Time to Get Mature: Collateral, Flexibility and the Hedging Horizon Decision

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Abstract

Hedging maturity, *i.e.*, how far out in time hedging activities stretch, is an important yet under-theorized aspect of corporate risk management. In this article, we analyse firms' hedging maturity decision and carry out a comprehensive empirical analysis. We develop three hypotheses to explain hedging maturity. The collateral hypothesis states that longer maturities are predicated on the availability of internal resources that serve as collateral in a hedging transaction. The flexibility hypothesis holds that the ability to change operations or investment strategies at low cost is conducive to shorter maturities. The matching hypothesis argues that firms match their hedging maturity with the maturity of their debt and investment portfolios. Using hand-collected data on derivative positions in the oil and gas industry, we find evidence consistent with all three hypotheses.

Keywords: *hedging maturity, collateral, investment maturity, debt maturity, flexibility*

JEL Codes: G32, G31, L71

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1. Introduction

The literature on corporate hedging has looked extensively into the issue of which firms use derivatives and the extent to which they do so ('the why hedge-question'). (Smith and Stulz, 1985; Tufano, 1996; Haushalter, 2000; Carter et al., 2006; Jankensgård and Moursli, 2020). Researchers have also analysed different techniques for modifying a risk profile ('the how hedge-question'), construed primarily as a choice between linear and option-based hedging techniques (Adam, 2009; Croci et al., 2017).

In this article, we focus on the third major aspect of hedging behaviour, namely the maturity of firms' derivative portfolios. Maturity refers to how far out in time the derivative contracts go. Does the firm manage its risk with a one year or a five-year horizon? We argue that this is a highly consequential decision with strong implication for liquidity management and funding availability, both of which are crucial factors in the successful execution of corporate strategy (Froot et al., 1993). Theoretical and empirical work on hedging maturity is very sparse, however. A notable exception is Dionne et al. (2018) who investigate the hedging maturity decision empirically using data from the oil and gas industry. Their findings indicate a relation between hedging maturity and financial distress for certain kinds of hedging instruments (swap contracts referring to the price of oil).

We contribute to the literature on hedging maturity by building on the work of Dionne et al. (2018) in several ways. First, we focus on the mechanism that links financial distress to corporate hedging, namely collateral. As argued by Rampini et al. (2014), the counterparty in a hedging transaction will worry about credit risk and may require the firm to pledge collateral, which is scarce in distressed firms. Additionally, firms must be able to cope with margin calls on unrealized losses, which calls for substantial amounts of liquidity to support hedging programmes (Mello and Parson, 2000) to the extent that this mechanism is present in the derivative contract. Both these collateral problems are exacerbated for longer hedging contracts, suggesting that collateral availability becomes increasingly important for the supply of derivatives as the hedging horizon grows. To test these ideas, we use hand-collected data on quarterly derivative positions in the oil and gas industry between 2013 and 2016. The evidence strongly suggests that the collateral hypothesis is descriptive of how hedging maturity is determined. We find that hedging maturity is positively related to the traditional proxies for collateral, cash and asset tangibility. More specifically to our chosen industry, banks frequently require oil producers to pledge collateral in the form of oil reserves (Ferriani and Veronese, 2022). Reflecting this fact, we are indeed able to verify that proven reserves (normalized by assets) have a strong and positive relation to hedging maturity. In our baseline regressions, a one standard deviation increase in these three variables is associated with an increase in hedging maturity of 64 days (22% of the median hedging maturity).

To pinpoint the impact of collateral constraints for corporate hedging maturity, we bring evidence from an exogenous shock in the form of the collapse in the oil price that occurred in late 2014. This collapse, which was unexpected by forward markets and industry analysts, entailed a halving of the oil price within the space of ten weeks (Dudley et al, 2022). It had the obvious effect of sharply deflating the value of oil reserves that were used as collateral to support financial transactions in the industry (OCC, 2018; Ferriani and Veronese, 2022). In such a circumstance, other forms of collateral (i.e., cash and tangible assets) become more valuable as substitutes for oil reserves in the collateral pool. In addition, as providers of both loans and derivative contracts became more concerned about counterparty credit risk, they were likely to require more collateral than before the shock. According to Rampini et al. (2014), borrowing to fund investment in real assets and hedging are competing uses of scarce collateral, a trade-off that came to a head during this industry crisis. In keeping with this interpretation, we find that the marginal impact of an additional unit of collateral (both cash and tangible assets) on hedging maturity increased post-shock. That is, as reserves become less valuable after the price collapse, the effect of other forms of collateral on hedging maturity becomes stronger. Without claiming that our empirical approach represents a solid identification strategy, we believe it mitigates endogeneity concerns.

A second contribution of our paper is to extend the theory regarding hedging maturity by focusing on the issue of flexibility. The flexibility hypothesis holds that the demand for longer maturities is smaller in firms that can adjust their operating or investment policies at low cost. Accordingly, hedging with longer maturities makes more sense for firms that find it hard or otherwise undesirable to exit its current policies. This topic is relevant to consider because of the profound technological shift in the oil and gas industry towards shale and fracking activities. During the early years of 2010, drilling for shale came to represent an economically significant portion of the asset portfolios of US exploration companies (Newell and Prest, 2019). Shale drilling is an inherently flexible business that can be discontinued and restarted within a much shorter time span compared to traditional oil fields, thus providing fewer incentives to hedge with long maturities. Consistent with the flexibility hypothesis, we find that hedging maturity decreases with exposure to shale gas activities.

Finally, we also contribute by elaborating and furnishing new evidence on the matching hypothesis of hedging maturity of Dionne et al. (2018). According to this view, the hedging horizon is chosen to match the firm's debt payment schedules. While Dionne et al. (2018) control for debt maturity in their empirical model, we add the investment dimension to this analysis. Based on Froot et al.'s (1993) theory, we posit that hedging maturity is associated with the maturity of the firm's investment plans to the extent that protecting these expenditures is an important objective of hedging. In contrast to

Dionne et al. (2018), we find that hedging maturity is positively and significantly related to debt maturity. In further support of the maturity hypothesis, our results show that hedging maturity increases with the maturity of the firm's capital expenditure programme, *i.e.*, for firms that can be assumed to face an accelerating level of investment spending in the future. A one standard deviation increase in debt maturity is associated with an 11-day increase in hedging maturity, whereas the analogous figure for investment maturity is a 14-day increase. What is more, the matching between debt and hedging maturity improves for financially healthy firms, for whom financial constraints are presumably less binding.

Similar to Dionne et al (2018), we show that hedging maturity has a positive correlation with the hedge ratio, defined as the hedged volume, in barrels of oil equivalents, divided by produced volume over a one-year time horizon. That is, if a firm hedges a large part of its exposure (a high hedge ratio), it is also more likely to hedge with a longer maturity. What this finding means is that hedge ratios, which are commonly used in the empirical literature as measures of hedging intensity, are biased downwards. There is clearly a sense in which hedging 70% of the expected production over two years is 'more' risk management than just hedging the same amount for the next year.

In an extension, we investigate the determinants of hedging maturity considering whether the firm uses options or contracts with a linear payoff (e.g., forwards or futures). The baseline results hold up for linear instruments, but not for option-based strategies to the same extent. This finding is consistent with the collateral hypothesis in that linear instruments are those that present the biggest concern about counterparty credit risk. To see why, consider that paying for put options upfront involves no credit risk for the counterparty, whereas unrealized losses on forward contracts do present such an issue, more so than in the case of option-based strategies in which the put options are financed by selling call options.[1] Another line of explanation is that linear instruments are more reliably used for risk management purposes, creating a better fit with the theory, whereas option-based strategies more frequently contain a speculative element (Jankensgård, 2019).

Do the relationships identified in our analysis indicate a causal relationship? As noted, the shock to collateral values allows us to infer a modicum of causality as regards the collateral hypothesis. For the matching hypothesis, causality is a moot point to the extent that the debt and hedging decisions tend to occur simultaneously. Only if the firm sets its policies in a clear sequence in which the debt maturity choice precedes the hedging maturity decision does it make sense to speak of causality. There is not much in the theory, however, to make a strong case for a sequential process. Quite the opposite: banks are known to sometimes lend money only conditional on firms' hedging. According to Bessembinder (1991), one of the ways hedging creates value is indeed by lowering the interest rate required by the lender, and there is a great deal of empirical evidence in this regard (e.g., Campello et al., 2011; Chen and King, 2014; Leão et al., 2022). For the flexibility hypothesis, in contrast, it seems reasonable to argue that this feature is exogenously given by the firm's production technology and not decided on in light of the availability of hedging instruments with certain maturities.

The remainder of this paper is as follows. Section 2 discusses the theoretical fundamentals for our hypotheses. Section 3 describes the data and presents our empirical methodology. Section 4 presents our estimations and inferences, and section 5 summarizes our conclusions and final remarks.

[1] When the put options bought are financed by selling call options in a so-called 'collar strategy', the sold calls do bring attention to credit risk and collateral. However, they do so to a lesser extent than linear instruments because the strike price on the calls will be a different and higher number than the prevailing forward price, which limits the size of the potential losses.

2. Hypotheses development

The hedging maturity decision is an integral aspect of a firm's hedging strategy. Basically, given a decision to hedge, it needs to decide on three things. First, how much of the exposure should be covered. Second, which kind of hedging instrument to use. Third, how far out in time the hedging contracts should go. Importantly, the maturity of the derivative contracts partly decides overall hedging intensity. A longer hedging maturity means "more hedging", just like a higher hedge ratio does. As noted earlier, hedging 70% for two years adds up to a heavier usage of derivatives than the same amount of hedging for only one year. However, hedging maturity can also be construed as part of the "how hedge" question. Just like the choice of hedging instrument is an implementation issue once the firm has decided to hedge a certain exposure, so is the choice of hedging maturity.

It is well understood from theoretical work that corporate hedging has a case when the firm has valuable investment opportunities and external funding is costly (Froot, et al., 1993). Hedging creates value to the extent it reduces the expected costs of various forms of financial distress, pointing to a higher marginal value of hedging in financially weak firms that are closer to distress (Smith and Stulz, 1985). How firms choose between derivatives with a linear payoff and option-based strategies has also been shown to be a function of the firm's financial health (Adam 2002; Adam, 2009; Dudley et al 2022). Options allow firms to coordinate the supply and demand for liquidity across scenarios more efficiently when exposures are non-linear, such as under conditions of financial distress.

Given these arguments, an association between hedging maturity and financial status is to be expected. As argued by Dionne et al. (2018), however, it may not be as straightforward as expecting financially distressed firms to hedge more by extending the maturities of their derivative contracts. The key is to recognize that, due to supply-side concerns, hedging needs to be either financed by cash or supported by collateral to mitigate the counterparty's concern about credit risk (Dudley et al, 2022). Both these internal resources are scarce in financially weak firms. Theoretical work has in fact established a convincing *negative* link between financial weakness and hedging intensity. Weaker firms lack the internal resources that would placate concerns about being able to cover losses on the contract, and they are therefore more likely to be denied access to hedging (Mello and Parsons, 2000). Lacking in internal resources could also spell difficulties in coping with margin calls that may occur during the contract's lifetime as unrealized losses accumulate, potentially to the point of causing acute liquidity stress. Credit risk, *i.e.*, the risk of a default on the terms in a financial contract, generally increases with maturity. In line with these arguments, the model of Rampini et al. (2014) predicts an absence of hedging with longer-dated contracts for collateral-constrained firms. We should therefore expect that the need to support hedging with collateral gets increasingly pressing the further out in time the contract goes.

H1.a *Firms supported by more collateral hedge with longer maturities*

In addition, as noted by Rampini et al. (2014), debt and hedging instruments compete for collateral, and collateral-constrained firms will choose to pledge collateral to secure borrowing rather than derivatives, because the first provides superior marginal returns (allowing firms to invest in profitable projects). Therefore, we expect that the relationship between collateral and hedging maturity becomes stronger in periods of an industry downturn, when financiers increase their demands for collateral, which consequently reduces the resources that can be pledged to access hedging.

H1.b *The positive relationship between collateral support and hedging maturities is stronger during an industry downturn.*

The collateral logic need not rule out that some firms extend their hedging maturities in response to a perceived potential for future financial distress. This would tend to happen if the firm's debt instalments and investment needs are skewed towards longer time horizons. That is, if a firm anticipates heavy expenditures beyond a one-year horizon, it could make sense to match those outflows with a hedging programme of similar maturity. This argument is essentially the same as in the model of Froot et al (1993) in which hedging serves to co-ordinate the supply and demand of liquidity, except that we extend the time horizon and allow for differing profiles with respect to the maturity of the firm's cash commitments. All of which leads us to expect longer hedging maturities in firms that have comparatively more cash outflows related to debt and investment occurring further out in time (in other words, those that have longer debt and investment maturities).

H2.a *Hedging maturity is positively related to the maturity of cash outflows*

Although *ceteris paribus* firms will benefit from matching debt and investment maturities to hedge maturities, supply side concerns will also make it more difficult for firms to effectively achieve this matching. Hence, we expect financially weaker firms to match their debt and investment maturities to hedging maturities to a lesser extent than stronger firms, i.e., firm default risk should moderate the effect of H2.a.

H2.b *The positive relation between hedging maturity and the maturity of cash outflows is weaker for firms with higher default risk*

Another consideration that could play into the hedging horizon decision is the degree of flexibility that the firm has to adjust its operating and investment policies at low cost. Having the flexibility to exit a position that has become unattractive is a very general risk management device (Christie et al., 2022). Risk is reduced to the extent company can scale its volume of business activities up or down in response to fluctuations in demand without incurring any substantial adjustment costs, in which case it is said to have a low operating leverage (Mandelker and Rhee, 1984.) Just as with debt obligations, not meeting contractual obligations related to operations amounts to a form of default with potential legal and reputational consequences.

The flexibility to adjust a firm's investment spending is also important to consider. Froot et al (1993) argue that certain investment opportunities become less attractive when the hedgeable risk factor moves in an unfavourable direction. In these cases, firms have a natural hedge in that the demand and supply of liquidity align dynamically, which reduces the need for hedging. These arguments carry over to hedging maturities, as firms endowed with higher degrees of flexibility in terms of adjusting investment spending should find it less attractive to enter derivative contracts with longer maturities. Such firms already have the means to adapt to changing circumstances, which reduces the marginal value of longer-dated hedging contracts that assume a fixed volume of activity.

H3 *Hedging maturity is negatively related to flexibility*

3. Data and Methodology

3.1 Sample

The sample used in this study consists of publicly traded oil and gas producers in the US (SIC code 1311) between Q1 2013 and Q2 2016. The advantages of using the oil and gas industry for studies of corporate hedging are well known. It is one of very few to disclose sufficiently detailed information about derivative positions. Jin and Jorion (2006) argue that it is a homogenous industry, yet it exhibits significant variation in hedge ratios. Furthermore, according to Bakke et al. (2016) the industry's cash flow volatility is high enough to make risk management economically important.

Firms are eligible for inclusion if they are headquartered in the US; publicly listed; and have at least $ 1million in total assets in all quarters. We furthermore require that 10-Qs (quarterly reports) be available from the online EDGAR database, and that firms report their derivative positions in sufficient detail to quantify different hedging strategies.[2] The latter criterion essentially means that firms must report their hedging position in tabular form. Fortunately, most firms use this form of disclosure. Firms that report a value-at-risk or a sensitivity measure, which are also allowed under U.S. accounting rules, are deleted because the information is insufficient to determine the extent and type of hedging. We restrict the sample to the hedging firm-quarters, because firms' hedging maturity-decision is naturally contingent on having decided to hedge its price exposure in the first place.

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[2] Hedging positions are identified by carefully reading the 10-Qs, as well as through a keyword search. Examples of search strings are: "item 7a," "hedg," "derivative," "market risk," "swap," "collar," "forward," "put option," and "risk management."

All financial statement data and industry specific operating data are obtained from Compustat. Our final sample is comprised of an unbalanced panel of 122 unique firms, corresponding to a total of 1,230 firm-quarter observations.

3.2 Empirical methodology

Our first regressions in the paper take the following general form:

$$\begin{aligned} HM_{i,t} = \alpha + \ & \beta_1 Cash_{i,t} + \beta_2 Tangible\ Assets_{i,t} + \beta_3 Reserves_{i,t} + \beta_4 Debt\ Maturity_{i,t} \\ & + \beta_5 Invest\ Maturity_{i,t} + \beta_6 Invest\ Flexibility_{i,t} + \beta_7 Oper\ Flexibility_{i,t} \\ & + \Gamma' Controls_{i,t} + \mu_i + \delta_t + \varepsilon_{i,t} \qquad (1) \end{aligned}$$

In Equation (1), the subscripts i and t refer to firm quarter, respectively. *HM* is a measure of the hedging maturity of the firm (described in detail in the next section). *Cash*, *Tangible Assets* and *Reserves* are proxies for the availability of different forms of collateral. *Debt_Maturity* and *Invest_Maturity* are measures of the time profile of the firm's debt and investment spending, respectively. *Invest_Flexibility* and *Oper_Flexibility* are proxies for the flexibility inherent in the firm's investment and operating policies, respectively. *Controls* is a set of control variables from the literature on corporate hedging (debt ratio, investment rate, and firm size). Importantly, we include the hedge ratio in the set of controls, as the test should analyze hedging maturity for any given volume of hedging. As our descriptive statistics will show, the hedge ratio is strongly correlated with hedging maturity. This correlation implies a confounding effect if the hedge ratio is absent from the empirical model. We provide the precise operational definition for all the variables in our next subsection. All the models are estimated with firm fixed effects (μ_i). The use of firm fixed effects alleviates concerns about time-invariant unobserved firm features that drive hedging maturity, such as corporate governance and the quality of risk managers and other time-invariant features. Season quarter fixed effects (δ_t) consider any seasonality that might be present in hedging maturity patterns. Finally, $\varepsilon_{i,t}$ is the error term. The standard errors are robust to heteroskedasticity and clustered at the firm level.

As mentioned earlier, a valid concern about our baseline model described in equation (1) is that the coefficients do not necessarily provide causal relationship effects. While we mitigate some of the omitted variable problems by using firm fixed effects, quarter fixed effects and control variables, one could still (correctly) be concerned about simultaneity bias, as it is likely that hedging maturity decisions might affect some of our right-hand side variables. We address these concerns in section 4.4 later in the paper.

3.3 Variable construction

Hedging maturity. We calculate *Hedging maturity* as the weighted average of the firm's reported hedging horizons. We first create weights by dividing the volume hedged within each maturity by the sum of all outstanding contracts. The hedging horizon is then multiplied with the corresponding weight. For example, in an annual report concerning the fourth quarter of 2014, any contracts maturing within the next 12 months (January through December 2015) would be summed up. Since we cannot perfectly identify the maturity of all the contracts, we use the midpoint of each of the maturity ranges reported in the 10-Q. Therefore, if a firm reports contracts that mature within the next 12 months, we consider those as having a half-year maturity. Contracts maturing between 12 and 24 months out from the balance sheet date are attributed a hedging maturity of 1.5 years, and so on. This way of coding follows from the way derivative contracts are reported in quarterly reports (10-Qs).[3] While some firms do report the exact

[3] To exemplify the calculation, consider a firm that reports that it has hedged 2000, 1500, and 1000 barrels of oil equivalent (boe) for the coming year and the two following years, respectively. The total hedged volume would sum to 4500 boe for this firm. Its average hedging maturity would be calculated as 2000/4500 * 0.5 + 1500/4500 * 1.5 + 1000/4500 * 2.5 = 1.27. It is important to

date that their outstanding contracts mature, most will lump several contracts into aggregates that correspond to a certain time interval in the future, usually based on calendar year. The weighted average collapses all the actual maturities into a summary measure that captures the firm's overall tendency to use longer or shorter hedging maturities.

In the calculations of hedging maturity, we only consider positions that hedge risk exposures, which for the producers in our sample imply forward contracts and long positions in put options. Consequently, we do not consider options that have been sold to finance these hedging positions since they do not constitute hedging of risk per se (see Dudley et al, 2022, for a detailed analysis of different ways of financing a hedging position). For the same reason, we exclude bought call options since they are likely to be speculative positions rather than hedging.

Linear maturity and *Option maturity*. We repeat some of our tests using measures that describe the average maturity conditional on the type of hedging instrument. Linear hedging instruments are those for which the payoff at maturity is a linear function of the product price being hedged, *i.e.,* forwards, futures, and swaps. Options, in contrast, are characterized by the ultimate payoff being a non-linear function of the underlying product price. For *Linear maturity*, we repeat the same calculation of average maturity, but considering only linear hedging contracts. We calculate *Option maturity* analogously, based only on the option contracts. As done with *Hedging maturity*, we do not consider sold put options or bought calls when calculating the average maturities.

Hedge Ratio is computed as the sum of linear hedging contracts and put option contracts bought with a maturity of less than 12 months, scaled by expected production within the

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distinguish between the average maturity, calculated as above, and the actual maturities of the firm's contracts (0.5, 1.5 and 2.5 in the example).

next 12 months (in boe).[4] Expected production is assumed to be equal to actual production.

Test variables

To test the collateral hypothesis, we use *Cash*, *Asset tangibility* and developed *Reserves*.[5] Cash represents liquid assets that can be used to absorb margin calls related to unrealized losses on derivative contracts (Mello and Parson, 2000) or to cover cash obligations the firm otherwise would have defaulted on. *Cash* is defined as cash and cash equivalents scaled by total assets. *Asset tangibility* refers to the amount of fixed collateral that can be pledged as collateral in financial contracts, and is defined as Plant, Property, and Equipment scaled by total assets. Oil reserves are a common form of collateral pledged by oil and gas firms in financial contracts (Ferriani and Veronese, 2022). *Reserves* is defined as the number of barrels of oil equivalent (boe) of developed reserves scaled by total assets.

We create *Debt maturity* and *Investment maturity* to verify whether firms match their funding and investments to their hedging strategy. *Debt maturity* is a measure of the time profile of the firm's interest-bearing liabilities and is defined as long-term interest-bearing liabilities scaled by total interest-bearing liabilities. A higher value thus means that a larger fraction of the firm's liabilities is due later than 12 months from the balance sheet date. Investment maturity is a measure of the time profile of the firm's capital expenditure. *Investment maturity* is equal to Tobin's Q, defined as assets minus book value of equity plus the market value of equity, divided by the book value of assets.

[4] Natural gas is converted into barrels of oil equivalents using the standard assumption that 6 million cubic feet (Mcf) of gas have the same energy content as 1 barrel (bbl) of oil.

[5] We use developed reserves (and not total reserves, which would include undeveloped reserves) because these reserves normally have a lower degree of uncertainty regarding volume, and because developed reserves already have the equipment that is necessary to produce these reserves in place. In contrast, undeveloped reserves figures are less precise, and still need capital expenditures before they can be extracted. Thus, banks are arguably less likely to accept undeveloped reserves as collateral.

A higher value thus means that the firm expects to spend a larger fraction of its capital expenditure further out in time compared to the amount it expects to spend in the near term. Capital expenditure (see below) is one of the control variables, so *Investment maturity* can be argued to capture the weight on future investment spending relative to current spending.

To test whether flexibility decreases the need to hedge longer maturities, we create operating and investing flexibility measures. *Operating flexibility* is the log of the number of times the word 'shale' appears in the firm's quarterly report (10Q). Drilling for shale gas (or shale oil) is an inherently more flexible business activity as it can be discontinued or scaled up on short notice if circumstances change in a material way. Investment flexibility is a measure of the flexibility that exists in the firm's investment program to modify the level of spending at low cost. *Investment flexibility* is defined as exploration expenses[6] scaled by capital expenditure. Exploration expenses can be easily scaled up or down by the firm, whereas traditional capital expenditure, in contrast, frequently involves a consortium of operators who commit to multi-year and legally binding development projects.

Other variables. We define *Size* as the natural logarithm of the total book value of assets (in $ million). *Capex* is capital expenditures scaled by total assets, while *Total debt ratio* is the ratio of total debt to total assets. *Distance-to-Default* is calculated based on Merton's distance to default measure, defined as in Badoer et al. (2020). The indicator

[6] The term "exploration" generally refers to the investments aimed at the discovery of new oil and gas deposits, ranging from geological studies of possible carbon deposits to the drilling of exploratory wells. Some of these investments may occur even before obtaining a concession to produce oil and gas in a certain area. Development investments take place after successfully completing the appraisal period, and generally after obtaining a concession from a regulator to a consortium of operators. Regulators normally require that the consortium firmly commits to a development investment schedule. If the firm decides not to pursue the investment schedule (either because it is unable or unwilling to do it), this may result in sanctions from the regulator and reputation damage with the consortium partners. Therefore, this commitment implies little investment flexibility.

variable *Post* captures the period following the negative shock to the oil price and takes the value 1 in Q4 2014 through Q2 2016, and 0 otherwise.

4. Results

4.1 Descriptive statistics

In Table 1 we report the frequencies of the longest hedging horizons associated with each observation. For example, a hedging horizon within the 4th year for a given firm-quarter observation means that the longest contract held by the firm matures within the 4th year. In the first two columns, we split between the longest hedging horizon for linear and non-linear contracts, respectively, for each observation. Longer hedging horizons are more common for linear instruments than for options.

In the third column, we describe the longest hedging horizon per observation, regardless of the type of instrument. In 206 of our firm-quarter observations, firms only have derivatives maturing in the year following the balance sheet date, meaning that their hedging horizon is within the 1st year. The most common horizon in the data is the 2nd year, with 454 (almost 37%) of the observations. For horizons longer than that, the number of observations drops by roughly 50% for each additional year. A respectable minority (10.57%) of firms use contracts that mature in the 5th year or beyond. However, hedging horizons longer than the 5th year are exceedingly rare and used in only 3.33% of hedging firm-quarters. The longest observed horizon is the 8th year, so the horizons range from the 1st to the 8th year.[7] In the last column of Table 1, we compute the weight, in terms of notional value, of the derivatives according to their maturities and average these weights across the observations. While the 2nd year hedging horizon is the most

[7] The 8-year hedging horizon is observed for Quicksilver Resources in 2013, who reports a contract maturing in 2021. However, the amounts are generally tiny for hedging horizons beyond 5 years. In the case of Quicksilver, the 2021-contract represented less than 1% of the total hedged volume.

common, the hedged amounts are much larger within the 1st year horizon, as indicated by their respective weights in the average maturity calculation (68.97% vs 22.44%). Derivatives with horizons within the 4th year or longer account for less than 3% of the overall hedging.

[Insert Table 1 about here]

Table 2 reports some descriptive statistics for the average hedging maturity. The figures shown in Panel A indicate that, as noted before, the average hedging maturities are compressed relative to the range of hedging horizons observed. This is due to the large weight attached to short-horizon derivatives. About half of our observations have an average hedging maturity in the 0.5 to 1-year range, which reflects the large weight of derivatives maturing in the first year and the second year. Still, more than 10% of our observations (133) have an average maturity that is larger than 1.5 years, suggesting substantial variation in the data.

Panel B of Table 2 maps out the mean of *Hedging maturity* for different threshold levels of the hedge ratio. Importantly, firms with high hedge ratios (in the upper tercile) tend to have longer average hedging maturities (1.189 years vs 0.737 for the 1st tercile). This relation is underscored by Figure 1, which plots the relationship between hedging maturity and the hedge ratio. It indicates a robust positive relation between these two variables. The nature of this relation implies that the hedge ratio, which is a widely used proxy for hedging intensity in empirical studies, is generally biased downward as a measure of overall hedging. Put differently, any observed difference between the hedge ratios of two firms will likely understate the true extent to which these firms differ in terms of their overall hedging intensity. To address this bias, future tests of the theories of hedging are best carried out using some composite measure that incorporates both the hedge ratio and hedging maturity aspects.

[Insert Table 2 about here]

[Insert Figure 1 about here]

Figure 2 shows the average hedging maturity along our sample period (between the 1st quarter 2013 and the 2nd quarter of 2016). There is a noticeable decrease following the drop in the oil price that occurred in the last quarter of 2014. This is consistent with hypothesis 1b, according to which we should expect to see an overall reduction in hedging maturity when there is a negative shock to collateral values. However, it is important to recognize that the observed decrease could reflect changes in both supply and demand conditions. The supply of longer dated hedging contracts would decrease to the extent that there was a heightened concern about future credit risk driven by the worsening outlook. Indeed, this evidence is consistent with Almeida et al. (2020), who show that firms switch from derivatives to purchase obligations during financial distress (Almeida et al., 2017). An alternative explanation is that firms were less inclined to hedge and lock in prices that they considered to be unattractive. We must also consider the possibility that some longer-dated contracts, being in-the-money following the sharp decrease in the oil price, may have been prematurely liquidated by firms that sought to resolve their financial distress or increase their liquidity for precautionary reasons. Finally, we observe an increase in hedging maturities in early 2016, when the oil price started to recover.

[Insert Figure 2 about here]

Table 3 reports summary statistics per hedging instrument type and for the combined hedging maturity variable. The mean of *Hedging Maturity* is 0.937, again reflecting the large weight of derivatives with horizons within the first and second years (considered as having maturity of 0.5 and 1.5 years, respectively). Comparing the maturities on linear and option contracts (0.929 *vs* 0.861 years, respectively) we find that they are generally lower for the latter category. We will come back to possible interpretations of this finding in section 4.3.

[Insert Table 3 about here]

Table 4 reports the descriptive statistics for the other variables used in this study. The size distribution and values for the financial variables are similar to those reported in other studies that have used oil and gas companies (see, for example, Bajo et al. 2022). *Operating flexibility* has a median value of 0, indicating that most firms did not engage in shale activities during the investigated period.

[Insert Table 4 about here]

4.2 Baseline results

Table 5 presents the results of our baseline regressions. In all the models, the dependent variable is *Hedging maturity*. Models 1-3 uses only the variables for each of hypotheses, one at a time, whereas Model 4 contains all three simultaneously, and is our preferred specification.

The results in Table 5 are in line with the predictions of the collateral hypotheses. Both Model 1 and 4 indicate statistical significance for all three variables related to collateral, *i.e.*, *Cash*, *Asset tangibility* and *Reserves*. The sign is positive for all the coefficients, consistent with the idea that these resources support longer maturities by mitigating credit risk to the suppliers of derivatives. Taking the coefficients reported in column 4, a 10 percentage points (pp) increase in *Cash* is associated with a 0.055 year (20-day) increase in hedging maturity, whereas a 10 pp increase in *Tangible Assets* is associated with a 0.05 year (19-day) increase in hedging maturity, on average. A one standard deviation increase in reserves entails a 32-day increase in hedging maturity.[8]

The findings in Table 5 are also consistent with the matching maturity hypotheses. In contrast to the findings in Dionne et al. (2018), the specifications reported in columns 2 and 4 of Table 5 indicate clear support for an association between debt maturity and hedging maturity. A one standard deviation change in *Debt Maturity* is associated with a change of 11 days in hedging maturity on average, using the estimate from column 4. We also find that a longer investment maturity leads to hedging with longer maturities, as a one standard deviation change in *Investment Maturity* is associated with a 14-day change in *Hedging Maturity* in the same direction.

Furthermore, we find, as expected, that *Operational Flexibility* is negatively associated with hedging maturity, although the coefficient is statistically significant only at the 10% level. Finally, we do not find any evidence that *Investment Flexibility* is related to hedging maturity.

As for the control variables, we note that a higher hedge ratio predicts a longer hedging maturity also in the multivariate setting. Firm size does not determine hedging maturity, whereas Capex is positively related to hedging maturity. The debt ratio is

[8] The computation is as follows: $0.0029*30.46*365 \approx 32$ days.

negatively related to hedging maturity according to the estimates shown in Table 5. The latter finding indirectly supports the collateral hypothesis, as it can be argued that the debt ratio captures the extent to which collateral has already been pledged to obtain loans and other forms of debt and is thus "used up" (Rampini and Viswanathan, 2013).

[Insert Table 5 about here]

4.3 Hedging maturity by instrument type

In this section we examine whether the determinants of hedging maturity change depending on hedging instrument type. As previously noted, maturities of option-based contracts are on average shorter than those of linear hedging instruments.

We report the results of this investigation in Table 6, Panels A and B. Table 6, Panel A, contains the models in which *Linear Maturity* (i.e., the average hedging maturity of linear contracts) is the dependent variable. Again, we find support across the board for the collateral hypothesis. Importantly, the magnitudes of the coefficients for *Cash Tangible Assets* and *Reserves* are larger, and their statistical significance stronger, than those reported in Table 5. According to the estimates in column 4 of Panel A, a 10-pp increase in *Cash* and *Tangible Assets* is associated with a 30-day and 28-day increase in *Linear Maturity*, respectively, whereas a one standard deviation increase in *Reserves* increases hedging maturity by 37 days. There is also a strong and positive relation between hedging maturity and both *Debt Maturity* and *Investment Maturity*, as was the case when overall hedging maturity was the dependent variable. Finally, we do not find evidence in favour of the flexibility hypotheses in these regressions: while the coefficient of *Operational Flexibility* is negative as expected, it is not statistically significant at the usual levels, and *Investment Flexibility* is not statistically significant either.

The results when *Option maturity* is the dependent (reported in Table 6 – Panel B) are generally weaker. The association with *Debt Maturity* remains significant, again with the expected sign, but the magnitude of the coefficient is smaller than the analogous coefficient for linear instruments. In contrast to the linear maturity results, *Operational Flexibility* is now statistically significant. As predicted by the flexibility hypothesis, this relationship is negative, as the ability to alter the volume of business according to circumstances at low cost would necessitate less long-term hedging of price exposures that may be very uncertain.

The collateral hypothesis, however, finds little support in explaining option maturity, as can be seen in Table 6, Panel B. One possible explanation is that longer-dated option-based hedging strategies require less collateral. The most common situation is that put options are financed by selling call options (Dudley et al., 2022), and the strike price on the options sold tend to be higher than the forward rate that prevailed at inception. That is, hedging strategies consisting of bought puts and sold calls, in combination, come with strike prices that are at some distance from the forward rate. Because of this, option-based strategies hold less potential for large losses and thus represent lower credit risk, which in turn should translate into less importance of collateral.

Another possibility is that linear instruments are more likely to be used for hedging purposes rather than taking an active view on markets for the sake of earning superior profits, or so-called selective hedging (Géczy et al., 2007; Adam et al., 2017; Jankensgård, 2019). According to Dudley et al. (2022), users of the collar strategy are, on average, in better financial condition, which affords them the means to engage in selective hedging without running too high a risk of default. Any such tendency towards selective hedging in these firms could explain the overall weaker ability of the theories used in the present study, and the collateral hypothesis in particular, to predict hedging maturity for option-based hedging instruments.

[Insert Table 6 about here]

4.4 The collateral hypothesis and the oil price shock

A valid concern about our baseline results in Table 5 is that the coefficients do not necessarily capture causal relationship effects. Hedging maturity could be endogenously determined, in the sense that hedging maturity is simultaneously determined with some of the independent variables of equation (1) (*i.e.*, the coefficients would suffer from simultaneity bias). In this section, we analyse the causality issue for the collateral hypothesis by using an exogenous shock to collateral that allows us to establish a modicum of causality.

The shock is given by the oil price collapse that occurred in late 2014 when the oil price essentially halved over a time span of only 10 weeks. After fluctuating for a prolonged period at an elevated price level and low levels of implied and realized volatility, the oil price roughly halved within the space of one quarter. From 2011 until Q3 2014, the oil price (WTI) averaged $96, never dipping below $80. In January 2015 the oil price was trading at roughly 50% of that average. In the last month of 2015, the average price was down to $37. While a modest decline appeared prior to Q4 2014, the price decrease accelerated in early October and, in particular, following the OPEC announcement on November 27, 2014, when the organization changed its policy objective from price targeting (abandoning its desired price range) to market-share stabilization.

According to Dudley et al. (2022), the accelerated fall that got underway in October was unforeseen by industry analysts and forward markets. For example, a poll of 30 analysts by Reuters, dated October 1st, predicted a Brent crude price of $103 for 2015. Even as late as October 26, 2014, Goldman Sachs revised their price forecast for Q1 2015 from $100 to $85. In the same week, CIBC World Markets maintained their predicted 2015 Brent average price of $100. Further underscoring the degree to which the collapse was unpredicted by markets, an analysis of net trading patterns in oil futures contracts on NYMEX indicates speculative trading on *increasing* oil prices (Dudley et al., 2022).

The shock thus implied a sudden, dramatic, and unexpected deterioration of the financial condition of the entire industry. The ensuing uncertainty, and the general scarcity of internal resources that arose, should reinforce the need for solid collateral in the context of getting access to hedging, in particular with longer maturities. We would therefore expect the role of collateral in determining hedging maturity outcomes to intensify post-shock. To this end, the estimations in Table 7 add the post-shock indicator variable (*Post*, which takes value 1 from Q4 2014 onwards), and its interactions with our three variables representing collateral. Columns 1, 2 and 3 of Table 7 show the estimation results for the overall *Hedging Maturity*, *Linear Maturity* and *Option Maturity* as dependent variables respectively.

Confirming the visual impression of a decline in average hedging maturities in Figure 2, the sign of *Post* on Table 7 is negative and statistically significant in the first two estimations. As already noted, while this is consistent with the view that collateral became sparser, thus triggering an overall decrease in hedging maturities because of supply-side concerns (as per hypothesis 1b), other explanations cannot be ruled out. For example, in the new environment, locking in the now-lower prices through longer-dated contracts would have appeared unattractive to managers who counted on the collapse to be temporary.

More interesting for our purposes is the fact that the interactions *Cash* × *Post* and *Tangible Assets* × *Post* in Model 1 are significant and positive. According to these results, the importance of cash and intangible assets in supporting longer hedging maturities increases after the price collapse. The coefficient of *Reserves* (by itself, i.e., pre-shock) is also positive and significant, suggesting that larger developed reserves allow firms to hedge with longer maturities. However, the coefficient of *Reserves* × *Post* is statistically insignificant, meaning that the importance of reserves as collateral did not increase after the shock. This is indeed expected, as reserves are essentially a type of in-kind collateral if the firm hedges the price of its expected future production of oil and gas.[9] While this analysis does not establish definitive evidence of causality, the results are suggestive of a deciding influence on hedging maturities from the availability of collateral, as the shock to collateral is arguably exogenous and unexpected. [10]

Table 7 also contains the results from the corresponding analysis when *Linear Maturity* and *Option Maturity* are the dependent variables (Models 2 and 3). Again, we find a close correspondence between the results for *Hedging maturity* and *Linear maturity*, for which our conjecture holds. The effect of additional collateral on maturity is amplified in both cases. The inability of the theories to predict *Option maturity* could be put down to the stronger speculative element in option-based strategies discussed earlier, but this explanation needs further scrutiny.

[Insert Table 7 about here]

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[9] Indeed, if the supplier of the contract can guarantee that the firm will be able to produce a certain amount of barrels from the firm's developed reserves in the future, counterparty credit risk is mitigated, regardless of the spot price of oil at maturity. This argument is valid regardless of the contract being settled through physical delivery or in cash.

[10] One final concern is that cash and collateral might be affected by the price shock itself through several channels. For example, *Cash* is arguably affected by smaller operational cash flows, early liquidation of derivatives, precautionary takedown of lines of credit induced by the oil price decrease. We repeat our estimations using lagged values of our collateral variables and our inferences are unchanged (results unreported).

4.5 Debt maturity and financial distress

As discussed by Dionne et al. (2018), there is a tension between the desirability of hedging and firms' ability to execute it as they approach financial distress. A lack of internal resources may prevent firms from accessing hedging and from extending the maturity on whatever hedging contracts they are able to negotiate. The debt maturity hypothesis, however, assumes that firms can freely select the time profile of both their hedging and debt portfolios. Considered together, these arguments suggest that we should expect the debt maturity to be more strongly related to hedging maturity for firms that are financially stronger. Only then are longer maturities on the table, so to speak, and firms have enough leeway to decide on their maturity profile for both debt and hedging. Weaker firms, in contrast, are more likely to use their scarce collateral to secure loans for investment in real assets that yield higher returns than financial hedging (Rampini and Viswanathan, 2010). These firms can therefore be expected to find it more difficult to match their longer-dated debt with hedging contracts of corresponding maturity.

The estimations in Table 8 bear out the intuition that the matching of debt and hedging maturities should be stronger for financially healthier firms (hypothesis 2b). For this analysis, we use *Distance-to-Default* as our measure of a firm's financial condition, where a higher value signals lower default risk and thus a better financial health. In the first regression reported in Table 8, we add the interactions of *Debt Maturity* and *Investment Maturity* with the continuous *Distance-to-Default* measure (defined as in Badoer et al., 2020). Consistent with our rationale above, *Hedging Maturity* increases with *Debt Maturity*, and this relationship is stronger for healthier firms, given the positive and significant coefficient for the first interaction term. In the second regression of Table 7, we replace the continuous *Distance-to-Default* measure with a dummy indicating below versus above median, and our inference is maintained. We do not find any evidence that *Distance-to-Default* modulates the relationship between *Hedging Maturity* and *Investment Maturity*, as the coefficients of interaction terms of *Investment Maturity* are statistically insignificant both in columns 1 and 2 of Table 8.

Discussing causality for the associations we find between debt maturity and hedging maturity is somewhat of a moot point. Debt maturity causing hedge maturity would imply that the decision is sequential and that firms first decide on the structure of their debt and then search out hedging contracts with matching maturities. However, there is plenty to suggest that firms choose the structure of their debt and hedging simultaneously or in the context of each other. In the model of Bessembinder (1991), one of the benefits of credibly committing to hedging is precisely that it allows for better contract terms with creditors. Moreover, creditors are also known to occasionally demand hedging to be put in place before granting a loan. In other words, a proper test of causality of the matching hypothesis would only be possible with a unique shock that would exogenously change debt maturity without directly affecting hedging maturity. Therefore, it is rather a question of using data to examine whether firms seem to *behave* according to this model rather than saying that one causes the other.

[Insert Table 8 about here]

4.6 Further robustness tests

In this section we continue to explore the robustness of our results. We start by re-estimating our baseline regressions previously reported in Table 5, but replacing season-quarter fixed effects with year-quarter fixed effects, as one might be concerned that macroeconomic variations could be driving the results. The coefficients of interest, reported in Table 9, are only slightly changed in comparison to the baseline results, and our main inferences are maintained.

[Insert Table 9 about here]

[Insert Table 10 about here]

In the estimations of Table 10 we run separate regressions using only the traditional measures of collateral (*Cash* and *Asset tangibility*), reported in column 1, and the variable suggested by Ferriani and Veronese (2022) (*Reserves*) in column 2. All the coefficients suffer only small changes relative to our baseline results of Table 5.

Additionally, the papers by Fehle and Tsyplakov (2005) and Dione et al. (2018) suggest the existence of a non-linear relationship between the debt ratio and hedging maturity. The estimations reported in Table 11 add the square of the debt ratio. The coefficients of this variable are positive but are not statistically significant at the usual levels. More importantly, our coefficients of interest are virtually unaffected by the inclusion of this variable, meaning that it is unlikely that the omission of this variable is causing any bias to our previous estimates.

Finally, we change the proxies used for *Investment maturity* and *Operational flexibility* in the regressions reported in columns 1 and 2, respectively of Table 12. The first is replaced with a measure of the undeveloped oil reserves in relation to developed reserves, on the view that firms with a greater share of undeveloped reserves face comparatively higher investment expenditures in the future.[11] In the second, we define operating flexibility as ratio of costs of goods sold (COGS) to annual operating costs (in which the latter is defined as COGS plus selling, general and administrative expenses, SG&A), on the grounds that COGS tend to contain more variable costs compared to

[11] Undeveloped reserves require long term investments like the drilling of new wells and the investment in new oil rigs, which take longer than investments in developed reserves.

SG&A, which contains more fixed costs. Finally, the estimation reported in column 3 of table 12 replaces the dependent variable *Hedging maturity* with a dummy variable *Maturity_over5* that is equal to one if the longest hedging horizon of the firm is equal or larger than 5 years, and 0 otherwise. Although the statistical significances of the coefficients are smaller in some cases, overall, the main inferences drawn from our baseline results are maintained.

5. Conclusions

In this study, we analyse the maturity of firms' hedging portfolios. Hedging maturity is the third main characteristic of a hedging strategy, alongside the fraction hedged and the type of instrument used. Yet, hedging maturity is a so far rarely discussed aspect in the corporate hedging literature, despite its potential significance for the availability of liquidity in future states.

We build on the literature that relates financial distress to hedging (and particularly on the paper of Dionne et al. (2018)) by proposing a mechanism through which distress affects hedging maturities (the collateral hypothesis). Additionally, we make contributions by offering a novel hypothesis that relates hedging maturity to operational and investment flexibility and by elaborating the hypothesis that firms match the maturities of debt and hedging; we also add the investment dimension to the matching hypothesis.

Using detailed and hand-collected data on derivative portfolios we find support for all our claims. The maturity of the firm's debt portfolio reliably predicts hedging maturity (and particularly more so for financially healthy firms), as does exposure to shale, a business that is inherently more flexible and short-term by nature than traditional oil field development. The most robust support, however, is for the collateral hypothesis. Both cash and intangible assets are positively related to the length of the hedging maturity as predicted by the hypothesis. What is more, the importance of these variables only intensified when the industry entered a period of financial distress and general scarcity of collateral following the collapse of the oil price in late 2014. We also find that developed oil reserves, which are generally a type of well accepted collateral (Ferriani and Veronese, 2022) increase hedging maturity both before and after the price collapse.

We conclude that hedging maturity behaves in predictable ways according to economic theories. The collateral, maturity, and flexibility claims are all supported by the data. Another important conclusion to follow from our analysis is that the hedge ratio, given its strong positive correlation with hedging maturity, has a downward bias as an indicator of overall hedging intensity. This suggests that empirical measures of hedging should consider hedging maturity alongside the proportion of the risk factor being hedged. It would be interesting to see future studies that combine both aspects into a comprehensive measure of overall hedging activity. Future theoretical work could also elaborate more on the precise determinants of the optimal hedging maturity.

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Figure 1– Hedging maturity and Hedge ratio

This graph shows the relationships between *Hedging maturity* (horizontal axis) and *Hedge ratio* (vertical axis) in the sample period (2013Q1-2016Q2). For each firm-quarter, we compute *Hedging maturity* as the weighted average of the firm's hedging horizons, where each hedging horizon is multiplied by the volume hedged in each maturity over the total hedged volume. To identify the firm's hedging horizons, we use the midpoint of each of the maturity horizon reported in the 10-Q. *Hedge ratio* is computed as the sum of linear hedging contracts and put option contracts bought with a maturity of less than 12 months, scaled by expected production within the next 12 months (barrels of oil equivalents).

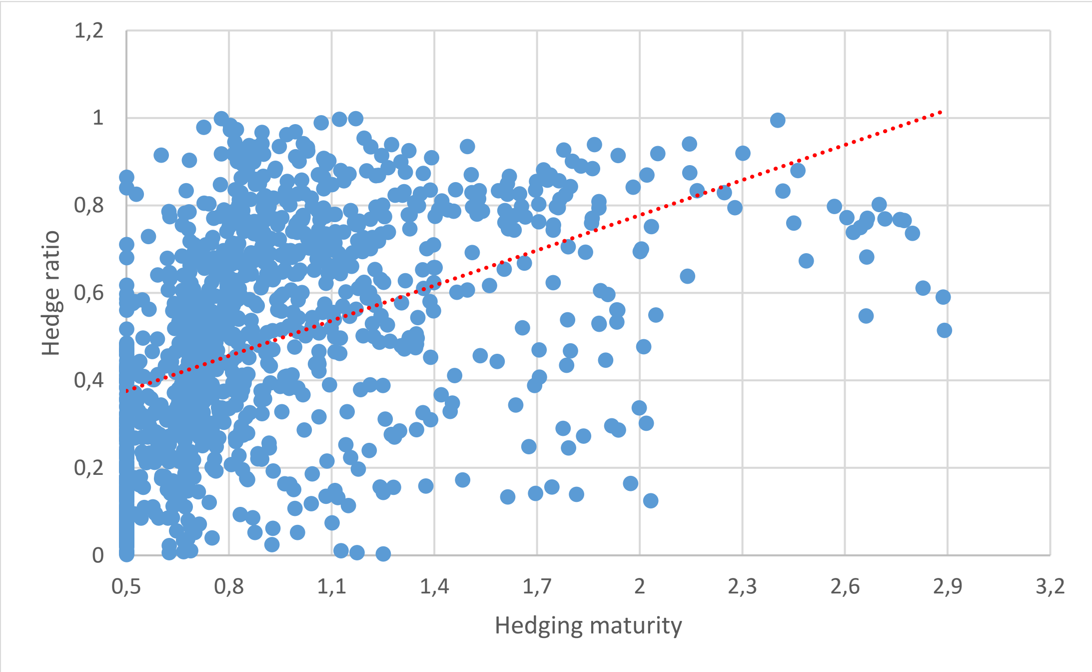

Figure 2 - Hedging maturity over time

This graph shows the average and the median *Hedging maturity* over time (sample period: 2013Q1-2016Q2). *Hedging maturity* is calculated as the weighted average of the firm's hedging horizons, where each hedging horizon is multiplied by the volume hedged in each maturity over the total hedged volume. To identify the firm's hedging horizons, we use the midpoint of each of the maturity horizon reported in the 10-Q.

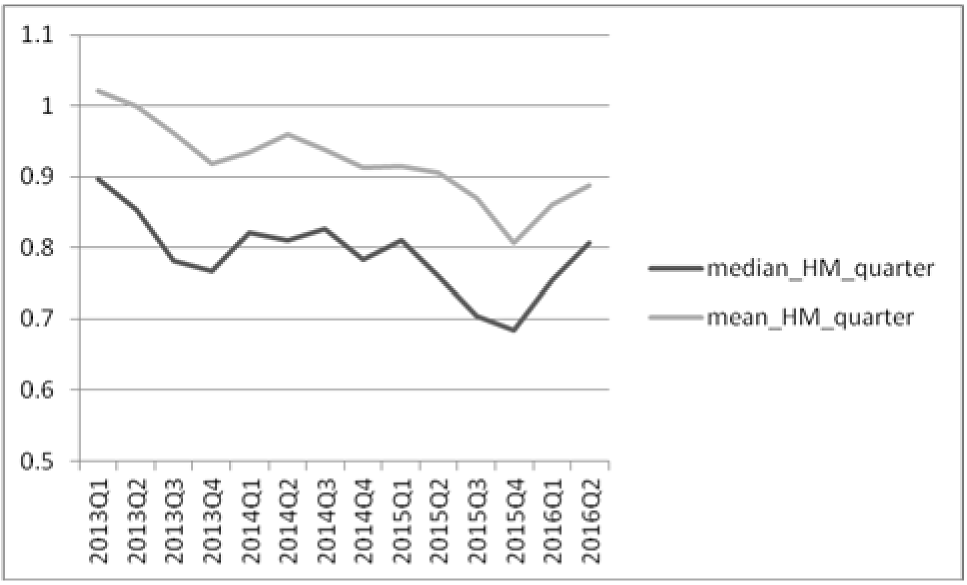

Table 1 – Hedging horizons

This table provides an overview of the hedging horizons associated to our sample firms. The first column denotes the horizon of the firm's derivative position (up to the N^{th} year) as reported in the 10-Q. The three first columns denote the *Longest hedge horizon (N. obs)*, which is the number of firm-quarter observations for which the longest maturity of the derivative position is the n^{th} year for linear contracts, option contracts and all the contracts, respectively. The last column describe the *Average maturity weight (%)*, i.e., the weight of the derivative position in terms of notional value according for each horizon.

	Longest hedge horizon			
	Linear contracts (N. obs)	**Option contracts (N. obs)**	**All contracts (N. obs)**	**Average maturity weight – all contracts (%)**
1st year	234	231	206	68.97
2nd year	399	346	454	22.44
3rd year	243	180	314	5.75
4th year	109	53	126	1.99
5th year	77	23	89	0.60
6th year	22	5	25	0.16
7th year	13	3	10	0.07
8th year	6	0	6	0.02

Table 2 – Hedging maturities

This table provides an overview of the hedging maturities associated to our sample firms. *Hedging maturity* is calculated as the weighted average of the firm's hedging horizons, where each hedging horizon is multiplied by the volume hedged in each maturity over the total hedged volume. To identify the firm's hedging horizons, we use the midpoint of each of the maturity horizon reported in the 10-Q. *Hedge ratio* is computed as the sum of linear hedging contracts and put option contracts bought with a maturity of less than 12 months, scaled by expected production within the next 12 months (in barrels of oil equivalent).

Panel A		
Hedging maturity (years)	**N. obs**	**% N. obs**
<= 0.5	206	16.75
0.5 - 1	653	53.09
1 - 1.5	256	20.81
> 1.5	133	10.81

Panel B			
Hedge ratio (terciles)	**Hedge ratio thresholds**	**Hedging maturity (mean)**	**Difference in maturity 1st - 3rd Tercile**
1st Tercile	<= 0.3256	0.7374	
2nd Tercile	0.3259 - 0.6246	0.8839	
3rd Tercile	>= 0.6247	1.1894	
			-0.4520 ***

Table 3 – Summary statistics – Hedging maturity (overall and by instrument)

This table reports summary statistics for the hedging maturity variables used in the study. These statistics are based on the same sample described in tables 1 and 2 and are used in the regression analyses. *Hedging maturity* is calculated as the weighted average of the firm's hedging horizons, where each hedging horizon is multiplied by the volume hedged in each maturity over the total hedged volume. To identify the firm's hedging horizons, we use the midpoint of each of the maturity horizon reported in the 10-Q. *Linear maturity* and *Option maturity* is the average weighted maturity calculated only for linear hedging contracts and put options contracts, respectively.

	N.obs	Mean	p25	p50	p75	Sd
Hedging maturity	1230	0.9369	0.6316	0.8113	1.0963	0.4539
Linear maturity	1097	0.9286	0.5743	0.7769	1.1077	0.4799
Option maturity	841	0.8610	0.5	0.7596	1.0265	0.3835

Table 4– Summary statistics – Independent variables

This table reports summary statistics for variables used in the study. These statistics are based on the data included in the regression analysis. *Cash* is defined as cash and cash equivalents scaled by total assets. *Asset tangibility* is defined as plant, property, and equipment scaled by total assets. *Developed reserves* is defined as proved developed reserves over total assets. *Debt maturity* is defined as long-term interest-bearing liabilities scaled by total interest-bearing liabilities. *Investment maturity* is equal to Tobin's Q, defined as assets minus book value of equity plus the market value of equity, divided by the book value of assets. *Operating flexibility* is the log of the number of times the word 'shale' appears in the firm's quarterly report (10Q). *Investment flexibility* is defined as the exploration expenses scaled by capital expenditures. *Size* is the natural logarithm of the total book of assets. *Capex* is capital expenditures scaled by total assets. *Total debt ratio* is the ratio of total debt to total assets. *Hedge ratio* is computed as the sum of linear hedging contracts and put option contracts bought with a maturity of less than 12 months, scaled by expected production within the next 12 months (barrels of oil equivalents). All variables are winsorized at the 1% level.

	N. obs	Mean	p25	p50	p75	Sd
Variables of interest						
Cash	1230	0.0406	0.0024	0.0132	0.0534	0.0629
Asset tangibility	1230	0.8291	0.7780	0.8544	0.9094	0.1046
Developed reserves	1230	42.2733	24.4253	35.8582	52.5474	30.4609
Debt maturity	1230	0.8458	0.9961	1	1	1.4156
Investment maturity	1230	1.3950	1.0292	1.2579	1.6383	0.5446
Operating flexibility	1230	1.0432	0	0	1.9459	1.3082
Investment flexibility	1230	0.0311	0	0	0.0114	0.1684
Control variables						
Size	1230	7.5813	6.6711	7.7262	8.6667	1.6608
Capex	1230	0.0600	0.0276	0.0478	0.0714	0.0581
Total debt ratio	1230	0.4348	0.2748	0.3948	0.5112	0.2579
Hedge ratio	1230	0.47062	0.2355	0.4718	0.7004	0.2893

Table 5 – Hedging maturity and collateral, matching maturity and flexibility hypotheses

This table reports the coefficients of unbalanced panel estimations of equation (1). Models (1)-(2)-(3) report our findings for each hypothesis separately (collateral, matching maturity and flexibility hypotheses, respectively). Model (4) reports our findings for the three hypotheses together. The dependent variable, *Hedging maturity* is calculated as the weighted average of the firm's hedging horizons, where each hedging horizon is multiplied by the volume hedged in each maturity over the total hedged volume. To identify the firm's hedging horizons, we use the midpoint of each of the maturity horizon reported in the 10-Q. *Cash* is defined as cash and cash equivalents scaled by total assets. *Asset tangibility* is defined as plant, property, and equipment scaled by total assets. *Developed reserves* is defined as proved developed reserves over total assets. *Debt maturity* is defined as long-term interest-bearing liabilities scaled by total interest-bearing liabilities. *Investment maturity* is equal to Tobin's Q, defined as assets minus book value of equity plus the market value of equity, divided by the book value of assets. *Operating flexibility* is the log of the number of times the word 'shale' appears in the firm's quarterly report (10Q). *Investment flexibility* is defined as the exploration expenses scaled by capital expenditures. *Size* is the natural logarithm of the total book of assets. *Capex* is capital expenditures scaled by total assets. *Total debt ratio* is the ratio of total debt to total assets. *Hedge ratio* is computed as the sum of linear hedging contracts and put option contracts bought with a maturity of less than 12 months, scaled by expected production within the next 12 months (barrels of oil equivalents). All variables are winsorized at the 1% level. All our specifications include firm and quarter fixed effects. Standard errors are in parentheses and are clustered at firm level. ***, ** and * denote significance at the 1, 5, and 10% level, respectively.

	(1)	(2)	(3)	(4)
Variables of interest				
Cash	0.6118**			0.5551**
	(0.274)			*(0.236)*
Asset tangibility	0.4888**			0.4971**
	(0.228)			*(0.226)*
Developed reserves	0.0032***			0.0029***
	(0.001)			*(0.001)*
Debt maturity		0.0211**		0.0167**
		(0.009)		*(0.007)*
Investment maturity		0.0690**		0.0560*
		(0.030)		*(0.029)*
Operating flexibility			-0.0190	-0.0247*
			(0.013)	*(0.013)*
Investment flexibility			-0.0163	0.0142
			(0.051)	*(0.051)*
Control variables				
Size	0.0228	-0.0210	-0.0382	0.0287
	(0.052)	*(0.047)*	*(0.052)*	*(0.045)*
Capex	0.3330***	0.1974*	0.3305***	0.2294**
	(0.117)	*(0.101)*	*(0.120)*	*(0.104)*
Total debt ratio	-0.2194***	-0.2241***	-0.2074**	-0.2049***
	(0.073)	*(0.083)*	*(0.081)*	*(0.071)*
Hedge ratio	0.1007*	0.1235**	0.1135*	0.1094**
	(0.059)	*(0.059)*	*(0.062)*	*(0.055)*
Constant	0.2382	1.0207***	1.2763***	0.1310
	(0.480)	*(0.388)*	*(0.413)*	*(0.432)*
Observations	1,230	1,230	1,230	1,230
R-squared	0.143	0.110	0.086	0.166
Firm FE	Yes	Yes	Yes	Yes
Quarter FE	Yes	Yes	Yes	Yes
SE clustering	Firm	Firm	Firm	Firm

Table 6 – Hedging maturity and collateral, matching maturity and flexibility hypotheses (per instrument type)

This table reports the coefficients of unbalanced panel regressions of *Linear maturity* (Panel A) and *Option maturity* (Panel B). Models (1)-(2)-(3) report our findings for each hypothesis separately (collateral, matching maturity and flexibility hypotheses, respectively). Model (4) reports our findings for the three hypotheses together. *Linear maturity* and *Option maturity* are calculated as the weighted average of the firm's hedging horizons for linear and put option contracts, respectively, where each hedging horizon is multiplied by the volume hedged in each maturity over the total hedged volume. To identify the firm's hedging horizons, we use the midpoint of each of the maturity horizon reported in the 10-Q. The independent variables are defined as in Table 5. All variables are winsorized at 1% level. Standard errors are in parentheses and are clustered at firm level. ***, ** and * denote significance at the 1, 5, and 10% level, respectively.

Panel A – Linear contracts

	(1)	(2)	(3)	(4)
Variables of interest				
Cash	0.9692***			0.8277***
	(0.335)			*(0.292)*
Asset tangibility	0.7515***			0.7665***
	(0.279)			*(0.272)*
Developed reserves	0.0038***			0.0033***
	(0.001)			*(0.001)*
Debt maturity		0.0313***		0.0215**
		(0.010)		*(0.010)*
Investment maturity		0.1190***		0.1013**
		(0.038)		*(0.039)*
Operating flexibility			0.0009	-0.0101
			(0.016)	*(0.018)*
Investment flexibility			-0.0028	0.0418
			(0.048)	*(0.046)*
Control variables				
Size	0.0379	-0.0204	-0.0441	0.0468
	(0.062)	*(0.055)*	*(0.064)*	*(0.053)*
Capex	0.3908***	0.2179*	0.3988**	0.2308*
	(0.145)	*(0.130)*	*(0.155)*	*(0.134)*
Total debt ratio	-0.2411**	-0.2752**	-0.2640**	-0.2396**
	(0.105)	*(0.113)*	*(0.115)*	*(0.101)*
Hedge ratio	-0.0235	0.0275	0.0030	-0.0017
	(0.086)	*(0.084)*	*(0.090)*	*(0.081)*
Constant	-0.0708	1.0085**	1.3800**	-0.2761
	(0.562)	*(0.463)*	*(0.541)*	*(0.498)*
Observations	1,097	1,097	1,097	1,097
R-squared	0.118	0.088	0.049	0.142
Firm FE	Yes	Yes	Yes	Yes
Quarter FE	Yes	Yes	Yes	Yes
SE clustering	Firm	Firm	Firm	Firm

Panel B – Option contracts

	(1)	(2)	(3)	(4)
Variables of interest				
Cash	0.2528			0.3358
	(0.460)			*(0.475)*
Asset tangibility	0.5807			0.5820
	(0.478)			*(0.471)*
Developed reserves	0.0023			0.0020
	(0.002)			*(0.002)*
Debt maturity		0.0165***		0.0141**
		(0.006)		*(0.006)*
Investment maturity		0.0179		0.0256
		(0.049)		*(0.054)*
Operating flexibility			-0.0476**	-0.0479**
			(0.022)	*(0.023)*
Investment flexibility			-0.0736	-0.0796
			(0.076)	*(0.073)*
Control variables				
Size	-0.0278	-0.0528	-0.0638	-0.0254
	(0.095)	*(0.095)*	*(0.090)*	*(0.096)*
Capex	0.1532	0.1381	0.1875	0.0865
	(0.214)	*(0.191)*	*(0.199)*	*(0.198)*
Total debt ratio	-0.3231**	-0.3461**	-0.3266**	-0.2931**
	(0.125)	*(0.144)*	*(0.137)*	*(0.120)*
Hedge ratio	0.0706	0.0592	0.0537	0.0621
	(0.124)	*(0.121)*	*(0.126)*	*(0.122)*
Constant	0.5804	1.3442*	1.5104**	0.5680
	(0.977)	*(0.748)*	*(0.689)*	*(0.960)*
Observations	841	841	841	841
R-squared	0.088	0.074	0.087	0.109
Firm FE	Yes	Yes	Yes	Yes
Quarter FE	Yes	Yes	Yes	Yes
SE clustering	Firm	Firm	Firm	Firm

Table 7 – The collateral hypothesis and the oil price shock

This table reports the coefficients of unbalanced panel regressions of *Hedging maturity* (Model 1), *Linear maturity* (Model 2) *and Option maturity* (Model 3), which are calculated as defined in Table 5, Table 6 (panel A) and Table 6 (panel B), respectively. *Post* is a dummy equal to 1 from 2014Q2 onwards. The independent variables are defined as in Table 5. Controls (coefficients unreported) are *Size*, *Capex*, *Total debt ratio* and *Hedge ratio*, and our measures of debt and investment maturity, operational and investment flexibility. All our specifications include firm and quarter fixed effects. All variables are winsorized at 1% level. Standard errors are in parentheses and are clustered at firm level. ***, ** and * denote significance at the 1, 5, and 10% level, respectively.

	(1)	(2)	(3)
Cash	0.0239	0.2120	-0.3476
	(0.381)	*(0.455)*	*(0.504)*
Asset tangibility	0.0204	0.1619	0.2807
	(0.279)	*(0.298)*	*(0.567)*
Developed reserves	0.0033***	0.0039***	0.0014
	(0.001)	*(0.001)*	*(0.002)*
Post	-0.6048**	-0.7542***	-0.3883
	(0.253)	*(0.266)*	*(0.420)*
Post*Cash	0.8419*	1.0741**	0.5990
	(0.449)	*(0.515)*	*(0.684)*
Post*Asset tangibility	0.6128**	0.7560**	0.2243
	(0.289)	*(0.308)*	*(0.459)*
Post*Developed reserves	-0.0004	-0.0005	0.0012
	(0.001)	*(0.001)*	*(0.001)*
Constant	0.4775	0.2143	0.6585
	(0.539)	*(0.607)*	*(0.989)*
Observations	1,230	1,097	841
R-squared	0.181	0.161	0.127
Controls	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes
Quarter FE	Yes	Yes	Yes
SE clustering	Firm	Firm	Firm

Table 8 – Matching maturity hypothesis and financial distress

This table reports the coefficients of unbalanced panel regressions of *Hedging maturity* on proxies for the matching maturity hypothesis conditional on the firm financial distress. *Hedging maturity* is defined as in Table 5. *Distance-to-Default* is defined as in Badoer et al. (2020) and is a measure of the firm's financial condition. *Distance-to-Default_median* is a dummy equal to one if the measure of the firm's *Distance-to-Default* is higher than the sample median. All the other variables are defined as in Table 5. Controls (coefficients unreported) are *Size*, *Capex*, *Total debt ratio* and *Hedge ratio* and our measures of collateral, operational and investment flexibility. All our specifications include firm and quarter fixed effects. All variables are winsorized at the 1% level. Standard errors are in parentheses and are clustered at firm level. ***, ** and * denote significance at the 1, 5, and 10% level, respectively.

	(1)	(2)
Debt maturity	0.0615***	0.0289**
	(0.007)	*(0.015)*
Investment maturity	0.0033	0.0311
	(0.040)	*(0.046)*
Distance-to-Default	-0.0038	
	(0.008)	
Distance-to-Default*Debt_maturity	0.0178***	
	(0.004)	
Distance-to-Default*Inv_maturity	-0.0023	
	(0.003)	
Distance-to-Default_median*Debt_maturity		0.1902**
		(0.093)
Distance-to-Default_median*Inv_maturity		-0.0143
		(0.042)
Constant	0.8991**	0.7539*
	(0.407)	*(0.420)*
Observations	1,111	1,111
R-squared	0.127	0.101
Controls	Yes	Yes
Firm FE	Yes	Yes
Quarter FE	Yes	Yes
SE clustering	Firm	Firm

Table 9 – Hedging maturity and collateral, matching maturity and flexibility hypotheses – Quarter-Year fixed effects

This table reports the coefficients of unbalanced panel regressions of *Hedging maturity* on proxies for the collateral, matching maturity and flexibility hypotheses adding quarter-year fixed effects. Specifically, Model (1)-(2)-(3)-(4) replicate the models reported in Table 5 but replacing quarter fixed effects with quarter-year fixed effects. All the variables are defined as in Table 5. Controls (coefficients unreported) are *Size*, *Capex*, *Total debt ratio* and *Hedge ratio*. All our specifications include firm fixed effects. All variables are winsorized at 1% level. Standard errors are in parentheses and are clustered at firm level. ***, ** and * denote significance at the 1, 5, and 10% level, respectively.

	(1)	(2)	(3)	(4)
Cash	0.6424**			0.6481***
	(0.281)			*(0.246)*
Asset tangibility	0.5124**			0.5379**
	(0.232)			*(0.233)*
Developed reserves	0.0032***			0.0030***
	(0.001)			*(0.001)*
Debt maturity		0.0217***		0.0158**
		(0.008)		*(0.007)*
Investment maturity		0.0294		0.0256
		(0.037)		*(0.032)*
Operating flexibility			-0.0230*	-0.0278**
			(0.013)	*(0.014)*
Investment flexibility			-0.0228	0.0106
			(0.063)	*(0.059)*
Constant	-0.2809	0.6446	0.7143*	-0.2815
	(0.496)	*(0.435)*	*(0.423)*	*(0.484)*
Observations	1,230	1,230	1,230	1,230
R-squared	0.225	0.182	0.172	0.241
Controls	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes
Quarter*year FE	Yes	Yes	Yes	Yes
SE clustering	Firm	Firm	Firm	Firm

Table 10 – Hedging maturity and collateral hypothesis – Different combinations of the collateral variables

This table reports the coefficients of unbalanced panel estimations of equation (1). Specifically, Model (1) includes only *Cash* and *Asset tangibility* as proxies for the collateral hypothesis, while Model (2) uses only *Developed reserves* as proxy for the collateral hypothesis. All the variables are defined as in Table 5. Controls (coefficients unreported) are *Size*, *Capex*, *Total debt ratio* and *Hedge ratio*. All variables are winsorized at 1% level. Standard errors are in parentheses and are clustered at firm level. ***, ** and * denote significance at the 1, 5, and 10% level, respectively.

	(1)	(2)
Cash	0.5507**	
	(0.251)	
Asset tangibility	0.5703**	
	(0.248)	
Developed reserves		0.0030***
		(0.001)
Debt maturity	0.0211**	0.0164**
	(0.009)	*(0.007)*
Investment maturity	0.0697**	0.0613**
	(0.028)	*(0.030)*
Operating flexibility	-0.0244*	-0.0236*
	(0.013)	*(0.014)*
Investment flexibility	0.0043	-0.0095
	(0.053)	*(0.051)*
Constant	0.5202	0.5524
	(0.406)	*(0.389)*
Observations	1,230	1,230
R-squared	0.132	0,153
Controls	Yes	Yes
Firm FE	Yes	Yes
Quarter FE	Yes	Yes
SE clustering	Firm	Firm

Table 11 – Hedging maturity and collateral, matching maturity and flexibility hypotheses – convex leverage effect

This table reports the coefficients of unbalanced panel regressions of *Hedging maturity* on proxies for the collateral, matching maturity and flexibility hypotheses adding the squared value of *Total debt ratio*. Specifically, Model (1)-(2)-(3)-(4) replicate the models reported in Table 5 but adding the squared value of *Total debt ratio* to the list of controls. All the variables are defined as in Table 5. All our specifications include firm fixed effects. All variables are winsorized at 1% level. Standard errors are in parentheses and are clustered at firm level. ***, ** and * denote significance at the 1, 5, and 10% level, respectively.

	(1)	(2)	(3)	(4)
Variables of interest				
Cash	0.5988**			0.5535**
	(0.266)			*(0.235)*
Asset tangibility	0.4980**			0.5006**
	(0.230)			*(0.230)*
Developed reserves	0.0032***			0.0029***
	(0.001)			*(0.001)*
Debt maturity		0.0208**		0.0166**
		(0.008)		*(0.007)*
Investment maturity		0.0661**		0.0548*
		(0.030)		*(0.029)*
Operating flexibility			-0.0192	-0.0246*
			(0.013)	*(0.013)*
Investment flexibility			-0.0104	0.0154
			(0.055)	*(0.051)*
Control variables				
Size	0.0256	-0.0190	-0.0307	0.0293
	(0.052)	*(0.047)*	*(0.053)*	*(0.045)*
Capex	0.3267***	0.1987**	0.3222***	0.2293**
	(0.117)	*(0.100)*	*(0.117)*	*(0.104)*
Total debt ratio	-0.3176**	-0.2927**	-0.3860**	-0.2333*
	(0.144)	*(0.137)*	*(0.162)*	*(0.130)*
Total debt ratio^2	0.0646	0.0444	0.1144	0.0188
	(0.070)	*(0.059)*	*(0.078)*	*(0.062)*
Hedge ratio	0.1018*	0.1236**	0.1149*	0.1095**
	(0.058)	*(0.059)*	*(0.062)*	*(0.055)*
Constant	0.2391	1.0282***	1.2674***	0.1340
	(0.478)	*(0.388)*	*(0.412)*	*(0.431)*
Observations	1,230	1,230	1,230	1,230
R-squared	0.144	0.111	0.089	0.166
Firm FE	Yes	Yes	Yes	Yes
Quarter FE	Yes	Yes	Yes	Yes
SE clustering	Firm	Firm	Firm	Firm

Table 12 – Hedging maturity and collateral, matching maturity and flexibility hypotheses – Further robustness tests

This table reports the coefficients of unbalanced panel estimations of equation (1). Specifically, Model (1) replaces *Investment maturity* with *Investment maturity_2*, which is the ratio of undeveloped oil reserves to developed reserves. Model (2) replaces *Operating flexibility* with *Operating flexibility_2*, which is the ratio of costs of goods sold (COGS) to annual operating costs (in which the latter is defined as the costs of goods sold plus sales and general administrative expenses). Model (3) reports the marginal effects of probit estimation where the dependent variable is *Maturity_over5*. *Maturity_over5* is a dummy that is equal to 1 if the longest hedging horizon of the firm is equal or more than 5 years. All the remaining variables are defined as in Table 5. Controls (coefficients unreported) are *Size*, *Capex*, *Total debt ratio* and *Hedge ratio*. All variables are winsorized at 1% level. Standard errors are in parentheses and are clustered at firm level. ***, ** and * denote significance at the 1, 5, and 10% level, respectively.

	(1)	(2)	(3)
Cash	0.5515*	0.5593**	0.3385*
	(0.280)	(0.247)	*(0.1831)*
Asset tangibility	0.5194*	0.5444**	0.2184
	(0.265)	(0.231)	*(0.1800)*
Developed reserves	0.0020*	0.0025***	0.0004
	(0.001)	(0.001)	(0.0003)
Debt maturity	0.0088	0.0186**	0.0681**
	(0.006)	(0.008)	*(0.0335)*
Investment maturity		0.0483	0.0155
		(0.031)	*(0.0175)*
Investment maturity_2	0.3429***		
	(0.118)		
Investment_flexibility	-0.0054	0.0183	-0.1793***
	(0.039)	(0.054)	*(0.0591)*
Operating flexibility	-0.0186		-0.0059
	(0.011)		*(0.0099)*
Operating flexibility_2		-0.0988*	
		(0.052)	
Constant	0.5680	0.2361	
	(0.523)	(0.441)	
Observations	1,142	1,215	1,230
R-squared (Pseudo R-squared)	0.152	0.166	(0.164)
Controls	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes
Quarter FE	Yes	Yes	Yes
SE clustering	Firm	Firm	Firm