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The Impact of Climate Policy on Oil and Gas Investment

Evidence from Firm-Level Data

Christian Bogmans, Andrea Pescatori, Ervin Prifti

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The Impact of Climate Policy on Oil and Gas Investment: Evidence from Firm-Level Data

Prepared by Christian Bogmans, Andrea Pescatori, Ervin Prifti*

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ABSTRACT: Using a text-based firm-level measure of climate policy exposure, we show that climate policies have led to a global decline of 6.5 percent in investment among publicly traded oil and gas companies between 2015 and 2019, with European companies experiencing the most significant impact. Similarly, climate policy uncertainty has also had a negative impact. Our empirical results support the Neoclassical investment model. According to this model, firms pre-emptively cut investment in response to downward shifts in future demand. These findings contrast with the Green Paradox theory, which predicts an increase in current investment by oil and gas firms aimed at shifting extraction toward the present.

JEL Classification Numbers:	C2, D2, Q4, Q54.
Keywords:	Fossil fuel phase out; firm-level climate policy exposure; energy transition; DiD; climate policy anticipation effects.
Author's E-Mail Address:	cbogmans@imf.org; apescatori@imf.org; eprifti@imf.org

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WORKING PAPERS

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1 Introduction

A smooth energy transition will require moving away from fossil fuels at a pace that is commensurate with the adoption of renewable energy. This challenging balancing act is complicated by the forward-looking nature of energy investment and the intertemporal dimension of extraction decisions, both of which saddle companies and investors with the difficult task of gauging future revenue streams in a potentially radically transformed environment. This poses a transition risk that is specific to each company and sector, but that for most oil and gas companies represents a (potentially existential) downside risk—that is, they may experience a substantial fall in revenues and in the value of their (physical and financial) assets (see van der Ploeg and Rezai (2020a) and Campiglio and van der Ploeg (2022)). These companies are, in fact, highly *exposed* to energy transition dynamics and changes in climate policies. The current paper, using firm-level data, focuses on understanding the implications of this exposure for investment by publicly-traded oil and gas firms.

We employ firm-level measures of climate policy exposure and climate policy risk, which are derived from text analysis conducted by Sautner, Lent, Vilkov, and Zhang (2023). Influenced by both current and expected climate policies, they are sources of plausibly exogenous variation in companies' investments. These measures are based on transcripts of earning calls of publicly-listed firms which are analyzed using machine learning and keyword discovery algorithms to identify climate change conversations. The *exposure* measure should capture revisions in expectations of climate policies and their impact on the firm's profitability while the *risk* measure should reflect the associated uncertainty.

Using a sample of 117 publicly traded oil and gas firms (accounting for about 40 percent of global oil production) and a control group consisting of non-energy firms, a panel regression shows that a one standard deviation increase in exposure to climate policy leads to a reduction in investment of around 3 percent for a typical oil and gas company. Climate policy risk has an even stronger effect than exposure (i.e., the first moment), with a typical shock in uncertainty reducing investment by around 4 percent. For the control group, instead, a one standard deviation increase in climate policy exposure increases investment by 4.9 percent—for non-fossil fuel firms, the energy transition may, on average, imply more opportunities than threats. These effects are also economically meaningful. Our estimates, when aggregated across firms, imply that upstream oil and gas investment fell by 6.5 percent between 2015 and 2019 as a result of a strengthening of climate policy pledges and announcements. A battery of robustness checks confirm the main results.

A difference-in-difference (DiD) analysis around 2015 also supports the view that the Paris agreement has constituted a watershed moment for the oil and gas industry. In fact, after 2015 capital expenditures by firms in the upstream oil and gas sector (the treatment group) were on average 22.6 percent lower compared to firms in other sectors of the economy (the control group). This analysis uses a large sample of non-energy firms as control group—along with a number of firm-level controls typically used in the literature (such as log total assets, leverage, and Altman credit strength) coupled with spot oil prices interacted with the treatment group dummy to control for oil market tightness. In absence of a firm-specific measure of exposure to climate policy, however, the DiD analysis is vulnerable to unobserved confounders (and concomitant causes) that vary across industry and time—such as the shale revolution which may have changed long-term supply prospects for the oil and gas industry.[1] We, thus, interpret this result as an upper-bound of the effects of energy transition risks induced by the Paris agreement, because it may be capturing the effect of other factors beyond climate policy all of which contributed to the widening of the cross-group gap in investment after 2015.

The literature has typically split transition risk into technology and regulatory (i.e., climate policy) risk. The latter seems to be especially relevant today: in contrast to previous energy transitions (e.g., from biomass to coal in the 19^{th} century), climate policies are believed to be crucial for controlling the direction and speed of the current transition. This difference is important because climate policies can be made more predictable than technological innovation and, thus, can operate also through powerful anticipation effects. Indeed, since the adoption of the Paris agreement late 2015, many countries have pledged and announced targets to reduce greenhouse gas emissions in a not-so-distant future, in some cases coupled with policies that should make those targets feasible.[2] The energy transition is, thus, a slow-

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[1] Using a structural world equilibrium model of the oil market, Bornstein, Krusell, and Rebelo (2023) show how the unconventional oil expansion results in large long-run declines in the level and volatility of oil prices by weakening OPEC's market power and responding more quickly to changes in demand. Also Baumeister and Kilian (2016) asserts that the shale oil boom of the early 2010s led to a slump in oil prices between 2014 and 2016 and to a strong fall in oil and gas investments contrary to other economics sectors.

[2] On May 17 2022 the EU parliament voted in favor of a comprehensive reform of the EU's carbon trading scheme, the EU ETS. The reform includes, among others, an accelerated carbon emissions reduction target (-62%

moving process that, though uncertain, has a level of predictability that has already induced some companies and investors to react and possibly adjust.[3]

A large and rapidly growing literature has already analyzed the effects of climate transition risks on various dimensions relevant for private firms. More specifically, research shows that risks related to environmental regulation are increasingly driving up the cost of capital for high emitters in corporate loan markets (Delis, De Greiff, and Ongena, 2019), through syndicated loans (Ehlers, Packer, and Greiff, 2022), corporate bonds (Seltzer, Starks, and Zhu, 2022), and higher interest rates charged by banks to dirtier firms (Fard, Javadi, and Kim, 2020). Investors have been shown to increasingly price in climate policy risks in Germany (see Sen and Schickfus (2020)) and in the U.S. (see Bolton and Kacperczyk (2021)).[4] It has also been documented that institutional investors are increasingly factoring in environmental policy risks in their investment decisions (e.g., Egli, Schärer, and Steffen (2022) and Krueger, Sautner, and Starks (2019)), and that fossil fuel divestment campaigns have recently gained in importance (Egli, Schärer, and Steffen, 2022). Increasingly, stringent environmental policies have also been shown to lead firms to shift their capital structure (Ginglinger and Moreau, 2019). In theory, a higher cost of capital due to stricter climate regulations should reduce investment in affected firms. Boer, Pescatori, and Stuermer (2022) show that such supply-side climate policies can potentially lead to increasing oil price paths in VAR based structural scenarios. None of these papers, however, has focused squarely on assessing the impact of climate transition exposure on oil and gas investment which, in turn, has direct implications for energy supply, energy prices, and, more generally, energy security. This paper aims to fill this gap.

The qualitative impact on oil and gas investment of announcing today future stricter climate policies is a priori ambiguous. Two opposing anticipation effects on investment could be at work, namely the divestment effect (see e.g., Schellnhuber, Rahmstorf, and Winkelmann (2016) and Baldwin, Cai, and Kuralbayeva (2020))

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by 2030 compared to a previous target of -42%) and an expansion of sectoral coverage. On the other side of the Atlantic, the Inflation Reduction Act (IRA) of 2022 has been called the most significant climate legislation in US history, and offers funding, programs, and incentives (both new and reinstated) to accelerate the clean energy transition in every sector of the economy.

[3] Between 2014 and August 2022 the total amount of financial assets subject to some form of fossil fuel divestment pledge has increased from $52 billion held by 181 investors to more than $39 trillion across almost 1500 investors (Pless, 2023).

[4] Hsu, Li, and Tsou (2022) show that a pollution premium related to environmental policy uncertainty also exists for companies that emit local industrial pollutants.

and the green paradox effect (see e.g., Sinn (2009), Pittel, van der Ploeg, and Withagen (2014) and Barnett (2023)). The divestment effect can be found in the neoclassical investment model—a workhorse in the macro-dynamic literature—which assumes that investment in an oil and gas-producing capital stock is subject to intertemporal adjustment costs.[5] The green paradox effect, instead, can be found in the Hotelling model—a workhorse in environmental and resource economics—which considers competitive producers who choose the path of extraction of a scarce and exhaustible resource to maximize resource rents. Only a few studies have tried to weigh these opposite anticipation effects. Bauer, McGlade, Hilaire, and Ekins (2018), for example, study the announcement effect of carbon taxes implemented with a delay using two rich multi-regional energy-economy models. They find that in various scenarios the divestment effect prevails over the green paradox unless the carbon tax is implemented slowly and with a long delay. The disadvantages of these models, however, is that they are not very tractable making it hard to dissect the mechanics, and results rely on parametrization as those models are not estimated.[6]

This paper also contributes to the literature by explaining, under a minimum set of assumptions, the mechanics of these two different approaches and showing how they can lead to starkly opposite predictions for oil and gas production and prices during the early stages of the energy transition. In the Hotelling model, to minimize the losses to resource rents from the policy-induced downward shift in future oil and gas demand, firms bring extraction forward in time, leading to lower prices and higher oil and gas consumption today (i.e., the green paradox). Furthermore, the relationship between the policy delay and the magnitude of the green paradox is non-monotonic, which contrasts with other findings in the literature such as Bauer et al. (2018) that the green paradox is most pronounced for large delays.[7] In the neoclassical investment model, instead, an expected future downward shift in oil and gas demand lowers the value of installed capital (i.e., Tobin's Q drops below one) leading the firm

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[5] The neoclassical theory of investment, first put forward by Jorgenson (1963) and later modified by Lucas Jr (1967), and the Tobin's Q theory of investment (based on replacement cost of capital) were reconciled by Hayashi (1982) who shows their equivalence.

[6] van der Ploeg and Rezai (2020b) construct a model with both reserves depletion and intertemporal adjustments costs of exploration capital and calibrate it the the global oil and gas sector.

[7] The non-monotonic relationship occurs because policy delays have two opposing effects. On the one hand, the longer the delay the larger the opportunity for resource owners to front-load oil and gas extraction to the no-tax period. On the other hand, the longer the delay the smaller the net present value of the losses to the resource owner's rents and the smaller the need for front-loading. For small delays the first effect prevails but for large delays the second effect is dominant and the green paradox weakens.

to immediately cut investment which, in turn, leads to higher prices and firms' free cash flow, until demand for oil and gas shifts down permanently.

Since the direction of the investment response is ultimately an empirical question, the main contribution of the current paper is to quantify empirically the impact of climate policy exposure and risk on investment by oil and gas companies.

Our findings have important implications as climate policy exposure and risk may dampen the strong correlation between spot oil and gas prices and investment that had long characterized the oil and gas industry (see Bornstein, Krusell, and Rebelo (2023), for a rationalization) and that has guaranteed stationary (and affordable) real oil prices over time. A period of low investment would also imply high energy price volatility, at least initially, with reduced buffers for the oil and gas industry to absorb shocks (as in the 2021-2022 energy crisis). Indeed, while investment was subdued between 2016 and 2019, oil consumption kept growing at a pace (of 1.3 mb/d per year) that was higher than that of the previous ten years. At the same time, the neoclassical investment model, favored by the data, would predict high free cash flow for oil and gas companies in the first stage of the energy transition which gives these companies time to adjust and therefore reduces the financial risk of stranded assets for the oil and gas industry.

2 Theoretical Frameworks and Testable Predictions

In this section, we model the oil and gas sector using two different frameworks: the neoclassical investment and the Hotelling exhaustible resource model. Both models, stripped down to a minimum set of assumptions, give testable predictions as to how investment by forward-looking oil and gas producers responds to a credible carbon tax announcement with delayed implementation. Each of the two models captures different aspects of the nature of production and investment in the the oil and gas industry, and yet, the two frameworks give qualitatively starkly different results: while investment *declines* in response to the carbon tax announcement in the first framework, it *increases* in the second framework—vice versa for oil and gas prices. The main lesson from this thought experiment is that the impact of climate policies on oil and gas investment in the initial phase of the energy transition is a priori ambiguous and, thus, ultimately an empirical questions.

2.1 The Neoclassical Investment Model: Capital Adjustment Costs

Our first framework is rooted in the neoclassical theory of investment and the adjustment approach to investment (see e.g. Jorgenson (1963), Lucas Jr (1967) and Abel and Blanchard (1986)). The level of oil and gas production is contingent on the size of the capital stock (e.g., drilling and extraction equipment, oil platforms, connecting pipelines, storage facilities etc.). Oil and gas reserves are implicitly modelled by assuming that production features diminishing returns to capital, but this resource base is not depleted by production. This set-up captures the idea that (unconventional) reserves are simply very large and not depleted anytime soon, a view that has become more prevalent with the advent of fracking. In other words, it is the extensive margin (e.g., developing existing or finding new oil fields) that matters for oil and gas production. This way of modelling fossil fuel production is close in spirit to some recent papers in the environmental macroeconomics literature, see e.g., Golosov, Hassler, Krusell, and Tsyvinski (2014), Acemoglu, Hemous, Barrage, and Aghion (2019) and Krusell and Smith Jr (2022). The climate policy is summarized by the announcement of a path for carbon taxes, τ_c, to be implemented at t_0, while τ_p is an investment tax that directly discourages investment in the oil and gas by increasing its relative price.

A representative oil and gas firm maximizes profits from selling oil and gas, y, taking the oil and gas price p as given, and choosing how much to invest I.[8]

$$\max_{\{I_t,k_t\}_{t=0}^{\infty}} V_0 = \sum_{t=0}^{\infty} \beta^t [p_t y_t - I_t(1+\tau_{p,t})] \text{ s.t.}$$

$$y_t = A_t k_{t-1}^{\alpha} \tag{1}$$

$$k_t = (1-\delta)k_{t-1} + I_t - \Phi(I_t/k_{t-1})k_{t-1} \tag{2}$$

where capital stock k is the only factor of production, A is an exogenous process representing total factor productivity in the oil and gas industry, β is the discount factor, and $\alpha < 1$ is the capital-output elasticity.[9] Adjustment costs, Φ, prevent capital, k, to quickly react to shocks. In what follows, we choose internal adjustment costs $\Phi(x_t) = 0.5\phi(x_t - \delta)^2$, where δ is the

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[8] The firm is assumed to be risk neutral as in Abel and Blanchard (1986). Since the model is solved under perfect foresight, this assumption has minor implications. In general, introducing revenue uncertainty would amplify our results discouraging investment today.

[9] Since the oil and gas industry is very capital intensive we abstract from labor inputs.

depreciation rate of the capital stock. The relative price of investment is normalized to 1, however.

The first order conditions of this dynamic optimization problem are:

$$\frac{\partial \mathcal{L}}{\partial I_t} = 0 \Longrightarrow \alpha p_{t+1} A_{t+1} k_t^{\alpha-1} + \lambda_{t+1}[1 - \delta - \Phi_{t+1} + \Phi'_{t+1} I_{t+1}/k_t] = \lambda_t/\beta \tag{3}$$

$$\frac{\partial \mathcal{L}}{\partial k_t} = 0 \Longrightarrow 1 + \tau_{p,t} = \lambda_t(1 - \Phi'_t) \tag{4}$$

We close the model with a iso-elastic demand function, with parameter η: $[(1+\tau_{c,t})p_t]^{-\eta}$. Thus, demand for oil and gas depends on its cum-tax price $(1+\tau_c)p$ where τ_c is the carbon tax. In equilibrium, assuming no change in inventories, demand and supply of fossil fuel equate:

$$y_t = [(1+\tau_{c,t})p_t]^{-\eta} \tag{5}$$

To illustrate the mechanics of the investment response, we feed the model with a permanent 25 percent carbon tax, announced at time 0 and implemented with certainty after 5 years.[10]

On impact, the value of installed capital (i.e., Tobin's Q) drops, since demand for oil and gas is expected to shrink with the implementation of the carbon tax. Therefore oil and gas investment declines immediately as firms anticipate the costly transition to a lower capital stock (Figure 1). Due to adjustment costs, investment doesn't immediately fall to its steady state value even after the implementation of the tax but slowly converges towards it. In addition, up to year 5 there is no carbon tax yet and so the existing capital stock is more valuable during that period and reducing capital too quickly would therefore be inefficient. Production of oil and gas declines only slowly as the capital stock gradually erodes with capital depreciation outweighing investment. In the initial phase of the transition, as oil and gas production decline, prices increase, but then fall once the carbon tax is implemented. A corollary is that initially firms' profits (or free cash flow), $py - (1+\tau_p)I$, increase, while the market valuations of oil and gas firms, V_0, decline.

Finally, an increase in taxes on fossil fuel investment (possibly capturing a higher cost of capital for oil and gas companies) would lead to a similar cut in investment and increase in

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[10] The transition path to the new steady state is found by solving numerically the system of difference equations made up by the first order conditions and the equilibrium in the oil and gas market (equations (1) to (5), solving for y, k, p, I, and λ starting from a zero tax steady state) coupled with tax policies fed as exogenous processes.

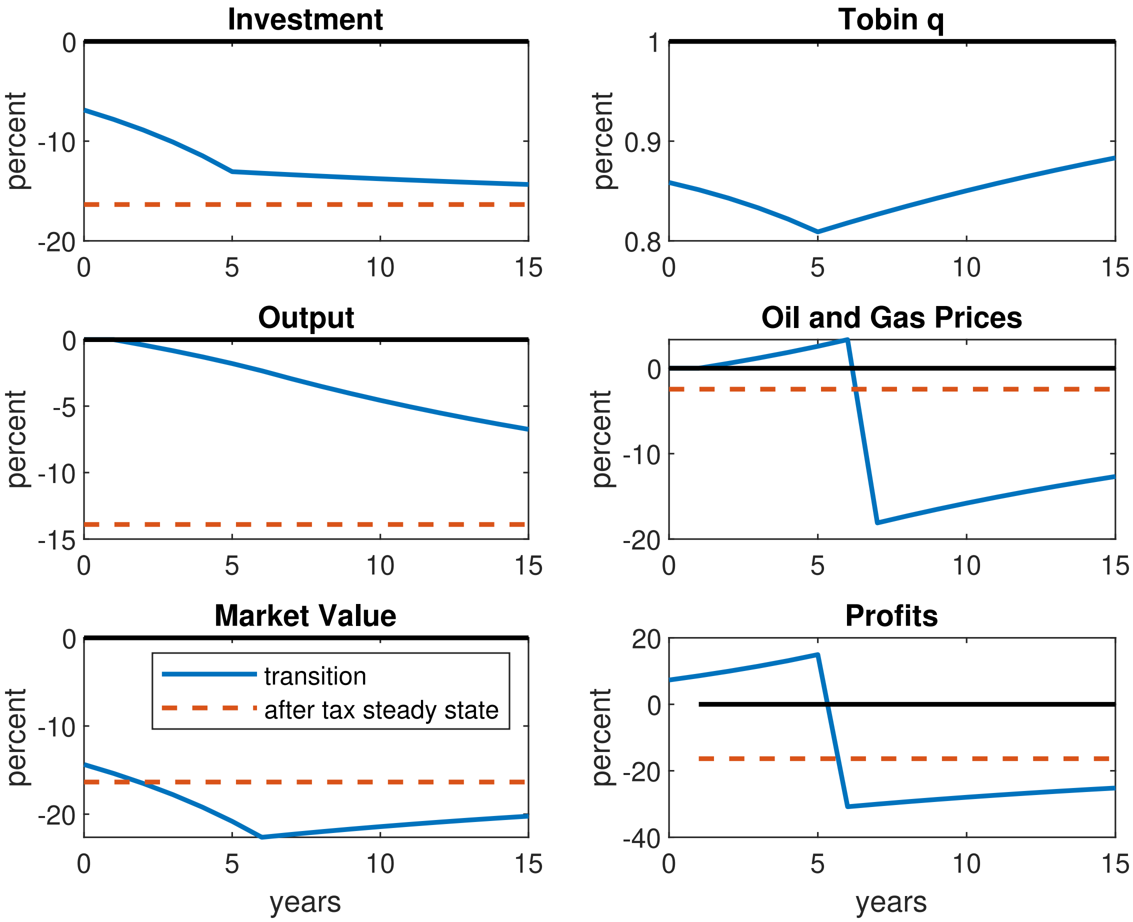

Figure 1: Response of investment, Tobin's Q, output, prices, market value, and profits of O&G firms to a delayed carbon tax in the Neoclassical Investment model. The dashed (solid black) line is the new (initial) steady state. Numerical solution and charts are based on the following parameter values: $A = 1$; $\alpha = 0.85$; $\delta = 0.07$; $\phi = 8$; $\beta = 0.96$; $c_0 = 1$; and $\eta = 0.7$.

energy prices, even though firms' profits would decline.[11]

2.2 Green Paradox: Intertemporal Arbitrage

Our second framework is a standard continuous-time version of the classic Hotelling (1931) model. In contrast to the first framework, oil and gas reserves are exhaustible, and they can not be enlarged through exploration activities. Lifetime or cumulative oil and gas production is thus capped. For simplicity, capital investment is not explicitly modelled, so to map the

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[11] Results are available upon request to the authors.

model to the empirics we assume investment increases with the level of extraction.[12]

A representative oil and gas firm maximizes profits by choosing extraction of oil and gas, R_t, from an exhaustible resource stock of size S:

$$\max \ V_0 = \int_0^T P_t R_t e^{-it} dt, \tag{6}$$

subject to the stock equation of motion, an initial condition on the resource stock, and the reserves constraint:

$$\dot{S}(t) = -R(t), \text{ with } S(0) = S_0 > 0, \tag{7}$$

$$\int_0^T R_t dt \leq S_0, \tag{8}$$

where T is the point in time where reserves become fully depleted, and i is the nominal interest rate. We close the model with the following inverse demand function, $(1 + \tau_{c,t})P_t = Ke^{-aR_t}$, where $\tau_{c,t}$ is a carbon-tax on oil consumption, $(1 + \tau_{c,t})P(t)$ is thus the consumer price of oil, and K is the so-called choke-price at which oil demand falls to zero (presumably because there exists a perfect substitute to oil with marginal cost of production K).

To illustrate the mechanics of the green paradox (see van der Ploeg and Withagen (2015) and Sinn (2009)) we again consider a scenario in which a regulator announces a constant carbon tax at time 0, which is implemented with certainty at time $t_0 > 0$. In contrast to the first, our second framework comes with a closed-form solution. This solution consists of two possible regimes (for details see the Online Appendix). Let $\overline{T}$ be the depletion time in the absence of a carbon tax. Then for sufficiently low values of t_0 the solution is interior, with oil firms supplying and selling oil both before and after the implementation of the carbon tax ($0 < t_0 < T < \overline{T}$). In contrast, for sufficiently high values of t_0 we have a corner solution in which oil firms decide to sell their last barrels of oil just in time before the implementation of the carbon tax and none thereafter ($T = t_0 < \overline{T}$).

If the solution is interior, the extraction (and investment) path, which is declining over time, immediately jumps up in the pre-tax period in response to the carbon tax announcement

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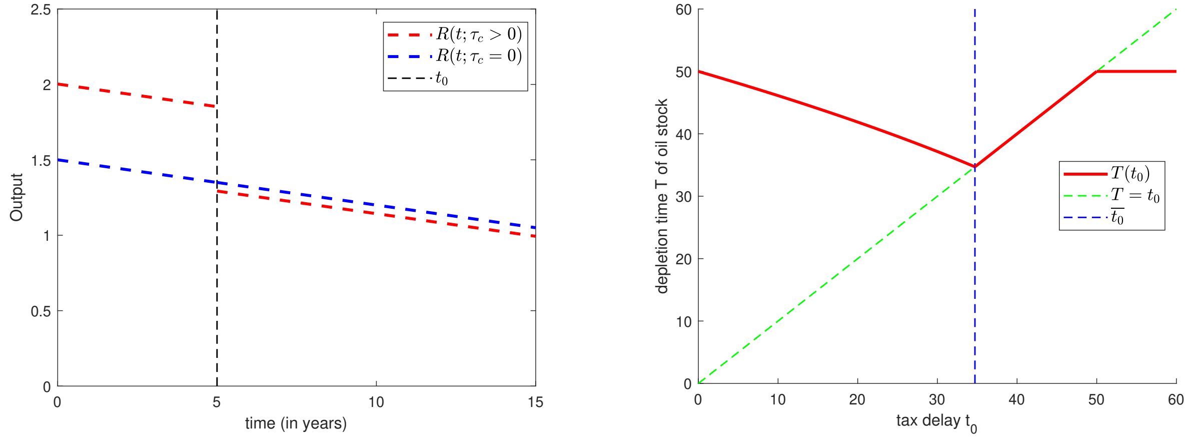
[12] One pragmatic way to model this would be to take marginal extraction costs as constant, and assume that a certain fraction of these extraction costs constitute capital expenditures. Since this wouldn't qualitatively affect the results, we abstract from extraction costs altogether.



(a) Extraction/output $R(t)$.

(b) Depletion time $T(t_0)$.

Figure 2: Charts correspond to model solution with the following parameter values: $a = 1, S_0 = 37.5, i = 0.03,$ and $\tau_c = 0.75$ which implies, see online appendix, $\overline{T} = 50$. For chart (A), which depicts an interior solution, we also have $t_0 = 5$.

as producers, through intertemporal arbitrage, seek to sell more oil before demand destruction from the carbon tax sets in. In the post-tax period, instead, extraction falls (Figure 2a).

Overall, the adjustment of the extraction path implies that depletion of the stock is brought forward in time (i.e., a green paradox occurs) for any carbon tax that is both delayed and binding, that is, $0 < t_0 < \overline{T}$. However, the relationship between t_0 and T is non-monotonic (a result which according to the best of our knowledge has gone unnoticed in the literature so far): up to time $\overline{t_0}$ we have an interior solution in which a larger delay brings extraction forward in time, $\frac{dT}{dt_0} < 0$ for $t_0 < \overline{t_0}$, but after $\overline{t_0}$ we have a corner solution in which further delays push extraction again backwards in time, $\frac{dT}{dt_0} > 0$ for $t_0 \geq \overline{t_0}$ (Figure 2b). Thus, for initial increases in the delay the green paradox worsens, but at some point further delays in the implementation of the carbon tax will soften the green paradox, until the policy, too far into the future, becomes irrelevant.

3 Climate Policy and Data

3.1 Climate Policy Exposure and Risk

Most climate policies, announced or enacted, might be felt by an oil and gas company over time, rather than immediately—as demand for fossil fuels is initially modestly affected. Therefore we want to capture not only current climate policy shocks, but also how the evolving prospects of the climate transition (due to climate policies) have influenced a firm's management behavior and decisions. To do so, we use a measure of firm-level *exposure* to climate policy recently introduced by Sautner et al. (2023). Their data covers 10000 firms in 34 countries across all industries during the period 2002-2021. They identify climate change conversations from transcripts of earnings calls of publicly-listed firms through a text analysis that uses machine learning and keyword discovery algorithms. An index is then constructed using the number of *signal* word combinations (bigrams) that indicate climate policy conversations, as a share of the total number of bigrams. Measures of exposure, uncertainty, and sentiment are then built around the main topic. We focus on climate regulatory (i.e., policy) topics, within the broader climate conversation, and use the measure of the firm's *exposure* to climate policy (first moment) and a measure of *uncertainty* around climate policy (second moment), as perceived by the firm and all market actors participating in the calls.[13] The exposure measure is the relative frequency of bigrams that capture policy shocks related to climate change. Such bigrams include "carbon tax" "carbon price," or "EPA regulation", which capture regulatory interventions. The uncertainty measure couples those bigrams with the words "risk", "uncertainty", or synonyms.

Sautner et al. (2023) conduct validation exercises showing that the text-based measures are strongly correlated with "hard" measures of a firm's exposure to climate policy - such as carbon emission intensity - and to risks and risk premiums embedded in the firm's option prices. With regard to the latter, higher regulatory exposure predicts a more negatively skewed distribution of returns and fatter tails, indicating that a firm's risk-return profile reflects variations in the text-based measure of climate policy exposure. Despite the perception of climate change and climate policy as aggregate risk factors, or at most sector-specific in certain cases,

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[13] The broad climate change index in Sautner et al. (2023) consists of three sub-indices capturing different aspects of climate change (topics): physical threats (e.g., extreme weather), technological opportunity, and regulatory aspects (e.g., climate policies such as carbon taxes). We focus on the sub-index of regulatory topics.

the authors use a variance decomposition exercise to show that the bulk of variation observed in the text-based measure occurs at the individual company level, rather than at the industry or aggregate level. Moreover, only a minor part of this variation (5-10%) can be attributed to noise or measurement error. The top-right chart in figure 3 shows that on average about 0.01% of all word combinations during earnings conference calls in the oil and gas sector were related to *climate policy* (exposure). In terms of geographic variation (figure 4), with a focus on Europe and North America, which constitute the majority of our sample (>80% of firms), it is noteworthy to mention the significant rise in climate policy exposure among oil and gas firms on the Old Continent after 2015.[14]

3.2 Other Firm-Level Data

Our second data source is Compustat, a global dataset of balance sheet information that includes around 100 thousand firms covering 99% of global market capitalization. We extract a firm-year dataset over the period 2012-20 for publicly traded firms with total assets above USD 50 million in the oil and gas sector (SIC code = 1311, 1381) and in most other sectors for the comparison group (construction, manufacturing, transportation, communications, services). Our outcome variable is investment (i.e., capital expenditures in million USD).[15] Other variables include total assets, the debt-to-equity ratio, the asset turnover ratio, and the Altman credit strength score, which is a proxy for a firm's financial health.[16] Indicators for the sector the company belongs to and the country it operates in are also included in the set of observables.

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[14] Approaches alternative to Sautner et al. (2023) have been used in the literature to proxy climate exposure, such as carbon intensities or ratings. However, even though firms' voluntary carbon emissions are gaining some traction, the data exist only for a limited and selected sample and are hard to compute for scope 3 emissions, which are the most relevant for the oil and gas sector. More importantly, disclosed emissions reflect firms' historic (rather than future) business models. Moreover, climate risk disclosure in annual reports is mostly cheap talk with firms cherry-picking the information they provide (see Bingler, Kraus, Leippold, and Webersinke (2022)).

[15] SIC 1311 includes firms primarily engaged in operating oil and gas fields with the aim of exploration, drilling, and all other activities in the preparation of oil and gas up to the point of shipment, while SIC 1381 contains firms engaged in drilling oil wells or gas field operations for others on a contract basis.

[16] A score above 3 on the Altman credit strength means the company is not likely to go bankrupt, while a score below 1.8 signals a high probability of bankruptcy.

3.3 Estimation Sample

Merging the two datasets gives an estimation sample of around 9200 firm-year observations. The estimation period is 2012-2019 to exclude the confounding effects of the pandemic. Depending on the year, this unbalanced panel includes between 73 and 117 energy firms and between 940 and 1500 non-energy firms. Oil and gas firms in the sample represent 40% of total capex and production in global oil and gas upstream industry and are spread out over North America (79), Europe (18), Australia and New Zealand (6), Asia (5), Latin-America (5), Middle East and North Africa (2), and SSA (2). While Compustat data does not include the breakdown of a company's investment in brown and green activities, available evidence suggests that fossil fuel firms remain predominantly focused on investment in oil and gas related activities, so that we are confident we are capturing an effect on brown investments. [17] [18]

Figure 3 describes the outcome variable and our regressors of interest. Two features seem worth highlighting: the fall in fossil fuel investment between 2014 and 2016 and the slower recovery relative to the rest of the economy in subsequent years. The former is the result of ample oil supply following the shale gas revolution (and perhaps also an anticipation effect associated with the signing of the Paris Agreement). The latter could reflect the impact of a strengthening in climate policies that affected the two groups differently. This is consistent with the evolution of the sample average of our text-based measures of climate policy exposure, shown in the bottom panel of figure 3.[19] The comparison group's exposure to the first and second moment of climate policy displays a relatively stable dynamic, supporting the idea of a good quasi-experimental counterfactual that remains unaffected by treatment throughout the observation window. Exposure in the oil and gas sector industry is mostly above that of the rest of the economy and rising substantially after 2015. Moreover, the dispersion of climate policy exposure increases dramatically over time within the oil and gas sector, mostly driven by European oil and gas companies. Taken together, figure 3 provides suggestive evidence that rising stringency of climate policy or policy uncertainty may explain part of the fall in

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[17] Green, Hadden, Hale, and Mahdavi (2022) show that renewable investment in the upstream oil and gas industry has been small to non-existent during the 2004-2019 period.

[18] If a substantial and increasing fraction of investment by oil and gas firms in recent years would have been allocated to green activities, this would actually work against finding any climate policy effects on brown investment and our results would represent a lower-bound of the true effect.

[19] Furthermore, the market-based component of the Environmental Protection Score that captures carbon taxes and cap-and-trade schemes in OECD countries increased by 29% by 2019 relative to its pre-Agreement average.

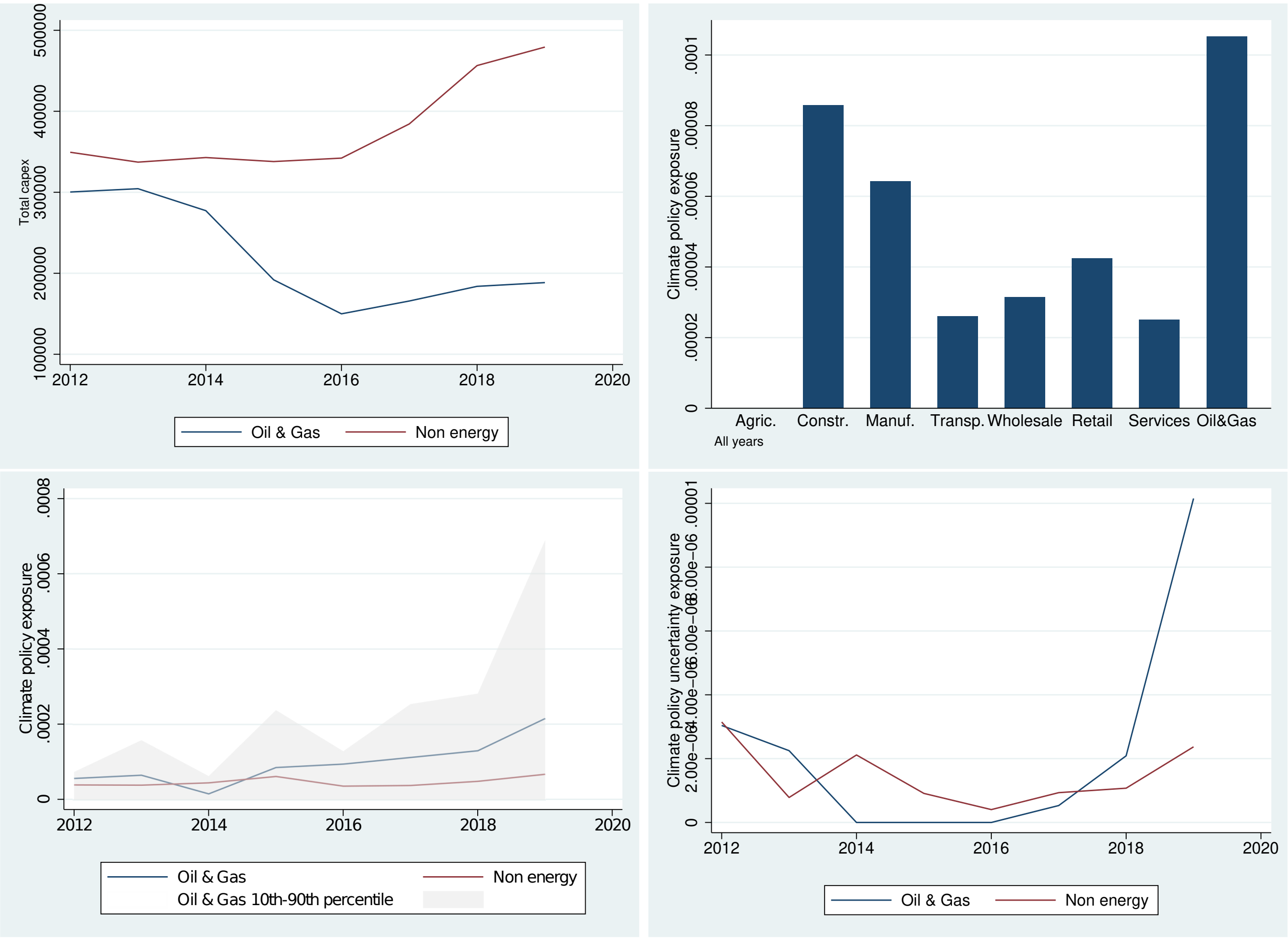

Figure 3: (A) Evolution of capex over time and by group (millions of USD). (B) Climate policy exposure by sector. (C) Evolution of climate policy exposure and (D) climate policy uncertainty in the oil and gas sector and non-energy sectors.

Table 1: Sample statistics by group and period

	Pre-2015				Post-2015			
	Non-energy		Oil and gas		Non-energy		Oil and gas	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Capex	376	(948)	3498	(6762)	342	(1003)	1791	3901
Altman	3.100	(3.561)	1.737	(1.513)	3.312	(5.236)	1.370	(1.911)
Total assets	8029	(16044)	28954	(65311)	7740	(16518)	22396	(54392)
Asset turnover	0.994	(0.658)	0.408	(0.565)	0.918	(0.591)	0.391	(0.546)
Debt-equity	1.685	(10.72)	0.851	(1.269)	1.464	(8.142)	1.333	(3.451)
Europe	0.176	-	0.159	-	0.176	-	0.159	-
Asia	0.070	-	0.052	-	0.070	-	0.052	-
Latin America	0.032	-	0.044	-	0.032	-	0.044	-
North America	0.676	-	0.664	-	0.676	-	0.664	-
Sub-Saharan Africa	0.008	-	0.015	-	0.008	-	0.015	-
MENA	0.012	-	0.015	-	0.011	-	0.015	-
Oceania	0.026	-	0.049	-	0.026	-	0.049	-
Agriculture	0	-	-	-	0.001	-	-	-
Construction	0.029	-	-	-	0.029	-	-	-
Manufacturing	0.547	-	-	-	0.547	-	-	-
Transp and Comm	0.182	-	-	-	0.182	-	-	-
Wholesale trade	0.049	-	-	-	0.049	-	-	-
Retail trade	0.005	-	-	-	0.005	-	-	-
Services	0.186	-	-	-	0.186	-	-	-

[a] **Note**: Standard deviations in parenthesis. Capex and total assets are in millions of USD. For industries and regions we show the share of firms in each category. The pre-2015 means refer to the window 2012-15, while those post-2015 to 2016-2019.

[b] **Source**: Authors' calculations on SP Market Intelligence data.

upstream oil and gas investment and the widening gap with respect to the rest of economy, especially after 2015.

Finally, table 1 shows summary statistics based on the estimation sample by group and time period for our outcome variable and the covariates used in the analysis. Oil and gas companies have higher total assets (million US $) reflecting the bigger average firm size and higher capital intensity of the sector. The financial capital structure is different across groups before 2015 with oil and gas firms being considerably less indebted, while the two groups appear to have a similar financing mix post 2015, as oil and gas firms increased their debt capital over time. Non-energy firms appear in better financial health on average, as shown by a higher Altman score. Asset turnover - ratio of sales to total assets - is higher among non-energy firms, indicating higher efficiency to generate revenues from their assets. Finally, between 70 and 97 percent of variation in our exposure measures plays out at the firm level

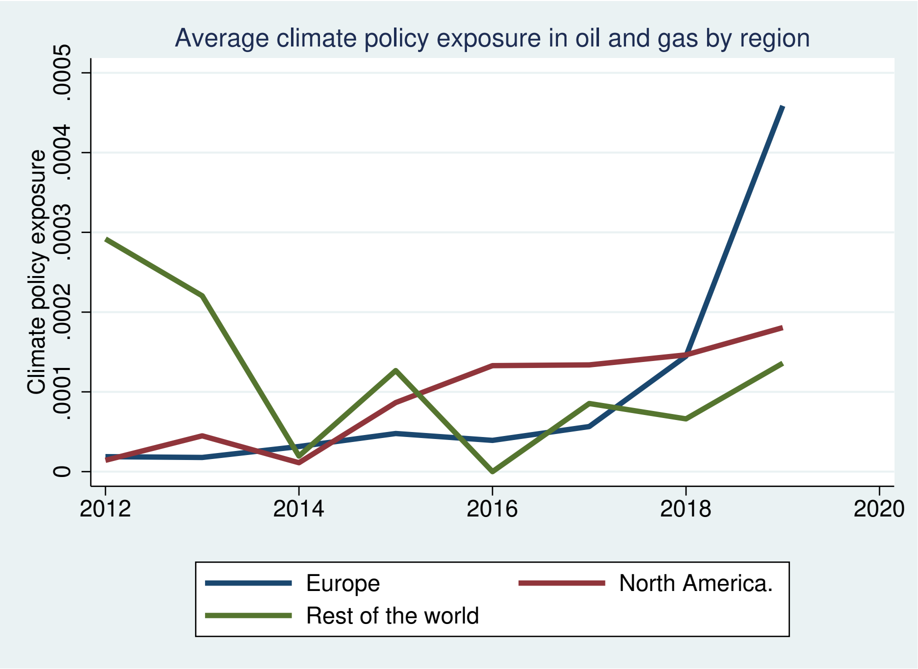

Figure 4: Evolution of climate policy exposure by region.

(rather than at the country or industry level or over-time). Only half of this firm-level variation is persistent, suggesting that firms within an industry are differentially exposed to climate policy over time.

4 Empirical Strategy

Following previous studies, we use the signing of the Paris Agreement as a regime change moment for climate policy (e.g., Delis, De Greiff, and Ongena (2019) and Ehlers, Packer, and Greiff (2022)). The difference-in-difference (DiD) identification rests on the comparison of the before-after change in investments for oil and gas firms with the corresponding change occurred in non-energy firms, whose risks implied by climate policy exposure were affected less or not at all. The specification reads

$$y_{it} = \beta_0 D_i + \beta_1 T_t + \left(\beta_2 P_{oil,t} + \beta_3 T_t\right) D_i + \beta_4 X_{it} + \lambda_s + \lambda_r + \lambda_{rt} + \epsilon_{it} \tag{9}$$

where y_{it} is the log capital expenditure for firm i in year t, D_i is the (treatment) group dummy equal to 1 for oil and gas companies and 0 otherwise. Further, T_t is a post-2015 period dummy aimed at capturing the regime change for the oil and gas sector induced by the Paris Agreement. The vector X_{it} is a set of controls that includes a constant, log total assets, debt to equity ratio, asset turnover, and the Altman credit strength. Log oil prices ($P_{oil,t}$) are introduced interacted with the group dummy, as they may affect the two groups differently. We include λ_s, λ_r, and λ_{rt}, which represent industry fixed effects, region fixed effects, and region-specific time fixed effects, respectively.[20]

An OLS estimate of β_3 identifies an economically meaningful treatment effect under the standard assumptions of parallel trends and no anticipatory effects. The latter is less of an issue. If the Paris Agreement was anticipated, oil and gas firms could have changed their investment decisions one year before the Agreement. Considering the influence of lobbying and the fact that governments consult industry professionals prior to implementing significant legislative changes, anticipation seems plausible. On the other hand, lessons from previous rounds (such as the Kyoto Protocol in 1997) were disappointing, likely curbing expectations on the ambition of the Paris' agreement.[21] All in all, even if anticipation played a role, this is less concerning since β_3 would be biased upward towards zero.

The parallel trends assumption (or violation thereof) is more concerning since it requires that, on average, investment by fossil fuel and non-energy firms would have followed parallel trends in absence of the Paris Agreement. However, time-varying macroeconomic factors might affect investment in the two groups in different ways. For example, the fall in oil prices, like the one observed between 2014 and 2016, probably pushed down investment in the fossil fuel sector while stimulating it in the rest of the economy.[22] Without controlling for oil prices, $\hat{\beta}_3$ would show a negative bias, since the coefficient on the treatment dummy would also pick up effects from the US shale revolution that in terms of timing overlaps with the adoption of the Paris Agreement. While the specification controls for spot oil prices, other global macro shocks not included in equation (9) that affect the two groups differently would

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[20] We group firms in seven geographical regions according to the country where the firm is located: Europe, Central Asia, East, South and Southeast Asia, North America, Central and South America, Middle East and North Africa, Sub-Saharan Africa. Subsidiaries are observed as separate entities. Industry groups include: Agriculture, Construction, Manufacturing (excluding refineries), Transportation and Communications (excluding pipelines and power sector), Wholesale Trade, Retail Trade, Services, (excluding Finance, Insurance, Real Estate and Public administration).

[21] Long-term views on the energy transition, however, were not affected significantly by Trump's election (Ramelli, Wagner, Zeckhauser, Ziegler, and Alexandre, 2018).

[22] A possible additional concern is firms' self-selection into or out of treatment groups; this is, however, not a problem if it has time-invariant impact on the the firm's investment (moreover it is reasonable to assume that a firm belonging to a specific industry in a given year is unrelated to climate regulation).

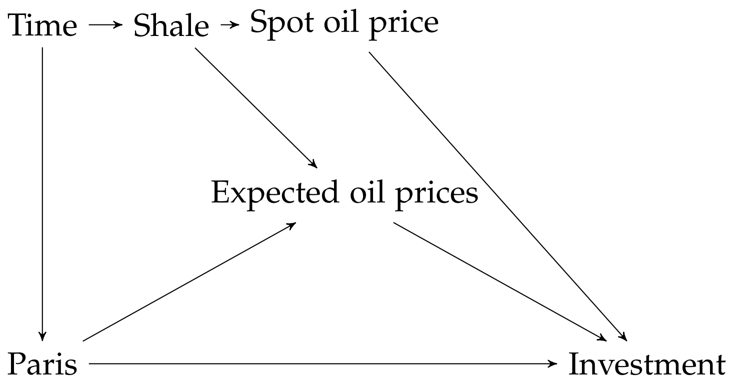

Figure 5: Identifying causal effects of Paris.

result in an omitted-variable bias for the coefficient of the interaction term, $\hat{\beta}_3$. Perhaps the most concerning issue is potential changes to long-dated oil price expectations which could have been induced by both Paris and the shale revolution, and that are not captured by spot oil prices since those mostly reflect current oil market conditions. (This possibility is shown in the directed acyclic graph (DAG) in figure 5). The shale revolution, in fact, may have reduced the scarcity rent in the oil market and OPEC's bargaining power, all else equal.[23] Previous research has also shown that the shale oil boom of the early 2010s led to a slump in oil prices between 2014 and 2016 and to a strong fall in oil and gas investments, while other sectors saw a slight uptick in investments, as windfall consumer income from lower oil prices increased demand for goods and services in other sectors (Baumeister and Kilian, 2016). Such asymmetric effects would lead to a violation of parallel trends. Although far from being a test of parallel trends, the top-left chart of figure 3 fails to provide suggestive evidence of the validity of such assumption. For these reasons, we view the estimate of β_3 in equation 9 as upward biased in magnitude since it may be capturing the effect of other factors beyond climate policy which contributed to widening the cross-group gap in investment after 2015 either by discouraging fossil fuel investments or stimulating investment in the rest of the economy.

Our richer, preferred specification exploits firm-level cross-sectional heterogeneity with respect to climate risk and exposure—which is substantial also within the oil and gas industry (see Figure 3, bottom left chart). We, thus, move from comparing investment across sectors and time to exploring how investment reacts to a marginal change in firm-specific exposure

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[23] The shale revolution for oil and gas in the US induced a shift in the industry from oil (and gas) scarcity to abundance (Pescatori and Stuermer, 2022).

to climate policy. This should dispel some of the above mentioned concerns. We estimate

$$y_{it} = \beta_0 D_i + \beta_1 C_t + \beta_2 C_t D_i + \beta_3 X_{it} + \beta_4 R_{it} + \beta_5 D_i R_{it} + \lambda_s + \lambda_r + \lambda_{rt} + \epsilon_{it} \tag{10}$$

where R_{it} is one of our text-based measures, i.e., exposure to climate policy or to uncertainty around climate policy. Equation 10 is obtained from 9 by adding R_{it} and it's interaction with D_i, and replacing the term in parenthesis in front of D_i with an all-encompassing set of year dummies, C_t. The sum of coefficients $\beta_4 + \beta_5$ captures the impact on fossil fuel investment. Here $C_t D_i$ is an interacted group and time fixed effect capturing all business cycle factors that may affect the two groups differently (including oil prices, which are thus not included separately). The incorporation of $group \times year$ effects, along with other comprehensive fixed effects included in equation 10, effectively eliminate the impact of numerous unobserved factors that jointly drive investments and climate policy exposure. This serves as an initial safeguard against potential endogeneity concerning R_{it} (Pierce and Schott, 2016). Notwithstanding that, greenwashing might be a potential concern by inducing a firm's management to talk about climate policy during an earnings call to justify cuts in investment that happened for reasons unrelated to climate policy (e.g., bad drilling prospects). However, Sautner et al. (2023) emphasize that in most bigrams it is financial analysts who initiate a climate topic, hence situations in which management controls the conversation on climate policy are unlikely. Furthermore, in a recent study Green et al. (2022), who analyzed earnings' call transcripts from a selection of upstream oil and gas companies, find little evidence to support a case for systemic green-washing.[24]

5 Results

Table 2 presents the results for the DiD specification (equation 9).[25] After the Paris agreement, capital expenditure of a typical oil and gas company was 22.6 percent lower than the control

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[24] Green et al. (2022) assesses the political stance of oil and gas companies on decarbonization. The results show that public statements made by these companies were generally consistent with their actions towards investing in renewable energy sources, which is considered a reflection of their business behavior.

[25] Table 7 in the appendix shows results for a specification that does not include region fixed effects and their interactions with year effects.

group, after factoring in firm-level control variables and net of the effect of oil prices.[26] The slump in oil prices related to the shale boom-bust cycle plays also an important part in explaining investment movements. Halving oil prices, as it happened between 2014 and 2015, implies a 20 percent fall in investment by oil and gas firms *vis-à-vis* non-energy firms.

Table 2: Baseline DiD estimates

	(1)
D_i	-0.515
	(0.641)
T_t	-4.276
	(4.914)
$D_i \times T_t$	-0.256***
	(0.091)
$D_i \times P_{oil,t}$	0.326**
	(0.141)
Altman	-0.001
	(0.002)
Log Total Assets	0.998***
	(0.006)
Log Asset Turnover	0.221***
	(0.027)
Debt-Equity	0.000
	(0.001)
Region FE	YES
Industry FE	YES
Region x Year FE	YES
R^2	0.83
N	9174

[a] **Note**: $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$. Estimates from equation 9. $D_i = 1$ for oil and gas firms and 0 otherwise, $T_{it} = \mathbf{1}[t > 2015]$.

The rest of the controls have the expected sign but are not always significant. Firms with a broader asset base and higher revenues per unit of asset also tend to invest more. Leverage and financial health proxied by the Altman score do not seem to affect investments. As robustness, we re-estimate equation 9 after replacing the group dummy with the full set of industry dummies that make up the comparison group. The interaction coefficients are

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[26] Let y_t (Y_t) be the natural log (level) of investment. Then the treatment effect of the Paris agreement is calculated as $y_t - y_{t-1} = log\left(1 + \frac{Y_t - Y_{t-1}}{Y_{t-1}}\right) = \hat{\beta}_3 \Rightarrow \frac{Y_t - Y_{t-1}}{Y_{t-1}} = e^{\hat{\beta}_3} - 1 = -0.226$, since the usual logarithmic approximation becomes less precise for larger values of the growth rate.

similar in magnitude indicating that our baseline results are not driven by any specific sector (table 3).[27]

Table 3: Baseline effects with alternative comparison groups

	(1)
Construction $\times T_t$	0.368**
	(0.187)
Manufacturing $\times T_t$	0.298***
	(0.093)
Transp and Comm $\times T_t$	0.258**
	(0.110)
Wholesale trade $\times T_t$	0.208
	(0.141)
Retail trade $\times T_t$	0.505**
	(0.242)
Services $\times T_t$	0.162
	(0.104)
Region FE	YES
Industry FE	YES
Year FE	YES
Group x Year FE	YES
Region x Year FE	YES
R^2	0.82
N	9174

[a] **Note**: $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$. Estimates from equation 9 in which the group dummy is replaced by the set of dummies spanning all industries in the comparison group, with the oil and gas group serving as the reference category. $T_{it} = \mathbf{1}[t > 2015]$. Agriculture is dropped due to lack of observations before 2015.

The DiD specification cannot disentangle the effects of climate policies and the shale revolution on long-term prospects for the industry and, more generally, other unobserved time-varying confounders may affect the two groups differently, thus unduly widening the cross-group gap after 2015. Both circumstances are bound to bias upwards the DiD estimates, which is why we turn to our preferred richer specification. Table 4 shows coefficient estimates from equation 10 for our two text-based measures.[28]

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[27] Only the coefficient estimates of the interaction terms $D_i C_{it}$ are shown. These have a positive sign, since oil and gas is the excluded category.

[28] Table 8 in the appendix shows results for a specification that does not include region fixed effects and

A 1 standard deviation increase in climate policy exposure leads to a 3 percent fall (0.078-0.049) in investment in the oil and gas sector. Climate policy uncertainty has an even stronger effect than the first moment, with a typical shock reducing investment by around 4 percent (0.023-0.064) (see R_{2it} in Table 4). In the control group, instead, investment increases by 4.9 percent (main effect of R_{1it})—possibly indicating that climate is more an opportunity than a threat for non-fossil fuel firms, overall. The effect of uncertainty is positive too, albeit smaller than the impact of the first moment (0.023) (column 2).

These effects are also economically meaningful. If an oil and gas firm was to move from the median to the 95th percentile of the climate policy exposure, the resulting fall in investment would be around 6 percent—that is, $(0.078 - 0.049) \times (2.42 - 0.24)$. We also estimate an aggregate effect for the upstream oil and gas industry. First, for each oil and gas firm we multiply $\beta_4 + \beta_5$ by the change in climate policy exposure between 2015 and 2019 experienced by the firm and the level of investment realized in 2015. We then aggregate over all oil and gas firms the change in investment implied by the exposure to climate policy during this period and divide it by total investment in the industry in 2015. Estimates based on equation 10 imply that upstream oil and gas investment fell by 6.5 percent in the post-2015 period as a result of a strengthening of climate policies.[29]

Finally, in column 3 of table 4 we show estimates for a specification of equation 10 where we include interactions of the two text-based measures between each other and with the group dummy. Climate policy uncertainty has a stronger effect conditional on a higher climate exposure, but, reassuringly, not vice versa.

Since empirical results support the Neoclassical investment model, we can hypothesize two main mechanisms are at work: 1) an expectation channel related to future demand-side climate policies aimed at curbing demand for carbon; and 2) a supply channel that makes today's oil and gas investment more costly (either by increasing the cost of capital for oil and gas firms or through a stricter climate regulatory stance, such as a tougher methane emissions regulation). Regarding the suppy-side channel, the Paris Agreement might have pushed economic agents to behave more prosocial, and induced individual and institutional investors to factor in more environmental concerns into their investment decisions or simply demand-

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region-year fixed effects.

[29] Repeating the exercise for the change in the climate policy exposure measure over 2015-2021, we find an even larger reduction in investment of 12.7 percent.

Table 4: Effects of climate policy exposure and risk

	(1)	(2)	(3)
D_i	1.083***	1.027***	1.128***
	(0.141)	(0.141)	(0.158)
$D_i \times R_{1it}$	-0.078***		-0.072***
	(0.020)		(0.021)
R_{1it}	0.049***		0.046***
	(0.014)		(0.015)
$D_i \times R_{2it}$		-0.064***	-0.083
		(0.019)	(0.065)
R_{2it}		0.023***	0.041***
		(0.007)	(0.015)
$D_i \times R_{1it} \times R_{2it}$			-0.002***
			(0.001)
$R_{1it} \times R_{2it}$			0.004
			(0.009)
Altman	-0.001	-0.001	-0.001
	(0.002)	(0.002)	(0.002)
Log Total Assets	0.999***	0.999***	0.999***
	(0.006)	(0.006)	(0.006)
Log Asset Turnover	0.221***	0.221***	0.223***
	(0.027)	(0.027)	(0.026)
Debt-Equity	0.000	0.000	0.000
	(0.001)	(0.001)	(0.001)
Region FE	YES	YES	YES
Industry FE	YES	YES	YES
Year FE	YES	YES	YES
Group x Year FE	YES	YES	YES
Region x Year FE	YES	YES	YES
N	9174	9174	9174
R^2	0.82	0.83	0.83

[a] **Note**: $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$. Columns 1 and 2 show estimates from equation 10. In column 3, we add an interaction of our text-based measures (R_{1it}, R_{2it}) among each other and of these two with the group dummy ($D_i = 1$). $D_i = 1$ for oil and gas firms and 0 otherwise, R_{1it} is the climate policy and R_{2it} is uncertainty about climate policy.

ing higher returns in recognition of the higher risks faced by oil and gas firms from stronger climate policy (Bolton and Kacperczyk, 2021). Public interest in the "energy transition", as measured by Google Search popularity indices of the term, increased by seven times in the second half of the 2010s following a quiet period in the first half.

Furthermore, net of green-washing attempts by parts of the financial sector, there may have been material cuts to funds available for equity or debt financing of fossil fuel firms, raising their cost of capital and discouraging investment. In fact, Delis, De Greiff, and Ongena (2019) find that banks started to price the risks of climate policy change after the Paris Agreement by charging higher rates to fossil fuel firms relative to non-energy firms. Using a broader sample, Fard, Javadi, and Kim (2020) and Ehlers, Packer, and Greiff (2022) also show that after the Paris Agreement banks started charging higher interest rates when loaning to more polluting firms.

The Neoclassical investment model (see section 2.1) predicts that both future demand-side and current supply-side climate policies would reduce oil and gas investment today and raise oil and gas prices. While both channels might be at work, we view it as more likely that the change in climate policy stance might have led oil and gas firms to permanently revise downwards their expectations about future demand for oil and gas products which in turn may have spurred a wave of investments cuts in the industry. By reducing the existing stock of capital (and, thus, oil reserves), these investment cuts would have served to minimize potential losses from stranded assets. In contrast to current supply-side policies, only future demand-side policies would also lead to an contemporaneous increase in oil and gas companies' free cash flow, which seems more consistent with recent events.

5.1 Sensitivity analysis

To assess possible endogeneity concerns, we estimate a two-stage least squares specification of equation 10, where we use internal instruments constructed as lagged values of the potentially endogenous variables (Kiviet, 2019). Our text-based measure R_{it} and its interaction with D_i are instrumented by $\{R_{i,t-1}, R_{i,t-2}\}$ and $\{D_i R_{i,t-1}, D_i R_{i,t-2}\}$, respectively. The underlying assumption is that past climate policy exposure does not affect current investment other than through its influence on current exposure. A good case can be made to exclude lagged values of R_{it} from equation 10, since investment decisions are forward looking. In fact, as shown at the bottom of table 5, an over-identification test could not reject the null hypothesis of exogeneity of our instrument (Hansen's J statistic p value = 0.97) for the first moment of climate policy exposure. On the relevance front, our instruments seems sufficiently strong predictors of current exposure to climate policy. 2SLS estimates of $\beta_4 + \beta_5$ remain negative, statistically significant and similar in magnitude to the OLS result. In the case of climate policy uncertainty, the instrument passes the text of over-identifying restrictions (p value = 0.82), but is

Table 5: Instrumental variables estimates

	(1)	(2)
D_i	1.908***	1.878***
	(0.095)	(0.098)
$D_i \times R_{it}$	-0.108***	-0.452
	(0.041)	(0.300)
Rit	0.080**	0.476
	(0.038)	(0.295)
Altman	-0.003*	-0.002
	(0.002)	(0.002)
Log Total Assets	1.007***	1.007***
	(0.007)	(0.007)
Log Asset Turnover	0.229***	0.224***
	(0.030)	(0.030)
Debt-Equity	0.001	0.000
	(0.001)	(0.001)
Region FE	YES	YES
Industry FE	YES	YES
Year FE	YES	YES
Group x Year FE	YES	YES
Region x Year FE	YES	YES
R^2	0.84	0.83
Over-identification test	0.03	0.39
	(0.97)	(0.82)
D_i (weak identification)	28.06	1.24
	(0.000)	(0.291)
$D_i \times R_{it}$ (weak identification)	5.81	0.72
	(0.000)	(0.58)
N	6956	6956

[a] **Note**: $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$. 2SLS estimates of equation 10. $D_i = 1$ for oil and gas firms and 0 otherwise. R_{it} represents climate policy in column 1 and climate policy uncertainty in column 2. The last two rows show results of an F-test of the null hypothesis that instruments are jointly insignificant in the first stage.

only weakly correlated with current levels of climate policy uncertainty. Because of this, both β_4 and β_5 are blown out of proportion, although their sum is similar in magnitude to the corresponding OLS estimate.

Table 6: Effects of text-based measures of exposure over time

	(1)	(2)
D_i	1.122***	1.034***
	(0.145)	(0.145)
$D_i \times R_{it}$	-0.124***	0.027
	(0.047)	(0.029)
Rit	0.021	0.020***
	(0.022)	(0.006)
$T_t \times R_{it}$	0.047*	0.010
	(0.027)	(0.018)
$D_i \times T_t \times R_{it}$	0.035	-0.111***
	(0.051)	(0.040)
Altman	-0.001	-0.001
	(0.002)	(0.002)
Log Total Assets	0.999***	0.999***
	(0.006)	(0.006)
Log Asset Turnover	0.221***	0.221***
	(0.027)	(0.027)
Debt-Equity	0.000	0.000
	(0.001)	(0.001)
Region FE	YES	YES
Industry FE	YES	YES
Year FE	YES	YES
Group x Year FE	YES	YES
Region x Year FE	YES	YES
R^2	0.84	0.83
N	9174	9174

[a] **Note**: $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$. Estimates from equation 10 augmented with the interaction of our text-based measure with the post-2015 dummy $T_t \times R_{it}$ and the triple interaction $D_i \times T_t \times R_{it}$. $D_i = 1$ for oil and gas firms and 0 otherwise, $T_t = \mathbf{1}[t > 2015]$. R_{it} represents climate policy in column 1 and climate policy uncertainty in column 2.

We also investigate whether the signing of the Paris Agreement led to a change in momentum, as it increased awareness of fossil fuel firms about the risks and costs of stronger climate policy and of climate change in general. We test the hypothesis of a change in the slope of the relationship between investments and climate policy. We recast equation 10 by adding interaction terms of R_{it} and $R_{it}D_i$ with a post-2015 dummy (T_t).

$$y_{it} = \beta_0 D_i + \beta_1 C_t + \beta_2 C_t D_i + \beta_3 X_{it} + \beta_4 R_{it} + \beta_5 D_i R_{it} + \beta_6 T_t R_{it} + \beta_7 T_t D_i R_{it} + \lambda_s + \lambda_r + \lambda_{rt} + \epsilon_{it} \tag{11}$$

Results reported in table 6 show that the triple-interaction term $R_{it}D_iT_t$ is not statistically significant for the first moment of climate policy exposure indicating that the effect on investment did not intensify after the Paris Agreement. The triple interaction term is negative and statistically significant for the second moment indicating that the effects of exposure to climate policy uncertainty intensified after the Paris Agreement. We find that the effect of uncertainty on oil and gas investment turns negative only after 2015 ($\beta_4 + \beta_5$ = -0.054 se=0.021), while it is positive before the Agreement ($\beta_4 + \beta_5 + \beta 6 + \beta 7 = 0.047$ se=0.028). Firms may have started to more prominently factor in climate policy after the Paris Agreement, but ambiguity surrounding its possible impacts on future profits may have been a stronger driver than actual legislative changes.

6 Conclusion

Our empirical findings point to a detrimental impact of climate policies, and the associated uncertainty, on investment in the upstream oil and gas industry. A perceived increase in the exposure of oil and gas firms to climate policies has led to a 6.5 percent global decline of their capital expenditures between 2016 to 2019 (i.e., a -1.45 percent annual rate), after controlling for oil market tightness (i.e, spot oil prices), global factors, and other typical firm-level control variables. The investment gap is even more significant relative to the non-energy control group. There is also substantial within-industry heterogeneity with European oil and gas companies being affected the most.

These findings support the Neoclassical investment theory which predicts that announcing a stricter path of climate policy and regulation should reduce investment and increase oil and gas prices (and, thus, oil and gas free cash flow) in the initial stage of the energy transition. Uncertainty around climate policies has also a direct and additional negative impact on oil and gas investment, consistent with the real options theory of investment (see e.g., Dixit and Pindyck (1994)). The cut in investment can therefore be rationalized as the optimal response of oil and gas firms to a downward revision of future oil and gas demand, aimed at minimizing (the risk of) stranded assets. Therefore, financial risks stemming from stranded oil and gas assets seem minor as oil and gas companies would have time to adjust thanks to an initial period of relatively high free cash flow.

In its 2016 flagship report, the International Energy Agency (IEA) estimated that the implementation of all pledges announced up to that point, including the Paris Agreement, would result in an average annual decrease in oil and gas investments of 0.7 percent through 2040, relative to a business-as-usual scenario in which climate policy stringency remained at its pre-2015 levels (see IEA, 2016). However, our empirical evidence suggests that the actual contribution of climate policy exposure to divestment has been even larger than what was forecasted in the IEA's stated policies scenario (compare -1.45 to -0.7), pointing to potential underinvestment as global oil and gas demand is curbed only in the more distant future. In fact, extrapolating our results, climate policy exposure accounted for a cumulative 12 percent reduction in oil and gas investment between 2015 and 2021, contributing to the reduced price elasticity of supply observed during the 2021-2022 energy crisis.

Overly optimistic expectations about the pace of the energy transition by fossil-fuel firms coupled with a negative effect of climate policy uncertainty (which in theory delays both fossil fuel and renewable investment) may thus result in a shortfall of energy supply, leading to sustained upward pressure on fossil fuel prices and a more volatile energy price environment. A credible commitment to a climate policy path by policymakers is, thus, vital for guiding market actors through the energy transition. There is also an international dimension to the problem requiring policy coordination between fossil fuel consumer and producer countries.

From the perspective of the private sector, clear and consistent signals by trusted authorities about the direction of climate policy and the pace of the energy transition can help them to adjust their investment plans and align expectations with the goals of the low-carbon transition. This can reduce uncertainty, encourage investment in renewable energy, and incentivize the proper amount of fossil fuel divestment. Indeed, a key challenge for policy makers is to ensure that the pace of fossil fuel phase out is commensurate to that of investment in renewable energy to minimize the risk of a disorderly transition and of macroeconomic shocks.

Declaration of Interest

The authors declare that they did not receive external funding for this research, and that they have no relevant or material financial interests that relate to the research described in this paper.

Data Availability Statement

The data underlying this article will be shared upon request to the corresponding author.

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Appendix: Tables and figures

Table 7: Baseline DiD estimates without regional FE

	(1)
D_i	-0.587
	(0.635)
T_t	0.032
	(0.154)
$D_i \times T_t$	-0.252***
	(0.090)
$D_i \times P_{oil,t}$	0.324**
	(0.139)
Altman	-0.001
	(0.002)
Log Total Assets	0.997***
	(0.005)
Log Asset Turnover	0.220***
	(0.026)
Debt-Equity	0.000
	(0.001)
Region FE	NO
Industry FE	YES
Region x Year FE	NO
R^2	0.83
N	9174

[a] **Note**: $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$. Estimates from equation 9 omitting regional fixed effects and their interactions. $D_i = 1$ for oil and gas firms and 0 otherwise, $T_{it} = \mathbf{1}[t > 2015]$.

Table 8: Effects of climate policy exposure and risk without regional FE

	(1)	(2)	(3)
D_i	1.001***	0.950***	1.045***
	(0.105)	(0.103)	(0.109)
$D_i \times R_{1it}$	-0.078***		-0.071***
	(0.019)		(0.021)
R_{1it}	0.048***		0.045***
	(0.014)		(0.015)
$D_i \times R_{2it}$		-0.065***	-0.082
		(0.019)	(0.064)
R_{2it}		0.022***	0.039***
		(0.007)	(0.015)
$D_i \times R_{1it} \times R_{2it}$			-0.002***
			(0.001)
$R_{1it} \times R_{2it}$			0.004
			(0.009)
Altman	-0.001	-0.001	-0.001
	(0.002)	(0.002)	(0.002)
Log Total Assets	0.998***	0.998***	0.998***
	(0.005)	(0.005)	(0.005)
Log Asset Turnover	0.220***	0.221***	0.220***
	(0.026)	(0.026)	(0.026)
Debt-Equity	0.000	0.000	0.000
	(0.001)	(0.001)	(0.001)
Region FE	NO	NO	NO
Industry FE	YES	YES	YES
Year FE	YES	YES	YES
Group x Year FE	YES	YES	YES
Region x Year FE	NO	NO	NO
N	9174	9174	9174

[a] **Note**: $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$. Columns 1 and 2 show estimates from equation 10 omitting regional fixed effects and their interactions. In column 3, we add an interaction of our text-based measures (R_{1it}, R_{2it})among each other and of these two with the group dummy ($D_i = 1$). $D_i = 1$ for oil and gas firms and 0 otherwise, R_{1it} is the climate policy and R_{2it} is uncertainty about climate policy.

Supplementary Appendix: Models

Neoclassical Oil and Gas Investment Model

The solution to the neoclassical investment model is found by combining the firm's first order conditions with the equilibrium in the oil and gas market. This gives a system of 5 equations in 5 unknowns, that is, $\{y, k, \lambda, I, p\}$:

$$
\begin{aligned}
y_t &= A_t k_{t-1}^{\alpha} && (12)\\
(1-\delta)k_{t-1} + I_t - \Phi(I_t/k_{t-1})k_{t-1} &= k_t && (13)\\
\alpha p_{t+1} A_{t+1} k_t^{\alpha-1} + \lambda_{t+1}[1-\delta-\Phi_{t+1}+\Phi'_{t+1} I_{t+1}/k_t] &= \lambda_t/\beta && (14)\\
1+\tau_{p,t} &= \lambda_t[1-(I_t-\delta k_{t-1})] && (15)\\
y_t &= c_0[(1+\tau_{c,t})p_t]^{-\eta} && (16)
\end{aligned}
$$

where $\{A_t\}_{t=0}^{\infty}$ and $\{\tau_t\}_{t=0}^{\infty}$ represent known exogenous processes, $\tau = (\tau_c, \tau_p)$. The initial steady state is solved under zero taxes and constant A and it is taken as starting point. The transition path to the new steady state is found by solving numerically the above system of difference equations. In the numerical exercise, $\tau_p = 0$ at all times.

Green paradox model

The current value Hamiltonian reads:

$$H_c = P_t R_t - \lambda_t R_t \tag{17}$$

where λ_t is the current shadow price of the resource stock. If a solution exists the following necessary conditions must hold:

$$R_t > 0 \text{ implies } \frac{\partial H_c}{\partial R_t} = P_t - \lambda_t = 0 \tag{18}$$

$$\dot{\lambda}_t - i\lambda_t = -\frac{\partial H_c}{\partial S} = 0. \tag{19}$$

Differentiating eq. (18) and combining it with eq. (19) we obtain Hotelling's rule,

$$\frac{\dot{P}}{P} = i, \tag{20}$$

which says that the oil producer price must rise with the rate of interest (reflecting the fact that all intertemporal arbitrage opportunities are exploited). Integrating eq. (20) we can solve for the producer price path,

$$P(t) = P_0 e^{it} \tag{21}$$

which will be fully pinned down once we have solved for P_0. We close the model with the following inverse demand function,

$$(1 + \tau_{c,t})P_t = Ke^{-aR_t} \tag{22}$$

where $\tau_{c,t}$ is a carbon-tax on oil consumption, $(1 + \tau_{c,t})P(t)$ is thus the consumer price of oil, $a > 0$ is a price elasticity of demand parameter, and K is the so-called choke-price at which oil demand falls to zero (presumably because there is a backstop technology).

Consider a scenario in which a regulator announces a constant carbon tax at time 0, which is implemented with certainty at time $t_0 > 0$. The solution consists of two regimes. For sufficiently low values of t_0 an interior solution exists, in which oil firms supply and sell oil both before and after the implementation of the carbon tax ($0 < t_0 < T$). In contrast, for sufficiently high values of t_0 there exists a corner solution in which oil firms decide to sell the last barrels of oil just in time before the implementation of the carbon tax ($T = t_0$).

Interior solution to delayed carbon tax: $0 < t_0 < \overline{t_0}$.

In this case the oil stock goes to zero at exactly the same time as demand and extraction go to zero. The terminal condition, i.e., the producer price at time T, thus equals:

$$P_T = P_0 e^{iT} = \frac{K}{1+\tau_c} \text{ for } t_0 \leq \overline{t_0} \tag{23}$$

where $\overline{t_0}$ (to be determined later) is the maximum delay for which there exists an interior solution, $t_0 < T$. Keeping T fixed, eq. (23) shows that on announcement P_0 and thus the entire price path are shifted downwards, $\frac{\partial P_0}{\partial \tau_c} < 0$. As in this solution regime depletion time T is endogenous we also need to know the effect of the carbon tax on T to fully understand the shift in the price path.

Substituting for P_t and K from respectively eq. (21) and eq. (23) into eq. (22), we can postulate the oil market equilibrium condition before and after tax implementation:

$$P_0 e^{it} = (1+\tau_c) P_0 e^{iT} e^{-aR_t}, \quad \text{for } 0 < t < t_0 \tag{24}$$

$$(1+\tau_c) P_0 e^{it} = (1+\tau_c) P_0 e^{iT} e^{-aR_t}, \quad \text{for } t_0 \leq t \leq T \tag{25}$$

which we can rearrange to get the path of extraction:

$$R_t = \begin{cases} \frac{i(T-t)+log(1+\tau_c)}{a} & \text{for } 0 < t < t_0 \\ \frac{i(T-t)}{a} & \text{for } t_0 \leq t \leq T \end{cases} \tag{26}$$

Substituting this solution into the resource constraint eq.7, we can solve for T,

$$T = T(t_0) = \sqrt{\frac{2}{i}\left(aS_0 - t_0 log(1+\tau_c)\right)} \tag{27}$$

from which we deduce that $\overline{T} = \sqrt{\frac{2aS_0}{i}}$.[30] Total depletion time is shorter the longer the delay,

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[30] From eq. (26) and eq. (27) we learn that, provided the delay is strictly positive ($t_0 > 0$), the rate of extraction till t_0 will jump at the date of announcement and be higher on the interval $[0, t_0)$ than before, while it falls from date t_0 onwards and be smaller over the interval $[t_0, T(t_0)]$ than before.

$\frac{\partial T}{\partial t_0} < 0$, and the greater the carbon tax, $\frac{\partial T}{\partial \tau_c} < 0$.

Corner solution to delayed carbon tax: $\overline{t_0} \leq t_0 < \overline{T}$

Eq. (27) suggests that t_0 and T will eventually "cross", that is, $\overline{t_0} = T(\overline{t_0})$. This upperbound equals the positive root of the quadratic equation that can be derived by setting $T = \overline{t_0}$ in eq. (27) and rearranging:

$$\frac{i}{2}\overline{t_0}^2 + log(1+\tau_c)\overline{t_0} - aS_0 = 0 \tag{28}$$

For values of t_0 beyond $\overline{t_0}$, the interior solution described by eq. (27) no longer holds, because it suggests that despite $t_0 > T$, further increases in t_0 continue to reduce the value of T, which is not possible.

This suggests there also exists a corner solution in which oil firms decide to fully deplete the stock just in time before the implementation of the carbon tax. Indeed, our conjecture is that for $t_0 \geq \overline{t_0}$ we have $T = t_0$, until the carbon tax no longer binds, i.e., $T = \overline{T}$ for $t_0 > \overline{T}$. So in the corner solution regime the depletion time is exogenous but the producer price at time $T = t_0$ is endogenous. We can now write the terminal condition as:

$$P_{t_0} = P_0 e^{it_0} = Ke^{-aR_{t_0}} \in \left(\frac{K}{1+\tau_c}, K\right) \tag{29}$$

where we note that P_{t_0} is bounded from above by K otherwise, as before, demand will fall to zero. There is also a lower bound, because if the terminal price in the before-tax period would fall below $\frac{K}{1+\tau_c}$, the firm would be better off selling some oil in the after-tax period too, during which $\frac{K}{1+\tau_c}$ is the maximum producer price.

We can then use this terminal condition to remove P_0 from the inverse demand equation, $P_0 e^{it} = Ke^{-aR_t}$, to write extraction as a function of the terminal price:

$$R_t = \frac{i(t_0 - t) + log\left(\frac{K}{P_{t_0}}\right)}{a} \tag{30}$$

Substituting this solution into the resource constraint, $\int_0^{t_0} R_t dt \leq S_0$, we can solve for the terminal price:

$$P^*_{t_0} = Ke^{-\left(\frac{aS_0 - i(t_0)^2}{t_0}\right)} \tag{31}$$

The initial price at time 0 then also immediately follows, i.e., $P_0 = e^{-it_0} P^*_{t_0}$.

If we set $P^*_{t_0}$ equal to the lower bound $\frac{K}{1+\tau_c}$, we can solve for the minimum delay $\underline{t_0}$ that is needed for this corner solution regime to be optimal for the representative oil firm. As it turns out, this expression reads:

$$\frac{i}{2}\overline{t_0}^2 + log(1+\tau_c)\overline{t_0} - aS_0 = 0 \tag{32}$$

which is identical to eq. (28). In other words, we have found $\overline{t_0} = \underline{t_0}$, such that we have "taped" the two solution regimes together.

Green Paradox: non-monotonic relationship between delay and depletion time T.

Inspecting the two solution regimes, we find that depletion of the stock is brought forward in time for any carbon tax that is both delayed and binding, that is, $0 < t_0 < \overline{T}$. However, the relationship between t_0 and T is non-monotonic: up to time $\overline{t_0}$ a larger delay brings extraction forward in time, $\frac{dT}{dt_0} < 0$ for $t_0 < \overline{t_0}$, but after $\overline{t_0}$ a larger delay pushes extraction backwards in time, $\frac{dT}{dt_0} > 0$ for $t_0 \geq \overline{t_0}$. Thus, for initial increases in the delay the green paradox worsens, but at some point further delays in the implementation of the carbon tax will soften the green paradox. Formally, we can write:

$$T = \begin{cases} \sqrt{\frac{2}{i}\left(aS - log(1+\tau_c)t_0\right)} \equiv T^*(t_0) & \text{for } \ 0 < t_0 < \overline{t_0} \\ t_0 & \text{for } \ \overline{t_0} \leq t_0 < \overline{T} \\ \overline{T} & \text{for } \ \overline{T} < t_0 \end{cases} \tag{33}$$

PUBLICATIONS

The Impact of Climate Policy on Oil and Gas Investment: Evidence from Firm-Level Data

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