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ABSTRACT

Do capital markets reflect the possibility that fossil fuel reserves may become "stranded assets" in the transition to a low carbon economy? We examine the relation between oil firms' value and their proved reserves. Using a sample of 679 North American oil firms for the period 1999 to 2018, we document that while reserves are an important component of oil firm value, the growth of these reserves has a negative effect on firm value. This negative effect on value is stronger for oil producers with higher extraction costs. When we decompose total reserves into developed and undeveloped reserves, we show that the negative effect of reserves growth on value is due to firms growing their undeveloped oil reserves. Unlike developed, undeveloped reserves require major capital expenditures and longer time before they can be extracted. We also document that the negative effect is stronger for undeveloped oil reserves located in countries with strict climate policies. Our evidence is consistent with markets penalizing future investment in undeveloped reserves growth due to climate policy risk. High level of institutional ownership, stock market liquidity and analyst coverage do not change the negative effect of undeveloped reserves growth on firm value.

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"…. according to Carbon Tracker, a think-tank, more than half the money the big oil companies plan to spend on new fields would be worthless in a world that halved emissions by 2030." *The Economist, September 21st, 2019*

"Stranded assets" are assets at risk of becoming obsolete from unanticipated or premature write-offs due to regulatory or environmental changes. In this paper, we examine whether the valuation of fossil fuel firms is affected by the risk that their reserves will become stranded in the transition to a low-carbon economy. This possibility could cause considerable losses for investors and other stakeholders of these firms thus highlighting the importance of pricing climate change risks.

We focus on North American oil producers and their reserves for several reasons. First, the markets for oil firms' equities and crude oil and many oil products are very liquid, whereas the markets for coal and coal firms' equities are more fragmented and less liquid, with the markets for natural gas in-between. Second, North American oil producers face very low political risk, and foreign exchange exposure. These firms are also subject to stringent regulation and monitoring unlike firms in other countries that are traded in markets that are (possibly) fragmented, illiquid, and vulnerable to manipulation. Finally, conventional oil production has now peaked and is on a long-run global decline. However, contrary to the conventional wisdom of the 1970s and 1980s, oil is not running out. It is, instead, changing form to unconventional oils that require new, highly energy intensive production techniques and new processes to deal with their inaccessible placements or unusual compositions[1]. Based on current technology, there are about 1,115 billion barrels of unconventional oil reserves in North America. According to scientists, if all of these were exploited, the resultant emissions would be 980 giga-tones of CO_2, with the corresponding increase in atmospheric CO_2 beyond the threshold above which we risk a global extinction event.

[1] Unconventional fossil fuels are much more energy intensive to produce and consequently generate far more carbon emissions: Canadian Oil Sand extraction produces three times the emissions of conventional oil, while US Oil Shale produces eight times the emissions.

In the United Nations Climate Change (UNCC) 2015 Paris agreement, world governments confirmed their intention to limit global warming "well below 2°C above pre-industrial level" and pursue efforts to "limit the temperature increase to 1.5°C". The upper limit of 2°C is a frequently used reference point for defining a carbon budget – the maximum amount of CO2 that can be emitted. The 2018 report of the International Energy Agency suggests that to have any chance of hitting the 2°C target requires drastic, immediate cuts in fossil fuel use.

In this paper, we document that total proved reserves are an important component of oil firm value. The growth of these reserves, however, decreases value[2]. When we decompose total reserves into developed and undeveloped, we show that the positive effect is due to the amount of developed oil reserves and the negative effect is due to the growth of undeveloped oil reserves. There is a distinction between developed and undeveloped proved oil reserves. The former are reserves which can be extracted from existing wells while the latter are classified as reserves from new wells on undrilled acreage or existing wells where a relatively major expenditure is required for completion[3].

Since both developed and undeveloped reserves are assets for the oil producer, they should have a positive (or at least non-negative) effect on their value.[4] Our results suggest that capital markets value only reserves that are already developed while the growth of undeveloped reserves has an economically and statistically significant negative effect on oil producers' value. In particular, one standard deviation increase in the growth of undeveloped proved reserves decreases firm value (Tobin's *Q*) by more than 1%. This effect is stronger for oil producers with

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[2] The U.S. Securities and Exchange Commission (SEC) uses the term "proved reserves" for oil and gas and "proven reserves" for coal reserves. Proved oil reserves are the estimated quantities of oil that, with reasonable certainty, are recoverable under existing economic and operating conditions. These estimates are based on available geologic and engineering data.

[3] Before 2010, the U.S. Securities and Exchange Commission, allowed only proved reserves to be publicly reported. After 2010, firms can also report probable and possible reserves. Probable reserves are reserves that have an estimated confidence level of approximately 50% of being successfully recovered. Possible reserves are those with only 10% estimated probability of recovery. The SEC requires the lower probability of recovery to be verified by a third party before an oil company can publicly report probable and possible reserves to potential investors.

[4] Oil reserves are by far the most important assets that oil firms own. Financial analysts and investors pay great attention to information related to reserve changes released from these companies. For example, when the Swedish oil company Lundin announced a significant discovery of oil and gas the Norwegian continental shelf in 2011, their share price appreciated more than 30% in one day. In January 2004, when Shell announced a 28% downward revision of their proved oil reserves, their share price fell 12% over the 3-4 weeks following the announcement.

higher extraction costs. Our results remain robust when we use alternative measures of firm value and oil reserves.

To examine further the effect of stranded assets risk on firm value, we hand collect data on reserves locations from the companies' annual reports. We show that the negative effect is stronger for oil producers with large undeveloped reserves in countries with strict climate policies. We also interact the growth in undeveloped reserves with an indicator variable for the period before the Paris (2015) agreement to examine if there has been a change in the sensitivity of firm value to undeveloped oil reserves growth. Our empirical results provide support for a strong negative effect after 2015. Overall, our evidence is consistent with markets penalizing firms' investment in undeveloped reserves growth due to climate policy risk. The markets seem to take into consideration, at least partially, that while these reserves require substantial capital expenditures to be developed, they might never be utilized.

We show that our main results remain the same when we carry out several robustness tests. We estimate our main results for the subsample of US firms only. Focusing on the sub-sample of US firms allows us to carry out a cleaner test of our main findings. For the US firms in our sample, we collect additional data on ownership and analysts' coverage. Therefore, we are able to examine the effect of these variables on the validity and strength of our results. Institutional investors are influential shareholders who can alter the information and trading environment of a firm and therefore affect its value. Our results show that while institutional ownership has a strong independent effect it does not explain or change the negative effect of undeveloped oil reserves growth on firm value. The results are similar when we consider analysts' coverage.

We also examine the effect of stock market liquidity on firm value and whether the effect of undeveloped reserves differs for stocks with different degree of liquidity. Our results suggest that stock market liquidity does not affect the relation between the growth of undeveloped oil reserves and the decrease in firm value. We include the (logarithm of) crude oil price in all our regression specifications to ensure that our results are not driven by the developments of the underlying commodity price, and in particular the large drop in oil prices after 2014.[5] Finally, in all our regression specifications, we control for the variables that have been shown to affect firm value as well as include firm and time fix effects.

Prior evidence suggests that investors are already considering climate change risks as relevant. For example, Krueger, Sautner and Starks, (2019) document that larger long-term, and environmental, social and governance (ESG)-oriented investors actively manage their climate risk exposure (e.g. analyzing portfolio firms' carbon footprints and stranded asset risks). Krueger et al (2019), however, show that perceived overvaluations of fossil fuel firms are not large and that most investors do not consider divestment as the most effective approach for addressing climate risks. Ilhan, Sautner and Vilkov, (2018) show that climate policy uncertainty is priced in the option market. Specifically, the cost of option protection against tail and variance risks is larger for firms with more carbon-intense business models.

We contribute to several strands of the literature. First, our paper is related to the literature on the so-called "carbon bubble". The Carbon Tracker Initiative (2013) was the first attempt to estimate the amount of stranded fossil fuel reserves of listed firms based on the global carbon budget from 2000-2050 aimed at limiting global warming to 2°C above pre-industrial levels. Papers in *Nature* (e.g. McGlade and Ekins, 2015) estimate that at least 33%-35% of current oil reserves will not be usable if this objective is to be met. Despite the large proportion of potentially unusable "stranded" reserves, oil companies still invest predominantly in locating and developing new reserves. Previous studies have failed to document a negative market reaction to these large exploration expenditures. This fact has prompted academics and policy makers to argue that financial markets might carry a "carbon bubble". Studies have also examined the effect of a possible carbon bubble on financial stability and economic development (see, e.g. Weyzig, Kuepper, van Gelder, and van Tilburg 2014; Schoenmaker, van Tilburg, and Wijffels 2015; Batten, Sowerbutts, and Tanaka 2016).

Our paper also contributes to the literature concerned with pricing the implications of climate risk (see, e.g., Andersson, Bolton, and Samama (2014), Daniel, Litterman, and Wagner (2015), or Litterman (2013)), and the uncertainty about climate change policies (see Freeman,

[5] In a robustness test, we show that our results remain the same when we use changes and volatility of oil prices instead of logarithm of oil price.

Wagner, and Zeckhauser (2015)). HSBC (2013) report is the first study to estimate the value-at-risk (VaR) from stranded assets for the six largest oil and gas companies (Shell, BP, Total, Statoil, Eni, and BG). They measure the amount of unburnable reserves based on costs data from Wood Mackenzie[6]. The study shows that a moderate reduction in the demand for oil (due to stranded reserves) could reduce the firms' equity value by 40% to 60%. Batten, Sowerbutts, and Tanaka (2016) analyze the market reaction to climate change news in an event study that covers the period 2011-2016. They examine news which contains the words "carbon bubble", "unburnable carbon", or "fossil fuel divestment". They find a positive and significant effect on the abnormal return for renewable energy companies, and a negative but insignificant effect on the abnormal return of oil and gas companies. The authors argue that the insignificant effect is the result of investors' having difficulties assessing future climate policies and their long-run risks for fossil fuel companies. In a similar spirit, Byrd and Cooperman (2016) use events announcements concerning developments in the Carbon Capture and Storage (CCS) technologies for the period 2011 to 2015. They find a positive and significant effect for news on breakthroughs in CCS developments. Setbacks in CCS development, however, have a negative but insignificant effect on the abnormal returns of fossil fuel companies. The authors interpret this as evidence that, either investors have already priced in the potential risk of climate-related stranded fossil fuels, or investors believe that governments would never limit the production of fossil fuel.

In addition, recent asset pricing models have highlighted the importance of climate risks as a long-run risk factor. For example, Bansal, Ochoa, and Kiku (2017) study the welfare implications of rising temperature and propose a temperature-augmented long-run risks model that accounts for the interaction between temperature, economic growth and risk. Bolton and Kacperczyk (2019) and Hsu, Li and Tsou (2019) highlight the importance of carbon risks and environmental pollution in the cross-section of stock returns. Growing evidence indicates that climate risks may be mispriced in financial markets (Hong, Li, and Xu 2019; Daniel, Litterman, and Wagner 2017; Kumar, Xin, and Zhang 2019). At the firm level, Addoum, Ng, and Ortiz-Bobea (2019) show that extreme temperatures can adversely affect corporate earnings and Kruttli, Tran and Watugala (2019) show that extreme weather is reflected in stock and option

[6] The VaR of stranded assets is calculated by aggregating the values of all unburnable projects.

market prices. Ginglinger and Moreau, (2019) provide evidence that suggests that after the Paris Agreement, greater climate risk leads to lower firm leverage with firms decreasing their demand for debt and lenders reducing their lending to firms with the greatest risk.

Finally, our paper is related to the literature concerned with the financial effects of environmental regulation (see, e.g. Porter and Van der Linde (1995), Palmer, Oates, and Portney (1995), or Ambec, Cohen, Elgie, and Lanoie (2013)). The risk of stranded fossil fuel reserves and climate change risks in general are no longer considered to affect only future generations. A survey of institutional investors attitude towards climate change reveals that a large fraction of investors considers climate change risks (especially transition risks) as already present and believe these risks will materialize within the next five years (Krueger, Sautner, and Starks 2018). Ilhan, Sautner, and Vilkov (2018) measure climate risks exposure with firms' carbon emissions and identify an effect of carbon emissions on the downside risk of put options with two-year maturities.

The remainder of this paper is as follows. Section 2 motivates the paper and discusses the context of our research questions. Section 3 discusses the sample data and presents summary statistics. Section 4 describes our research design and Section 5 presents the main results of the paper. Section 6 concludes the paper.

2. Background to the study

Economic and population growth in the post-industrial era has caused large increases in carbon dioxide (CO_2) emissions that have been identified as the primary source of global warming. Since 1750, human induced carbon emissions have totaled almost 2,000 gigatonnes of CO_2 ($GtCO_2$). The 2014 report of the Intergovernmental Panel on Climate Change (IPCC) compares the global surface warming projections under different scenarios. Data from the IPCC report show that the major sources of emissions have been coal (34%), oil (25%), gas (10%), cement (2%) and land-use (29%). According to the report, global surface temperatures have warmed at a rate of about 0.15°C per decade since 1990, with the projections ranging from about 0.10°C to 0.35°C per decade. The IPCC, however, projects that from the mid-21st century onwards, the global temperature will depend crucially on the global emission path chosen by regulators and society in general.

Governments around the world have responded to the risk of such climate changes[7]. In December 2015, the United Nations Framework Convention on Climate Change (UNFCCC) established the Paris Climate Agreement to limit the rise in global warming to 2°C compared to pre-industrial levels by the end of the century and further put forward an even more ambitious limit of 1.5°C. Limiting global warming to 2°C above pre-industrial temperature will require massive reduction in CO_2 emissions. To meet the 2°C limit in 2100 with a probability larger than 66%, the total cumulative emissions must not exceed 2900 $GtCO_2$. By 2011 already about 1900 $GtCO_2$ have been emitted, leaving a budget of about 1000 $GtCO_2$ for the remaining 89 years (IPCC 2014). In their Nature paper, Allen et al. (2009) concluded that strict limits on the total carbon budget would be required if global warming by 2050 were not to exceed 2°C above pre-industrial levels. Meinshausen et al. (2009) estimated that to meet such goal, less than one-half of the world's economically recoverable oil, gas, and coal reserves could be extracted during the period 2007–2050. In a similar vein, McGlade and Ekins (2015) estimate that 33% to 35% of current global oil reserves, 49% to 52% of current global gas reserves, and 82% to 88% of global coal reserves would be unusable. The large fraction of potentially unburnable fossil fuels poses the risk of substantial financial losses to fossil fuel companies and their shareholders.[8]

Despite the large fraction of potentially stranded reserves, fossil fuel companies themselves find it "highly unlikely" that carbon emissions could be cut to reach the 2°C target by 2050 (Exxon Mobil, 2014). In addition, the largest fossil fuel firms have argued that carbon capture and sequestration (CCS) technology will become sufficiently feasible and affordable, therefore more of current fossil fuel reserves can be burned without exceeding the carbon budget. Caldecott, Kruitwagen, and Kok (2016), however, find that the slow deployment and

[7] The anticipated spike in temperatures will not affect the world evenly. Studies show that productivity peaks when temperatures average 55°F (13°C), meaning global warming may increase productivity in the northern countries while having devastating effects on the tropical countries, i.e. climate change could worsen global inequality.
[8] Recent lawsuits against oil giants such as BP, Chevron, Conoco-Phillips, ExxonMobil and Royal Dutch Shell, have highlighted claims that the companies and the industry they are part of have known for some time about the consequences of global-warming gases through the oil and gas products they have sold over the years, but sought to obscure them.

high cost of CCS make it very unlikely that the IPCC scenarios for wide-spread full-capacity CCS will be met.[9] Based on a cost comparison by Rubin, Davison, and Herzog (2015), CCS technology costs as much (and more) in 2015 as it did in 2005. In contrast, wind levelized cost of energy (LCOE) has decreased by 61% from 2009 to 2015 and utility-scale solar LCOE has decreased by 82%.[10],[11] Lazard's (2017) LCOE calculations show that utility-scale solar photovoltaic (PV) and wind energy have become cheaper than nuclear, coal, and even natural gas combined cycle.[12]

Nevertheless, Yergin and Pravettoni (2016) reject the existence of a carbon bubble for fossil fuel companies. They argue that 80% of the market capitalization for large oil companies reflects short to medium-term reserves (i.e. reserves that will reach the market in five to ten years), whereas the transition to renewable energy may take decades[13]. With strong advocates arguing for and against the likelihood of fossil fuel reserves becoming unburnable, investors may find it difficult to confidently embed carbon risk into fossil fuel companies share prices. With widespread growth in passive portfolio management in diversified indexes that includes a large weighting for fossil fuel stocks, institutional investors may also be unable to divest coal and oil and gas corporation stocks to reduce their stranded asset risk. Similarly, active portfolio managers may fear lower returns relative to market benchmarks as performance goals (see, e.g. Gilbert 2015). This paper examines whether (and when) capital markets have recognized the potential loss of value to oil companies due to unburnable carbon.

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[9] The think tank Ceres estimates that $12.1 trillion are needed as investment in new clean power generation over the next 25 years to limit climate change to 2°C.

[10] The levelized cost of energy (LCOE) is an economic measure of the average cost to build and operate a power-generating asset divided by energy output of this asset over its lifetime. The measure is the minimum price at which electricity generated by the asset must be sold to break-even. LCOE is often cited as a convenient summary measure of the overall competitiveness of different generating technologies.

[11] Utility-scale solar refers to large scale electricity generation either through a photovoltaic power or through concentrated solar power. The utility-scale solar sector has led the overall U.S. solar market in terms of installed capacity since 2012.

[12] The nuclear fuel cycle, for example, starts with exploration for uranium and the development of mines to extract uranium ore and ends with highly radioactive material that must be removed and stored under water at the reactor site in a spent fuel pool for several years. The natural gas combine cycle is currently the most economical of all conventional energy sources.

[13] Based on a survey of industry analysts, a 2017 report ominously titled "All Swans are Black in the Dark" found that equity research firms generally "only look at the next five years" to incorporate risk considerations. This creates systematically mismatched time horizons between risk considerations and sources of stranded reserves risks.

3. Sample Data and Summary Statistics

We begin with the universe of publicly traded firms in the COMPUSTAT Industry Specific: Oil & Gas dataset with SIC code 1311 (Crude Petroleum and Natural Gas) for the period 1999 to 2018[14]. For each firm, we collect annual firm-level data on developed and total proved oil reserves, oil production and exploration costs. We collect accounting data and share price data for each firm from COMPUSTAT Fundamentals, and data on analyst coverage and ownership data for US firms from Thomson Reuters. We also hand collect data for the location of both developed and undeveloped proved oil reserves from the companies' annual reports for each firm-year of our sample.

Figure 1 presents the distribution of firms and the annual average crude oil price for each year of our sample period. Over 37% of the firms in our original sample become inactive during our sample period with almost a third of them after the sharp decline in oil prices in 2014. Table 1 provides the distribution of firms by country together with summary statistics on total book value of assets (averaged by firm and year), total proved oil reserves (aggregated by country and averaged by year), Tobin Q and capital expenditures (averaged by firm and year).[15] Most of the firms in the COMPUSTAT Industry specific sample are from the US and Canada with most of them being small companies as shown by the average value of total assets and barrels of total proved oil reserves. As discussed in the introduction to this paper, we focus only on the sample of North American oil producers, i.e. we eliminate all firms that are not incorporated in the US or Canada. We also eliminate observations for which total assets, a measure of profitability (EBITDA), share price, number of shares outstanding and total proved oil reserves are missing, or total assets are zero. We carry out the usual winsorizing for all variables at the 1% and 99% to remove outliers.[16] The final sample consists of 679 US and Canadian oil producers for the period 1999 to 2018.

Panel A of Table 2 presents summary statistics for our sample firms. The average firm has over $10 billion USD in total assets. The median firm, however, is small with only $306

[14] Prior to 1999, the data on oil reserves in COMPUSTAT Industry Specific: Oil & Gas have very low coverage.

[15] Our sample also does not cover several international firms with very large oil reserves as they are not publicly traded companies. For example, Saudi Arabian Oil Company, whose total proved oil reserves exceed 200 billion barrels, is fully owned by the government of Saudi Arabia.

[16] The winsorized observations are mostly penny stocks or firm with negative book equity.

million USD in total assets. The average firm in our sample has had poor stock-market performance during the period 1999-2018. The average (median) Tobin's Q value is 1.43 (1.06). Compared to the average firm in the COMPUSTAT Fundamentals database, the average firm in our sample has similar mean (median) book leverage 26% (20%) but unlike firms in the COMPUSTAT universe, on average (for the median firm) almost 72% (97%) of this debt is long-term. The average firm in our sample has large capital expenditures, 30.15% of book assets, compared to the COMPUSTAT universe average of 5.36%.

In panel B of Table 2, we illustrate our idea in a simple way. Panel B shows the financial characteristics of the sample firms with high (top quartile) and low (bottom quartile) of levels and growth in total reserves. Not surprisingly, the large firms in our sample has large levels of total oil reserves. However, on average, it is the smaller firms that contribute more to the growth in reserves. More importantly, firms with higher reserves growth have significantly lower Tobin's Q than firms with low total reserves growth. The firms also have higher leverage and lower capital expenditures than firms with low reserves growth. The next section provides more context to this idea and discusses the research design for our study.

4. Research design

4.1. Empirical Specifications

Our measure of firm value is Tobin's Q, calculated as the sum of the market capitalization of the firm's common equity, the liquidation value of its preferred stock, and the book value of its debt divided by the book value of assets. To test the link between oil reserves and firm value, we estimate the following general form panel regression model:

$$ln(Q_{it}) = \alpha_i + \beta_1 Reserves_{it} + +\beta_2 Res\ Growth_{it} + \beta_3 Controls + \varepsilon_{it} \qquad (1)$$

where *Reserves* is calculated as oil reserves in barrels scaled by firm's total assets, i.e. the unit is barrels per US dollar of total assets and *Res Growth* is the percentage change in oil reserves $\left(\frac{Reserves_{i,t} - Reserves_{i,t-1}}{Reserves_{i,t-1}}\right)$. First, we use the amount of total proved reserves, then we split total proved reserves into developed proved reserves (*Developed*) and undeveloped proved reserves

(*Undeveloped*).[17] To get the most comprehensive data, we only consider the amount of proved oil reserves and do not include possible or probable reserves.[18] Table A1, in the Appendix, provides the definitions of all variables used in the study. Regression specification (1) captures the relation between firm's growth in total proved oil reserves and firm value as well as the separate effect of developed and undeveloped reserves. For all regression specifications, we cluster standard errors at the firm level and include firm-year fixed effects.

The dependent variable in most of our analysis is *lnQ* (the natural logarithm of Tobin's *Q*) rather than *Q*. Amihud, Schmid and Solomon (2017) show that the regression model fits the data much better with *lnQ* as the dependent variable compared to *Q*.[19] Other researchers use *lnQ* when studying the effects of some variables on firm value. For example, Sanders and Block (2011) show that the effect of intangible capital (measured by R&D expenditures, patents and trademarks) on firm's value, is best explained in a model where the dependent variable is *lnQ*. We carry out several robustness checks, where we estimate specification (1) using Tobin's *Q* as a measure of firm value or the annual market-to-book ratio of equity (MTB) in line with studies in the accounting literature. Our results remain unchanged.

When we estimate regression specification (1), we control for all the variables that have been shown to possibly affect firm value. The control variables are as follows. We include market leverage defined as total book debt divided by equity market cap plus debt. Size is the log of beginning of year total assets and profitability is defined as the earnings before interest, taxes, depreciation, and amortization scaled by lagged assets. The effect of profitability on Tobin's Q is ultimately an empirical issue as on one hand more profitable firms may have more favorable investment opportunities, leading to higher valuations. On the other hand, high levels of cash flow may also signal that the firm is in a mature phase and has limited growth opportunities.

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[17]We also estimate the dollar amount of developed and undeveloped proved reserves by multiplying the number of barrels by the (end of year) oil price per barrel and then scale them by total assets. The results remain the same.
[18] Proved oil reserves are "the estimated quantities of oil, which, by analysis of geoscience and engineering data, can be estimated with "reasonable certainty" to be economically producible from a given date forward, from known reservoirs, and under existing economic conditions, operating methods, and government regulations" (US Security and Exchange Commission-SEC).
[19] The logarithmic transformation makes lnQ have a smaller positive skew and smaller deviation from the normal distribution than that of Q.

We also include capital expenditures divided by lagged total assets as a more direct measure of firms' investment opportunities, i.e. the investments that the firm undertook. Firms that invest more likely have higher growth opportunities that should translate into a higher Q value. We also include dividends calculated as the dividends paid in the year divided by lagged assets. On one hand, this variable may capture the effect of capital constraints. Alternatively, firms that pay dividends may have more free cash flow, which may potentially be used to overinvest in marginal or even negative NPV projects such as the acquisition or exploration of undeveloped oil reserves. Shareholders may value high dividends as they will mitigate such agency costs. All these controls have been used in previous studies, e.g., Allayannis and Weston (2001), Carter, Rogers, and Simkins (2006), Roll, Schwartz and Subrahmanyam (2007) and Bolton, Chen and Wang (2011).

The value of an oil firm should clearly be related to the price of oil, so we control for the price of crude oil. This also allows us to ensure that our results are not driven by the large drop in oil prices after 2014. Our results remain robust when we use alternative measures of firm value and oil reserves.

Next, we examine the effect of costs on the relation between oil firm value and its reserves. The shift to a low-carbon world will require a dramatic change in the current growth model for oil producers. Carbon Tracker's (2019) reports shows that no new oil sands projects fit within a Paris-compliant world. Despite this, in 2018 ExxonMobil approved the $2.6bn Aspen oil sand project. US shale specialists also have portfolios that are entirely out of the permissible carbon budget.[20] We argue that oil producers with higher extraction costs will face higher risk of stranded assets as firms will develop first the reserves with the lowest extraction costs. To analyze this issue, we estimate the following regression model:

$$\begin{aligned} ln(Q_{it}) = {} & \alpha_i + \beta_1 Reserves_{it} + \gamma_1 Reserves_{it} \times Cost_{it} \\ & + \beta_2 Res\ Growth_{it} + \gamma_2 Res\ Growth_{it} \times Cost_{it} + \beta_3 Controls + \varepsilon_{it} \end{aligned} \quad (2)$$

[20] In 2018 and 2019, all the major oil companies approved projects that fall outside a "well below 2 degrees" budget on cost grounds. These will not deliver adequate returns in a low-carbon world. Examples include Shell's $13bn Canada LNG project and BP, Total, ExxonMobil and Equinor's Zinia 2 project in Angola and BP, Chevron, ExxonMobil and Equinor's ACG project in Azerbaijan (see Carbon Tracker (2019) for more details.).

where *Cost* is a measure of the operating costs per barrel of oil for firm *i* in year *t*. The control variables are the same as in regression specification (1).

We also carry out a battery of robustness tests. Since we have access to supplementary data for the US firms in our sample that allows us to carry out additional tests, first, we estimate regression specification (1) for the sub-sample of US firms only. Then, we examine the effect of institutional ownership, analysts' coverage and stock market liquidity on the validity and strength of our results. Institutional investors are influential shareholders who can alter the information and trading environment of a firm and therefore affect its value. In recent years, the percentage of institutional ownership has increased significantly.[21] The institutional investors' choice to increase their holdings of a company might be a valuable signal affecting the decisions of not only the management of the company but also of analysts and individual investors. We estimate the effect of institutional ownership, analysts' coverage and stock market liquidity in separate regressions as they are highly correlated. Previous studies have examined the effects of institutional ownership on firms' information and trading environment. For example, Boone and White (2015) show that higher institutional ownership is associated with greater management disclosure, analyst following, and liquidity, resulting in lower information asymmetry. In contrast, Kadach and Schain (2016) document a negative effect of institutional ownership on analysts' coverage.

In addition, some activists' institutional investors have urged divestment of coal and oil and gas firms. In 2017, Norway began work to divest its giant sovereign-wealth fund. The World Bank, committed to no longer be lending money for oil and gas exploration. Some University endowment funds, such as Harvard, have approved divestment from fossil fuel industry. Recent research, however, suggests that it is unlikely that any existing or previous divestment campaigns have produced any substantial effect on firm value. Teoh, Welch, and Wazzan (1999) provide empirical evidence that the South African boycott to end apartheid, the most prominent divestment campaign to date, did not have any effect on the valuation of companies with ties to South Africa or on the South African financial markets. Two papers have looked at the class of stocks that may be unacceptable to proponents of socially responsible

[21] Institutional ownership more than doubled since 1999. Mean institutional ownership for the US companies in our sample for 1999 is 16.27% and 38.28% in 2018.

investing (SRI), who refuse to hold stocks in firms that they view as generating social harm. Hong and Kacperczyk (2009) argue that these stocks, called "sin stocks," have lower price-to-book ratios, less institutional ownership, and less analyst coverage. Geczy, Stambaugh, and Levin (2005) provide similar evidence. We add to this literature by examining whether institutional ownership influences the relation between firm value and stranded asset risk.

Studies have also shown that analyst coverage and stock market liquidity improve firm value. Jiraporn, Chintrakarn and Kim (2012) show that analysts, as information intermediaries, provide oversight over management and thus help alleviate agency conflicts. Similarly, Fang, Noe and Tice (2009) document that firms with liquid stocks have better performance as measured by the firm market-to-book ratio.

4.2. Stranded Assets Risk and Firm Value

In this section, we further examine the effect of stranded assets risk on firm value. First, as an alternative measure of oil reserves, we use *Modified reserves*. This measure was suggested by Delis, Greiff and Ongena (2019) to address a possible problem that might arise because large firms could hold oil reserves in more than one country to (potentially) exploit lax climate policies of countries and to move their exploration activities there. An oil firm owing exploration rights for reserves in a country with strict climate policy faces a higher probability of reserves becoming stranded than a firm with fossil fuel reserves in a country with loose climate policy.

To examine this question, for each firm-year, we require data on the amount of total, developed and undeveloped proved oil reserves for each location across different countries. As such data are not readily available in conventional databases, we hand-collect them from the firms' annual reports. To capture the differences in the firms' allocation of oil reserves by country, we calculate the *Modified reserves* of firm i in year t as:

$$Modified\ Reserves_{it} = \sum Reserves_{ij,t} \times Climate\ Policy_{jt} \quad (3)$$

and

$$Modified\ Res\ Growth_{it} = \sum Res\ Growth_{ij,t} \times Climate\ Policy_{jt} \quad (4)$$

where we compute *Modified reserves* measure separately for total reserves and for developed and undeveloped proved oil reserves. In equation (3), *Reserves* is the amount in barrels per dollar of book value of the assets of (total or developed and undeveloped) oil reserves of firm i in country j in year t. In equation (4), *Res Growth* is the percentage change in (total or developed and undeveloped) oil reserves of firm i in country j in year t. *Climate policy* is the climate policy index of country j in year t. A detailed measure of a country's climate policy stringency should include both its climate policy goals and its actual climate policy effort. The former is measured by the efficiency in climate policy implementation while the latter is measured by climate policy outcomes such as CO_2 emissions.

Thus far, we are aware of only two datasets that offer information both on emissions and on policy efforts for a large number of countries: the Climate Change Performance Index (CCPI) by the non-governmental organization and think-tank Germanwatch and the Climate Change Cooperation Index (C3I) by Bernauer and Böhmelt (2013). The CCPI is an index that evaluates and compares the climate protection performance of 56 countries for the period 2007-2018. A country's performance is assessed based on 14 indicators in the following four categories: (1) GHG Emissions (weighting 40%); (2) Renewable Energy (weighting 20%); (3) Energy Use (weighting 20%); (4) Climate Policy (weighting 20%).

The C3I, on the other hand, evaluates countries' overall climate policy performance, as well as performance in terms of political behavior (output) and emissions (outcome). Currently, the index is available for 172 countries for the period 1996-2014. Both indices take values between 0 and 100 (inclusive) with higher values indicating stricter climate policy (more climate-friendly countries) and as shown by Bernauer and Böhmelt (2013) the two climate policy indices are very highly correlated. We generate a firm-year measure of climate policy exposure (risk) from the product of their reserves (reserves growth) and the C3I from 1999 to 2014 and the CCPI climate policy measure from 2015 to 2018[22]. Based on the above discussion, a higher Modified Reserves measure indicates a higher average level of oil reserves in countries with stricter climate policy.

[22] We calculate two different types of the modified reserves measures using separately the C3I and the CCPI data. The results are the same as when we combine the two datasets.

While the risk of stranded fossil fuel reserves was initially considered to be mostly a long-term risk (Caldecott, Tilbury, and Carey 2014), the 2015 Paris climate agreement was a departure that brought policy action much more forward in time. The transition to a low-carbon economy has now become a medium (and even a short) term concern for financial markets. The second part our analysis examines whether the risk of stranded fossil fuel reserves has become stronger after 2015, i.e. after the Paris agreement. The next section presents our empirical results.

5. Benchmark Estimation Results

5.1. Firm Value and Developed vs Undeveloped Reserves

In this subsection, we discuss the main results to our study. Table 3 shows the estimation results from regression specification (1). Columns (1) and (4) show the effect of reserves (total reserves for column (1) and developed and undeveloped reserves for column (4)) on firm value (*ln(Q)*). Columns (2) and (5) show the effect of reserves growth whereas columns (3) and (6) combine the two measures of reserves. From column (1), it can be seen that total reserves are an important component of oil producers' value as the coefficient is positive as well as economically and statistically significant. Firms with total proved reserves one standard deviation bigger that the mean value have almost 30% higher value. From column (2), however, we see that the positive effect of reserves is decreasing. The coefficient of the total reserves' growth variable is significantly negative. The magnitude and sign of the coefficients remain the same when we estimate the two measures of reserves (column 3).

When we split total reserves into developed and undeveloped (columns (4) to (6)), we see that the positive effect of reserves on value (columns (1) and (3)) is due to the amount of developed reserves, which have a significant positive effect. The negative effect of reserves growth (columns (2) and (3)), on the other hand, is due to the growth of undeveloped reserves as it has a significant negative effect on firm value. The effect of undeveloped reserves growth is also economically large with one standard deviation increase in the growth in undeveloped reserves decreasing firm value (Tobin's Q) by more than 1%.

This is the key result of our study: the growth in undeveloped reserve has a negative effect on firm value. The 2019 Carbon Tracker report highlights the fact that future oil reserves that are generated from current capital expenditures will most likely remain in the ground. Our result suggest that market participants recognize, at least partially, that these investments are potentially negative NPV projects that will destroy firm value. This finding is very robust; as the negative relation between firm value and the growth in undeveloped reserves remains significantly negative in all the robustness tests.

The sign and magnitude of the control variables is largely as expected. Firm size has a large negative effect on value suggesting that the larger oil firms in our sample have fewer growth opportunities. Leverage also has a negative effect. This result is consistent with the findings in Gilje, Loutskina and Murphy (2019) who show that, for their sample of 69 oil and gas firms, the highly-levered firms pull forward investment and completing projects early at the expense of long-run project returns and project value. They show that this behavior is particularly pronounced prior to debt renegotiations consistent with equity holders sacrificing long-run project returns to enhance collateral values and, by extension, mitigate lending frictions at debt renegotiations.

In contrast to previous studies, capital expenditures do not have a significantly positive effect on oil firm's value. This finding is consistent with financial markets considering capital investments in developing oil reserves, that might never be utilized, to not be a positive NPV projects. The coefficients of dividends and profitability are also not significant. Finally, the effect of oil prices is large, positive and significant as expected where one standard deviation increase in oil prices increases firm value by almost 8%.

Table 4 shows the estimation results from regression specification (2) which extends specification (1) by including the interactions of our reserves measures with the operating costs per barrel of oil for firm i in year t. The control variables are the same as in regression specification (1). We argue that oil producers with higher extraction costs will face higher risk of stranded assets as firms will develop first the reserves with the lowest extraction costs. Columns (1) and (3) show the effect of total reserves on firm value is much smaller for oil producers with high extraction costs. The growth in total reserves is not significant. Columns

(5) and (6), however, show that it is the high extraction costs producers that generate the negative effect of undeveloped reserves growth on firm value. The control variables remain the same as in Table 3.

5.2. Stranded Asset Risk and Firm Value

Table 5 shows the estimation results from regression specification (1) using the modified reserves measure in (3) and the modified reserves growth in (4). The modified measure of reserves accounts for the location diversification of reserves across countries. An oil firm owing exploration rights for reserves in a country with strict climate policy faces a higher probability of reserves becoming stranded than a firm with oil reserves in a country with loose climate policy.

The results in Table 5 are similar to our main results in Table 3. The table shows that the growth in modified undeveloped reserves have a significant negative effect on firm value. Our evidence supports the conjecture that for countries with stricter climate policies, the effect of undeveloped reserves on value, is larger than for countries with lax climate policy. The coefficient of the growth in modified undeveloped reserves in Table 5 is larger than the same coefficient in Table 3 and the adjusted R-squared is around 50% higher than in all the other regressions. In Table 3 (column 6), one standard deviation increase in undeveloped reserves growth decreases firm value (Tobin's Q) by almost 1%. In Table 5 (column) 6, one standard deviation increase in the modified undeveloped reserves growth decreases firm value (Tobin's Q) by more than 10%.

We next show that our results are consistent with markets penalizing firms' investment in undeveloped reserves growth due to climate policy risk. In particular, we look at the effect of the 2015 Paris agreement on the sensitivity of firm value to the growth in oil reserves. Table 6 presents the estimation results from regression specification (1) when we include the interaction of the level and growth in our measures of reserves with a dummy variable for the period before the Paris agreement, i.e. 1999-2014 to examine if there has been a change in the sensitivity of firm value to oil reserves. Our empirical results provide support for a strong negative effect after 2015. The negative effect of undeveloped reserves growth on firm value, is significantly more negative after the Paris agreement. The control variables remain the same as in Table 3. Overall, our evidence is consistent with capital markets penalizing future investment in undeveloped reserves growth due to climate policy risk.

5.3 Institutional ownership, Liquidity and Analysts Coverage

In this section, we carry out several robustness tests to our main results. Table 7 presents the results for the sub-sample of US firms only. The results are similar to those obtained for the full sample in Table 3. In particular, the growth in undeveloped reserves have a negative and significant effect on firm value.

For the US firms in our sample, we have access to supplementary data on institutional ownership and analysts' coverage. We examine the effect of these variables on the validity and strength of our results. Institutional investors have the ability to alter the information and trading environment of a firm and therefore affect its value. Most empirical studies on institutional ownership find that, given their independence, expertise, and ability to monitor managers effectively, institutional investors have a positive effect on firm value that is attributable to better monitoring and changes in the corporate governance structures (Aggarwal et al., 2011; Gompers & Metrick, 2001; McConnell & Servaes, 1990; Smith, 1996). Using international samples, Ferreira and Matos (2008) and Bena et al. (2017) document a positive effect of institutional ownership on firm value, with this effect driven primarily by foreign and thus more independent institutions. Homanen and Liang (2018) show that higher institutional ownership is unconditionally correlated with higher firm valuation.

We obtain quarterly data on institutional ownership (as a percentage of shares outstanding) from the Thomson 13F database. We use the yearly average as our measure of institutional ownership. Panel A of Table 8 presents the estimation results from regression specification (1) when we split firms into two subsamples based on their institutional ownership. We use the annual median value of our measure of institutional ownership as the cutoff point between high level (above the median) and low level (below the median) of institutional ownership. For brevity, we only report the coefficients on the reserves' measures. The rest of the coefficients are similar to those in Table 3[23].

[23] The full results are available on request.

The results in Panel A of Table 8 support previous evidence that the main purpose of institutional investors' monitoring pressure is to increase shareholder value as for firms with high institutional ownership, total reserves contribute more to value than for firms with low institutional ownership. Institutional ownership, however, does not mitigate the negative effect of undeveloped reserves on firm value. The positive effect on developed reserves, on the other side, seems to be largely due to institutional ownership. Overall, our findings suggest that the effect of institutional ownership on the interaction between oil reserves and firm value is less important than the effect of stranded asset risk, both in terms of significance and economic magnitude.

Panel B of Table 8 presents the results for analysts' coverage and its effect on the relation between firm value and oil reserves. We obtain analyst information from the I/B/E/S database. For each fiscal year of a firm, we take the average of the 12 monthly numbers of earnings forecasts given by the summary file and treat that as a raw measure of analyst coverage (Coverage). This measure relies on the fact that most analysts following a firm issue at least one earnings forecast for that firm during the year before its fiscal year ending date and that most them issue at most one earnings forecast. We then take natural logarithm of (one plus) this raw measure and construct our main measure of analyst coverage (LnCoverage). The results are similar to the results for institutional investors. Increase in analysts' coverage does not mitigate the negative effect of undeveloped reserves growth on firm value.

Finally, in Panel C of Table 8, we also examine the effect of stock market liquidity on firm value and whether the effect of undeveloped reserves differs for stocks with different degree of liquidity. Our measure is the annual turnover, calculated as the annual volume traded (in number of shares) divided by the number of common equity shares outstanding. The results in Panel C of Table 8 show that stock liquidity also does not change the negative relation between firm value and the growth in undeveloped reserves.

We also carry out additional robustness tests not reported here using different definitions of some of the reserve measures and different control variables. The negative effect of undeveloped reserves growth on firm value remain the same in magnitude and significance.

6. Conclusions

Global temperatures have increased significantly in the past half century and extreme weather events, such as cold and heat waves, droughts and floods, as well as natural disasters, are becoming more frequent and severe. A persistent rise in temperature, changes in precipitation patterns and/or more volatile weather events can have long-term macroeconomic effects by adversely affecting labor productivity, slowing investment and damaging human health. Recent studies on climate science provide strong evidence that the main cause of contemporary global warming is the release of CO2 gases to the atmosphere by human activities (Mitchell et al., 2001 and Brown et al., 2016).

In this paper, we provide evidence on the relation between oil companies' firm value and the growth in their developed and undeveloped oil reserves. Previous studies have failed to document a significant negative stock market reaction to stranded asset risk. Our results suggest that while oil reserves are an important component of firm value, the effect of growth in these reserves, on the other hand, has a significantly negative effect on value throughout the sample period. This negative effect is particularly stronger after the 2015 Paris agreement.

When we decompose total reserves into developed and undeveloped, we show that the positive effect is due to the amount of developed oil reserves and the negative effect is due to the growth of undeveloped oil reserves. One standard deviation increase in the growth of undeveloped proved oil reserves decreases firm value (Tobin's q) by more than 1%.

Our evidence is consistent with markets penalizing firms' undeveloped reserves growth due to climate policy risk. First, we document that oil producers with higher extraction costs face higher risk of stranded assets as firms develop first the reserves with the lowest extraction costs. Our results show that the positive effect of total reserves on firm value is much smaller for oil producers with high extraction costs. On the other hand, the negative effect of undeveloped reserves growth on firm is generated by the high extraction costs oil producers.

Second, our estimation results based on the modified reserves measure also suggest that capital markets consider the possibility of future stranded assets. An oil producer owing exploration rights for oil reserves in a country with strict climate policy faces a higher probability of reserves becoming stranded than a firm with oil reserves in a country with loose climate. We show that the growth in modified undeveloped reserves have a stronger negative effect on firm value.

Finally, our results show that while institutional ownership has an independent effect it does not explain or change the negative effect of undeveloped oil reserves growth on firm value. The results are similar when we consider analysts' coverage and stock market liquidity. Overall, our results suggest that the firm's trading environment or informational opacity do not explain the relation between the growth of undeveloped oil reserves and the decrease in firm value.

Our paper contributes to research that documents evidence for the climate change risk of fossil fuel firms. To the best of our knowledge, we are the first study to show that investing in developing future oil reserves is a not a positive NPV proposition that could potentially destroy firm value. We hope that our findings help to spur both theoretical and empirical research in this area. Future research should also examine whether a transition to a renewable energy and greener production in general is recognized by capital markets and therefore increases firm value.

References

Battistion, S., A. Mandel, I. Monasterolo, F. Schuetze, and G. Visentin (2017). A Climate Stress-Test of the Financial System. Nature Climate Change 7, 283-288.

Bernauer, T. and T. Böhmelt (2013). National Climate Policies in International Comparison: The Climate Change Cooperation Index. Environmental Science & Policy 25, 196–206.

Botta, E. and T. Kozluk (2014). "Measuring Environmental Policy Stringency in OECD Countries: A Composite Index Approach", OECD Economics Department Working Papers, No. 1177, OECD Publishing, Paris.

Burck, J., L. Hermwille, and C. Bals (2016). CCPI Background and Methodology. Germanwatch and Climate Action Network Europe.

Byrd, J. and E. S. Cooperman (2016). Ecological Limits, Technology and Stranded Coal Reserve Assets. Working paper. 33

Caldecott, B., J. Tilbury, and C. Carey (2014). Stranded Assets and Scenarios. Stranded Assets Programme Discussion Paper, University of Oxford's Smith School of Enterprise and the Environment.

Carbon Tracker Initiative (2011). Unburnable Carbon –Are the World's Financial Markets Carrying a Carbon Bubble? Technical report.

Carbon Tracker Initiative (2013). Unburnable Carbon 2013: Wasted Capital and Stranded Assets. Technical report.

De Haas, R., and A. Popov (2018). Financial development and industrial pollution. EBRD Working Paper No. 217. European Bank for Reconstruction and Development,

Dyer, E. (2015). Climate change study says most of Canada's oil reserves should be left underground. Canadian Broadcasting Corporation. Retrieved 6 November 2015.

ESRB (2016). Too Late, Too Sudden: Transition to a Low-Carbon Economy and Systemic Risk. Reports of the Advisory Scientific Committee No 6, ESRB Advisory Scientific Committee.

ExxonMobil (2014). Energy and Carbon – Managing the Risks. http://cdn.exxonmobil.com/~/media/global/files/energy-and-environment/13report---energy-and-carbon---managing-the-risks.pdf. Accessed February 9, 2017. 34

HSBC (2013). Oil & Carbon Revisited: Value at Risk from Unburnable Reserves. HSBC Global Research.

Hong, H., and M. Kacperczyk (2009). The Price of Sin: The Effects of Social Norms on Markets. Journal of Financial Economics 93, 15-36.

Ilhan, E., Z. Sautner, and G. Vilkov (2018). Carbon Tail Risk. Working Paper. Frankfurt School of Finance & Management.

Intergovernmental Panel on Climate Change IPCC (2014). Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. IPCC, Geneva, Switzerland, 151 pp.

Intergovernmental Panel on Climate Change (IPCC) 2018, Special Report: Global Warming of 1.5°C.

Jacob, M. and J. Hilaire (2015). Unburnable Fossil-fuel Reserves. Nature 517, 150–152.

King, D., D. Schrag, Z. Dadi, Q. Ye, and A. Ghosh (2015). Climate Change: A Risk Assessment. The Centre for Science and Policy, University of Cambridge.

Kleimeier, S., and M. Viehs (2016). Carbon Disclosure, Emission Levels, and the Cost of Debt. Working Paper. Maastricht University.

Krueger, P., Z. Sautner, and L.T. Starks (2019). The Importance of Climate Risks for Institutional Investors. Review of Financial Studies "Climate Finance". Forthcoming.

Le Page, M. (2011). Carbon Bubble Could Threaten Markets. New Scientist, October 2011. Available at: https://www.newscientist.com/article/dn21031-carbon-bubble-could-threaten-markets-maybe/

McGlade, C. and P. Ekins (2015). The Geographical Distribution of Fossil Fuels Unused When Limiting Global Warming to 2 °C. Nature 517, 187–190.

Schoenmaker, D., R. van Tilburg, and H. Wijffels (2015). What Role for Financial Supervisors in Addressing Systemic Environmental Risks? Sustainable Finance Lab Working Paper, Sustainable Finance Lab.

Tordo, S., D. Johnston, and D. Johnston (2010). Petroleum Exploration and Production Rights: Allocation Strategies and Design Issues. World Bank Working Paper no. 179. Washington, DC. World Bank.

Weyzig, F., B. Kuepper, J. W. van Gelder, and R. van Tilburg (2014). The Price of Doing Too Little Too Late; The Impact of the Carbon Bubble on the EU Financial System. Green New Deal Series volume 11, The Greens/EFA Group – European Parliament.

Figure 1: Sample Firms Distribution and Oil Prices

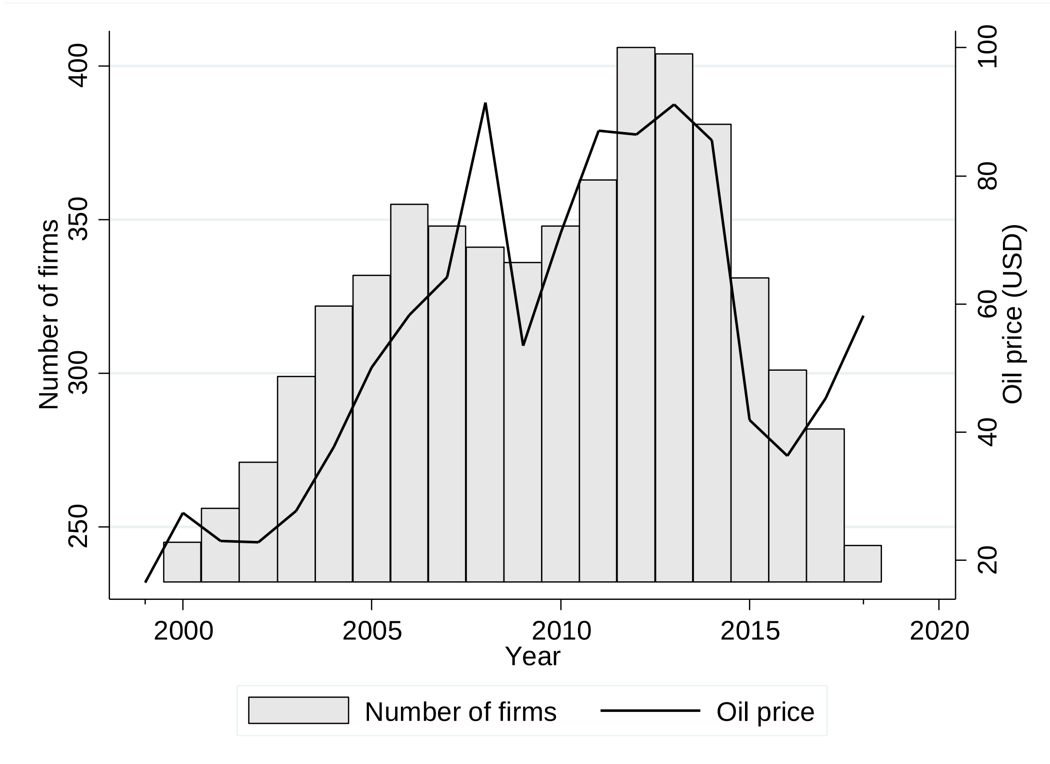

Table 1: COMPUSTAT Oil&Gas Firm Distribution by Country

The table presents average book value of assets, Tobin's Q, market leverage, capital expenditures and total reserves for firms with SIC code 1311 in the COMPUSTAT Industry Segment database for the period 1999 to 2018. Column (5) reports the total proved reserves for all sample firms in a given country. Column (6) reports the average total proved reserves for all firms in a given country.

Country	Number of Firms	Book Assets (million US$)	Tobin's Q	Leverage	CAPEX	Country Reserves (thousand barrels)	Firm Reserves (thousand barrels)
		(1)	(2)	(3)	(4)	(5)	(6)
Argentina	3	$ 9,037.63	0.651424	29.15%	10.99%	1,038,229.68	346,076.56
Australia	5	$ 22,218.12	0.932303	35.76%	25.47%	681,874.07	136,374.81
Bermuda	5	$ 2,503.33	0.958629	48.68%	16.18%	325,053.24	65,010.65
Brazil	1	$ 178,345.37	1.006356	35.63%	13.32%	9,547,536.84	9,547,536.84
Canada	382	$ 1,127.82	1.005527	17.74%	25.57%	19,363,454.75	46,435.14
China	2	$ 178,809.48	0.809407	25.64%	15.03%	13,422,231.58	6,711,115.79
Columbia	1	$ 44,032.87	1.317068	12.73%	11.38%	1,194,763.64	1,194,763.64
Cayman Islands	6	$ 291.76	0.726113	39.03%	9.50%	105,309.02	17,551.50
Spain	1	$ 56,954.72	0.808904	40.50%	7.07%	1,913,919.25	1,913,919.25
France	1	$ 184,474.58	0.839166	24.75%	10.14%	5,651,764.71	5,651,764.71
Great Britain	5	$ 123,689.66	0.78428	6.26%	9.07%	18,190,031.95	3,638,006.39
Hong Kong	1	$ 52,162.64	1.504232	7.17%	16.64%	2,151,516.67	2,151,516.67
Italy	1	$ 128,047.72	0.733818	25.84%	8.64%	3,529,300.00	3,529,300.00
Jersey	2	$ 197.21	1.786209	5.86%	36.53%	43,849.60	21,924.80
Netherlands	1	$ 85,467.90	1.392851	6.20%	8.02%	4,955,400.00	4,955,400.00
Norway	2	$ 58,667.70	0.790122	24.40%	9.76%	3,029,583.33	1,514,791.67
Russia	3	$ 104,787.94	0.385885	42.69%	8.35%	29,498,122.50	9,832,707.50
USA	297	$ 3,780.66	1.180564	26.05%	21.09%	41,330,980.25	130,381.64
South Africa	1	$ 28,881.96	1.02785	18.99%	14.24%	987,975.00	987,975.00

Table 2: Summary statistics

This table contains summary statistics for 679 oil producers in North America during the period 1999 to 2018. Panel A reports statistics for firm-level financial variables, and oil reserves. Panel B compares the financial characteristics of firms with low growth (bottom quartile of total reserves growth) to the financial characteristics of high growth (top quartile of total reserves growth) firms in the sample. Difference is a t-test for differences in means. * indicates significance at the 10% level, ** at the 5% level, and *** at the 1% level.

Panel A: Summary Statistics					
	Median	Mean	Std dev	5%	95%
Assets (million $US)	$ 306.89	$ 10,832.15	$ 41,065.88	$ 4.01	$ 51,779.00
Tobin's Q	1.0622	1.4637	1.4311	0.3879	3.9337
Leverage	20.15%	26.38%	24.89%	0.00%	80.87%
Capital expenditures	18.92%	30.15%	37.58%	0.94%	93.43%
Profitability	12.80%	7.26%	33.29%	-45.30%	43.62%
Dividends	0	0.0235	0.2713	0	0.0975
Oil Reserves (barrels per US$ of total assets)					
Total reserves	0.0226	0.1386	5.094	0	0.1519
Developed reserves	0.0131	0.104	5.1614	0	0.0775
Undeveloped reserves	0.0057	0.038	0.7745	0	0.0674

Panel B: Total Reserves, Growth and Financials						
	High Reserves	Low Reserves	Difference	High Growth	Low Growth	Difference
Assets (million $US)	$ 9,478.30	$ 2,575.20	6903.1***	$ 3,591.60	$ 6,149.40	-2557.8
	(28663.1)	(15489.0)		(18015.0)	(30657.7)	
Tobin's Q	1.698	1.631	0.067	1.347	1.479	-0.132**
	(1.922)	(1.473)		(1.360)	(1.212)	
Leverage	0.260	0.231	0.029	0.321	0.247	0.074***
	(0.246)	(0.260)		(0.292)	(0.229)	
Capital expenditures	0.299	0.285	0.014	0.216	0.381	-0.165***
	(0.370)	(0.407)		(0.269)	(0.210)	

Table 3: Oil Reserves and Firm Value

The table presents estimates from regression specification (1) for a sample of 679 North American oil producers. The estimation period is from 1999 to 2018. The dependent variable is the logarithm of Tobin's Q. Variable definitions are in Table A1 in the Appendix. All specifications include firm-year fixed effects. The p-statistics (in parenthesis) are based on clustered standard errors across firms. * indicates significance at the 10% level, ** at the 5% level, and *** at the 1% level.

	(1)	(2)	(3)	(4)	(5)	(6)
Total reserves	0.00155***		0.00174***			
	(0.002)		(0.001)			
Growth total reserves		-0.000227***	-0.000227***			
		(0.000)	(0.000)			
Developed reserves				0.00122***		0.891*
				(0.000)		(0.079)
Undeveloped reserves				0.0402		-0.276
				(0.815)		(0.460)
Growth developed reserves					0.00113	0.00178
					(0.577)	(0.399)
Growth undeveloped reserves					-0.0000543***	-0.0000538***
					(0.005)	(0.008)
Size	-0.124***	-0.0957***	-0.0952***	-0.112***	-0.0853***	-0.0798***
	(0.000)	(0.010)	(0.011)	(0.000)	(0.001)	(0.002)
Leverage	-0.633***	-0.668***	-0.670***	-0.620***	-0.706***	-0.704***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Capital Expenditures	-0.0128	0.0195	0.0197	0.0230	0.0407	0.0376
	(0.339)	(0.431)	(0.425)	(0.343)	(0.234)	(0.278)
Profit	-0.00136	-0.00944	-0.00952	-0.00219	-0.0153	-0.0162
	(0.683)	(0.316)	(0.313)	(0.566)	(0.564)	(0.569)
Dividends	0.163	0.193	0.193	0.0966	0.451	0.383
	(0.405)	(0.418)	(0.418)	(0.632)	(0.232)	(0.323)
Oil price	0.698***	0.693***	0.692***	0.703***	0.704***	0.706***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Observations	4,446	4,242	4,242	4,182	3,385	3,385
Adjusted R-squared	0.296	0.305	0.305	0.294	0.335	0.337

Table 4: Oil Reserves, Operating Costs and Firm Value

The table presents estimates from regression specification (2) for a sample of 679 North American firms from 1999 to 2018. The dependent variable is log Tobin's Q. Cost is a measure of operating costs per barrel of oil. Variable definitions are in Table A1 in the Appendix. All specifications include firm-year fixed effects. The p-statistics (in parenthesis) are based on clustered standard errors across firms. * indicates significance at the 10% level, ** at the 5% level, and *** at the 1% level.

	(1)	(2)	(3)	(4)	(5)	(6)
Total reserves	0.0265***		0.0277***			
	(0.000)		(0.001)			
Total reserves*Cost	-0.000659***		-0.000686***			
	(0.000)		(0.002)			
Growth total reserves		-0.000511	-0.000529			
		(0.135)	(0.122)			
Growth total reserves*Cost		0.000119	0.000127			
		(0.418)	(0.388)			
Developed reserves				0.0406***		1.758***
				(0.000)		(0.007)
Undeveloped reserves				-0.214		0.296
				(0.318)		(0.601)
Developed reserves*Cost				-0.0111		-0.919**
				(0.270)		(0.042)
Undeveloped reserves*Cost				-0.0757		-0.0896
				(0.364)		(0.869)
Growth developed reserves					0.00151	0.00747
					(0.869)	(0.369)
Growth undeveloped reserves					0.0000124	0.0000130
					(0.218)	(0.215)
Growth developed reserves*Cost					-0.00774	-0.0124*
					(0.297)	(0.058)
Growth undeveloped reserves*Cost					-0.000115***	-0.000116***
					(0.000)	(0.000)
Size	-0.119***	-0.0959***	-0.0949***	-0.0997***	-0.0911***	-0.0801***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.003)
Leverage	-0.641***	-0.668***	-0.670***	-0.628***	-0.742***	-0.753***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Capital Expenditures	-0.0195	0.0194	0.0184	0.0295	0.0393	0.0567
	(0.141)	(0.433)	(0.456)	(0.233)	(0.413)	(0.253)
Profit	-0.00491*	-0.00938	-0.00915	-0.00766***	-0.0188	-0.102*
	(0.067)	(0.319)	(0.318)	(0.004)	(0.510)	(0.054)
Dividends	0.182	0.193	0.198	0.0955	0.783**	0.731**
	(0.356)	(0.420)	(0.410)	(0.636)	(0.010)	(0.018)
Oil price	0.683***	0.689***	0.689***	0.689***	0.630***	0.614***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Observations	4,405	4,233	4,233	4,141	2,850	2,850
Adjusted R-squared	0.302	0.305	0.306	0.302	0.343	0.347

Table 5: Firm Value, Oil Reserves Location and Climate Policy

The table presents estimates from regression specification (1) using the modified reserves measures. The estimation period is from 1999 to 2018. The dependent variable is the logarithm of Tobin's Q. Variable definitions are in Table A1 in the Appendix. All specifications include firm-year fixed effects. The p-statistics (in parenthesis) are based on clustered standard errors across firms. * indicates significance at the 10% level, ** at the 5% level, and *** at the 1% level.

	(1)	(2)	(3)	(4)	(5)	(6)
Total modified reserves	0.0910		0.147			
	(0.746)		(0.600)			
Growth total modified reserves		-0.000368***	-0.000360**			
		(0.006)	(0.019)			
Developed modified reserves				0.055		0.056*
				(0.144)		(0.057)
Undeveloped modified reserves				0.448		0.759
				(0.307)		(0.518)
Growth developed modified reserves					0.00138	0.00272
					(0.654)	(0.358)
Growth undeveloped modified reserves					-0.000245***	-0.000453***
					(0.007)	(0.001)
Size	-0.176***	-0.162***	-0.161***	-0.161***	-0.0987**	-0.0826**
	(0.000)	(0.000)	(0.000)	(0.000)	(0.015)	(0.036)
Leverage	-0.678***	-0.716***	-0.720***	-0.670***	-0.712***	-0.719***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Capital Expenditures	-0.0338	-0.0196	-0.0198	-0.0189	0.0476	0.0476
	(0.276)	(0.603)	(0.601)	(0.609)	(0.572)	(0.568)
Profit	-0.00542**	-0.0298	-0.0350	-0.00616***	0.0519	0.0333
	(0.019)	(0.789)	(0.753)	(0.003)	(0.732)	(0.802)
Dividends	0.137	0.180	0.174	-0.0388	0.336	0.200
	(0.605)	(0.594)	(0.606)	(0.882)	(0.382)	(0.595)
Oil price	0.366**	0.414**	0.413**	0.384**	0.482***	0.488***
	(0.016)	(0.011)	(0.011)	(0.013)	(0.000)	(0.000)
Observations	1,831	1,722	1,722	1,665	1,256	1,256
Adjusted R-squared	0.417	0.426	0.426	0.425	0.450	0.459

Table 6: Firm Value, Oil Reserves and the Paris Agreement

The table presents estimates from regression specification (1) for a sample of 679 North American firms. The estimation period is from 1999 to 2018 and the oil reserves measures are interacted with a dummy for the period 1999-2014. The dependent variable is the logarithm of Tobin's Q. Variable definitions are in Table A1 in the Appendix. All specifications include firm-year fixed effects. The p-statistics (in parenthesis) are based on clustered standard errors across firms. * indicates significance at the 10% level, ** at the 5% level, and *** at the 1% level.

	(1)	(2)	(3)	(4)	(5)	(6)
Total reserves	0.0956		0.502			
	(0.937)		(0.693)			
Total reserves*1999-2014	-0.0940		-0.500			
	(0.938)		(0.694)			
Growth total reserves		-0.000388***	-0.000386***			
		(0.000)	(0.000)			
Growth total reserves*1999-2014		0.000175**	0.000173**			
		(0.024)	(0.025)			
Developed reserves				0.00126***		0.611
				(0.000)		(0.158)
Undeveloped reserves				0.259		-0.0483
				(0.786)		(0.474)
Undeveloped reserves*1999-2014				-0.233		
				(0.806)		
Growth developed reserves					0.000907	0.00156
					(0.659)	(0.459)
Growth undeveloped reserves					-0.0126**	-0.0126**
					(0.032)	(0.031)
Growth undeveloped reserves*1999-2014					0.0123***	0.0120***
					(0.000)	(0.001)
Size	-0.122***	-0.0852***	-0.0845***	-0.113***	-0.0624***	-0.0553**
	(0.000)	(0.001)	(0.001)	(0.000)	(0.008)	(0.021)
Leverage	-0.671***	-0.727***	-0.730***	-0.665***	-0.785***	-0.784***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Capital Expenditures	-0.0134	0.0217	0.0222	-0.00458	0.0572	0.0514
	(0.313)	(0.404)	(0.394)	(0.766)	(0.107)	(0.151)
Profit	-0.00140	-0.00760	-0.00807	-0.00167	-0.00535	-0.00422
	(0.671)	(0.338)	(0.324)	(0.627)	(0.804)	(0.844)
Dividends	0.190	0.297	0.297	0.105	0.201	0.178
	(0.481)	(0.373)	(0.373)	(0.713)	(0.613)	(0.666)
Oil price	0.736***	0.727***	0.726***	0.759***	0.766***	0.767***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Observations	3,945	3,743	3,743	3,742	2,969	2,969
Adjusted R-squared	0.302	0.316	0.316	0.301	0.343	0.344

Table 7: Firm Value and Oil Reserves: US Oil Producers

The table presents estimates from regression specification (1) for 297 US firms for the period from 1999 to 2018. The dependent variable is the logarithm of Tobin's Q. Variable definitions are in Table A1 in the Appendix. All specifications include firm-year fixed effects. The p-statistics (in parenthesis) are based on clustered standard errors across firms. * indicates significance at the 10% level, ** at the 5% level, and *** at the 1% level.

	(1)	(2)	(3)	(4)	(5)	(6)
Total reserves	0.00141***		0.00167***			
	(0.009)		(0.002)			
Growth total reserves		-0.000209***	-0.000209***			
		(0.000)	(0.000)			
Developed reserves				0.00108***		0.594
				(0.000)		(0.246)
Undeveloped reserves				0.0176		-0.0454
				(0.175)		(0.574)
Growth developed reserves					0.00108	0.00196
					(0.740)	(0.564)
Growth undeveloped reserves					-0.000393**	-0.000460***
					(0.040)	(0.004)
Size	-0.0914***	-0.0597***	-0.0589**	-0.0853***	-0.0862***	-0.0793***
	(0.000)	(0.010)	(0.011)	(0.000)	(0.001)	(0.002)
Leverage	-0.528***	-0.576***	-0.580***	-0.521***	-0.629***	-0.625***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Capital Expenditures	-0.000103	0.0388	0.0393	0.0458	0.0451	0.0411
	(0.993)	(0.212)	(0.206)	(0.190)	(0.228)	(0.277)
Profit	0.00165	-0.00851	-0.00863	0.00129	-0.0160	-0.0131
	(0.387)	(0.279)	(0.272)	(0.579)	(0.516)	(0.573)
Dividends	0.0760	0.0709	0.0710	0.0000361	-0.0191	-0.0333
	(0.743)	(0.791)	(0.791)	(1.000)	(0.976)	(0.960)
Oil price	1.088***	1.015***	1.015***	1.094***	1.043***	1.047***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Observations	2,290	2,202	2,202	2,249	1,856	1,856
Adjusted R-squared	0.224	0.237	0.237	0.226	0.282	0.284

Table 8: Institutional Ownership, Analysts Coverage and Liquidity

The table presents estimates from regression specification (1) for a sample of 297 US oil producers from 1999 to 2018. The regressions are estimated separately for high level (above median) and low level (below median) firms. Difference represents t-test for differences in coefficients. Panel A splits sample firms by their institutional ownership (% of shares held by institutional investors); Panel B by analysts coverage (number of analysts forecasts); and Panel C by stock market liquidity (Annual volume traded divided by shares outstanding). The dependent variable is the logarithm of Tobin's Q. Variable definitions are in Table A1 in the Appendix. For brevity, we do not report the coefficients of the control variables. All specifications include firm-year fixed effects. The p-statistics (in parenthesis) are based on clustered standard errors across firms. * indicates significance at the 10% level, ** at the 5% level, and *** at the 1% level.

	(1)			(2)		
	High	Low	Difference	High	Low	Difference
Panel A: Institutional ownership						
Total reserves	0.00413***	0.00198**	0.00215**			
	(0.008)	(0.021)				
Growth total reserves	-0.00033	-0.000713	0.0004			
	(0.253)	(0.424)				
Developed reserves				0.394**	0.362	0.0320
				(0.027)	(0.119)	
Undeveloped reserves				0.00064	0.000139	0.0005
				(0.979)	(0.669)	
Growth developed reserves				-0.0199	0.00765	-0.0276
				(0.450)	(0.520)	
Growth undeveloped reserves				-0.00019***	-0.00023***	0.00004
				(0.009)	(0.001)	
Observations	1,134	1,008		923	919	

Table 8: Institutional Ownership, Analysts Coverage and Liquidity (CONTINUED)

	(1)			(2)		
	High	Low	Difference	High	Low	Difference
Panel B: Analysts coverage						
Total reserves	0.00686**	0.00253***	0.00433***			
	(0.024)	(0.000)				
Growth total reserves	-0.00994***	-0.00967	-0.00027			
	(0.000)	(0.474)				
Developed reserves				0.0390***	0.0217*	0.0173
				(0.004)	(0.089)	
Undeveloped reserves				0.000242	0.000257	-0.00002
				(0.569)	(0.327)	
Growth developed reserves				-0.01517	-0.0250	0.0098
				(0.138)	(0.157)	
Growth undeveloped reserves				-0.00202**	-0.00187*	-0.00015
				(0.034)	(0.090)	
Observations	1,131	1,003		921	915	
Panel C: Stock Market Liquidity						
Total reserves	0.00217	0.001799	0.0004			
	(0.864)	(0.172)				
Growth total reserves	-0.000397*	-0.000232***	-0.0002			
	(0.087)	(0.000)				
Developed reserves				0.164	0.291**	-0.127*
				(0.684)	(0.022)	
Undeveloped reserves				0.000128	-0.000150	0.00028
				(0.646)	(0.936)	
Growth developed reserves				0.00330	-0.000345	0.0036
				(0.110)	(0.940)	
Growth undeveloped reserves				-0.00115***	-0.00185***	0.0007
				(0.001)	(0.000)	
Observations	1,132	1,003		921	917	

Appendix A1: Variable definitions

Variable	Definition
Panel A: Firm characteristics	
Tobin's Q	Market value of equity pus liquidation value of preferred equity plus book value of debt divided by assets.
Assets (million USD)	Book value of total assets; Size is the log of total assets.
CAPEX	Capital expenditures divided by lagged assets.
Leverage	Market leverage is defined as total book debt divided by equity market cap plus debt.
Profit	Profitability is earnings before interest, taxes, depreciation, and amortization scaled by lagged assets.
Dividends	Dividends are dividends paid divided by lagged assets.
Cost	Operating costs divided by total oil production.
Inst. ownership	Percentage of shares outstanding held by institutional investors.
Analysts coverage	The average number of analysis forecasts for the year.
Stock market liquidity	Annual volume traded divided by number of shares outstanding.
Panel B: Industry specific	
Total reserves	Total proved reserves/Assets (barrel per $ of total assets)
Developed reserves	Developed proved reserves/Assets (barrel per $ of total assets)
Undeveloped reserves	Undeveloped proved reserves/Assets (barrel per $ of total assets)
Modified reserves	Weighted average measure of reserves; weights are countries climate index