specific component that captures the exposure that a firm has to the climate regulation through the greenhouse gas emissions intensity of its operations, and an aggregate component related to the probability of the climate regulation being implemented. In the model, we make no distinction on which of the two is driving changes in λ.

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 of 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 higher borrowing cost at time 1, and an increase in λ increases the expected borrowing cost at time 1 all else equal, encouraging early investment. In summary, an increase in λ increases the relative cost of investing later. 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 financing cost faced by the firm in the state where regulatory risk occurs generates an incentive to invest early in the polluting technology, which itself counteracts the efforts of the regulation.

The extended model in the appendix shows that this result does not require that the interest rate at time 0 is lower than R_λ. Rather, the critical aspect of the model is that the time-1 borrowing rate in the regulation state is higher than if no regulation occurs. Thus, an increase in λ, by increasing the likelihood of costlier borrowing, increases the relative cost of investing at time 1 vis-à-vis investing at time 0, and thus creates an incentive to invest early.

A consequence of higher early investment for a firm with higher regulatory risk (i.e., higher λ) is that the firm also has a higher probability of exercising the option at time 1. Hence, firms with a higher probability of regulation affecting them are more likely to complete the dirty project and 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 assumes time-0 investment is irreversible.[10] We next explore implications that result from this assumption. Because the irreversibility of investment becomes more or less relevant depending on the volatility of operating profits, we study how firms that face higher regulatory risk at time 1 change their early investment decisions if they also have higher operating profit volatility. For the next result, we again assume that the operating profit is a normal random variable.

Proposition 3. *Let the conditions in Proposition 1 hold. Then, at an interior optimum, I_0^* is decreasing in σ_π. And*

- *a firm with higher λ and higher σ_π experiences a larger probability of exercising the option to invest at time 1 if $\partial^2 I_0^*/\partial\lambda\partial\sigma_\pi > 0$.*

Intuitively, for the first result, increases in volatility increase the value of the option to invest at time 1. Since I_0 is irreversible, to preserve the value of the option, it is optimal to invest less at time 0.

The second result in the proposition says that firms with higher λ and higher σ_π are more likely to complete the investment at time 1, and thus, to pollute: $\partial^2(1 - F(\kappa + R_\lambda(I - I_0))/\partial\lambda\partial\sigma_\pi > 0$. That is, with higher λ and with the associated relatively higher I_0, the option to invest at time 1 is more likely in the money as σ_π increases. As a consequence of the higher probability of completing the option to invest at time 1, the firm with higher

[10] The main results discussed above hold if the cost of reversing the early investment is sufficiently high.

volatility of operating profit and higher regulatory risk is more likely to see increases in pollution. We test this prediction in Section 5.1.3.

To determine the last condition in Proposition 3—how σ_π affects the impact of λ on early investment I_0—is more challenging. We are unable to analytically sign the cross-partial derivative $\partial^2 I_0^*/\partial\lambda\partial\sigma_\pi$.[11] However, under the distributional assumptions specified in Proposition 1, and when an interior maximum exists, we find for a wide range of parameters that the cross-partial derivative is positive. Further, we find empirical support for this condition in Section 5.1.3. The positive sign of this cross-partial derivative is intuitive. The first result in Proposition 3 shows that higher volatility reduces early investment. However, a higher λ shifts the weight to the state where the investment option is already relatively less in the money (the state of the world with abatement costs and higher interest rates) and for which an increase in volatility has a muted effect. Therefore, relatively speaking, early investment increases.

3.2 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 and define

[11] Let $g(.)$ denote the left hand side of equation (2). Using the implicit function theorem, and the short-hand notation $g_x = \partial g/\partial x$,

$$\frac{\partial^2 I_0^*}{\partial\lambda\partial\sigma_\pi} = -\frac{g_{\lambda\sigma}}{g_I} + \frac{g_{I\lambda}g_\sigma + g_{I\sigma}g_\lambda}{g_I^2} - \frac{g_{II}g_\lambda g_\sigma}{g_I^3}. \tag{4}$$

Under the assumption that $\mu_\pi = 1.96\sigma_\pi + \kappa + R_\lambda I$, it is cumbersome but straightforward to show that all terms are positive, except one. The term that is negative is $\frac{g_{I\lambda}g_\sigma}{g_I^2}$, since in an interior solution, $g_{I\lambda} = -f(z_1)R^2 + f(z_2)R_\lambda^2 > 0$, while $g_I^2 > 0$ and $g_\sigma < 0$.

$\Lambda(mI_0)$ as the probability that the regulator initiates climate regulation. We assume that Λ is an increasing function of the industry's early investment in the polluting technology and that 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 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 $\Lambda(mI_0^*)$ is consistent with firms' investment decisions. That is, the equilibrium λ^* is a fixed point: $\lambda^* = \Lambda(mI_0^*(\lambda^*))$. Figure 2 illustrates the regulation equilibrium for a specific functional form for $\Lambda()$. 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 1), after which I_0^* increases with λ. The dashed line depicts the function $\Lambda(.)$ (plotted on the x-axis) against values of I_0 (plotted on the y-axis). Points where the two curves intersect are equilibrium points.

Depending on the curvatures of the $\Lambda(.)$ and $I_0^*(.)$, there can be multiple equilibria as the figure illustrates: an (stable) 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. 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), 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. Our model differs from the model in Biais and Landier (2022) where there is a 'green' equilibrium with high regulation and high investment in the green technology. In their model, the regulator imposes emission caps in response to firms investing in green technology, because the widespread adoption of green technology makes emission caps less costly.[12] While both models offer stories of complementarities between regulation and firm investment, the complementarities have different implications for equilibrium outcomes.

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 Ivanov, Kruttli, and Watugala (2024) and Duchin, Gao, and Xu (2025). Second, the existence of multiple equilibria suggests that the threat of regulatory action without follow through 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).[13]

[12] One could think of a green paradox mechanism where firms investing in polluting technologies discourages politicians from imposing climate regulation due to, for example, labor (voter) backlash. However, rising pollution levels do not only increase the cost but also the benefits of regulation (e.g., health benefits). Further, a firm has to be large to assume that its pollution levels can sway government regulation. In our empirical analysis, we include a wide cross-section of firms including smaller private firms.

[13] The symmetric nature of our predictions yields that changes in policy stance that suggest less future regulation, can result in less pollution.

3.3 Discussion

3.3.1 Unconditionally higher financing cost

The model's main prediction 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. What would be required to have higher borrowing rates unconditionally in period 1? First, aggregate conditions could be such that everyone is certain that climate regulation will be implemented, and thus, borrowing rates will be higher in the future. Second, firms may feel threatened today by an increase in future financing costs independent of the climate regulation because the capital market decides to penalize them even if the regulatory shock does not occur. The actions of the regulator and financiers would be complementary in this case in bringing down investment in polluting technologies.

3.3.2 External financing

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 at the same cost. This makes explicit that the hypothesis developed in this paper relies on firm exposure to financial markets, and how these markets penalize the firm when climate regulation is implemented.

An alternative interpretation for the interest rates in the baseline model is that they represent project hurdle rates and that the firm is comprised of the investment option studied as well as other assets that we do not model. In that case, R and R_λ, being hurdle rates, are positively associated to the cost of outside financing.

3.3.3 Equity financing

In our model, the investment is financed through one-period corporate bonds or loans. The investment could also be financed through an equity issuance instead. Unlike the one-period bond, the stock would not mature before the regulatory shock, and thus, the cost of equity for equity issued at time 0 will price in the possibility of the regulatory shock at time 1. However, if the firm's management pays more attention to the future regulatory environment of the firm than the investors do, the cost of equity might not fully reflect the potential regulatory shock, and the firm still has an incentive to invest before the regulatory shock in the polluting technology.

3.3.4 Clean technology

We model only a high-pollution investment option for the firm. This setting is motivated by the fact that heavily emitting industries, for example, cement and steel manufacturing, are difficult to decarbonize.[14] However, in some instances, 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. Likewise, Fang, Hsu, and Tsou (2025) suggest that in the presence of financial constraints firms may prefer to invest in their existing technology and engage less in pollution abatement because of the low returns associated with the later. Enlarging the set of firm responses to regulation uncertainty can result in a weakening of the green paradox mechanism, which makes the strength of the green paradox effect also an empirical question.

[14]The difficulty in decarbonization in such industries can come from the chemical process of manufacturing releasing greenhouse gases in addition to the high energy consumption.

3.3.5 Regulation implementation

Our model predicts that the anticipation of climate regulation can lead to a temporary spike in polluting technology investment and emissions. However, the long-term path of emissions is outside of our model and depends on whether the regulation is ultimately implemented. Despite the anticipatory spike in emissions, the regulation can be effective in the long run as any future investment in polluting technology will face higher financing costs and emissions abatement costs. Our model suggests that episodes of heightened climate regulation uncertainty without the implementation of regulation can be particularly harmful to the cause of reducing overall greenhouse gas emissions.

4 Empirical design

4.1 Paris Accord

We analyze the adoption of the Paris Accord to test model predictions on the effect of climate policy uncertainty on firm investments and emissions. The legally binding treaty was agreed by 195 Parties on December 12, 2015 and entered into force on November 4, 2016.[15] The adoption of the Accord likely increases firms' anticipation of more stringent future regulation of GHG emissions, thereby raising the likelihood of additional costs for firms with a carbon-intensive business (Ladika, Pazaj, and Sautner, 2025). Such uncertainty is particularly relevant for firms considering investments in high-emissions projects, for which future regulatory constraints could tighten project financing availability.

[15] See https://unfccc.int/process-and-meetings/the-paris-agreement.

4.1.1 Data

We use data from multiple sources. The emissions data measured in CO2 equivalents (CO2e) are from the 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 US emissions (roughly 85 to 90%), 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, emissions from industrial processes and through the combustion of fossil fuels by boilers and furnaces. Indirect emissions are the emissions from materials sold by the facility and combusted elsewhere. In Figure 3, we show the county-level distribution of high GHG-emitting facilities as of 2015 for EPA facilities that are mapped to Capital IQ firms. GHG emissions are geographically dispersed across the US.

We obtain the balance sheet data of US 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.

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 dataset 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. 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. Table C.4 in Appendix C presents the variable definitions. Emissions intensity (emissions divided by revenues) is highly skewed so we take the logarithm of emissions intensity, resulting in a mean (median) of 5.56 (5.97). For 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 6.9% (5.2%). The additional balance sheet variables shown are debt, net property plant and equipment, and cash, all divided by total assets.

4.1.2 Regression specification

We analyze the effects of a shock to climate regulation risk on firm investments, emissions, and financing using the following baseline panel regression specification:

$$y_{i,t} = \beta_0 EmissionsIntensity_{i,t-1} + \beta_1 EmissionsIntensity_{i,t-1} \times PostParis_t + \gamma Z_{i,t-1} + \theta_{i,t} + \epsilon_{i,t}, \quad (5)$$

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 firm annual capital expenditures, capital expenditures normalized by assets, and firm emissions intensities or levels.

The main independent variable of interest is the interaction between the indicator variable $PostParis_t$, which captures the period following the 2015 Paris Climate Accord, and $EmissionsIntensity_{i,t-1}$, which is either an indicator for the firm having above median emissions intensity, $IsHighEOR_{i,t-1}$ or the logarithm of the lagged value of emissions intensity, $Log\frac{Emissions_{i,t-1}}{Revenue_{i,t-1}}$. This interaction term is our proxy for the model parameter λ. The interaction term has a firm-specific component that measures the exposure that a firm has to the climate regulation through emissions intensity, and an aggregate component related to the

probability of climate regulation being implemented. In the model, these components are both captured by λ.

The reasoning behind this empirical design is that the Paris Accord delivered country-wide commitments to act to keep global warming at most at 1.5 degrees Celsius above pre-industrial temperatures. These commitments and the regulatory changes that they entail are likely to impact more acutely more polluting firms before the regulations take place. The importance of scaling firm emissions to measure exposure to climate regulation like a price on carbon has been discussed by, for example, Hsu, Li, and Tsou (2023); Aswani, Raghunandan, and Rajgopal (2024); Zhang (2025).

We control for lagged firm-level variables, $Z_{i,t-1}$, which capture observed variation at the firm level of determinants of investment policy and bond characteristics. These controls include $log(Assets_{i,t-1})$ (size), $\frac{Debt_{i,t-1}}{Assets_{i,t-1}}$ (leverage), $\frac{NPPE_{i,t-1}}{Assets_{i,t-1}}$ (asset tangibility), $\frac{Cash_{i,t-1}}{Assets_{i,t-1}}$ (liquidity), and $\frac{CAPEX_{i,t-1}}{Assets_{i,t-1}}$ (investment rate). We include specifications with different combinations of fixed effects, broadly identified as $\theta_{i,t}$: year and industry fixed effects; year and firm fixed effects; and firm and industry $\times$ year fixed effects to control for unobservables. Industry $\times$ year fixed effects allow us to account for industry-wide shocks that affect firm decisions, such as oil price shocks that may also affect firm investment in the oil and gas industry and related industries (e.g., Jagannathan, Meier, and Sokolovski (2025) and Shi and Zhang (2025)). 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 2 predicts that investment is relatively lower in 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 for the coefficient of the interaction $EmissionsIntensity_{i,t-1} \times PostParis_t$ when the

dependent variable is log emissions intensity.

We augment the baseline specification to test the predictions linked to Proposition 3 that exposed firms will invest more in the period prior to the regulatory shock if it has higher volatility of operating cash profit. Consequently, exposed firms with higher volatility of cash flows have higher emissions following the regulatory shock. We use the panel regression specification:

$$\begin{aligned} y_{i,t} = {} & \beta_0 EmissionsIntensity_{i,t-1} + \beta_1 EmissionsIntensity_{i,t-1} \times PostParis_t \\ & + \beta_2 EmissionsIntensity_{i,t-1} \times PostParis_t \times CashFlowVol_{i,t-1} \\ & + \beta_3 EmissionsIntensity_{i,t-1} \times CashFlowVol_{i,t-1} + \beta_4 PostParis_t \times CashFlowVol_{i,t-1} \\ & + \beta_5 CashFlowVol_{i,t-1} + \gamma Z_{i,t-1} + \theta_{i,t} + \epsilon_{i,t}, \end{aligned} \tag{6}$$

where $CashFlowVol$ is a measure of a firm's volatility of cash flows (i.e., operating profits). We use the standard deviation of quarterly $\frac{EBITDA}{Assets}$ over three or five year horizons. We consider both the continuous measure and an indicator $IsHighCashFlowVol$ that takes a value of one if a firm's $CashFlowVol$ is above the median and zero otherwise. The other variables are as defined in the baseline specification (5).

Here, the coefficient of interest is β_2 on the triple interaction. In this setting, a negative β_2 in regressions with investments outcomes and a positive β_2 for emissions outcomes will be consistent with the model predictions.

4.2 Waxman-Markey cap-and-trade bill

The American Clean Energy and Security Act of 2009, commonly known as the Waxman–Markey bill, named after its sponsors, Henry Waxman and Edward Markey, is to date the most significant attempt at a federally mandated emissions trading system, also known

as cap-and-trade.[16]

During the period between the bill's passage in the House in June 26, 2009 and its subsequent consideration in the Senate, there was a high probability of the legislation eventually being enacted (Meng, 2017). The bill ultimately did not pass in the Senate and the threat of regulation diminished after July 22, 2010 (i.e., in early 2010 Q3). An important design element of the Waxman-Markey bill in implementing the cap-and-trade program was the issuance of emission allowance rebates, which are essentially free emission permits. The bill would have granted free permits to manufacturing firms (NAICS code beginning with 31, 32, or 33) with an energy intensity above 5% and trade intensity above 15%.[17] The distribution of the free allowances was scheduled to gradually phase out from 2026 to 2035. As discussed in Meng (2017) and Ivanov, Kruttli, and Watugala (2024), this policy design enables us to use a difference-in-difference methodology to identify causal effects. For firms that satisfy the 15% trade intensity threshold, those near the 5% energy intensity threshold have similar emission profiles. The treated (non-exempt) group consists of firms with energy intensity below 5%, while the control group includes firms with energy intensity above 5% that would receive free permits.[18] We show specifications both for the sample of all US manufacturing firms and those with with energy intensity between 1% and 9%.

To ameliorate any confounding effects due to the global financial crisis and narrow the focus around the bill, we include eight quarters in our sample—the first quarter of 2009 to the fourth quarter of 2010. The reference quarter is the first quarter of 2009. In the

[16]Cap-and-trade systems are designed to set a limit on total GHG emissions (the cap component) and establish a market in which regulated emitters can buy and sell emission allowances (the trade component). Following the establishment of the first major emission trading system, the European Union Emission Trading System in 2005, the United States saw the implementation of cap-and-trade programs at the regional level (e.g., the Regional Greenhouse Gas Initiative launched in 2009 to regulate power-sector emissions in participating states, and the California Cap-and-Trade Program established in 2013).

[17]See description under "Subpart 1 – Emission Allowance Rebate Program", Section 763. https://www.congress.gov/bill/111th-congress/house-bill/2454/

[18]In theory, one could estimate a difference-in-difference specification around the 15% trade intensity threshold. However, in practice there are few firms with energy intensity above 5% but trade intensity below 15% (see Meng (2017)).

first quarter of 2009, the anticipation of the bill was very limited.[19] For the other seven quarters, we include quarter indicator variables interacted with the treated firm indicator ($NoExemption$). We then test if investment increased for treated firms after the House passed the bill and the bill was still under consideration in the Senate. During this period, treated firms likely anticipated that the Senate passing the bill and the bill becoming law will lead to an increase in their cost of capital. Therefore, the interaction of the treated firm indicator ($NoExemption$) with quarter dummies from 2009 Q2 (after the House passed the legislation) to 2010 Q2 (after which the Senate dropped its consideration) capture the effect of the model parameter λ.

Ivanov, Kruttli, and Watugala (2024), show that treated firms faced higher borrowing constraints on their bank loans after the Waxman-Markey bill passed the House. Meng (2017) finds an effect on the cost of capital of treated firms through relatively lower stock prices. Given these results, firms likely anticipated even costlier financing if the bill were to eventually pass in the Senate and become law.[20]

The empirical setting of this analysis differs somewhat from the Paris Accord analysis described in Section 4.1. The anticipation period for the Waxman-Markey analysis is clearly set between the passage of the bill by the House and the failure of the bill in the Senate. This setting allows us to compare the anticipation to the pre-anticipation period and test for an increase in investment. For the Paris Accord, we compare the post-passage period to the anticipation period and test for a decrease in investment.[21]

[19] Google Trends shows that the search term "Waxman Markey" had zero search interest in the first quarter of 2009 (see Figure C.2). However, in the second quarter of 2009, the search interest spiked. Meng (2017) discusses how the 5% energy intensity threshold for free permits was unique to the Waxman-Markey bill.

[20] These results suggest that not only borrowers but also lenders and investors anticipate future regulation. Our baseline model assumes that the one-period borrowing rate in period 0 does not reflect the potential regulation in period 1. However, the extended model in Appendix B endogenizes the one-period borrowing rates in periods 0 and 1 and confirms the predictions of the baseline model.

[21] Unlike for the Waxman-Markey bill, the exact anticipation period is difficult to determine for the Paris Accord as similar international agreements were attempted over decades leading up to 2015, for example, the 1997 Kyoto Protocol and the 2009 Copenhagen Accord. We show that our estimates for the Paris Accord analysis are robust to using a shorter window around 2015 (see Table C.2) relative to our baseline analysis.

Proposition 2 predicts that the anticipation of the Waxman-Markey bill being passed by the Senate and becoming law should manifest in both higher firm investment ahead of the higher borrowing costs and subsequent increases in emissions. Because the EPA's GHGRP emissions data are not available prior to 2010 and due to the absence of comparable comprehensive emissions data for that period from other sources, we focus our Waxman-Markey analysis on investment effects.

We use S&P Capital IQ quarterly financial data for US public and private firms. The quarterly frequency allows us to better capture firms' responses during the policy uncertainty window from May 2009 to December 2010 (seven quarters). To identify firms' eligibility for free permits, we obtain six-digit NAICS codes from S&P Capital IQ and supplement missing or shorter codes using S&P Capital IQ Pro, Compustat, and Mergent Intellect. All codes are converted to the 2002 NAICS classification, which is the industry definition used in the original bill. We merge these data with energy intensity and trade intensity measures at six-digit NAICS code level from the bill to define the treated and control groups. We obtain the energy and trade intensity measures for six-digit NAICS industries from Meng (2017). For the six-digit NAICS industries that are not in the sample of Meng (2017) but are in ours, we use the Annual Survey of Manufacturers or alternatively the Census to compute the energy intensity and data from USITC to compute the trade intensity.

5 Results

We show results for the analyses around the Paris Accord and then the Waxman-Markey bill, respectively.

5.1 Paris Accord

5.1.1 Corporate investment

Proposition 2 suggests that with anticipated 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 2 presents results from estimating the regression specification described in equation (5) with changes to capital expenditures and capital expenditures divided by assets as the dependent variables. The independent variable of interest is the interaction $IsHighEOR \times PostParis$. For each dependent variable, we present three regressions with different combinations of fixed effects. All regressions include the baseline set of 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 results show that in the post-Paris period and relative to the pre-period, firms with a higher emissions intensity see disproportionally lower subsequent capital expenditures, consistent with the model prediction. The results are economically and statistically significant for the regression specifications that include firm and industry times year fixed effects. In column (5), in the post-Paris period, firms 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. This effect corresponds to 16% (1.1/6.9) 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 the CAPEX growth rate decreasing by roughly 10%. Ladika, Pazaj, and Sautner (2025) also find that high-emission firms had relatively higher capital expenditures pre- than post-Paris.[22]

[22] Ladika, Pazaj, and Sautner (2025) use S&P Trucost data to identify high-emission firms and interpret the reduction in investments post-Paris as precautionary—before investing, firms want clarity about the

High-emissions intensity firms have a higher investment rate in the pre-Paris period (columns (4) through (6)), though none of the estimated coefficients are statistically significant. Regarding the other 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 possibly debt overhang. Firms with more cash to assets have higher investment. The negative coefficient on lagged CAPEX over assets potentially captures mean reversion in firm investment rates.

5.1.2 CO2e emissions

Proposition 2 predicts higher emissions following the shock to regulatory risk. We test this prediction using our baseline regression specification (5) for both emissions intensity (i.e., emissions inefficiency) and emissions levels.

Table 3 presents the results with firm emissions intensity as the dependent variable. In columns (1) to (3), the treatment variable is lagged log emissions intensity, a continuous measure, and in columns (4) to (6) the treatment variable is the indicator variable for emissions intensity above the sample median (thus avoiding the potential issue of the Nickel bias). The control variables and the various combinations of fixed effects are the same as in Table 2. Further, we control for baseline levels of autocorrelation in emissions intensity

In columns (1) to (3), we see that post-Paris, firms with higher emissions intensity, that is, the firms more exposed to the climate regulatory shock, subsequently have greater emissions intensity.[23] This indicates that, paradoxically and consistent with the model predictions,

regulation. This mechanism is more likely to apply to firms that have polluting and non-polluting technology options available (see Section 3.3.4). Our empirical finding that emissions increase post-Paris (see Section 5.1.2) suggests that for our sample of EPA-reporting firms the green paradox mechanism dominates.

[23] In unreported results, we also include lagged emissions levels, $log(Emissions)$ and obtain qualitatively unchanged estimates.

polluting firms become even more emissions inefficient and emit more CO2e per dollar of revenue following the Paris Accord, despite the reduction in investment post Paris.

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 positively related to emissions intensity, suggesting that asset tangibility and asset liquidity are both linked to firm emissions intensity. We also find that leverage is negatively associated with emissions intensity, which could be because creditors dislike the risks associated with high-emitting firms.

In Table 4, we present results for how the level of emissions changes post Paris—that is, the pollution is not normalized by the size of the firm. In Panel A, the dependent variable is log emissions. The coefficient estimates are consistent with firms' more exposed to climate regulation increasing their emissions post Paris relative to less exposed firms. In Panel B, the dependent variable is changes in log emissions. The coefficient estimates are in line with a relative increase in the growth rate of emissions post Paris. However, the statistical significance is somewhat lower than in Panel A, which suggests that the increase in emissions post Paris was more immediate than gradual.

We conclude that high emission intensity firms increased both their emissions intensity and levels post Paris relative to low emission firms, consistent with the model and the predicted anticipatory investment by these firms.

5.1.3 Cash flow volatility

The model predicts that the green paradox effects related to firm investments are stronger for firms with higher cashflow volatility. We empirically test the relationship between cash flow volatility, early investment, and emissions as described in the regression specification in equation (6).

Table 5 presents the results for investments using the same two outcome variables as in

the baseline investments analysis in Table 2, $\Delta log(CAPEX)$ and $\frac{CAPEX}{Assets}$. For parsimony, the table shows the coefficients and significance of the triple interaction variable of interest for both continuous and indicator variables capturing the volatility of firm operating profits. The coefficient estimates are negative and significant and imply that firms with a higher cash flow volatility invest disproportionally more pre- than post-Paris. These estimates are in line with the positive cross-partial derivative $\partial^2 I_0^*/\partial\lambda\partial\sigma_\pi$ discussed in Section 3.1.

Table 6 presents the results with the same emissions outcome variables that are in Tables 3 and 4, which capture emissions intensity ($log(\frac{Emissions}{Revenue})$) and emission levels ($\Delta log(Emissions)$ and $log(Emissions)$). For parsimony, the table shows the coefficients and significance of the triple interaction variable of interest for indicator variables capturing the volatility of firm operating profits. The coefficient estimates are positive and significant, consistent with the model prediction in Proposition 3 that firms with higher cash flow volatility are more likely to take the option and follow through with their investment in polluting technology.

5.1.4 Total debt and cash holdings

We study two more financial variables, total debt and corporate cash holdings. Our model does not make predictions about total debt and corporate cash. However, debt could grow at a slower pace for high-pollution firms after the regulatory shock compared to low-pollution firms, consistent with costlier financing after the regulatory shock. In addition, a riskier regulatory environment post-Paris may motivate a precautionary reduction in debt and an increase in cash holdings relative to total assets. The cash flow used to fund these changes in debt and cash post Paris may come from the investments made prior to the regulatory shock that start paying out or from the reduced investment post Paris.

Table C.1 in Appendix C 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 the same control variables and fixed effects as in the previous regressions.

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.

5.2 Waxman-Markey bill

Table 7 contains summary statistics for the variables used in the analysis. Panel A contains the baseline sample, a sample that includes all firms in the relevant manufacturing NAICS codes (codes 31, 32, and 33) for which we have emissions and balance sheet data. There are a total of 8,587 firm-quarter observations, representing just under 1,100 unique firms. Panel B contains the sample of firms that are in a 4 percentage points range around the 5% threshold of energy intensity. There is a significant drop in the number of observations to 3,018 firm-quarter observations or roughly 380 unique firms. The firms in the smaller sample have higher energy intensity and higher CAPEX, but are not significantly larger firms; they are otherwise similar in terms of average statistics. Below, we present results using the baseline sample and the sample with tighter identification using the proximity to the threshold of 5%.

Table 8 presents the analysis of the effects of climate policy uncertainty on firm investment during the 8-quarter period surrounding the passage of the Waxman-Markey bill through Congress, as described in section 4.2. The table presents results for the two samples. In Panel A, we use the baseline sample and define treated firms as those with energy intensity below 5%. In Panel B, we again define treated firms as those with energy intensity below 5%, but restrict the sample to firms within 4 percentage points of this threshold. Treated firms are identified with the indicator variable $NoExemption$.

Both panels display results for changes in log CAPEX in columns (1) through (3) and for CAPEX to total assets in columns (4) through (6), mirroring the Paris CAPEX regressions in Table 2. We interact the $NoExemption$ with quarter dummies to track the treatment effect over time, with the first quarter of 2009 as the reference quarter. The regressions include combinations of year-quarter, industry, and firm fixed effects as indicated, and the baseline set of 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 assets.

Both panels show a significant increase in the growth rate of CAPEX and in CAPEX to assets in the first quarter of 2010 for the treated firms relative to the first quarter of 2009 compared to the control group. For example, the coefficient estimate for the interaction between the $NoExemption$ and $2010Q1$ indicators is around 0.5 across the specifications in columns (1) to (3) in both panels. This estimate implies that in the first quarter of 2010, firms without free permits had a 50 percentage point higher quarterly investment growth rate than the firms with free permits relative to Q1 2009. While this effect is large and supports the prediction of the model—investments by exposed firms increase in anticipation of climate regulation—it was also short lived. The coefficient estimates for the interaction between $NoExemption$ and the remaining quarters is insignificant. This pattern is in line with the likelihood of the bill passing the Senate and investment lags. The firms likely started with investment plans when the likelihood of the bill becoming law was high, that is, during the second half of 2009 and early 2010 (see Meng (2017)). These investment plans are subsequently realized and show up in the first quarter of 2010. The probability of the bill passing declined in subsequent quarters, which explains why differences in investment rates in the remaining quarters of 2010 between exempt and non-exempt firms are much smaller and not statistically significant.

Columns (4) to (6) in both panels report results where the dependent variable is CAPEX

to assets. The results are qualitatively similar to the estimates for the CAPEX growth rate. CAPEX to assets is significantly elevated in the first and second quarters of 2010 for firms without free permits. The coefficient estimates are between 0.005 and 0.009. These estimates are economically significant as they predict an increase in CAPEX to assets that is around 25% to 50% of the variable's standard deviation (see Table 7).

Regarding the control variables, the coefficients are broadly similar to the investments analysis for the Paris analysis presented in Table 2. Firms with more cash to assets invest more during the period. Unsurprisingly, CAPEX to assets is autocorrelated. Also, firms with more CAPEX to assets have lower subsequent growth in investment levels, suggesting mean reversion in firm investment.

6 Conclusion

We show how the anticipation of tighter financing constraints under future climate regulation can interact with firm policies inducing firms to exhibit behavior consistent with a "green paradox." Polluting firms increase investment in polluting technology when expecting that such technology is costlier to finance under future climate regulation and the options for cleaner technology are limited. These firms eventually pollute more than without the risk of 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 and the Waxman-Markey bill as climate regulation shocks, we find evidence consistent with the model. In both settings, more exposed firms have higher investment in anticipation of the climate regulation. For the Paris Accord setting, where we have emissions data, we find an increase in emissions intensity and levels post Paris. This results confirms the prediction of the model that polluting firms can become more polluting

in anticipation of higher financing costs under climate regulation. These investment and emissions effects are stronger for firms with higher cash flow volatility, as predicted by our theory.

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 investment by polluting firms.

Our findings show that high-emissions firms that expect financing frictions to intensify under future climate regulation 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 can lead to spikes in emissions. The model also suggests that these unintended effects of delays in regulation can be reversed if polluting firms' expect the capital market to penalize them independently of whether the regulator takes action. However, the literature is yet unclear about what financial trade-off investors are willing to accept to do so.

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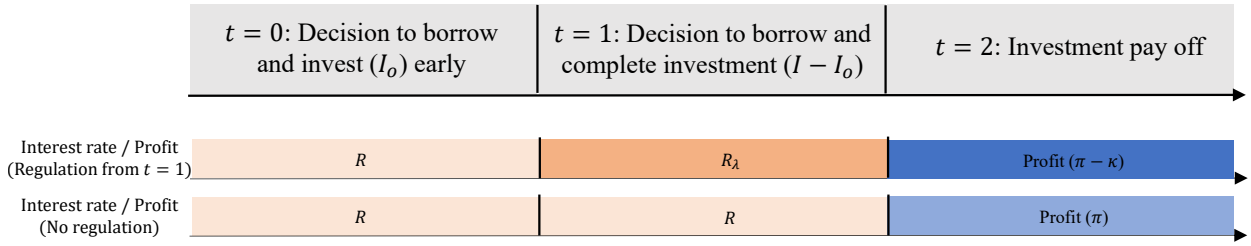


Figure 1: Model timeline

This figure shows the model timeline. The model has three periods. R is the interest rate of a one-period bond absent climate regulation. R_λ is the interest rate of a one-period bond under climate regulation. π is the pay off of the project, and κ is the regulatory cost. The climate regulation is implemented in t_1 with probability λ.

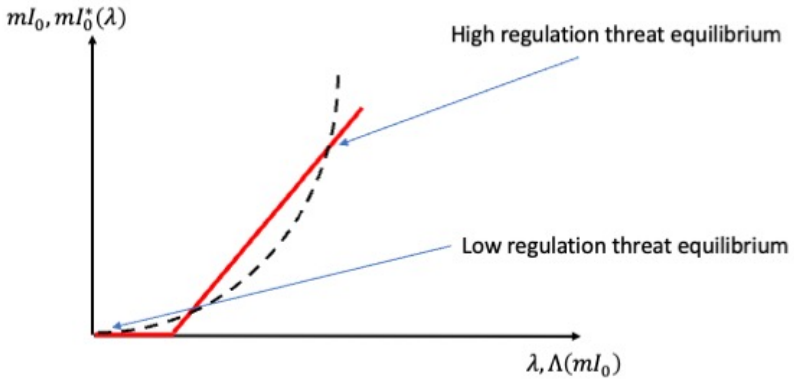


Figure 2: Equilibrium regulation levels and industry investment

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.

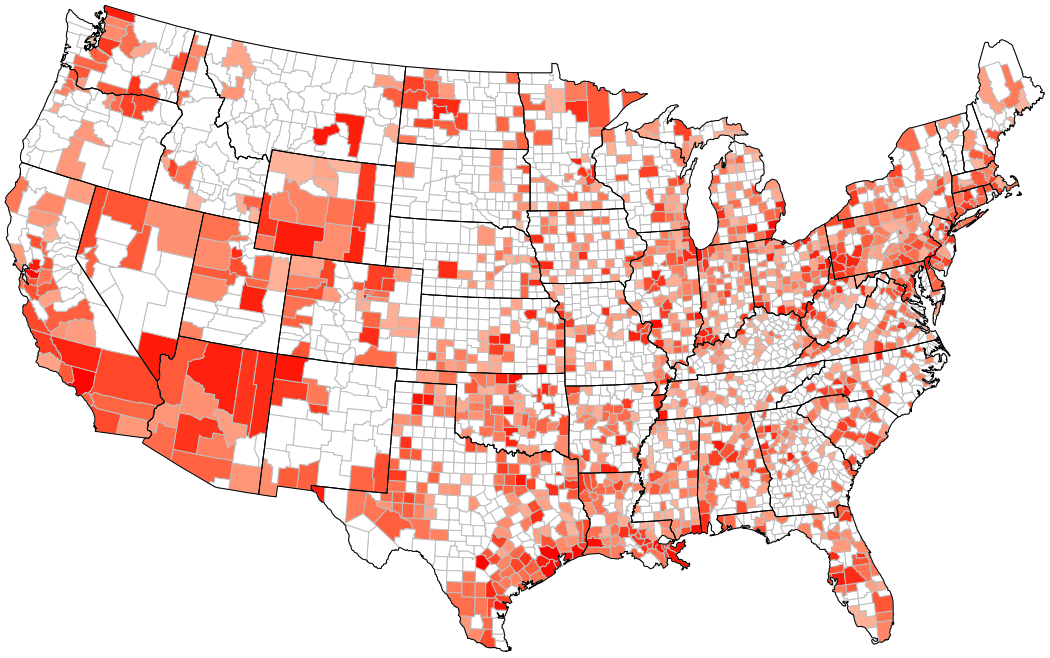


Figure 3: County-Level Emissions Based on EPA Facilities

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 - Paris Accord Analysis

This table shows the summary statistics for the main variables used in the Paris Accord analysis. The data are annual from 2010 to 2020. The N column shows the number of observations used to calculate the statistics in a particular row. The last four columns show percentiles. Table C.4 presents all variable definitions.

	N	Mean	Median	Stdev	25th	75th	10th	90th
$log(Emissions)$	2,679	13.537	13.255	2.409	11.502	15.604	10.642	17.053
$log(\frac{Emissions}{Revenue})$	2,628	5.562	5.972	2.510	3.671	7.681	1.896	8.658
$\Delta log(Emissions)$	2,679	0.012	0.000	0.425	-0.083	0.082	-0.238	0.270
$log(CAPEX)$	2,599	5.667	5.759	1.971	4.505	7.150	3.155	8.127
$\Delta log(CAPEX)$	2,597	0.019	0.033	0.495	-0.188	0.247	-0.530	0.544
$\frac{CAPEX}{Assets}$	2,599	0.069	0.052	0.065	0.031	0.082	0.018	0.137
$log(Assets)$	2,666	8.579	8.647	1.826	7.422	9.980	6.259	10.873
$\frac{Debt}{Assets}$	2,666	0.359	0.338	0.205	0.231	0.460	0.127	0.610
$\frac{NPPE}{Assets}$	2,664	0.507	0.527	0.243	0.308	0.718	0.153	0.810
$\frac{Cash}{Assets}$	2,642	0.058	0.036	0.066	0.011	0.083	0.003	0.144
$CashFlowVol5Y$	2,590	0.014	0.009	0.016	0.005	0.016	0.004	0.029
$CashFlowVol3Y$	2,590	0.012	0.008	0.013	0.005	0.014	0.003	0.026

Table 2: Firm Capital Expenditure

This table presents results of the panel regression model given in equation (5). The data are annual from 2010 to 2020. The dependent variables are $\Delta log(CAPEX_{i,t})$, change in log of firm capital expenditure, in Columns (1) - (3), and $\frac{CAPEX_{i,t}}{Assets_{i,t}}$, the ratio of firm capital expenditure to total assets, in Columns (4) - (6). $IsHighEOR_{i,t}$ is an indicator variable that takes the value of 1 if log of emissions intensity, $log(\frac{Emissions_{i,t}}{Revenue_{i,t}})$, is above the median and 0 otherwise. $PostParis_t$ is an indicator variable that takes the value of 1 after the 2015 passage of the Paris Accord. All specifications include balance sheet control variables, as defined in Table C.4, and incorporate the indicated combinations of year, industry, firm, and industry–year fixed effects. 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
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
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

Table 3: Firm Greenhouse Gas Emissions Intensity

This table presents results of the panel regression model given in equation (5). The data are annual from 2010 to 2020. The dependent variable is $log(\frac{Emissions_{i,t}}{Revenue_{i,t}})$, log of emissions over revenue (i.e., emissions intensity). $log(\frac{Emissions_{i,t-1}}{Revenue_{i,t-1}})$ is the lagged natural log of emissions intensity. $IsHighEOR_{i,t}$ is an indicator variable that takes the value of 1 if log of emissions intensity is above the median and 0 otherwise. $PostParis_t$ is an indicator variable that takes the value of 1 after the 2015 passage of the Paris Accord. All specifications include balance sheet control variables, as defined in Table C.4, and incorporate the indicated combinations of year, industry, firm, and industry–year fixed effects. 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
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
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

Table 4: Firm Greenhouse Gas Emissions Level

This table presents results of the panel regression model given in equation (5). The data are annual from 2010 to 2020. The dependent variable is $log(Emissions_{i,t})$, log of emissions level, for Panel A and $\Delta log(Emissions_{i,t})$, change in log of emissions, for Panel B. $log(\frac{Emissions_{i,t-1}}{Revenue_{i,t-1}})$ is the lagged natural log of emissions intensity. $IsHighEOR_{i,t}$ is an indicator variable that takes the value of 1 if log of emissions intensity is above the median and 0 otherwise. $PostParis_t$ is an indicator variable that takes the value of 1 after the 2015 passage of the Paris Accord. All specifications include balance sheet control variables, as defined in Table C.4, and incorporate the indicated combinations of year, industry, firm, and industry-year fixed effects. 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 $p < 0.01$.

Panel A: Outcome variable: $log(Emissions_{i,t})$

	(1)	(2)	(3)	(4)	(5)	(6)
$log(\frac{Emissions_{i,t-1}}{Revenue_{i,t-1}}) \times PostParis_t$	0.034***	0.019**	0.043**			
	3.603	2.330	1.968			
$log(\frac{Emissions_{i,t-1}}{Revenue_{i,t-1}})$	0.016	0.067	0.035			
	0.486	0.654	0.326			
$IsHighEOR_{i,t-1} \times PostParis_t$				0.179***	0.118**	0.197*
				3.509	2.317	1.809
$IsHighEOR_{i,t-1}$				-0.113	-0.086	-0.117
				-1.607	-0.719	-0.883
$log(Emissions_{i,t-1})$	0.855***	0.379***	0.371***	0.888***	0.452***	0.425***
	20.858	3.047	2.931	33.300	6.533	5.763
$log(Assets_{i,t-1})$	0.114***	0.297***	0.364***	0.085***	0.251***	0.332***
	3.043	3.572	3.907	3.747	4.127	4.660
$\frac{Debt_{i,t-1}}{Assets_{i,t-1}}$	-0.013	-0.112	-0.101	-0.022	-0.122	-0.112
	-0.168	-0.837	-0.744	-0.272	-0.937	-0.841
$\frac{NPPE_{i,t-1}}{Assets_{i,t-1}}$	0.501***	0.431*	0.509*	0.538***	0.465*	0.534*
	4.095	1.677	1.769	4.400	1.930	1.933
$\frac{Cash_{i,t-1}}{Assets_{i,t-1}}$	0.201	0.766***	1.051***	0.177	0.749***	0.990***
	0.771	2.805	3.201	0.680	2.803	3.125
$\frac{CAPEX_{i,t-1}}{Assets_{i,t-1}}$	0.103	-0.108	-0.057	0.095	-0.099	-0.051
	0.388	-0.257	-0.116	0.350	-0.233	-0.103
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
Observations	2,610	2,610	2,610	2,610	2,610	2,610
Adjusted R^2	0.930	0.946	0.945	0.930	0.946	0.945

Panel B: Outcome variable: $\Delta log(Emissions_{i,t})$

	(1)	(2)	(3)	(4)	(5)	(6)
$log(\frac{Emissions_{i,t-1}}{Revenue_{i,t-1}}) \times PostParis_t$	0.022***	0.010*	0.021			
	4.055	1.683	1.235			
$log(\frac{Emissions_{i,t-1}}{Revenue_{i,t-1}})$	-0.022	-0.057	-0.101*			
	-1.047	-1.079	-1.823			
$IsHighEOR_{i,t-1} \times PostParis_t$				0.115***	0.050*	0.076
				3.383	1.711	1.201
$IsHighEOR_{i,t-1}$				-0.125***	-0.173**	-0.197**
				-2.799	-2.034	-2.229
$log(Emissions_{i,t-1})$	-0.049**	-0.264***	-0.243***	-0.048***	-0.285***	-0.293***
	-2.483	-4.791	-4.226	-4.372	-6.463	-5.886
$log(Assets_{i,t-1})$	0.038**	0.120***	0.150***	0.038***	0.140***	0.193***
	2.164	2.634	2.836	3.736	3.333	3.901
$\frac{Debt_{i,t-1}}{Assets_{i,t-1}}$	-0.009	-0.084	-0.128	-0.021	-0.083	-0.125
	-0.178	-0.812	-1.252	-0.410	-0.797	-1.189
$\frac{NPPE_{i,t-1}}{Assets_{i,t-1}}$	0.331***	0.414**	0.461**	0.340***	0.418**	0.457**
	4.367	2.192	2.276	4.504	2.279	2.262
$\frac{Cash_{i,t-1}}{Assets_{i,t-1}}$	0.155	0.568***	0.660***	0.125	0.551***	0.621***
	0.944	2.822	2.995	0.758	2.801	2.895
$\frac{CAPEX_{i,t-1}}{Assets_{i,t-1}}$	0.082	-0.110	-0.015	0.054	-0.139	-0.049
	0.396	-0.354	-0.039	0.259	-0.437	-0.128
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
Observations	2,610	2,610	2,610	2,610	2,610	2,610
Adjusted R^2	0.066	0.262	0.256	0.068	0.264	0.256

Table 5: Firm Cash Flow Volatility and Capital Expenditure

This table presents results of the panel regression model given in equation (6). The data are annual from 2010 to 2020. The dependent variables are $\Delta \log(CAPEX_{i,t})$, change in log of capital expenditure, in Columns (1)–(4) and $\frac{CAPEX_{i,t}}{Assets_{i,t}}$, ratio of firm capital expenditure to total assets, in Columns (5)–(8). $IsHighEOR_{i,t}$ is an indicator variable that takes the value of 1 if log of emissions intensity is above the median and 0 otherwise. $PostParis_t$ is an indicator variable that takes the value of 1 after the 2015 passage of the Paris Accord. $CashFlowVol3Y_{i,t-1}$ and $CashFlowVol5Y_{i,t-1}$ are the lagged standard deviations of quarterly $\frac{EDITDAi,t}{Assets_{i,t}}$ over the last three-year and five-year windows, respectively. $IsHighCashFlowVol3Y_{i,t-1}$ and $IsHighCashFlowVol5Y_{i,t-1}$ are lagged indicator variables equal to 1 if $CashFlowVol_3Y_{i,t}$ or $CashFlowVol_5Y_{i,t}$ is above the median, and 0 otherwise. All specifications include lower-order interaction terms and balance sheet controls and incorporate the indicated combinations of year and firm fixed effects. 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)	(7)	(8)
$IsHighEOR_{i,t-1} \times PostParis_t$								
$\times CashFlowVol5Y_{i,t-1}$	-10.222***				-0.573*			
	-2.841				-1.686			
$\times CashFlowVol3Y_{i,t-1}$		-12.710***				-0.662*		
		-2.769				-1.650		
$\times IsHighCashFlowVol5Y_{i,t-1}$			-0.219***				-0.016**	
			-2.732				-2.416	
$\times IsHighCashFlowVol3Y_{i,t-1}$				-0.182**				-0.019***
				-2.329				-2.760
Lower-order terms	Y	Y	Y	Y	Y	Y	Y	Y
Controls	Y	Y	Y	Y	Y	Y	Y	Y
Year FE	Y	Y	Y	Y	Y	Y	Y	Y
Firm FE	Y	Y	Y	Y	Y	Y	Y	Y
Observations	2,501	2,501	2,501	2,501	2,502	2,502	2,502	2,502
Adjusted R^2	0.236	0.237	0.236	0.236	0.755	0.755	0.756	0.756

Table 6: Firm Cash Flow Volatility and Emissions

This table presents results of the panel regression model given in equation (6). The data are annual from 2010 to 2020. The dependent variables are $\log(\frac{Emissions_{i,t}}{Revenue_{i,t}})$, log of emissions over revenue (i.e., emissions intensity), in Columns (1)–(2), $\Delta \log(Emissions_{i,t})$, change in log of emissions level, in Columns (3)–(4), and $\log(Emissions_{i,t})$, log of emissions level, in Columns (5)–(6). $IsHighEOR_{i,t}$ is an indicator variable that takes the value of 1 if log of emissions intensity is above the median and 0 otherwise. $PostParis_t$ is an indicator variable that takes the value of 1 after the 2015 passage of the Paris Accord. $IsHighCashFlowVol3Y_{i,t-1}$ and $IsHighCashFlowVol5Y_{i,t-1}$ are lagged indicator variables equal to 1 if $CashFlowVol_3Y_{i,t}$ or $CashFlowVol_5Y_{i,t}$ is above the median, and 0 otherwise. All specifications include lower-order interaction terms and balance sheet controls and incorporate the indicated combinations of year 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 $p < 0.01$.

	$log(\frac{Emissions_{i,t}}{Revenue_{i,t}})$		$\Delta log(Emissions_{i,t})$		$log(Emissions_{i,t})$	
	(1)	(2)	(3)	(4)	(5)	(6)
$IsHighEOR_{i,t-1} \times PostParis_t$						
$\times IsHighCashFlowVol5Y_{i,t-1}$	0.245**		0.111		0.212*	
	2.277		1.628		1.924	
$\times IsHighCashFlowVol3Y_{i,t-1}$		0.225**		0.119*		0.188*
		2.204		1.803		1.785
Lower-order terms	Y	Y	Y	Y	Y	Y
Controls	Y	Y	Y	Y	Y	Y
Year FE	Y	Y	Y	Y	Y	Y
Firm FE	Y	Y	Y	Y	Y	Y
Observations	2,502	2,502	2,547	2,547	2,547	2,547
Adjusted R^2	0.956	0.957	0.262	0.261	0.947	0.947

Table 7: Summary Statistics - Waxman-Markey Analysis

This table shows the summary statistics for the main variables used in the Waxman-Markey analysis. The financial data are quarterly from 2009 to 2010. Table C.4 presents all variable definitions. Panel A presents summary statistics for the baseline sample. Panel B gives summary statistics for the sample with energy intensity between 1% and 9%. 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: Baseline sample

Variable	N	Mean	Median	Stdev	25th	75th	10th	90th
$log(CAPEX)$	8,587	-0.112	0.129	3.066	-2.404	2.097	-4.279	3.761
$\Delta log(CAPEX)$	8,587	-0.017	0.000	1.039	-0.496	0.464	-1.198	1.108
$\frac{CAPEX}{Assets}$	8,526	0.010	0.005	0.017	0.002	0.010	0.001	0.020
$log(Assets)$	8,587	5.255	5.299	2.626	3.388	7.087	1.765	8.614
$\frac{Debt}{Assets}$	8,586	0.266	0.158	0.415	0.013	0.333	0.000	0.582
$\frac{NPPE}{Assets}$	8,586	0.207	0.163	0.172	0.079	0.290	0.035	0.428
$\frac{Cash}{Assets}$	8,526	0.173	0.111	0.183	0.043	0.238	0.014	0.425
EI	8,587	0.015	0.008	0.025	0.006	0.012	0.004	0.026
TI	8,107	0.504	0.482	0.300	0.298	0.720	0.112	0.849

Panel B: With energy intensity between 1% and 9%

Variable	N	Mean	Median	Stdev	25th	75th	10th	90th
$log(CAPEX)$	3,018	0.619	0.987	2.873	-1.418	2.650	-3.320	4.102
$\Delta log(CAPEX)$	3,018	0.007	0.016	0.990	-0.445	0.449	-1.053	1.055
$\frac{CAPEX}{Assets}$	2,996	0.012	0.006	0.020	0.003	0.013	0.001	0.025
$log(Assets)$	3,018	5.717	5.859	2.502	4.012	7.552	2.160	8.759
$\frac{Debt}{Assets}$	3,018	0.273	0.214	0.334	0.048	0.370	0.000	0.572
$\frac{NPPE}{Assets}$	3,017	0.292	0.264	0.193	0.145	0.391	0.073	0.560
$\frac{Cash}{Assets}$	2,991	0.130	0.085	0.143	0.031	0.177	0.009	0.309
EI	3,018	0.024	0.017	0.018	0.012	0.026	0.011	0.052
TI	2,766	0.474	0.435	0.296	0.220	0.764	0.157	0.785

Table 8: Firm Capital Expenditure - Waxman-Markey Bill

This table presents results of the panel regression model for Waxman-Markey analysis. The data are quarterly from 2009 to 2010. Panel A presents results for the baseline sample. Panel B shows results for the sample of firms with energy intensity between 1% and 9%. For both panels, the dependent variables are $\Delta log(CAPEX_{i,t})$, change in log of firm capital expenditure, in Columns (1) - (3), and $\frac{CAPEX_{i,t}}{Assets_{i,t}}$, ratio of firm capital expenditure to total assets, in Columns (4) - (6). Firm-level treatment is defined by $NoExemption_i$, an indicator variable that takes the value of 1 if the firm's energy intensity is below 5% and therefore receives no free emission permits according to the Waxman-Markey Bill. $NoExemption_i$ is interacted with quarter dummies from 2009 Q1 to 2010 Q4. All specifications include balance sheet control variables, as defined in Table C.4, and incorporate combinations of year–quarter, industry, and firm fixed effects as indicated. Standard errors are clustered at the six-digit NAICS 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 $p < 0.01$.

Panel A: Baseline

	$\Delta log(CAPEX_{i,t})$			$\frac{CAPEX_{i,t}}{Assets_{i,t}}$		
	(1)	(2)	(3)	(4)	(5)	(6)
$NoExemption_i$	0.206	0.191	0.078	0.005	0.005	0.004*
$\times 2009Q2_t$	1.592	1.505	0.544	1.520	1.583	1.655
$\times 2009Q3_t$	-0.094	-0.098	-0.117	0.001	0.002	0.002
	-0.578	-0.592	-0.803	0.440	0.507	0.930
$\times 2009Q4_t$	0.120	0.114	0.023	0.003	0.003	0.002
	0.637	0.604	0.144	0.819	0.827	0.797
$\times 2010Q1_t$	0.457***	0.457***	0.462***	0.005**	0.005*	0.006**
	3.652	3.469	3.095	2.083	1.965	2.444
$\times 2010Q2_t$	-0.050	-0.066	-0.031	0.007*	0.007*	0.008***
	-0.253	-0.321	-0.193	1.845	1.798	2.643
$\times 2010Q3_t$	0.003	-0.005	0.107	0.000	0.000	0.004
	0.016	-0.022	0.607	0.022	0.063	1.037
$\times 2010Q4_t$	-0.016	0.002	-0.065	0.004	0.005	0.004
	-0.083	0.010	-0.361	1.466	1.491	1.537
$NoExemption_i$	-0.084			-0.004		
	-0.628			-1.271		
$log(Assets_{i,t-1})$	-0.007**	-0.009**	-0.257***	-0.000***	-0.000*	-0.001
	-2.013	-2.109	-3.910	-2.773	-1.865	-0.959
$\frac{Debt_{i,t-1}}{Assets_{i,t-1}}$	0.039	0.055	0.026	0.001	0.001	-0.002
	1.138	1.383	0.198	0.933	1.008	-0.762
$\frac{NPPE_{i,t-1}}{Assets_{i,t-1}}$	0.383***	0.360***	-0.930*	0.011***	0.013***	-0.032**
	4.945	2.980	-1.940	4.524	4.014	-2.564
$\frac{Cash_{i,t-1}}{Assets_{i,t-1}}$	0.192***	0.251***	0.430**	0.005**	0.006***	0.004
	2.945	2.897	2.366	2.391	2.650	1.130
$\frac{CAPEX_{i,t-1}}{Assets_{i,t-1}}$	-13.532***	-15.234***	-28.742***	0.482***	0.431***	0.068
	-11.837	-11.008	-14.524	14.730	11.060	1.503
YearQtr FE	Y	Y	Y	Y	Y	Y
Industry FE	N	Y	N	N	Y	N
Firm FE	N	N	Y	N	N	Y
Observations	8,524	8,524	8,524	8,464	8,464	8,464
Adjusted R^2	0.087	0.074	0.101	0.351	0.375	0.559

Panel B: With energy intensity between 1% and 9%

	$\Delta log(CAPEX_{i,t})$			$\frac{CAPEX_{i,t}}{Assets_{i,t}}$		
	(1)	(2)	(3)	(4)	(5)	(6)
$NoExemption_i$	0.078	0.054	-0.057	0.005	0.005	0.003
$\times 2009Q2_t$	0.468	0.326	-0.300	1.110	1.143	1.224
$\times 2009Q3_t$	-0.220	-0.221	-0.218	0.001	0.001	0.002
	-1.011	-1.010	-1.088	0.131	0.225	0.659
$\times 2009Q4_t$	-0.017	-0.024	-0.129	0.004	0.004	0.002
	-0.067	-0.095	-0.587	0.786	0.793	0.708
$\times 2010Q1_t$	0.542***	0.546***	0.548***	0.006*	0.006*	0.007**
	3.656	3.526	3.144	1.866	1.859	2.335
$\times 2010Q2_t$	-0.148	-0.164	-0.112	0.008*	0.008*	0.009***
	-0.607	-0.646	-0.529	1.787	1.760	2.712
$\times 2010Q3_t$	-0.076	-0.078	0.083	0.000	0.001	0.005
	-0.295	-0.294	0.352	0.010	0.092	1.057
$\times 2010Q4_t$	-0.040	-0.009	-0.071	0.006	0.007*	0.006*
	-0.164	-0.036	-0.298	1.622	1.722	1.683
$NoExemption_i$	-0.013			-0.005		
	-0.080			-1.260		
$log(Assets_{i,t-1})$	-0.019***	-0.013	-0.303***	-0.001**	-0.000	-0.000
	-3.036	-1.594	-2.942	-1.980	-0.697	-0.084
$\frac{Debt_{i,t-1}}{Assets_{i,t-1}}$	0.029	0.068	-0.322	0.002	0.002	-0.005
	0.497	1.039	-1.375	1.043	1.023	-0.926
$\frac{NPPE_{i,t-1}}{Assets_{i,t-1}}$	0.183	0.103	-0.904	0.008**	0.009*	-0.035**
	1.617	0.679	-1.458	2.566	1.773	-2.270
$\frac{Cash_{i,t-1}}{Assets_{i,t-1}}$	0.523***	0.597***	0.886**	0.019***	0.022***	0.013
	4.510	3.778	2.356	3.384	2.949	1.331
$\frac{CAPEX_{i,t-1}}{Assets_{i,t-1}}$	-12.790***	-14.846***	-26.029***	0.466***	0.395***	0.047
	-6.887	-6.136	-11.753	8.301	5.218	0.555
YearQtr FE	Y	Y	Y	Y	Y	Y
Industry FE	N	Y	N	N	Y	N
Firm FE	N	N	Y	N	N	Y
Observations	2,990	2,990	2,990	2,968	2,968	2,968
Adjusted R^2	0.115	0.100	0.129	0.329	0.366	0.547

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. Noting that both the marginal benefit curve and the marginal cost curve slope upward with I_0, by intersecting from above, the marginal benefit curve must have a smaller slope than the slope of the marginal cost curve. Hence, the second order condition is satisfied. Other maxima may exist.

□

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

function theorem on g obtains

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

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. □

Proof of Proposition 3. Assume F is the cumulative normal distribution with parameters μ_π and σ_π. For the first result, denote the left-hand side of (2) by $g(I_0, \sigma_\pi)$. Consider the partial derivative of $g(I_0, \sigma_\pi)$ with respect to σ_π,

$$g_\sigma = (1 - \lambda)\frac{z_1}{\sigma_\pi}\phi(z_1)R + \lambda\frac{z_2}{\sigma_\pi}\phi(z_2)R_\lambda \tag{A.7}$$

where $z_1 = \frac{R(I - I_0) - \mu_\pi}{\sigma_\pi}$ and $z_2 = \frac{\kappa + R_\lambda(I - I_0) - \mu_\pi}{\sigma_\pi}$ and $\phi()$ is the standard normal density function. Under the condition in Proposition 1 that $\mu_\pi = 1.96\sigma_\pi + \kappa + R_\lambda I$, then $z_1, z_2 < 0$ and $g_\sigma < 0$. Using the implicit function theorem, and noting from the proof of Proposition 2 that $g_I < 0$, then I_0^* is decreasing in σ_π.

For the second result,

$$\begin{aligned}
\frac{\partial^2(1 - F(\kappa + (I - I_0^*)R_\lambda))}{\partial\sigma_\pi\partial\lambda} &= \frac{z_2^2 - 1}{\sigma_\pi^2}R_\lambda\phi(z_2)\frac{\partial I_0^*}{\partial\lambda} \\
&+ \frac{z_2}{\sigma_\pi^2}R_\lambda^2\phi(z_2)\frac{\partial I_0^*}{\partial\lambda}\frac{\partial I_0^*}{\partial\sigma_\pi} \\
&+ \frac{1}{\sigma_\pi}R_\lambda\phi(z_2)\frac{\partial^2 I_0^*}{\partial\lambda\partial\sigma_\pi}.
\end{aligned}$$

With $z_2^2 > 1$ and $\frac{\partial I_0^*}{\partial\lambda} > 0$, the first term is positive. The second term is also positive because $z_2 < 0$ and $\frac{\partial I_0^*}{\partial\sigma_\pi} < 0$. Lastly, the third term is positive if and only if the cross partial derivative is positive, which is assumed in the proposition. □

B Extended model

The extended model generalizes the setting in the main text by endogenizing the interest rates and by guaranteeing that dividends are always nonnegative. We also do not need the agency cost to help obtain an interior solution in the extended model; with endogenous interest rates, as I_0 increases, so does the time-0 cost of borrowing.

We show two main results: i) we give conditions under which the borrowing rate in period 1 in the regulation state is larger than that in the no regulation state, $R_{1\lambda} > R_1$, and ii) we show simulations where early investment increases in λ.

We borrow many aspects from the baseline model in Section 3, but deviate for some aspects to endogenize the interest rates and guarantee non-negative dividends. At time 1, and having invested I_0 earlier, the continuation value for a firm that paid all its debt from period 0 and remains active is

$$V(I_0; 1) = (1-\lambda)E_{\tilde{\pi}}\left[\max\left(\tilde{\pi} - R_1 I_1, 0\right)\right] + \lambda E_{\tilde{\pi}}\left[\max\left(\tilde{\pi} - R_{1\lambda}(I_1+\kappa), 0\right)\right].$$

Note that the realization of the time 2 investment payoff, $\tilde{\pi}$, is no longer observed at time 1. If the regulatory state occurs, with probability λ, the firm will have to invest $I_1 + \kappa$ if it wants to complete the project, or stop producing.[24] Otherwise, the firm only needs to invest I_1. Note that if the firm does not exit after repaying the time 0 debt, then it will always complete the investment since it has nothing to lose—that is, the firm will profit from a high realization of $\tilde{\pi}$ and default on its debt otherwise. At time 1, the cost of debt if the regulatory shock does not occur, R_1, solves

$$RI_1 = \int_{R_1 I_1}^{\infty} dF(\tilde{\pi}) R_1 I_1 + (1-\alpha)\int_0^{R_1 I_1} \tilde{\pi} dF(\tilde{\pi})$$

and if the regulatory shock occurs, $R_{1\lambda}$, solves

$$R(I_1+\kappa) = \int_{R_{1\lambda}(I_1+\kappa)}^{\infty} dF(\tilde{\pi}) R_{1\lambda}(I_1+\kappa) + (1-\alpha)\int_0^{R_{1\lambda}(I_1+\kappa)} \tilde{\pi} dF(\tilde{\pi}),$$

where $\alpha > 0$ is a proportional bankruptcy cost.

We now turn to the firm's problem at time 0. We assume the firm has some ongoing

[24] In the baseline model, the cost from the climate regulation, κ, reduces the payoff of the investment at time 2. In this extended model, the κ is paid as part of the investment at time 1. This modification ensures that dividends are non-negative at time 2.

operations that pay x at time 1, a random cash flow with cdf G(.), and an intermediate cash flow from the early investment, which equals ηI_0^ν, where $\eta \geq 0$ and $0 \leq \nu \leq 1$. Default occurs if the firm does not generate enough cash flow, $x + \eta I_0^\nu$, to cover the debt payments, $R_0 I_0$, which also guarantees that dividends are nonnegative at time 1.[25] The value function at time 0 is

$$\begin{aligned} V(0) &= \max_{I_0 \leq I} E\left[1_{x+\eta I_0^\nu - R_0 I_0}(x + \eta I_0^\nu - R_0 I_0 + V(I_0; 1))\right] \\ &= \max_{I_0 \leq I} \int_{-\eta I_0^\nu + R_0 I_0}^{+\infty} (x + \eta I_0^\nu - R_0 I_0 + V(I_0; 1)) dG(x) \end{aligned}$$

Note that as in the main model, the early investment I_0 is made at time zero using borrowed money, which then must be repaid with interest at time 1, that is, before the possible regulatory shock. We make the simplifying assumption that the firm prefers to distribute as dividend any remaining cash flow at time 1 instead of using it to fund the left over investment I_1.

At time zero, the cost of funding for the one-period debt is given by the break even condition for the lender:

$$RI_0 = \int_{-\eta I_0^\nu + R_0 I_0}^{\infty} dG(x) R_0 I_0 + (1 - \alpha) \int_0^{-\eta I_0^\nu + R_0 I_0} x dG(x).$$

To determine the optimal firm decision and the model equilibrium, we assume the firm is a price taker in the bond market. That is, the firm does not consider how interest rates vary with the choice of I_0 when differentiating the value function with respect to I_0. The equilibrium solution to the problem is $(I_0^*, R_0^*, R_1^*, R_{1\lambda}^*)$ and solves a system of equations composed of the first order condition with respect to I_0 and the three equations for the interest rates.

The first result gives conditions under which $R_{1\lambda} > R_1$. This gap in interest rates is the mechanism that drives the increased early investment when the probability of regulation hitting the firm increases. The only difference in the two interest rates is the increased investment needed in the regulation state due to abatement costs. Thus, the inequality can

[25] Because the payoff ηI_0^ν is deterministic, investing at time 0 is attractive for the firm. However, this extended model shows that investing at time 0 is even more attractive when the probability of climate regulation, λ, is high.

be proven by signing the derivative $\frac{dR_1}{dI_1}$. Using the implicit function theorem on R_1 yields

$$\frac{dR_1}{dI_1} = \frac{R - (1 - F(R_1 I_1))R_l + \alpha R_1^2 I_1 f(R_1 I_1)}{(1 - F(R_1 I_1))I_1 - \ R_1 I_1^2 f(R_1 I_1)}.$$

Since $R - (1 - F(R_1 I_1))R_1 = (1 - \alpha) \int_0^{R_1 I_1} \tilde{\pi}/I_1 dF(\tilde{\pi}) > 0$ in equilibrium, the numerator is positive. The sign of the denominator is the same as the sign of $H(x) = 1 - F(x) - xf(x)$, with $x = R_1 I_1$. The rest of the proof assumes $\tilde{\pi}$ is normally distributed, with mean μ_π and variance σ_π^2. Note the following properties of $H(x)$: i) $H(0) > 0$; ii) $H(x)$ is continuous and differentiable; iii) $H'(x) = [-2 + x(x - \mu_\pi)/\sigma_\pi^2]f(x)$, which because $f(x) > 0$ for any finite x, can be signed by signing $-2 + x(x - \mu_\pi)/\sigma_\pi^2$, and we can show that this expression takes two zeros $x_1 < 0$ and $x_2 > 0$, and ignoring the negative root, we have that $H'(x) < 0$ for $0 \leq x < x_2$ and $H'(x) > 0$ for $x \geq x_2$; iv) $\lim_{x\to\infty}[1 - F(x)]/[xf(x)] = 0^-$ and so $H(x) < 0$ for large x. These properties imply that the function $H(x)$ has one and only one zero, x_0, in the region $x \geq 0$, such that $H(x) > 0$ for $x < x_0$ and $H(x) < 0$ for $x \geq x_0$. Hence $\frac{dR_1}{dI_1} > 0$ if and only if $R_l I_1 < x_0$. Note that x_0 is only a function of the distributional properties of $\tilde{\pi}$, namely μ_π and σ_π.

Next, we show numerical examples that yield the property that I_0^* is increasing in λ, the main result in the paper. Consider the parameter values $\kappa = 0.1$, $\eta = 0.5$, $\nu = 1$, $I = 1$, $\sigma_\pi = 1.25$, $\mu_\pi = 2.5\sigma_\pi$, $\sigma_x = 1.25$, $\mu_x = 1.5\sigma_x$, $R = 1.05$ and $\alpha = 0.5$. We solve for the equilibrium for different values of λ. In all simulations, we verify numerically that the second order condition for maximization is satisfied. With these parameters and $\lambda = 0.4$, the intermediate cash flow from the early investment represents 6.5% of the average final cash flow. Also, $R_l I_1 < x_0$ as required for $R_{1\lambda} > R_1$. Figure B.1 gives the results across several values of λ. The figure shows that I_0^* increases with λ. Note that some early investment is desired in the model because of the intermediate cash flow that it generates. This can cause the interest rate at time 0, R_0, to be higher than those at time 1. The higher time 0 interest rate discourages further investment acting as the agency cost in the model in the main text. However, in the presence of an intermediate cash flow, what is relevant for the result that I_0^* increases with λ is not that the period 0 interest rate is lower than $R_{1\lambda}$ but that $R_{1\lambda} > R_1$. When λ increases, the expected cost of investment at time 1 goes up (loosely speaking, $\lambda R_{1\lambda} + (1 - \lambda)R_1$ increases) relative to the cost of investing at time 0, all else equal, driving more investment at time 0. The figure also illustrates that in the extended model the time 1 interest rates decrease in λ. The fact that I_1 decreases when λ increases implies that debt holders have less at risk when lending at time 1 and charge lower rates.

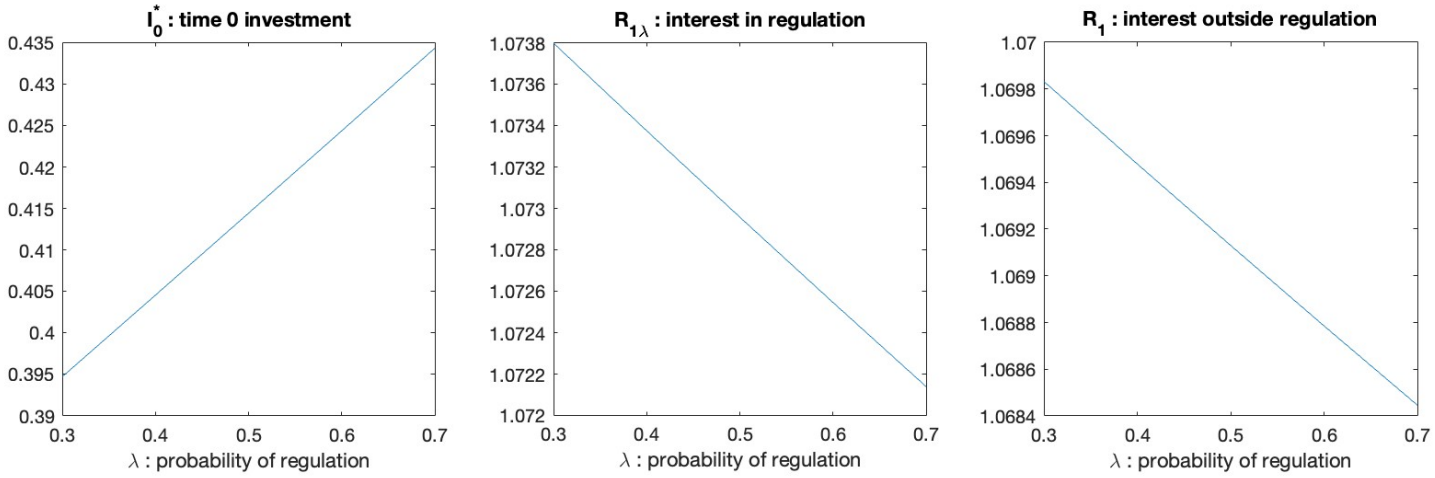


Figure B.1: Equilibrium values for I_0, $R_{1\lambda}$ and R_1 for various levels of λ.

Numerical values are $\kappa = 0.1$, $\eta = 0.5$, $\nu = 1$, $I = 1$, $\sigma_\pi = 1.25$, $\mu_\pi = 2.5\sigma_\pi$, $\sigma_x = 1.25$, $\mu_x = 1.5\sigma_x$, $R = 1.05$ and $\alpha = 0.5$.

C Additional figures and tables

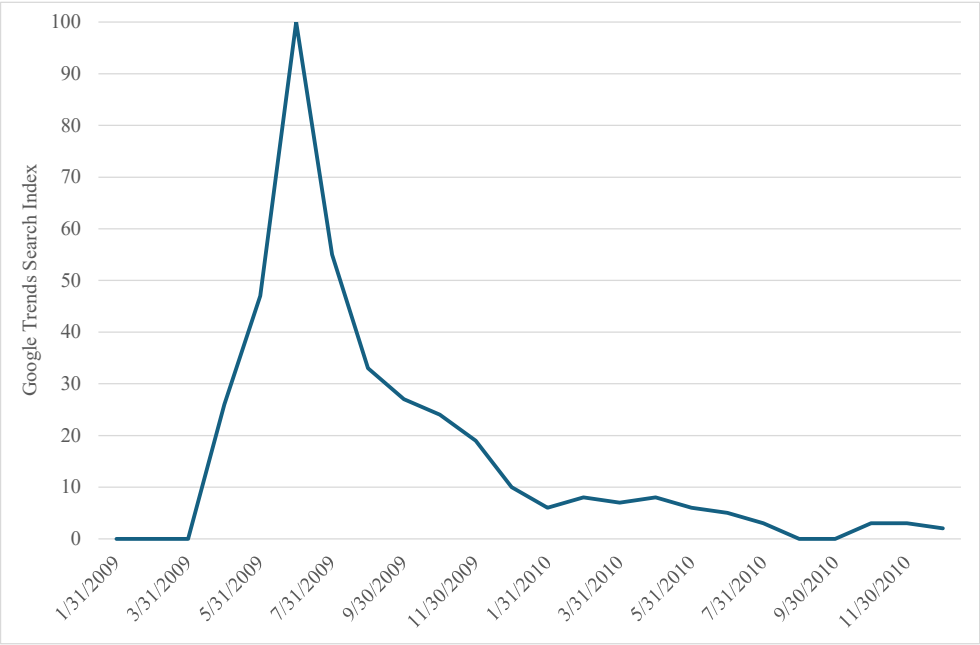


Figure C.2: Google Trends Search Index for "Waxman Markey"

This figure shows the Google Trends search index from 2009 to 2010 in the US for the search term "Waxman Markey".

Table C.1: Firm Cash and Debt

This table presents results of the panel regression model given in equation (5). The data are annual from 2010 to 2020. The dependent variables are $\Delta log(Cash_{i,t})$, change in log of cash, in Columns (1) - (2), $\frac{Cash_{i,t}}{Assets_{i,t}}$, ratio of firm cash to total assets, in Columns (3) - (4), $\Delta log(Debt_{i,t})$, change in log of debt, in Columns (5) - (6), and $\frac{Debt_{i,t}}{Assets_{i,t}}$, ratio of firm debt to total assets, in Columns (7) - (8). $IsHighEOR_{i,t}$ is an indicator variable that takes the value of 1 if log of emissions intensity is above the median and 0 otherwise. $PostParis_t$ is an indicator variable that takes the value of 1 after the 2015 passage of the Paris Accord. All specifications include balance sheet control variables, as defined in Table C.4, and incorporate the indicated combinations of year, firm, and industry-year fixed effects. 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
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
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

Table C.2: Firm Capital Expenditure, 2014-2017

This table presents results of the panel regression model given in equation (5). The data are annual from 2014 to 2017. The dependent variables are $\Delta log(CAPEX_{i,t})$, change in log of capital expenditure, in Columns (1) - (3), and $\frac{CAPEX_{i,t}}{Assets_{i,t}}$, ratio of firm capital expenditure to total assets, in Columns (4) - (6). $IsHighEOR_{i,t}$ is an indicator variable that takes the value of 1 if log of emissions intensity is above the median and 0 otherwise. $PostParis_t$ is an indicator variable that takes the value of 1 after the 2015 passage of the Paris Accord. All specifications include balance sheet control variables, as defined in Table C.4, and incorporate the indicated combinations of year, industry, firm, and industry-year fixed effects. 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)
$IsHighEOR_{i,t-1} \times PostParis_t$	-0.124**	-0.181***	-0.157**	-0.011**	-0.017***	-0.012*
	-2.305	-3.493	-2.060	-2.238	-3.767	-1.824
$IsHighEOR_{i,t-1}$	0.045	0.030	0.090	0.004	0.010	0.015
	0.814	0.223	0.690	0.848	0.876	1.218
$log(Assets_{i,t-1})$	-0.023**	-0.343***	-0.376***	-0.000	0.004	-0.007
	-2.419	-2.915	-3.606	-0.426	0.584	-0.967
$\frac{Debt_{i,t-1}}{Assets_{i,t-1}}$	-0.180*	-0.350	0.204	-0.017**	-0.095***	-0.043*
	-1.729	-1.110	0.594	-2.018	-3.799	-1.650
$\frac{NPPE_{i,t-1}}{Assets_{i,t-1}}$	0.071	-1.191***	-1.115***	0.023**	-0.112***	-0.124***
	0.604	-3.060	-2.796	2.314	-3.726	-3.640
$\frac{Cash_{i,t-1}}{Assets_{i,t-1}}$	0.932***	0.506	0.667	0.102***	0.073*	0.091**
	2.953	1.033	1.368	2.915	1.905	2.216
$\frac{CAPEX_{i,t-1}}{Assets_{i,t-1}}$	-2.437***	-5.963***	-6.469***	0.604***	0.121*	0.013
	-6.406	-8.785	-9.710	14.240	1.726	0.160
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
Observations	1,040	1,040	1,040	1,043	1,043	1,043
Adjusted R^2	0.141	0.250	0.303	0.672	0.776	0.802

Table C.3: Firm Greenhouse Gas Emissions, 2014-2017

This table presents results of the panel regression model given in equation (5). The data are annual from 2014 to 2017. The dependent variables are $log(\frac{Emissions_{i,t}}{Revenue_{i,t}})$, log of emissions over revenue (i.e., emissions intensity), in Columns (1) - (4), $log(Emissions_{i,t})$, log of emissions level, in Columns (5) - (8), and $\Delta log(Emissions_{i,t})$ (change of log of emissions level in %) in Columns (9) - (12). $log(\frac{Emissions_{i,t-1}}{Revenue_{i,t-1}})$ is the lagged log of emissions intensity. $IsHighEOR_{i,t}$ is an indicator variable that takes the value of 1 if log of emissions intensity is above the median and 0 otherwise. $PostParis_t$ is an indicator variable that takes the value of 1 after the 2015 passage of the Paris Accord. All specifications include balance-sheet control variables, as defined in Table C.4, and incorporate the indicated combinations of firm and industry–year fixed effects. 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 $p < 0.01$.

	$log(\frac{Emissions_{i,t}}{Revenue_{i,t}})$				$log(Emissions_{i,t})$				$\Delta log(Emissions_{i,t})$			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
$log(\frac{Emissions_{i,t-1}}{Revenue_{i,t-1}}) \times PostParis_t$	0.050*	0.061**			0.082**	0.072**			0.053**	0.049*		
	1.867	1.979			2.348	2.125			2.298	1.954		
$log(\frac{Emissions_{i,t-1}}{Revenue_{i,t-1}})$	0.881***	0.472***			0.032	0.028			-0.016	-0.028		
	22.608	3.326			0.409	0.165			-0.387	-0.242		
$IsHighEOR_{i,t-1} \times PostParis_t$			0.182	0.199			0.295*	0.240			0.146	0.096
			1.237	1.464			1.866	1.429			1.645	1.103
$IsHighEOR_{i,t-1}$			0.338**	-0.301			-0.319**	-0.353*			-0.224***	-0.301*
			2.134	-1.439			-2.039	-1.769			-2.598	-1.689
$log(Emissions_{i,t-1})$	0.033	-0.285*	0.766***	0.258*	0.860***	0.207	0.954***	0.332***	-0.046	-0.456***	-0.011	-0.394***
	0.809	-1.655	14.326	1.904	8.768	0.974	21.397	2.603	-1.010	-3.257	-0.498	-3.172
$log(Assets_{i,t-1})$	-0.028	0.094	-0.649***	-0.222*	0.115	0.304*	0.036	0.226	0.035	0.168	0.007	0.129
	-0.711	0.660	-14.191	-1.772	1.371	1.746	0.960	1.628	0.931	1.429	0.358	1.237
$\frac{Debt_{i,t-1}}{Assets_{i,t-1}}$	0.187*	0.248	0.348*	0.170	0.119	0.287	0.109	0.212	0.057	0.190	0.042	0.153
	1.681	0.833	1.768	0.545	0.827	1.012	0.764	0.724	0.730	0.764	0.511	0.595
$\frac{NPPE_{i,t-1}}{Assets_{i,t-1}}$	0.467***	0.979	1.426***	1.254*	0.184	0.822	0.289*	0.837	0.147	0.717*	0.179	0.725*
	2.899	1.582	4.805	1.911	1.065	1.373	1.878	1.374	1.249	1.766	1.616	1.744
$\frac{Cash_{i,t-1}}{Assets_{i,t-1}}$	0.590	1.108*	0.883	1.276*	0.690	1.595**	0.657	1.565**	0.385	1.149**	0.336	1.091**
	1.402	1.693	1.289	1.880	1.254	2.408	1.211	2.266	1.345	2.420	1.170	2.292
$\frac{CAPEX_{i,t-1}}{Assets_{i,t-1}}$	-0.571	0.272	0.306	0.210	-0.224	0.467	-0.126	0.417	-0.119	0.209	-0.088	0.154
	-1.363	0.304	0.400	0.226	-0.520	0.429	-0.296	0.377	-0.333	0.257	-0.245	0.185
Firm FE	N	Y	N	Y	N	Y	N	Y	N	Y	N	Y
Industry × Year FE	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Observations	1,035	1,035	1,035	1,035	1,054	1,054	1,054	1,054	1,054	1,054	1,054	1,054
Adjusted R^2	0.943	0.961	0.906	0.960	0.918	0.947	0.918	0.947	-0.030	0.250	-0.024	0.251

Table C.4: 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
$\Delta log(Emissions_{i,t})$	Change in the natural logarithm of emissions (aggregated to parent-firm level)	EPA Greenhouse Gas Reporting Program (GHGRP)
$log(\frac{Emissions_{i,t}}{Revenue_{i,t}})$	Natural logarithm 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
$IsHighEOR_{i,t}$	Indicator variable that takes the value of 1 if $log(\frac{Emissions_{i,t}}{Revenue_{i,t}})$ is above the median, 0 otherwise	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
$\frac{NPPE_{i,t}}{Assets_{i,t}}$	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
$CashFlowVol3Y_{i,t}$	Standard deviation of quarterly $\frac{EDITDAi,t}{Assets_{i,t}}$ over the last three years	S&P Capital IQ
$CashFlowVol5Y_{i,t}$	Standard deviation of quarterly $\frac{EDITDAi,t}{Assets_{i,t}}$ over the last five years	S&P Capital IQ
$IsHighCashFlowVol3Y_{i,t}$	Indicator that takes a value of 1 if $CashFlowVol_3Y_{i,t}$ is above the median, 0 otherwise	S&P Capital IQ
$IsHighCashFlowVol5Y_{i,t}$	Indicator that takes a value of 1 if $CashFlowVol_5Y_{i,t}$ is above the median, 0 otherwise	S&P Capital IQ
$PostParis_t$	Indicator variable that equals one if the year is after the 2015 passage of the Paris Accord	

Variable	Description	Source
EI	Energy intensity of the six-digit NAICS	Meng (2017), Annual Survey of Manufacturers, and the Census
TI	Trade Intensity of the six-digit NAICS	Meng (2017), USITC
$NoExemption_i$	Indicator variable that equals one if the firm do not receive free emission trading permits under the Waxman-Markey bill.	