Dynamic Corporate Risk Management:
Motivations and Real Implications

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8 August 2017

Abstract

We investigate the dynamics of corporate hedging programs used by US oil producers and examine the effects of hedging maturity choice on firm value. We find evidence of a concave relationship between hedging maturity and the likelihood of financial distress and oil spot prices. We further investigate the motivations of the early termination of outstanding hedging contracts. Using the essential heterogeneity approach, we evaluate the causal effects of hedging maturity on firm value. Marginal firm value increases with short-term hedging maturity. The causal effects vary across oil producers with different hidden attributes.

Keywords: Hedging maturity; Early termination of contracts; Firm value; Heterogeneous treatment effects; Essential heterogeneity models; Oil industry.

JEL classification: D8, G32.

1. Introduction

We explore the dynamics of corporate risk management through which firms could create value by considering the following questions: How far ahead do firms hedge? What are the determinants of the maturity structure of firms' hedging programs? What are the motivations for the early termination of hedging contracts? What are the real effects of hedging maturities on firm value? These questions related to the dynamics of corporate hedging are largely unexplored because of the lack of empirical analysis due to limitations of appropriate data. Using an extensive and new hand-collected dataset on the risk management activities of 150 US oil producers with quarterly observations over the period 1998–2010, we fill this gap in the literature and answer the above questions. It is important to understand why firms within the same industry and with the same oil price risk exposure differ in terms of their hedging maturity structure.

We contribute to the literature on corporate hedging in several ways. Previous studies, with the exception of Fehle and Tsyplakov (2005), discuss the maturity structure of hedging but do not investigate its determinants.[1] Our first contribution is to provide empirical evidence of the determinants of the maturity structure of hedging contracts. We are also the first researchers to empirically study the rationales for the early termination of outstanding hedging contracts. We then apply the *essential*

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[1] Dolde (1993) surveys the hedging practices of 244 Fortune 500 companies and finds that the common practice is to hedge cash flow exposures within a horizon of two to four quarters. In line with Dolde (1993), Tufano (1996) provides statistics about the percentage of the production hedged for North American gold mining firms for 1991–1993, and finds that they hedge 61.2% of their gold production for the current year (1991) and 10% and 11% for the subsequent two years. In a Wharton survey of the financial risk management practices and derivatives of 399 US nonfinancial firms, Bodnar, Hayt, and Marston (1998) report that 82% of the questioned firms use foreign currency derivatives with an initial maturity of 91 days or less and only 12% use foreign currency derivatives with maturities exceeding three years. They also find that hedging ratios at longer maturities decreased dramatically during 1998. Adam and Fernando (2006, 2008) study the cash flow gains from selective hedging for a sample of 92 North American gold producers from 1989 to 1999 and report the descriptive statistics of hedging ratios up to five years. They find that gold producers use hedging programs with one-year maturities in 90% of firm–quarters with nonzero hedging with a mean hedging ratio of 54% of the expected gold production, hedging programs with three-year maturities in 51% of hedging quarters with an average hedging ratio of 25%, and programs with five-year maturities in 18% of hedging quarters with an average hedging ratio of 28%. The authors also affirm that near-term hedging ratios are more volatile than those with longer horizons. Carter, Rogers, and Simkins (2006) investigate the jet fuel hedging activities of US airline firms during 1992–2003 and find that hedging maturities vary significantly between firms (e.g., from one year to six years ahead) and that the hedging ratios of the next year's fuel consumption are very disparate (e.g., from 1% to 43%).

heterogeneity model of Heckman, Urzua, and Vytlacil (2006) to evaluate the causal effects of hedging maturity structure on oil producers' values. The essential heterogeneity model lets us differentiate either short- or long-term maturities effects on marginal firm value. To our knowledge, our study is among the first empirical works in the corporate finance literature that uses this methodology. Our data, collected from publicly disclosed information, provide detailed information about hedging activities. This detailed information allows us to study maturity structure by hedging instrument, namely, swap contracts, put options, and costless collars, which provides deeper insight into the hedging behavior of oil producers.

Some of our findings corroborate the predictions and results drawn from the theoretical model developed by Fehle and Tsyplakov (2005) based on simulations of the gold price paths and calibrated for firms in the gold mining industry. In their model, risk management contracts are modeled as a portfolio of forward contracts on the firm's product price. They further estimate some relationships with real data. In line with their prediction and empirical results in the gold mining industry, we obtain strong evidence of a non-monotonic (concave) relationship between the hedging maturity and likelihood of financial distress measured by the leverage ratio. This non-monotonic relation means that hedging maturities increase and then decrease with the likelihood of financial distress and this is more evident for swap contracts. Results further show that the higher the distress costs, the longer the maturity of put options. There are at least two plausible explanations for this situation. First, distressed oil producers (i.e., those with insufficient cash inflows and higher leverage ratios) do this as a risk–shifting strategy. Costly put options with long maturities decrease assets available for debtholders. Second, distressed oil producers are undesirable hedging counterparties because of their high credit risk, thus put options are the only derivatives they can access for which their counterparties face no credit risk.

In line with the theoretical contribution of Fehle and Tsyplakov (2005), we observe strong evidence of the impact of oil spot prices on the oil hedging maturity structure. In particular, the maturities of swaps contracts and costless collars increase and then decrease with oil spot prices. Results further show that larger oil producers tend to use put options with longer maturity, suggesting the presence of economies of scale in the hedging behavior of oil producers. There is also evidence of maturity matching between the expected life of oil reserves and the maturity of put options. Additional results show that hedging contract features (i.e., moneyness indicator and oil spot price at initiation of the hedging contract) have a significant impact on hedging maturity dynamics. Oil producers keep in–the–money hedging contracts until they mature. The results further imply that a hedging contract initiated when oil spot prices are sufficiently high is more likely to be kept for longer periods. Control variables related to gas production and hedging appear to have significant impacts on oil hedging maturity structure. Particularly, the gas hedging ratio for expected gas production is positively and significantly related to oil hedging maturity. Interestingly, the hedges of oil and gas market risks seem to be complementary.

We provide the first direct evidence of the motivations for the early termination of hedging contracts and find that the likelihood of financial distress has a convex relationship with the early termination of swap contracts in particular, indicating that oil producers with significantly higher leverage ratios terminate their swap positions prematurely. Moreover, oil spot prices have a convex relation with the early termination of costless collars, indicating that costless collars are terminated prematurely when oil prices are significantly high. This is probably done to stop losses due to the selling of a covered call option to form the costless collar. Larger oil producers, with longer debt maturity and longer expected oil reserve life, are reluctant to terminate their put options early.

To gain insight into the causal effects of the hedging maturity on firm value, we estimate the marginal treatment effects (MTEs) of using short-term versus long-term hedging contracts. We identify

a credible instrument arising from the economic literature studying the macroeconomic responses to crude oil price shocks, namely the Kilian (2009) index which gives a measure of the demand for industrial commodities driven by economic perspectives. In our application an MTE is the value effect on the marginal firm entering long-term oil hedging contracts (treatment). After controlling for unobserved heterogeneity using the instrumental model of Heckman, Urzua, and Vytlacil (2006, 2006b), we show that the marginal firm value related to the use of long-term hedging contracts is lower than that related to the use of shorter contracts. This newly developed methodology allows us to better gauge the effects of hedging maturity choice on oil producers' values because it controls for bias arising from selection on unobservables (i.e., omitted variables) and selection on gain into treatment (i.e., self–selection) due to firms' hidden background attributes.

The rest of the paper is organized as follows. Section 2 states our hypotheses. Section 3 describes our data and variables. Section 4 reports univariate results and Section 5 investigates the empirical evidence of the maturity structure of corporate risk management. Section 6 studies the early termination of hedging contracts. Section 7 examines the real implication of hedging maturity on firm value and Section 8 concludes the paper.

2. Hypotheses

The lack of testable theoretical predictions of hedging maturity structure is compensated for by Fehle and Tsyplakov (2005), who present an infinite–horizon continuous time model of a firm that can dynamically adjust the hedge ratio and maturity of its hedging instruments in response to fluctuations in firm output price. Their model is calibrated to replicate empirical observations for a gold mining firm and produces a number of new theoretical predictions pertaining to the optimal timing, adjustment, and rollover of hedging contracts and their maturities, which we will describe in depth to develop our

hypotheses in this section and test empirically later. It is worth mentioning that Fehle and Tsyplakov's model is based on forward contracts but these contracts are not often used during our period of analysis. We will however test empirically their theoretical predictions for hedging instruments with linear payoffs (i.e., swap contracts) and other hedging tools with nonlinear payoffs (i.e., put options and costless collars).

2.1.   *Financial distress*

A large body of the empirical literature has analyzed the positive relationship between financial constraints and firms' hedging activities (e.g., Nance, Smith, and Smithson, 1993; Géczy, Minton, and Schrand, 1997; Tufano, 1996; Gay and Nam, 1998; Adam, 2002, 2009). In line with this literature, Fehle and Tsyplakov (2005) analyze the implications of financial distress on risk management adjustments. Based on simulations of gold spot prices, they find, in the presence of transaction costs, a non-monotonic relationship between hedging maturity and measures of financial distress probability. This non–monotonicity means that hedging maturity first increases and then decreases with the probability of financial distress. Thus, firms near distress are often observed with short–run hedging contracts and could terminate longer contracts at a high cost due to risk–shifting behavior. Firms far from distress do not hedge or opt for short–term contracts because of the low marginal benefits of hedging (e.g., Stulz, 1996).

Fehle and Tsyplakov (2005) also find, theoretically, that financial distress costs are negatively related to hedging maturity. Distress costs increase when the firm's cash inflows are insufficient to cover production costs and debt payments. Their simulations show that firms with high distress costs tend to use shorter maturity hedging. Hence we posit the following empirical hypothesis:

Hypothesis 1: Hedging maturity is negatively related to i) either the high or low likelihood of financial distress, and ii) higher distress costs.

Fehle and Tsyplakov (2005) also tested part (i) of the above hypothesis empirically with data from the gold mining industry. To further verify the empirical relevance of this prediction, we use the leverage ratio as measured by the book value of liabilities scaled by the book value of total assets. We add leverage squared to capture nonlinearity between financial soundness and hedging maturity. We predict a positive sign for the leverage ratio and a negative sign for its squared values.

We measure a firm's incurred distress costs by the product $I[\ Leverage - L]\ Max[0, -p + c + d]$, where I is an indicator function, *Leverage* is the leverage ratio, and *L* is the median leverage ratio of our oil producers' sample, with $I[Leverage - L] = 1$ if $Leverage > L$ and zero otherwise. $Max[0, -p + c + d]$ indicates that a firm incurs distress costs that are proportional to the shortfall of its realized selling prices p compared with its production costs, represented by cash costs c and debt payments d. These realized prices include the monetary effects of hedging activities, if any. Debt payments d are measured by quarterly interest expenses and the outstanding proportion of long-term debt in current liabilities at the end of the quarter. The variables p, c, and d are expressed per barrel of oil equivalent (BOE). Therefore, a firm incurs distress costs when its leverage is above the industry's median and its actual cash inflows (i.e., realized selling prices net of production costs) are insufficient to meet debt requirements. These distress costs could entail higher future external financing costs.

2.2.   Market conditions

The corporate hedging literature shows that market conditions, namely, spot prices and their volatilities, play a crucial role in why firms hedge, how much they hedge, and how they hedge (e.g., Bodnar, Hayt, and Marston, 1998; Brown and Toft, 2002; Adam, 2009). Fehle and Tsyplakov (2005)

investigate the evolution of risk management contracts and spot price history by simulating the stochastic process of gold spot prices. They find strong evidence of a non-monotonic relationship between spot prices and hedging contract maturity. This result means that when spot prices are very high or very low, firms choose short maturity hedging. For the range of spot prices between these two extremes, firms tend to adjust their risk management instruments more frequently and then tend to enter into newly initiated contracts with longer maturities. Moreover, Fehle and Tsyplakov (2005) find that firms with higher price volatility tend to choose longer hedging contracts. In a higher price uncertainty environment, firms tend to refrain from costly early termination of their outstanding contracts unless spot prices increase significantly. These firms, in a higher–volatility environment, often conclude long–run contracts. We therefore posit the following hypothesis, which has not yet been tested with real data:

Hypothesis 2: Hedging maturity is negatively related to either very high or very low spot prices. Moreover, firms prefer longer-maturity contracts when product price volatility is higher.

We extract the oil spot prices observed at the end of each quarter from the Bloomberg Financial Markets Information database.[2] We calculate the volatility of oil for each quarter as the standard deviation of daily spot prices within the quarter. We expect a positive sign for spot prices and volatilities and a negative sign for spot prices squared.

2.3. *Hedging contract features*

Fehle and Tsyplakov (2005) find that moneyness, remaining maturity, and spot prices at initiation of existing hedging contracts play an important role in optimal rollover and adjustment decisions. Regarding these features, they derive the following prediction, which we are the first to investigate empirically.

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[2] We use the West Texas Intermediate (WTI) crude oil index as a proxy for oil spot prices.

Hypothesis 3: Hedging contracts initiated when oil spot prices are higher are more likely to be kept until maturity because they are more likely to be in the money for a longer period.

We use the mean of oil spot prices during the quarter of the initiation of the hedging contract. To capture initiation dates, we skim the time series of the weighted-average maturity and detect initiation dates by choosing observations where maturity at time t is superior to that at time $t - 1$. Until another initiation date, we include a moneyness indicator that takes the value of 1 when the spot price at initiation of the outstanding hedging contract is greater than or equal to the average oil spot price during the current quarter and -1 otherwise.[3] We predict a positive sign for both the spot price at initiation and the moneyness indicator on hedging maturity. More precisely, we use the following three definitions of moneyness indicator for each hedging contract type.

For swap contracts, the moneyness indicator takes the value of 1 if the oil spot price at the inception of the swap contract is greater than or equal to the average oil spot price during the current quarter. Otherwise, it takes the value of –1. The oil spot price at the initiation represents the fixed-leg component specified by the swap contract, namely the swap price. We suppose that the company receives the fixed price and agrees to pay the floating-leg component of the swap tied to the WTI index.

For an oil producer, a hedge by costless collar includes buying a put option and selling a call option on crude oil, which creates a floor and a ceiling. For simplicity, we suppose that both options are initiated at the same strike price represented by the oil spot price at initiation of the collar. The moneyness indicator for a collar contract takes the value of 1 if the oil spot price at the inception of the collar contract is greater than or equal to the average oil spot price during the current quarter. Otherwise, it takes the

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[3] An anonymous referee suggested that moneyness is the difference between contract guaranteed price and the spot price when the contract is forward. Therefore, for a forward contract, the contract guaranteed price should be the forward price. On the other hand, for a commodity swap, the price should be the price which equates the values between the fixed contract and a stream of discounted forward prices. For an option, it should be the strike price. For a costless collar, there should be two prices which are the floor and the cap. Unfortunately, we do not have the data permitting to use these definitions. We tank a referee for introducing them to us.

value of –1. When the oil spot price at the initiation of the collar is greater than the oil spot price during the current quarter, the oil producer incurs a hedging gain due to the exercise of its put option. Conversely, there will be hedging losses when the current oil spot price is greater than the guaranteed oil price by the collar due to the sold call option.

For put options, the moneyness indicator takes the value of 1 if the oil spot price at the inception of the put option is greater than or equal to the average spot price during the current quarter. Otherwise, it takes the value of -1.

2.4. Control variables

2.4.1. Production uncertainty

Several studies,[4] mostly theoretical, investigate the role of production activity characteristics on firms' hedging behavior. These studies demonstrate the importance of production uncertainty (i.e., quantity risk) in firms' hedging programs. By deriving the optimal hedge analytically, Brown and Toft (2002) show that firms tend to hedge less for longer exposures because of the difficulty in accurately forecasting their future production. Consequently, production uncertainty should accentuate the inability to make accurate forecasts for future production. We explore the effects of production uncertainty and expect hedging maturity to be negatively related to production uncertainty. For each firm, we measure production uncertainty by the coefficient of the variation of daily production of oil with rolling windows of 12 quarterly observations available until the current quarter.

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[4] These studies include those of Moschini and Lapan (1995), Brown and Toft (2002), Gay, Nam, and Turac (2002, 2003), and Adam (2009).

2.4.2. Maturity matching

Maturity matching is a common best practice in corporate finance. We estimate the effect of the following two measures: 1) the weighted average maturity of debt, and 2) the expected life duration (in years) of developed oil reserves. The average debt maturity is calculated as the book value–weighted average maturities of debt that mature within one to five years. The expected life of reserves is calculated by dividing the current quantity of developed oil reserves by current annual oil production. These two variables allow us to capture any maturity matching between the firm's hedging positions and its major assets and future debt commitments.

2.4.3. Gas production and hedging

Natural gas production is an important part of our sample firms' operations. We include control variables related to gas production and hedging to avoid overlocking this important aspect and to capture any effect on oil hedging behavior among the sample firms. [5] We control for the quantity of proved gas reserves and gas production uncertainty. We further include the average hedging ratio for the expected future gas production over the subsequent five fiscal years. Gas spot prices and volatilities are also included.

Table 1 summarizes the definitions, construction, and data sources of the variables.

[Table 1 here]

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[5] We thank an anonymous referee for this suggestion.

3. Sample construction and characteristics

3.1. *Sample construction*

Our study is implemented on a sample of 150 US oil producers over the period 1998–2010. The oil industry is an excellent laboratory to test corporate risk management motivations and implications for several reasons. First, firms in this industry share homogeneous risk exposures (i.e., fluctuations in crude oil prices). Hence, diversity in hedging strategies is not due to differences in oil price risk exposure and is more likely to result from differences in firm characteristics such as oil and gas reserves, production risk and financial constraints. Second, financial derivatives on crude oil offer these firms several price hedging methods. Third, improvements in accounting disclosure related to petroleum producing activities have made operational data available. These data pertain to exploration, production and reserve quantities, cash costs, and so forth.

A preliminary list of 413 US oil producers with the primary Standard Industrial Classification (SIC) code 1311[6] (crude petroleum and natural gas) was extracted from Bloomberg. Only firms that met the following criteria were retained: They have at least five years of oil reserve data during the period 1998–2010, their 10–K and 10–Q reports are available from the EDGAR website, and the firm is covered by Compustat. The filtering process produced a final sample of 150 firms with an unbalanced panel of 6,326 firm–quarter observations. To our knowledge, this sample is the most recent and the largest in the empirical literature on risk management in the petroleum industry.

Data on these firms' financial and operational characteristics were gathered from several sources. Data regarding financial characteristics were taken from the Compustat quarterly dataset held

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[6] The SIC code 1311, crude petroleum and natural gas, comprises companies primarily involved in the operation of properties for the recovery of hydrocarbon liquids and natural gas.

by Wharton Research Data Services (WRDS). Other items related to institutional shareholding were taken from the Thomson Reuters dataset maintained by WRDS. Data related to oil and gas reserves, production quantities, cash costs, and realized selling prices were taken from Bloomberg's annual data set and verified and supplemented by data hand–collected directly from 10–K annual reports. Quarterly data about oil producers' hedging activities were hand–collected from 10–K and 10–Q reports.

3.2. Sample characteristics

3.2.1. Descriptive statistics: Dependent variable

Our dependent variable is hedging maturity measured by the average remaining maturity weighted by the hedged notional quantity, as follows:

(1)
$$HM_{i,j,t} = \sum_{T=g}^{g+5} \frac{N_{j,T} \times T}{\sum_{T=g}^{g+5} N_{j,T}}$$

where $HM_{i,j,t}$ is the weighted-average remaining maturity for firm i at quarter t and hedging instrument j. The hedging instrument could be swap contracts, put options, costless collars, forward or futures contracts, and three-way collars; $N_{j,T}$ is the hedged notional quantity[7] for instrument j and horizon T; and T ranges from the current fiscal year to five years ahead. We retain a maximum of five years ahead because we rarely find firms with hedging positions exceeding this horizon. The term g takes the value of one at the beginning of the current fiscal year or a fraction of the year otherwise (e.g., 0.75 for nine months). We then have a maximum of six years covered when g takes the value of one at the beginning of the current year.

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[7] We follow Haushalter (2000) and use notional quantities for put options because we lack detailed information to calculate a delta percentage for these options. At least three attributes of our sample could mitigate this shortcoming in our study: i) Put options are used, on average, in 12% of firm–quarters with oil hedging; ii) put options are used most with either swaps or collars; and iii) the fraction of the quantity hedged by put options does not exceed 50%.

The weighted–average hedging maturity is a more refined measure of the hedging activities of nonfinancial firms. It simultaneously combines both sides of hedging programs, namely hedging extents and hedging horizons. It then appears to capture the motivations and real implications of the hedging activities of nonfinancial firms more efficiently.

Table 2 contains descriptive statistics of the weighted–average hedging maturity by hedging instruments. Overall, Table 2 shows average maturities (in years) of 1.227, 1.221, 1.083, 0.818, and 1.448 for swap contracts, costless collars, put options, forward/futures contracts, and three–way collars, respectively. It seems that oil hedgers adopt different hedging horizons for each hedging instrument. We also calculate the weighted–average maturity for the entire oil hedging portfolio, which could include two or more instruments used simultaneously. In this case, the weighted–average maturity for each instrument is weighted by its hedging ratio. The oil hedging portfolio has an average remaining maturity of 1.204. The statistics in Table 2 are in line with previous empirical findings that firms tend to hedge near–term positions.

[Table 2 here]

Table 2 also shows that oil hedging occurred in 2,607 firm–quarters (41.21% of the firm–quarters in the sample) and presents a breakdown of the frequency of use for each hedging instrument. The most common hedging vehicles are swap contracts, with 45.25% of use (i.e., 1,711 firm–quarters out of 3,781 instrument–quarters of oil hedging). The second most frequently used instrument is costless collars, with 37.11% out of all instrument–quarters of oil hedging. Next are put options, with 11.85% of use. The least used instruments are forward or futures contracts, with only 2.78%, and three-way collars, with only 3.02% of use.

3.2.2. *Descriptive statistics: Independent variables*

Descriptive statistics are computed for the pooled dataset. Table 3 gives the mean, median, first quartile, third quartile, and standard deviations for the 150 US oil producers in the sample. Statistics show that oil producers have leverage ratios with a mean and median of about 52%, which indicates little asymmetry in the distribution of the financial solvency of the sample firms. The statistics also indicate that oil producers incurred, on average, distress costs of $3 per barrel. However, there are only 306 firm–quarters with positive financial distress costs (i.e., with a leverage ratio above the median and where the realized selling prices of oil are insufficient to cover production costs and debt requirements). For these observations, the average incurred distress cost incurred is about $57 per barrel. The statistics further show relatively moderate oil production uncertainty, as measured by the coefficient of variation in daily production, with a mean (median) of 0.27 (0.17) and one–fourth of the coefficients of variation exceeding 0.34. This finding implies that oil producers have relatively stable production quantities. Debt maturity has a mean and median of two years. We see that developed oil reserves have expected life durations with a mean (median) of nine (7.5) years. Firm size has a mean (median) of about $10 billion ($481 million), indicating that our sample is constituted by a majority of small oil producers and a few larger ones. The summary statistics also indicate that our sample firms are not intensive gas hedgers. Half of the sample firms have nonzero gas hedging ratios with an average hedging ratio around 4% of the expected future gas production during the subsequent five fiscal years, albeit with substantial variation. We see high asymmetry in the distribution of gas reserves. As for oil production, the average gas production uncertainty could be considered moderate.

[Table 3 here]

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4. Univariate results

Table 4 presents univariate results comparing oil producers' characteristics and oil market conditions based on the remaining maturities of the outstanding hedging portfolios. We then classify the remaining weighted–average maturities as (1) short–term maturities (i.e., below the 33rd percentile, which corresponds to one year ahead), (2) medium–term maturities if they fall between the 33rd and 67th percentiles (i.e., between one and 1.33 years ahead), and (3) long–term maturities, which exceed the 67th percentile (i.e., more than 1.33 years ahead). We conduct tests of the differences between the means and medians of relevant variables to contrast short– to long–term maturities, short– to medium–term maturities, and medium–to long–term maturities. We compare means by using a t–test assuming unequal variances; medians are compared with a nonparametric Wilcoxon rank–sum Z–test and two–sided p–values.

[Table 4 here]

We base our interpretation on univariate tests between firm–quarters with short– and long–term hedging maturities to ease the presentation of our results. The univariate tests in Table 4 show considerable differences in firm characteristics and oil market conditions between firm–quarters with long–term hedging maturities and those with short–term hedging maturities. The results indicate that oil producers with higher leverage ratios tend to choose longer maturities. This first univariate result does not corroborate our first hypothesis related to the non-monotonic relationship between hedging maturity and firm's financial distress as proxied by the leverage ratio. The results further show no significant differences for distress costs. Contrary to our predictions, higher production uncertainty is more closely related to long–run hedging maturities contracts. The results also provide empirical evidence of maturity matching between either firms' assets or liabilities and hedging positions. In fact,

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oil producers with a longer debt structure and a higher expected reserve life tend to use longer hedging horizons. The results pertaining to market conditions suggest that higher oil spot prices and volatilities are associated more with longer oil hedging positions. These univariate results do not test the non-monotonicity relationship between oil spot price and hedging maturity of Hypothesis 2 which will be studied in the multivariate analysis. Concerning control variables related to gas production and hedging, univariate tests show that users of long–term oil hedging contracts hedge their expected future gas production to a larger extent and have higher gas production uncertainty. Gas reserves appear to have no discernable differences between the different oil hedging maturities. As indicated in the last two lines of Table 4, gas spot prices and volatilities are associated more with the use of long–term oil hedging contracts. Univariate tests contrasting short– to medium–term maturities and medium– to long–term maturities reveal the same patterns as does the comparison between short– and long–term maturities. Overall, the mean and median comparisons yield very similar results.

Table 5 presents our results, comparing moneyness indicators and oil spot prices at initiation of hedging instruments based on their remaining maturities. For conciseness, we concentrate our analysis on the three major hedging instruments used by oil producers: swap contracts, put options, and costless collars.[8] As before, for each of the three instruments, we classify the hedging maturity as short, medium, or long term, based on the 33rd and 67th percentiles. The tests contrast short– with long–term maturities, short– with medium–term maturities, and medium– with long–term maturities. In line with the predictions, the comparisons reveal that hedging contracts with the shortest maturities have the least moneyness indicator value. This finding should show that oil producers tend to terminate their hedging positions that become deeply out-of-the money early, despite the incurred termination costs. In addition,

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[8] We skip the observations related to forward/futures contracts and three-way collars in the analysis because they do not contribute enough to oil hedging. See Table 2. We have only 105 observations on forward and futures contracts for 8 companies, and 114 observations on three-ways collars.

the results indicate that hedging contracts initiated when oil spot prices are high are more likely to be maintained for longer periods.

[Table 5 here]

5. Maturity structure of corporate risk management

To investigate the determinants of hedging maturity choice by oil producers, we estimate fixed effects regressions where the weighted–average remaining maturity is regressed on variables that measure financial distress likelihood and costs, production uncertainty, oil market conditions (oil spot price and volatility), asset–liability management, and hedging contract features. Other control variables related to gas reserves, production uncertainty, hedging, spot prices and volatilities are included. To obtain more insights into the hedging dynamics of oil producers, we estimate the regressions reported in Table 6 for the entire oil hedging portfolio and for the following major hedging instruments: swap contracts, put options, and costless collars.[9]

In line with our first hypothesis, the results pertaining to financial distress provide strong evidence of a non-monotonic (concave) relationship between hedging horizons and the likelihood of financial distress, as measured by the leverage ratio, for either the entire oil hedging portfolio or swap contracts individually. In fact, we find that the leverage ratio and leverage squared have economically and statistically significant positive and negative coefficients, respectively. These findings mean that oil

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[9] To control for the possibility of sample selection bias, our regressions are derived in the context of the two–step Heckman regression with selection. This procedure captures the sequential decisions of oil producers: first, a decision to hedge oil or not and, second, a decision about hedging maturity. In the first step, we model the oil hedging decision as a function of the following variables: firm size, taxes, distance to default as a measure of the likelihood of financial distress, liquidity, dividend payout, investment opportunities, institutional ownership, geographical diversification in oil production, and managerial shareholding. See Table 1 for more details in the construction of these variables. The results of the first step are reported in Table A.1. This first step leads to the estimation of the inverse Mills ratio for the second step. Apart from the dividend payout, we find that all other variables are statistically significant and with appropriate signs, consistent with the literature on the decision to hedge (Tufano, 1996; Géczy, Minton, and Schrand, 1997; Graham and Rogers, 2002; Dionne and Garand, 2003).

hedging maturities should first increase and then decrease with the likelihood of financial distress. It appears that oil producers that are either far from financial distress or deeply financially distressed neither initiate new hedging contracts nor roll over their expiring contracts, particularly swap contracts; and are thus observed with shorter hedging positions.

Distressed oil producers tend to choose shorter maturities because they do not seek the maximum insulation of firm value from oil price fluctuations as a risk-shifting strategy. Conversely, oil producers far from financial distress do not seek maximum protection in terms of maturity because their marginal benefit from oil hedging cannot outweigh the incurred transaction costs. For costless collars, this concave relationship is statistically less evident with a negative coefficient for leverage squared, which is only significant at conventional level of 10%. In contrast, put options do not exhibit any relationship with the leverage ratio. Interestingly, latter findings show that the non-monotonic relationship between hedging maturity and financial distress, as predicted by Fehle and Tsyplakov's model based on forward contracts, is not confirmed for hedging tools with nonlinear payoffs, particularly put options.

Figure 1 illustrates this non-monotonic relationship for the whole oil hedging portfolio, swap contracts, and costless collars, and contrasts our findings with those of Fehle and Tsyplakov (2005) for their sample of gold mining firms. The comparison with the empirical findings of Fehle and Tsyplakov (2005) for the gold mining industry indicates a lower magnitude of the coefficients related to financial distress proxies. In addition, the coefficients of leverage squared are markedly lower than those of the leverage ratio itself. It seems that the non-monotonic relationship between financial distress and hedging maturities is more pronounced for the gold mining industry than for the petroleum industry. [10] [11]

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[10] Fehle and Tsyplakov (2005) theoretical model is based on forward contract, and does not consider options and other hedging tools with nonlinear payoffs. However, one of their empirical estimations (see Table 16, page 41 in their paper) was made with all derivatives (including nonlinear instruments) in the aggregate hedging portfolio without explicitly taking their non-linearity into account.

[11] The leverage ratio for the gold mining firms studied by Fehle and Tsyplakov (2005) has an average (median) of 18% (17%). This leverage ratio is lower than that observed in our sample. Adam (2009), who studies relatively the same sample as Fehle and Tsyplakov (2005),

[Table 6 and Figure 1 here]

In addition, we find that distressed oil producers incurring a higher dollar loss per BOE tend to use put options with longer maturities. Jensen and Meckling's (1976) risk–shifting theory is one possible explanation for these findings. By entering costly long–term put options, distressed oil producers increase their firms' payoff volatility, decrease assets available for debtholders, and preserve any upside potential for shareholders. A second possible explanation is that distressed oil producers are likely to be undesirable hedging counterparties because of high credit risk. Buying options provides the only mechanism through which low–credit–quality firms can engage because this is the only derivative position in which their counterparties will not face credit risk.

Our results also provide strong evidence of a non-monotonic (concave) relationship between oil spot prices and hedging maturities for the entire hedging portfolio, swap contracts, and costless collars, as predicted in our second hypothesis. Oil spot prices and spot prices squared have highly significant positive and negative coefficients, respectively. Figure 2 illustrates this non-monotonic relationship for the whole oil hedging portfolio, swap contracts, and costless collars and shows that it is more pronounced for costless collars. Contrary to the prediction, oil price volatility is negatively related to hedging maturity for the entire hedging portfolio and not significant otherwise.

[Figure 2 here]

Hedging contract features appear to have an obvious impact on hedging maturity choice, as predicted by Hypothesis 3. The results in Table 6 indicate that swap contracts and costless collars are more likely to be kept for longer periods when oil spot prices at the initiation of these contracts are sufficiently high. One possible explanation is that in a high oil spot price environment, hedging contracts

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asserts that the leverage levels in the gold mining industry are characteristically low. He considers this as a sign of financial constraint because most of the gold mining firms are not sufficiently creditworthy to attract significant amounts of debt.

are more likely to be initiated at higher prices, and hence to be in the money for longer periods. The maturity of the entire oil hedging portfolio is also significantly positively related to oil spot prices at initiation, however, the relation for put options is negative and statistically insignificant. As predicted, the results also show that hedging contracts with higher moneyness indicator tend to have longer maturities, showing that oil producers keep in–the–money hedging contracts until they mature.

The results further indicate that oil production uncertainty and average debt maturity appear to have no discernable impact on maturity for either the entire oil hedging portfolio or each of the hedging instruments. The expected life of developed oil reserves has a statistically significant positive impact on hedging maturity through put options. This finding provides empirical evidence of maturity matching between oil producers' major assets and hedging horizons by put options. This result suggests that oil producers with higher expected oil production tend to use longer put options to fix a floor selling prices in the future. We also find that larger oil producers, in terms of size, tend to use longer put options. This finding adds support to economies of scale in hedging maturity choices, indicating that larger firms are more likely to have sufficient financial resources to finance put options' premiums.

Relative to the other control variables related to gas production and hedging, we find that the hedging ratio of future gas production, over the subsequent five fiscal years, has an economically and statistically significant positive impact on maturity for either the entire oil hedging portfolio or each of the hedging instruments. Interestingly, this finding indicates some symmetric effects between hedging of oil and gas market risks. Similar to oil spot price, gas spot prices have a significant positive effect on the maturity of the entire oil hedging portfolio, swap contracts and costless collars. Gas price volatility has mixed effects. Although it reduces the maturity of swaps, it is positively related to collars' maturity. Gas reserves have no evident impact on the maturity structure of oil hedging. Gas production uncertainty appears to motivate the use of costless collars to hedge longer oil exposures. Remarkably, gas price

volatility and gas production uncertainty risk have an evident effect on the maturity of oil hedging by costless collars. Conversely, oil volatility and production risk do not have a similar impact on collars' maturity. Given that the oil and gas spot prices have a correlation coefficient equal to 0.66 during our sample period (1998–2010), we can infer that oil and gas hedges are used complementarily.

To further gauge the relevance of our findings, we re–calculate hedging maturities by using the maximum hedging horizon without accounting for the notional quantities for each point in time for oil hedging activity. Table A.2 reports the results of these additional regressions and reveals fairly similar results to the previous ones, yet with greater economic and statistical significance. However, the negative impact of oil price volatility is also statistically significant for swaps and collars' maturities which denies the second statement of our Hypothesis 2.

6. Early termination of hedging contracts

In this section, we take a closer look at risk management dynamics by studying the determinants of the early termination of outstanding hedging contracts. Termination of a hedging contract is considered early termination when the outstanding hedging contract has a remaining weighted–average maturity greater than or equal to six months. For each instrument, we create a dummy variable that takes the value of one when we find observations of no hedging preceded by an outstanding hedging contract with remaining maturity equal to six months or more, and zero otherwise. We then run random effects logit regressions of these dummy variables on the firm covariates previously used and the moneyness indicator and remaining maturity of the terminated hedging contract. Table 7 reports the results.

[Table 7 here]

We find evidence of a convex relationship between the early termination of swap contracts and leverage ratios in particular. This finding means that the likelihood of early termination of swap

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contracts decreases and then increases with the probability of financial distress, as shown by the economically and statistically significant negative and positive coefficients for the leverage ratio and its squared value, respectively. The results further show a not surprising convex relationship between oil spot prices and the early termination of costless collars, indicating that when oil spot prices attain higher levels, outstanding collars are actively terminated prematurely. Recall that costless collars involve buying a protective put option (i.e., floor) and selling a covered call option (i.e., ceiling), the early termination of collars could stop losses due to the short call position.[12] Moreover, the early termination of collars lets firms profit from rising oil prices either by having no outstanding hedging vehicles to be fully exposed to the increasing oil prices or by negotiating new collar contracts with higher guaranteed oil price.

The early termination of swap contracts exhibits a less evident convex relationship with a negative coefficient for oil spot price, which is only significant at the conventional level of 10%. Results further show that when oil price volatility is high, oil producers tend to terminate their put options' positions prematurely. Although this latter finding contradicts the prediction, one possible explanation is that oil producers close out their positions by selling put options via a sell–to–close transaction in the options market and realize some revenue due to the increase in the put options' value caused by high oil price volatility.

Results in Table 7 also show that in–the–money swap contracts are less likely to be prematurely terminated. The remaining weighted maturity seems to have no significant impact on early termination decisions. In alternative specifications reported in the appendix (Table A.3), we rerun regressions using the remaining maturity without weighting by hedged quantities, and find a significant negative impact

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[12] For example, when oil prices reached unprecedented levels in 2008, many oil producers that had used costless collars faced heavy margin calls, which were difficult to meet.

on early termination decisions of put options and costless collars, indicating that these hedging vehicles are less likely to be prematurely terminated when they have longer remaining maturity. A possible explanation is that oil producers refrain from terminating their longer option-like contracts prematurely because they hope for more favorable prices in the future and to avoid transactions costs and premium payments associated to newly options' contracts. In-the-money swap contracts are kept until they mature, as predicted.

Further, production uncertainty prevents the early termination of swap contracts in particular. It seems that during periods of economic uncertainty, oil producers refrain from the early termination of their swap contracts to stabilize their generated cash flows. We further find that debt maturity, oil reserve life, and firm size are significantly negatively related to the early termination of outstanding put options. The longer the debt maturity, the longer the hedging maturity by put options. The reason for the positive relationship between oil reserve life and the maturity of put options is that the firm has a longer perspective due to the number of oil reserves.

7. Real implications of hedging maturity structure

In this section, we extend the controversial literature that focuses on the relationship between corporate hedging and firm value. One strand of this empirical literature finds either no support for the firm value maximization theory or a value discount due to derivative usage (Guay and Kothari, 2003; Lookman, 2003; Jin and Jorion, 2006; Fauver and Naranjo, 2010; and Phan, Nguyen and Faff, 2014). In contrast, another strand of the literature shows that firms' derivative transactions translate into increases in shareholder value (Allayannis and Weston, 2001; Graham and Rogers, 2002; Adam and Fernando, 2006; Carter, Rogers, and Simkins, 2006; Bartram, Brown, and Conrad, 2011; Choi, Mao,

and Upadhyay, 2013; Pérez–Gonzales and Yun, 2013; Mnasri, Dionne, and Gueyie, 2017). Aretz and Bartram (2010) review the empirical literature on corporate hedging and firm value.

We complement the empirical literature by going into further detail and investigating the real implications of the maturity structure of corporate risk management on firm value. Firm value is measured by Tobin's q calculated by the ratio of the market value of equity plus the book value of debt plus the book value of preferred shares to the book value of total assets. Tobin's q is expressed with a logarithmic transformation because its distribution is strongly right skewed.

Endogeneity due to any reverse causality between firm hedging behavior and other firm financial decisions is a crucial concern in such a study; it is identified as the major source of inconsistency in some of the previous findings. To control for this endogeneity, we study the effects of choosing short-term versus long–term hedging maturities on firm value using an econometric methodology that controls for biases related to omitted variables and self–selection, namely, *essential heterogeneity* models.

7.1. Instrumental variable

We identify one candidate instrument coming from the economics literature. For the choice of our candidate instrument, we build on our previous results in Table 6 (Columns 1 and 2) showing a significant impact of oil market conditions (spot price and volatility) on the maturity structure of the aggregate oil hedging portfolio. Armed with this strong empirical evidence, we look for an instrument that can explain the fluctuations of the real price of oil and that cannot affect the value of an oil producer directly. A large body of economic literature affirms that one of the most important fundamentals deriving industrial commodity prices is demand pressures or shocks induced by real economic activity. We consequently chose as instrument the Kilian (2009) index, a measure of the component of global

real economic activity that derives demand for industrial commodities. This new measure is based on dry cargo (grain, crude oil, coal, iron ore, etc.) single-voyage ocean freight rates that captures demand shifts in global industrial commodity markets. The Kilian index, constructed monthly, accounts for different fixed effects for different routes, commodities and ship sizes. It is also deflated with the US consumer price index and linearly detrended to remove the decrease in real term over time of the cost of shipping of dry cargoes. Kilian (2009) shows that aggregate shocks for industrial commodities cause long swings in the real prices of oil, which differ from the increases and decreases in the price of oil induced by the oil market-specific demand shocks, which are more transitory. For our purposes, we calculate the changes in the Kilian (2009) index for each fiscal quarter in the sample. Changes in the Kilian index are calculated by taking the level of the index at the end of the current fiscal quarter (i.e., at the end of the last month of the fiscal quarter) minus its level at the end of the previous fiscal quarter.

7.2. *Essential heterogeneity approach*

To obtain insight into the dynamics of oil hedging maturities and their related real implications, we introduce potential heterogeneity between firms in the marginal evaluation of hedging maturity on firm value. As before, we classify oil hedging maturities below the 33rd percentile, which corresponds to one year, ahead as short–term maturities; and those exceeding the 67th percentile, which corresponds to 1.33 years ahead, as long–term maturities. We then create a dummy variable that takes the value of one for long–term maturities and zero for short–term maturities. In doing so, we are able to distinguish either short– or long–term hedging maturities' contributions to value enhancement for oil producers. To overcome the endogeneity problem outlined previously, we use the newly developed IV methodology that controls for bias related to omitted variables and self–selection in the estimation of the Marginal

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Treatment Effects[13] (MTEs) of hedging maturity choice, namely, the *essential heterogeneity* model of Heckman, Urzua, and Vytlacil (2006). We describe the model in the online appendix.

In Table A.4, we estimate the choice equation by a probit model, leading to the estimation of the propensity score of using long–term hedging maturities. The dependent variable is a dummy variable that takes the value of one for long–term maturities and zero for short–term maturities, as defined previously. Regressors in the choice equation are our candidate instrument (the Kilian index) and a set of control variables. Firm–level controls include return on assets, investment opportunities, quantity of oil reserves, oil production uncertainty, leverage ratio, liquidity, a dividend payout dummy, geographical diversification in oil production, institutional ownership, gas hedging ratio, gas reserves, and gas production uncertainty. Control variables also include oil and gas spot prices and volatilities. We further control for the recent financial crisis, accompanied by markedly higher oil volatility, by including dummy variable for the years 2008 and 2009 respectively. Table 1 describes the construction of these control variables.

The results show that the Kilian index appears to be a strong predictor of hedging maturity choice, with an economically and statistically significant negative coefficient, suggesting that oil producers tend to use short–term hedging positions in periods of increasing aggregate demand for industrial commodities because crude oil prices are more likely to increase driven by a vigorous real economic activity.

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[13] The estimated MTE shows how the increment in the marginal firm value by going from choice 0 (short-term maturities) to choice 1 (long-term maturities) varies with different quantiles of the unobserved component of the desire to use long-term hedging maturity.

Table 8 reports the results of the estimation of the outcome equation with respect to firm value. The output in Table 8 gives the estimations for both the treated and untreated groups.[14] The outcome equation also indicates the average treatment effect (ATE), which captures the expected average benefit associated with the inducement in the treatment (i.e., using long–term hedging maturities in our case) conditional on observable independent variables. The ATE coefficient is not statistically significant, meaning that observable factors do not influence firm value. Further, Table 8 shows that return on assets (ROA) is significantly related to Tobin's q for users of short-term hedging contracts. Liquidity and dividend payout appear to positively influence the Tobin's q ratio for users of long-term hedging contracts. Oil price volatility has a statistically significant negative impact on firm value, indicating that investors prefer higher exposure to oil price fluctuations and tend to penalize hedging efforts at the firm level. However, this negative effect is statistically similar for the two groups (the p-value of the t-test is 0.87). Importantly, oil spot price is significantly negatively related to firm value for oil producers using long-term hedging maturities. When oil price tend to be higher, investors tend to penalize oil producers with longer hedging positions that do not allow benefit from this upward potential. Hedging extent for future gas production seems to influence negatively the firm value for users of long-term hedging maturities. Gas spot price has a significant positive effect on firm value which is statistically the same for the two groups (the p-value of the t-test is 0.1019). Gas reserves are associated with lower Tobin's q for users of long–term hedging contacts. Gas production uncertainty influences negatively (positively) the firm value for users of long (short)–term hedges. Importantly, the propensity of inducement in oil hedging, as measured by the inverse Mills ratio, seems to be negatively related to the firm value of both groups with statistically the similar effect (the p-value of the t-test is 0.9191).

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[14] The treated group consists of users of long-term hedging positions. The untreated group consists of users of short-term hedging positions. We use the Stata routine *MARGTE* developed by Brave and Walstrum (2014) to estimate the model of essential heterogeneity. We use the parametric normal approximation of the MTE with bootstrapped standard errors corrected for within-firm clustering. We run 500 replications.

[Table 8 here]

The differences between the firms can be greater when non-observable factors are considered. Applying the standard IV approach with the two groups would reveal the effect of these observable differences on firm value. Yet all firms are considered homogenous (with respect to unobserved factors) in deriving an average maturity effect (one coefficient) on firm value.[15] With the marginal treatment effect (MTE) methodology we may find that the marginal effect differs between the firms that have to be categorized in either group by adding the possibility of self-selection explained by unobserved factors.

Figure 3 plots the estimated MTEs with 95% confidence intervals, evaluated at the means of the independent (observable) characteristics of oil producers over different quantiles of the unobserved resistance to use long–term hedging positions, namely, U_D. The ATE is also plotted (dashed line) as a reference point. In addition, estimated MTEs with their respective standard errors are reported in Table A.5 for different evaluation quantile points of U_D, from 0.01 to 0.99. Estimated MTEs in the upper percentile are positive and statistically significant. Figure 3 shows that estimated MTEs are increasing with different quantiles of U_D, reflecting that the marginal Tobin's q is lowest for oil producers that are more likely to use long–term hedging maturities (i.e., lower values of the unobserved component U_D). Table A.5 shows that estimated MTEs range from –51% for high propensities to use long–term hedging positions to 90% for high propensities to use short–term hedges. This finding indicates that marginal oil producer's value increases with hedging short–term horizons. Overall, our results show that marginal firm value decreases with the propensity to use longer hedging horizons or equivalently, increases with the propensity of using short-term horizons.

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[15] As mentioned above, this average effect is not significant in our data.

[Figure 3 here]

Interestingly, the curvature of the depicted MTEs in Figure 3, with respect to different quantiles of the unobserved component of the decision process of using long–term hedging positions, exhibits substantial heterogeneity in marginal treatment effects. This provides evidence of selection into treatment or a self–selection bias, indicating that the causal effects of the hedging maturity structure on firm value also vary across oil producers due to unobserved factors.

8. Concluding remarks

A substantial body of the theoretical corporate risk management literature has increased our understanding of the motivations, virtues, and value implications of hedging. This literature derives its theoretical and empirical predictions based on the extent of hedging or participation in hedging activities. Due to the lack of data, the dynamics structure of corporate risk management has been discussed in a largely descriptive manner in the empirical literature. In this study, we go beyond the classical questions in the corporate hedging literature to investigate: How far ahead do firms hedge? What are the determinants of the maturity structure of hedging programs of nonfinancial firms? And what are the effects of hedging maturities on firm value?

Using an extensive and new hand–collected dataset on the risk management activities of 150 US oil producers, we provide strong evidence that hedging maturities for swap contracts increase and then decrease with the likelihood of financial distress, as determined by Fehle and Tsyplakov (2005). Distressed oil producers, incurring high distress costs, enter longer put options as a risk-shifting strategy or due to their high credit risk. Consistent with the prediction, our results show a non-monotonic (concave) relationship between oil spot prices and hedging maturities, particularly for swap contracts and costless collars. In addition, hedging contract features (i.e., moneyness indicator, oil spot price at

initiation) have an obvious impact on hedging maturity structure. Swap contracts and costless collars initiated when oil spot prices are high are more likely to have longer maturities. Results further show that oil producers keep their in-the-money contracts until they mature.

We also find evidence of maturity matching between put options and the expected life of developed oil reserves. Firm size is positively related to put option maturity, indicating economies of scale in hedging maturity choice due to option premiums. Interestingly, the gas hedge ratio of expected gas production, over the subsequent five fiscal years, is positively related to the maturity of oil hedges. This seems to provide evidence of maturity matching between oil and gas hedges. Gas market conditions have a significant impact on oil hedging maturity. The higher the gas spot prices, the longer the maturity of swap contracts and costless collars. Gas volatility has mixed effects. Gas production uncertainty is positively related to costless collar maturity.

We also provide the first direct evidence of the motivations for early termination of hedging contracts, which appears to be influenced by the likelihood of financial distress, oil spot prices, oil production uncertainty, debt maturity and the expected life of developed oil reserves, along with the contract's moneyness indicator. However, the impact of these determinants depends on the nature of the hedging contract (swap, put option, collar).

Finally, we explore the real effects of hedging maturity on firm value. To obtain further insight into the dynamics of these real implications, we consider heterogeneity between firms in the evaluation of the impact of hedging maturity on firm value. We use a newly developed methodology that deals with both sources of selection bias, namely, selection on unobservable variables and selection on gain into treatment. Our results show that the marginal firm value gain of selecting different hedging maturities is essentially due to the use of short-term hedging positions. More importantly, our results show an evident selection on gain into treatment due to unobserved factors in the choice of hedging

maturity design (long– versus short–term horizon). Selection on gain into treatment means that the causal effects of the hedging maturity structure on firm value vary across oil producers.

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Table 1: Variables' Definitions, Construction, and Sources

Variable Definition	Variable Name	Construction	Source
Panel A: Variables in the hedging maturity structure regressions to test our main hypotheses			
Leverage ratio	Leverage	Book value of total debts scaled by the book value of total assets.	Compustat
Financial distress costs	Distress Costs	Measured by $I[\,Lev - L\,]\,Max[0, -p + c + d]$, where Lev is the leverage ratio, L is the median leverage ratio of the oil producers in the sample, p is realized selling price, c is production cost, and d is debt payments, including interest payments and debt reimbursements, with p, c and d expressed per BOE. This variable is $I[Lev - L] = 1$ if $Lev > L$ and zero otherwise.	Manually constructed
Oil spot price	Oil Spot Price	Oil spot price represented by the WTI index on the NYMEX at the end of the current quarter.	Bloomberg
Oil price volatility	Oil Volatility	Historical volatility (standard deviation) using the daily spot prices during the quarter.	Manually constructed
Firm size	Firm Size	Number of common shares outstanding × end–of–quarter per share price + book value of assets – book value of equity. The raw value of this variable (in $ millions) is used in Table 3 (Summary Statistics). The logarithm transformation of this variable is used elsewhere.	Compustat
Oil spot price at the initiation of the hedging contract	Spot Price at Initiation	Measured by the average oil spot price during the quarter of the initiation of the hedging contract.	Manually constructed
Contract moneyness indicator	Moneyness Indicator	A dummy variable that takes the value of one if the oil spot price at the inception of the hedging contract is greater than or equal to the average spot price during the current quarter. Otherwise, it takes the value of –1.	Manually constructed
Contract's remaining maturity	Remaining Maturity	The remaining weighted–average maturity at the termination date of the hedging contract (in years).	Manually constructed
Panel B: Other control variables in the hedging maturity structure regressions to test our main hypotheses			
Oil production uncertainty	Oil Production Risk	Coefficient of variation of daily oil production. This coefficient is calculated for each firm by using rolling windows of 12 quarterly observations. Daily oil production is disclosed annually. We repeat the same observation for the same fiscal year quarters.	Manually constructed Bloomberg and 10–K reports
Weighted–average maturity of debt (in years)	Debt Maturity	Calculated as the book value–weighted average maturities of debt that mature within one, two, three, four, and five years.	Manually constructed
Expected life of oil reserves (in years)	Oil Reserves Life	Calculated by dividing the current quantity of developed oil reserves by the current annual oil production.	Manually constructed
Gas spot price	Gas Spot Price	Constructed as an average index established from principal locations' indices in the United States (Gulf Coast, Henry Hub, etc.).	Bloomberg
Gas price volatility	Gas Volatility	Historical volatility (standard deviation) using the daily spot prices during the quarter.	Manually constructed
Hedging ratio of the expected future gas production	Gas Hedge Ratio	The average hedging ratio of the expected future gas production over the subsequent five fiscal years. For each fiscal year, we measure the gas hedging ratio by the Fraction of Production Hedged (FPH) calculated by dividing the notional hedged gas quantity by the expected gas production. We then average these five hedging ratios.	Manually constructed
Gas production uncertainty	Gas Production Risk	Coefficient of variation of daily gas production. This coefficient is calculated for each firm by using rolling windows of 12 quarterly observations. Daily gas production is disclosed annually. We repeat the same observation for the same fiscal year quarters.	Manually constructed Bloomberg and 10–K reports
Gas reserves	Gas Reserves	The quantity of the total proved developed and undeveloped gas reserves. This variable is disclosed annually. We repeat the same observation for the same fiscal year quarters. The raw value of this variable (in billions of cubic feet) is used in Table 3 (Summary Statistics). The logarithm transformation of this variable is used elsewhere.	Bloomberg and 10–K reports

Table 1 *(continued)*

Panel C: Variables in the oil hedging decision regression

Tax save	Tax Save	Tax liability saving arising from a reduction of 5% of taxable income (Graham and Smith, 1999).	Manually constructed
Distance to default	DTD	Market-based measure of default risk based on Merton's (1974) approach and used by Moody's KMV. The DTD is equal to $\frac{V_a - D}{V_a \sigma_a}$, where D is defined as long-term debt in current liabilities plus one-half of long-term debts, V_a is the market value of assets, and σ_a is one-year asset volatility. The quantities V_a and σ_a are unobservable and are approximated from Merton's (1974) model by using the market value and volatility of equity, the three-month Treasury bill rate, and debts (D). See Crosbie and Bohn (2003) for more details on the construction of the DTD.	Manually constructed
Investment opportunities	Investment Opportunities	Following Haushalter (2000), we use the total costs incurred in property acquisition, exploration, and development, scaled by net property, plant, and equipment at the beginning of the quarter.	Bloomberg and 10–K reports
Liquidity	Liquidity	Book value of cash and cash equivalents divided by the book value of current liabilities.	Manually constructed
Dividend payout	Dvd Payout	Dummy variable for dividends declared during the quarter.	Manually constructed
Institutional ownership	Inst Ownership	Percentage of firm shares held by institutional investors.	Manually constructed
Geographical diversification in oil production activities	Geo Diversification	Equals $1 - \sum_{i=1}^{N}\left(\frac{q_i}{q}\right)^2$, where q_i is the daily oil production in region i (Africa, Latin America, North America, Europe, and the Middle East) and q is the firm's total daily oil production.	Manually constructed
Market value of shared owned by the CEO	CEO Ownership	Measured by the logarithm of 1 plus the market value of common shares held by the CEO at the end of each quarter.	Thomson Reuters

Panel D: Variables in the firm value implications regression

Firm value	Tobin's q	Calculated by the ratio of the market value of equity plus the book value of debt plus the book value of preferred shares divided by the book value of total assets.	Manually constructed
Oil reserves	Oil Reserves	The quantity (in millions of barrels) of the total proved developed and undeveloped oil reserves (in logarithm). This variable is disclosed annually. We repeat the same observation for the same fiscal year quarters.	Bloomberg and 10–K reports
Return on assets	ROA	Quarterly net income divided by the book value of total assets.	Manually constructed
Financial crisis	2008 and 2009	Dummy variable for each year 2008 and 2009.	Manually constructed

Panel E: Instrumental variable

Changes in Kilian (2009) index	Δ Kilian Index	Variations in the Kilian (2009) Index. This index is publicly available in a monthly frequency (http://www-personal.umich.edu/~lkilian). For each firm in the sample, we calculate changes in the Kilian index by taking the level of the index at the end of the current fiscal quarter (i.e., at the end of the last month in the fiscal quarter) minus its level at the end of the previous fiscal quarter.	Web site of the author Lutz Kilian

This table presents the definitions, construction, and data sources for the independent variables.

Table 2: Weighted–average maturity by hedging instrument (in years)

Hedging instrument	Obs	% of use	Mean	Median	1st Quartile	3rd Quartile	Min	Max	Std Dev
Swap contracts	1711	45.25%	1.227	1.061	0.750	1.530	0.250	3.758	0.644
Costless collars	1403	37.11%	1.221	1.050	0.799	1.500	0.250	4.439	0.621
Put options	448	11.85%	1.083	1.000	0.750	1.416	0.250	2.970	0.548
Forwards or futures	105	2.78%	0.818	0.750	0.500	1.000	0.250	1.750	0.332
3–way collars	114	3.02%	1.448	1.230	0.855	1.840	0.250	4.212	0.878
Oil hedging portfolio maturity(a)	2607		1.204	1.061	0.820	1.489	0.250	3.935	0.575

This table presents summary statistics pertaining to the weighted–average maturity by hedging instrument and for the whole oil hedging portfolio. The observations are firm-quarters.

(a) The number of firm-quarters for the aggregate hedging portfolio should not be calculated as the sum of firm-quarters for each instrument. In fact, for a given firm-quarter, an oil producer can use more than one instrument simultaneously.

Table 3: Summary statistics

Variables	Obs	Mean	Median	1st Quartile	3rd Quartile	Std.Dev
Leverage	6,044	0.516	0.523	0.342	0.658	0.285
Distress Costs ($/BOE)	5,732	3.056	0.000	0.000	0.000	34.167
Oil Production Risk	6,246	0.272	0.168	0.079	0.344	0.302
Debt Maturity (in years)	6,116	2.000	2.000	0.000	3.349	1.640
Oil Reserves Life (in years)	6,157	9.055	7.542	5.050	10.639	10.846
Firm Size (in $millions)	5,920	9,782	481	91	2,901	44,542
Gas Hedge Ratio	6,326	0.044	0.000	0.000	0.043	0.104
Gas Reserves (in Billions of cubic feet)	6,326	1,504	99	14	572	5,888
Gas Production Risk	6,222	0.272	0.181	0.092	0.360	0.281
Firm value (Tobin's q)	5,912	1.811	1.442	1.130	1.935	1.426

This table provides quarterly summary statistics for the 150 US oil producers for the period 1998–2010. Variables are defined in Table I. The observations are firm-quarters.

Table 4: Characteristics of oil producers and market conditions by hedging maturity

Variables	Short maturity			Medium maturity			Long maturity			Short vs. Long		Short vs. Medium		Medium vs. Long	
	Obs	Mean	Median	Obs	Mean	Median	Obs	Mean	Median	t–test	Z–score	t–test	Z–score	t–test	Z–score
Leverage	837	0.595	0.568	889	0.580	0.567	858	0.618	0.595	-2.089**	-3.500***	1.338	0.578	-3.747***	-4.256***
Distress Costs	814	0.689	0.000	857	1.166	0.000	828	1.113	0.000	-1.197	0.555	-1.187	0.433	0.115	0.134
Oil Production Risk	846	0.219	0.154	894	0.220	0.154	867	0.269	0.171	-4.171***	-0.977	-0.078	0.372	-4.115***	-1.271
Debt Maturity	846	2.281	2.537	894	2.576	3.000	867	2.804	3.021	-6.665***	-6.738***	-3.737***	-4.024***	-2.937***	-2.775***
Oil Reserves Life	846	7.779	6.927	894	8.119	7.426	867	9.634	8.892	-7.595***	-9.760***	-1.633	-2.086**	-6.268***	-7.545***
Firm Size (in log)	828	7.179	6.985	879	7.455	7.416	852	7.702	7.687	-6.232***	-6.089***	-3.374***	-3.404***	-3.095***	-2.999***
Oil Spot price	845	46.924	32.50	894	53.724	49.64	867	68.509	69.89	-16.799***	-16.702***	-5.013***	-5.402***	-11.488***	-11.554***
Oil Volatility	845	3.092	2.371	894	3.672	2.738	867	4.617	3.548	-10.618***	-13.729***	-4.277***	-5.135***	-6.055***	-9.257***
Gas Hedge Ratio	846	0.042	0.008	894	0.053	0.024	867	0.145	0.098	-15.818***	-17.439***	-3.154***	-4.293***	-14.000***	-14.619***
Gas Reserves (in log)	841	5.703	5.755	889	5.792	5.763	861	5.836	5.765	-1.474	-1.517	-0.989	-0.965	-0.501	-0.551
Gas Production Risk	846	0.209	0.155	894	0.217	0.162	867	0.293	0.185	-7.178***	-4.504***	-0.912	-0.253	-6.212***	-4.317***
Gas Spot Price	845	4.885	4.740	894	5.454	5.280	867	6.149	5.790	-10.457***	-12.451***	-4.641***	-5.518***	-5.709***	-6.331***
Gas Volatility	845	0.676	0.455	894	0.797	0.543	867	0.903	0.889	-8.729***	-10.775***	-4.571***	-5.681***	-4.182***	-5.535***

This table provides the mean and median values of oil producer characteristics and market conditions according to the weighted–average maturity of the oil hedging portfolio. For each firm–quarter with hedging activity, a hedging portfolio maturity is classified as short term if it is less than the 33rd percentile of the weighted-average maturity (i.e., one year ahead), medium term if it is between the 33rd and 67th percentiles (i.e., between one and 1.33 years ahead), and long term if it exceeds the 67th percentile (i.e., more than 1.33 years ahead). The variables are defined in Table 1. Comparison of means is constructed using a t–test assuming unequal variances; comparison of medians is constructed by using the nonparametric Wilcoxon rank sum Z–score. Two sided p–values are reported. The superscripts ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

Table 5: Contract features by hedging maturity

Variables	Short maturity			Medium maturity			Long maturity			Short vs. Long		Short vs. Medium		Medium vs. Long	
	Obs	Mean	Median	Obs	Mean	Median	Obs	Mean	Median	t–test	Z–score	t–test	Z–score	t–test	Z–score
Swap contracts															
Moneyness Indicator	564	-0.337	-1.000	582	0.306	1.000	565	0.094	1.000	-7.461***	-7.286***	-11.479***	-10.873***	3.681***	3.664***
Spot Price at Initiation	564	41.237	31.155	582	47.976	43.182	565	62.502	60.048	-14.822***	-14.712***	-4.594***	-5.326***	-10.051***	-10.349***
Put options															
Moneyness Indicator	150	-0.120	-1.000	145	0.227	1.000	153	0.412	1.000	-4.838***	-4.672***	-3.025***	-2.983***	-1.678*	-1.676*
Spot Price at Initiation	148	49.435	38.314	145	52.470	48.305	152	66.316	64.952	-4.755***	-4.729***	-0.929	-1.484	-4.133***	-3.803***
Costless collars															
Moneyness Indicator	468	-0.252	-1.000	472	0.317	1.000	463	0.127	1.000	-5.903***	-5.799***	-9.110***	-8.737***	2.995***	2.984***
Spot Price at Initiation	468	50.266	43.908	472	55.040	59.685	463	67.996	63.181	-10.129***	-10.359***	-2.814***	-3.777***	-7.860***	-6.559***
Forward contracts															
Moneyness Indicator	29	-0.379	-1.000	34	0.000	0.000	42	0.523	1.000	-4.110***	-3.760***	-1.537	-1.512	-2.391**	-2.356**
Spot price at initiation	29	40.971	31.155	34	38.786	30.685	42	59.487	43.908	-2.725***	-2.127**	0.373	0.628	-3.055***	-2.821**

This table provides the mean and median values of the hedging instruments features (i.e., moneyness indicator and spot price at the initiation of the hedging contract) according to the weighted-average maturity. Hedging contracts are swap contracts, put options, costless collars, and forward contracts. Spot Price at Initiation is measured by the average oil spot price during the quarter of initiation of the hedging contract. The variable Moneyness Indicator is a dummy variable that takes the value of 1 when the spot price at initiation of the hedging contract is greater or equal to the average oil spot price during the current quarter, and -1 otherwise. For each instrument, hedging maturity is classified as short term if it is less than the 33rd percentile of the weighted-average maturity, medium term if it is between the 33rd and 67th percentiles, and long term if it exceeds the 67th percentile. Comparison of means is constructed using a t–test assuming unequal variances; comparison of medians is constructed by using the nonparametric Wilcoxon rank sum Z–score. Two sided p–values are reported. The superscripts ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

Table 6

Oil hedging maturity structure

Variables	(1) Oil Hedging	(2) Oil Hedging	(3) Swap Contracts	(4) Swap Contracts	(5) Put Options	(6) Put Options	(7) Costless Collars	(8) Costless Collars
Leverage	0.9724***	1.1751***	1.7418***	2.0104***	-0.4836	-0.1961	0.7803	0.8549
	(0.361)	(0.370)	(0.495)	(0.500)	(0.639)	(0.631)	(0.702)	(0.686)
Leverage Squared	-0.6388**	-0.7369***	-1.2114***	-1.3268***	0.6601	0.4929	-0.5492	-0.5982*
	(0.244)	(0.246)	(0.310)	(0.318)	(0.427)	(0.431)	(0.370)	(0.359)
Distress Costs	0.0028	0.0027	0.0034	0.0033	0.0075**	0.0047	0.0011	0.0005
	(0.002)	(0.002)	(0.003)	(0.003)	(0.003)	(0.003)	(0.001)	(0.001)
Oil Spot Price		0.0214***		0.0242***		0.0017		0.0147***
		(0.004)		(0.006)		(0.005)		(0.003)
Spot Squared		-0.0001***		-0.0001***		-0.0000		-0.0001***
		(0.000)		(0.000)		(0.000)		(0.000)
Oil Volatility	-0.0156***		-0.0102		-0.0030		-0.0155	
	(0.004)		(0.006)		(0.008)		(0.010)	
Spot Price at Initiation	0.0037***		0.0061***		-0.0010		0.0038**	
	(0.001)		(0.002)		(0.002)		(0.002)	
Moneyness Indicator		0.0847***		0.1181***		0.1049***		0.1179***
		(0.009)		(0.013)		(0.026)		(0.014)
Oil Production Risk	0.0527	0.1183	0.1961	0.2505	0.3557	0.3557	0.0496	0.0502
	(0.089)	(0.087)	(0.181)	(0.175)	(0.237)	(0.236)	(0.148)	(0.139)
Debt Maturity	0.0082	-0.0003	0.0083	-0.0033	0.0047	-0.0040	-0.0019	-0.0107
	(0.012)	(0.012)	(0.016)	(0.015)	(0.026)	(0.025)	(0.024)	(0.024)
Oil Reserves Life	0.0035	0.0034	0.0147	0.0124	0.0108*	0.0114**	-0.0043	-0.0033
	(0.004)	(0.004)	(0.009)	(0.008)	(0.006)	(0.005)	(0.007)	(0.007)
Firm Size	0.0395	-0.0511	0.0258	-0.0897	0.2116**	0.1708*	-0.0891	-0.1112
	(0.053)	(0.047)	(0.059)	(0.067)	(0.095)	(0.095)	(0.088)	(0.081)
Gas Hedge Ratio	1.0486***	1.0039***	0.7614***	0.7092***	0.4132***	0.4641***	1.1047***	1.2104***
	(0.233)	(0.208)	(0.201)	(0.192)	(0.150)	(0.165)	(0.209)	(0.226)
Gas Spot Price	0.0151*	0.0346***	0.0114	0.0335**	-0.0014	0.0091	0.0137	0.0390***
	(0.009)	(0.009)	(0.011)	(0.013)	(0.010)	(0.011)	(0.010)	(0.012)
Gas Volatility	0.0408**	-0.0362**	0.0170	-0.0531***	0.0431	-0.0036	0.0695**	-0.0171
	(0.018)	(0.015)	(0.022)	(0.019)	(0.041)	(0.034)	(0.028)	(0.025)
Gas Reserves	0.0197	0.0425	-0.0788	-0.0287	-0.1180	-0.1141	0.1302	0.1144
	(0.064)	(0.047)	(0.065)	(0.060)	(0.076)	(0.093)	(0.080)	(0.069)
Gas Production Risk	0.0498	0.0441	0.0466	0.0410	0.2922	0.2526	0.5766***	0.5745***
	(0.128)	(0.121)	(0.173)	(0.172)	(0.281)	(0.302)	(0.195)	(0.196)
Inverse Mills Ratio	0.0832	0.1253*	0.1065	0.1174	-0.0326	-0.1262	0.0850	-0.0036
	(0.057)	(0.071)	(0.072)	(0.091)	(0.086)	(0.105)	(0.152)	(0.152)
Constant	0.0007	-0.1358	0.2382	0.1509	-0.0622	0.0419	0.3424	0.2607
	(0.279)	(0.277)	(0.371)	(0.366)	(0.532)	(0.610)	(0.527)	(0.550)
Observations	2,400	2,400	1,580	1,580	396	399	1,304	1,304
R–Squared	0.2191	0.2580	0.2289	0.2205	0.2444	0.2973	0.1430	0.1734
Number of firms	101	101	89	89	36	39	80	80
Rho	0.4381	0.4562	0.5520	0.5932	0.5438	0.5254	0.4716	0.4872
Sigma of random effects	0.3561	0.3504	0.5096	0.5287	0.4083	0.3824	0.4223	0.4182
Sigma of error terms	0.4033	0.3825	0.4591	0.4378	0.3739	0.3634	0.4470	0.4290
AIC	2363.184	2110.504	1946.326	1797.032	320.1387	297.4503	1532.211	1425.483
BIC	2449.933	2203.036	2026.804	1882.875	379.8599	361.2737	1609.809	1508.255

This table provides the results of the fixed effects regressions for the determinants of the weighted–average remaining maturity for the whole oil hedging portfolio, swap contracts, put options, and costless collars, respectively. All the variables are defined in Table 1. Independent variables related to oil producer characteristics (leverage ratio and its squared value, distress costs, oil production risk, debt maturity, oil reserves' life, firm size, gas hedging ratio, gas reserves, gas production risk) and oil and gas market conditions (oil spot price and its squared value, oil volatility, gas spot price, and gas volatility) are included in lagged values (first lag). The inverse Mills ratio is obtained from the first–step Heckman regression (Table A.1). Heteroskedasticity–consistent standard errors clustered at the firm level are reported in parentheses. The superscripts ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

Table 7

Determinants of the early termination of hedging contracts

Variables	(1) Swap Contracts	(2) Swap Contracts	(3) Put Options	(4) Put Options	(5) Costless Collars	(6) Costless Collars
Leverage	-4.7386**	-5.0008***	-1.1806	-0.4433	6.6384	5.1647
	(1.876)	(1.901)	(4.181)	(4.035)	(4.563)	(3.362)
Leverage Squared	3.0929***	3.0707**	0.4135	0.0021	-4.5736	-3.4904
	(1.172)	(1.215)	(4.124)	(3.941)	(3.915)	(2.702)
Distress Costs	-0.0893	-0.0928	-0.0021	0.0070	-0.0491	-0.0683
	(0.061)	(0.070)	(0.027)	(0.028)	(0.039)	(0.044)
Oil Spot Price		-0.0423*		-0.0125		-0.0906***
		(0.024)		(0.049)		(0.025)
Spot Squared		0.0001		0.0002		0.0005***
		(0.000)		(0.000)		(0.000)
Oil Volatility	0.0793		0.1397**		0.0040	
	(0.056)		(0.069)		(0.076)	
Remaining Maturity	0.0992		0.5535		0.1146	
	(0.193)		(0.497)		(0.249)	
Moneyness Indicator		-0.3384**		-0.0025		-0.1064
		(0.159)		(0.320)		(0.158)
Oil Production Risk	-2.5845**	-2.7317**	0.3522	0.4191	-0.0349	-0.4532
	(1.253)	(1.317)	(1.295)	(1.154)	(0.861)	(0.843)
Debt Maturity	-0.0039	0.0032	-0.2689**	-0.2444**	0.0005	0.0746
	(0.101)	(0.105)	(0.116)	(0.110)	(0.090)	(0.099)
Oil Reserves Life	0.0069	-0.0021	-0.1759*	-0.1410**	0.0142	0.0028
	(0.024)	(0.029)	(0.093)	(0.071)	(0.025)	(0.035)
Firm Size	-0.1204	0.1955	-1.0621***	-0.9979***	-0.0655	0.3360
	(0.265)	(0.345)	(0.268)	(0.349)	(0.248)	(0.264)
Gas Hedge Ratio	-8.1605***	-5.9258**	-0.6694	-0.8931	-4.5820	-1.3428
	(2.470)	(2.665)	(5.359)	(6.840)	(3.288)	(2.394)
Gas Spot Price	-0.1582	-0.0246	0.0679	-0.0369	-0.0507	0.0638
	(0.098)	(0.095)	(0.144)	(0.168)	(0.084)	(0.081)
Gas Volatility	-0.5416	-0.4432	-0.0018	0.2703	0.2566	0.3459
	(0.495)	(0.479)	(0.551)	(0.687)	(0.316)	(0.333)
Gas Reserves	0.1700	-0.1025	0.8023**	0.7934*	-0.2119	-0.4526**
	(0.268)	(0.321)	(0.375)	(0.411)	(0.205)	(0.227)
Gas Production Risk	0.0864	-0.0110	-3.5684**	-3.5351**	-1.5111	-1.0409
	(1.028)	(0.897)	(1.542)	(1.463)	(1.028)	(1.011)
Constant	-0.4017	0.1445	1.7008	2.0131	-3.7425**	-2.5637
	(1.072)	(1.310)	(1.564)	(1.541)	(1.530)	(1.601)
Observations	1,654	1,654	430	430	1,389	1,389
Number of firms	89	89	40	40	80	80
Log Likelihood	-206.9945	-203.5725	-73.0966	-73.4411	-195.7764	-186.7756
AIC	445.989	441.1449	178.1932	180.8822	423.5527	407.5511
BIC	532.5643	533.1311	243.2138	249.9665	507.3342	496.5689

This table provides the results of random effects logit regressions of the determinants of the early termination of swap contracts, put options, and costless collars, respectively. The dependent variable is a dummy variable that takes the value of one when there is an early termination of the hedging contract and zero otherwise. All the variables are defined in Table 1. Independent variables related to oil producer characteristics (leverage ratio and its squared value, distress costs, oil production risk, debt maturity, oil reserves' life, firm size, gas hedging ratio, gas reserves, gas production risk), oil and gas market conditions (oil spot price and its squared value, oil volatility, gas spot price, and gas volatility), and hedging contract features (moneyness indicator and remaining maturity) are included in lagged values (first lag). Heteroskedasticity–consistent standard errors clustered at the firm level are reported in parentheses. The superscripts ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

Variables	(1) Treated	(2) Untreated
	Tobin's q	
ROA	-0.0212	0.5792**
	(0.192)	(0.226)
Investment Opportunities	0.0195	0.3379
	(0.078)	(0.297)
Leverage	0.0556	-0.0035
	(0.107)	(0.123)
Liquidity	0.0684***	0.0719
	(0.026)	(0.046)
Dividend Payout	0.1697***	0.0556
	(0.047)	(0.082)
Oil Reserves	-0.0313	-0.0289
	(0.023)	(0.046)
Inst ownership	0.0220	-0.0313
	(0.094)	(0.095)
Geo Diversification	0.0972	0.0002
	(0.104)	(0.121)
Oil Volatility	-0.0265***	-0.0279***
	(0.004)	(0.008)
Oil Spot Price	-0.0027**	-0.0021
	(0.001)	(0.004)
Oil Production Risk	0.0509	-0.1467
	(0.085)	(0.114)
Gas Hedge Ratio	-0.6577**	-0.1392
	(0.278)	(0.973)
Gas Spot Price	0.0246***	0.0430***
	(0.005)	(0.011)
Gas Volatility	-0.0263	-0.0346
	(0.018)	(0.030)
Gas Reserves	-0.0637***	0.0114
	(0.018)	(0.035)
Gas Production Risk	-0.1921**	0.2565*
	(0.079)	(0.136)
Inverse Mills Ratio	-0.3374***	-0.3183*
	(0.102)	(0.164)
2008	0.0531	0.0408
	(0.066)	(0.195)
2009	-0.1124**	0.0750
	(0.051)	(0.083)
Constant	1.3600***	0.5277*
	(0.238)	(0.303)
ATE	0.1944	
	(0.202)	
Observations	1,614	

This table provides the results of the second–step regressions (outcome equation) of the *essential heterogeneity* models for the real implications of using long–term versus short–term hedging maturities. The dependent variable is the Tobin's q, calculated by the ratio of the market value of equity plus the book value of debt plus the book value of preferred shares to the book value of total assets. All the variables are defined in Table 1. Independent variables related to oil producer characteristics (ROA, investment opportunities, leverage ratio, liquidity, dividend payout, oil reserves, institutional ownership, geographical diversification, oil production risk, gas hedge ratio, gas reserves, and gas production risk), and oil and gas market conditions (oil spot price, gas spot price, oil volatility, and gas volatility) are included in lagged values (first lag). The inverse Mills ratio is from the first–step Heckman regression (Table A.1). The term ATE stands for the average treatment effect. Treated is for user of long–term hedging positions and Untreated is for user of short–term hedging positions. Bootstrapped standard errors clustered at the firm level using 500 repetitions are reported in parentheses. The superscripts ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

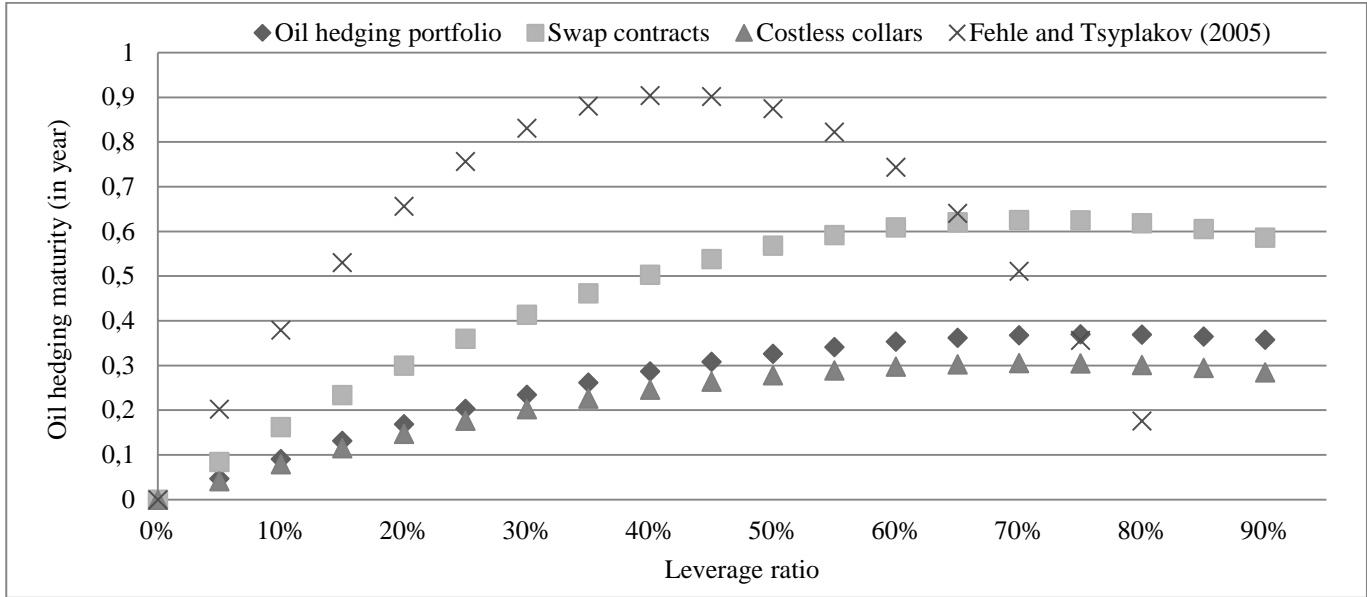Figure 1: Non–monotonic relationship between oil hedging maturity and the leverage ratio

This figure illustrates the relationship between hedging maturity and the leverage ratio: $Maturity = \alpha \times Leverage + \beta \times Lverage^2 + \sum Controls$, with α and β calculated from the estimation of the fixed effects regressions reported in Table 6. The coefficients α and β, respectively, equal 0.9724 and –0.6388 for the oil hedging portfolio, 1.7418 and –1.2114 for swap contracts, and 0.8549 and –0.5928 for costless collars (see Table 6, columns 1, 3, and 8). For Fehle and Tsyplakov (2005), α and β equal 4.30 and –5.10 (see Table 16, pp. 41 from Fehle and Tsyplakov, 2005).

Figure 2: Non–monotonic relationship between oil hedging maturity and oil spot prices
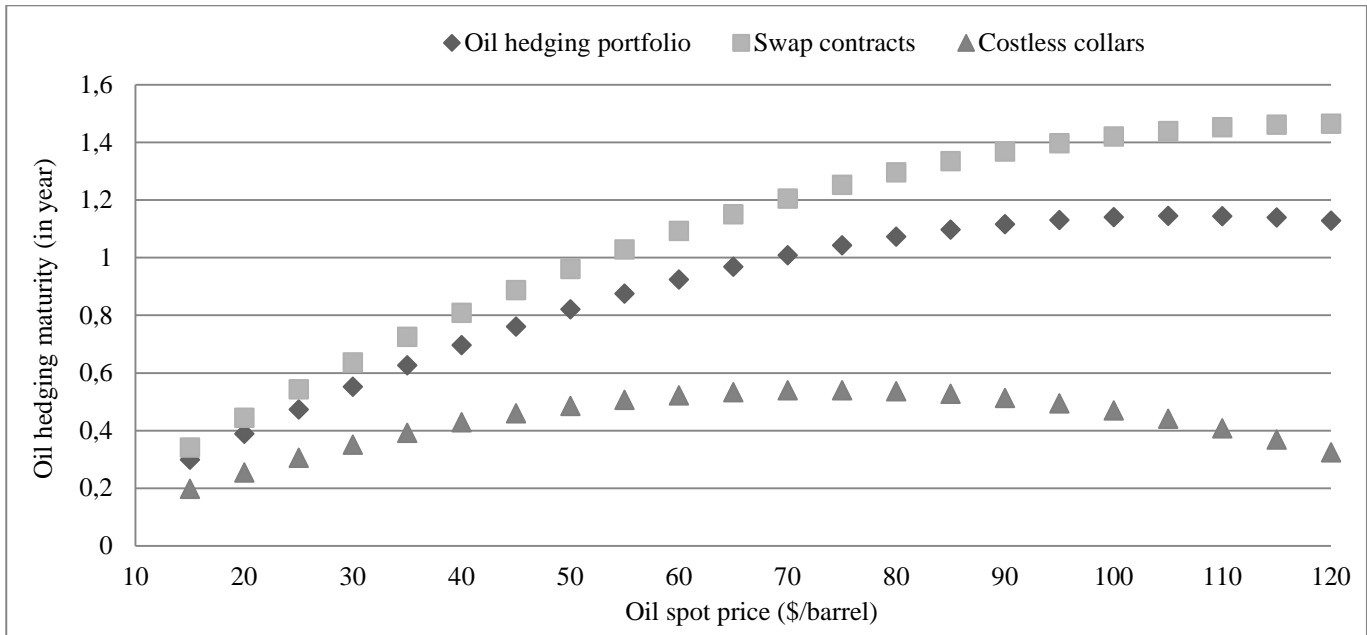
This figure illustrates the relationship between hedging maturity and oil spot prices: $Maturity = \alpha \times Oil\ spot\ price + \beta \times Oil\ spot\ price^2 + \sum Controls$, with α and β calculated from the estimation of the fixed effects regressions reported in Table 6. The coefficients α and β, respectively, equal 0.0214 and –0.0001 for the oil hedging portfolio, 0.0242 and –0.0001 for swap contracts, and 0.0147 and –0.0001 for costless collars (see Table 6, columns 2, 4, and 8).

Figure 3: Estimated MTEs
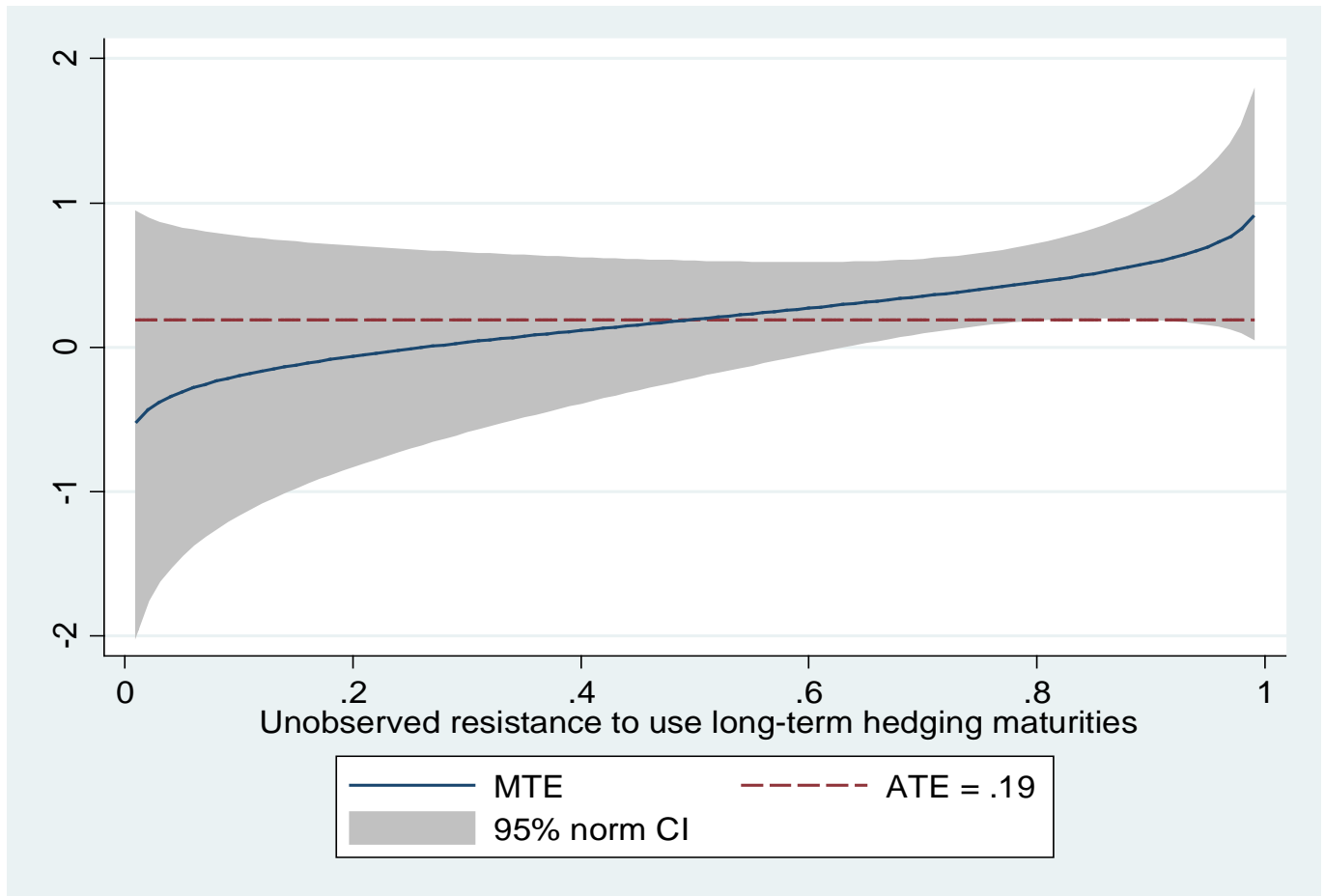
This figure plots the estimated MTE for firm value, measured by the Tobin's q, over the common support of the unobserved resistance among US oil producers to use long–term hedging maturities. Average treatment effect (ATE) and 95% normal confidence interval are also plotted.

Dynamic corporate risk management: Motivations and real implications

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Online appendix

A. Tables

Table A.1: Determinants of the oil hedging decision

Variables	Oil Hedge
Firm Size	0.1828***
	(0.065)
Tax Save	0.9667*
	(0.584)
DTD	-0.1142**
	(0.055)
Liquidity	-0.1818***
	(0.047)
Dvd Payout	-0.1866
	(0.210)
Investment Opportunities	0.1332***
	(0.044)
Institutional Ownership	0.7746***
	(0.299)
Geographic Diversification	-0.7193*
	(0.393)
CEO Ownership	2.2290**
	(0.882)
Constant	-1.6489***
	(0.356)
Observations	5,384
Pseudo–R squared	0.2254
Chi–squared	305.1534
Significance	0.0000
AIC	5879.909
BIC	6288.563

This table reports the coefficient estimates of the probit model. The dependent variable is the hedging decision dummy variable, which takes the value of one if the oil producer has any oil hedging position for the quarter and zero otherwise. All the variables are defined in Table 1. The independent variables are included in lagged values (first lag). Heteroscedasticity–consistent standard errors clustered at the firm level are reported in parentheses. Time dummies for quarters are not reported. The superscripts ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

Table A.2: Oil hedging maturity structure—Alternative specification

Variables	(1) Oil Hedging	(2) Oil Hedging	(3) Swap Contracts	(4) Swap Contracts	(5) Put Options	(6) Put Options	(7) Costless Collars	(8) Costless Collars
Leverage	2.0327***	2.3003***	3.1333***	3.5560***	0.4500	1.1478	1.4213	1.5145
	(0.748)	(0.741)	(0.925)	(0.939)	(1.448)	(1.410)	(1.332)	(1.217)
Leverage Squared	-1.3399***	-1.4392***	-2.1396***	-2.3130***	0.5045	0.0281	-0.9305	-1.0138
	(0.474)	(0.467)	(0.558)	(0.574)	(0.916)	(0.895)	(0.722)	(0.662)
Distress Costs	0.0067*	0.0066*	0.0082	0.0075	0.0108*	0.0137**	0.0030	0.0018
	(0.003)	(0.004)	(0.006)	(0.006)	(0.006)	(0.006)	(0.002)	(0.003)
Oil Spot Price		0.0344***		0.0412***		0.0066		0.0267***
		(0.008)		(0.011)		(0.011)		(0.008)
Spot Squared		-0.0002***		-0.0002***		-0.0000		-0.0002***
		(0.000)		(0.000)		(0.000)		(0.000)
Oil Volatility	-0.0326***		-0.0284**		0.0154		-0.0449**	
	(0.010)		(0.013)		(0.013)		(0.019)	
Spot Price at Initiation	0.0070***		0.0120***		-0.0009		0.0077**	
	(0.003)		(0.004)		(0.005)		(0.003)	
Moneyness Indicator		0.1150***		0.1802***		0.1763***		0.1848***
		(0.022)		(0.025)		(0.040)		(0.028)
Oil Production Risk	0.1348	0.2535	0.4155	0.4556	0.5808	0.5515	0.0388	0.0554
	(0.194)	(0.188)	(0.347)	(0.346)	(0.376)	(0.393)	(0.260)	(0.249)
Debt Maturity	0.0089	-0.0105	-0.0261	-0.0359	-0.0097	-0.0232	0.0037	-0.0091
	(0.029)	(0.027)	(0.033)	(0.030)	(0.045)	(0.044)	(0.049)	(0.047)
Oil Reserve Life	0.0107	0.0103	0.0244*	0.0205	0.0208**	0.0190**	0.0042	0.0043
	(0.010)	(0.008)	(0.014)	(0.013)	(0.009)	(0.008)	(0.015)	(0.014)
Firm Size	0.0567	-0.1241	0.1773	-0.0034	0.4015***	0.2662**	-0.1263	-0.1658
	(0.128)	(0.119)	(0.134)	(0.133)	(0.132)	(0.128)	(0.183)	(0.180)
Gas Hedge Ratio	2.2057***	2.1893***	1.5828***	1.6320***	0.8698***	0.8522***	1.8961***	2.1481***
	(0.482)	(0.460)	(0.400)	(0.428)	(0.280)	(0.274)	(0.633)	(0.684)
Gas Spot Price	0.0353**	0.0651***	0.0271	0.0669***	0.0001	0.0083	0.0383*	0.0801***
	(0.017)	(0.017)	(0.020)	(0.025)	(0.014)	(0.021)	(0.020)	(0.022)
Gas Volatility	0.0462	-0.0760**	-0.0056	-0.1362***	0.0548	-0.0217	0.1099**	-0.0459
	(0.032)	(0.030)	(0.039)	(0.038)	(0.063)	(0.052)	(0.049)	(0.047)
Gas Reserve	0.0115	0.0904	-0.1908	-0.1105	-0.2143	-0.1734	0.2315	0.2058
	(0.157)	(0.121)	(0.147)	(0.133)	(0.146)	(0.164)	(0.188)	(0.171)
Gas Production Risk	0.2429	0.2373	0.1379	0.1460	0.5187	0.4378	0.9336***	0.9345***
	(0.267)	(0.260)	(0.355)	(0.356)	(0.561)	(0.599)	(0.319)	(0.319)
Inverse Mills Ratio	0.0114	0.1137	0.1526	0.1601	-0.2918*	-0.4327**	0.2026	0.0828
	(0.152)	(0.169)	(0.176)	(0.220)	(0.166)	(0.194)	(0.263)	(0.260)
Constant	-0.2465	-0.4770	-0.5294	-0.6985	-1.1970	-0.7739	-0.2684	-0.4076
	(0.663)	(0.644)	(0.874)	(0.878)	(1.097)	(1.058)	(1.013)	(0.995)
Observations	2,296	2,400	1,580	1,580	396	399	1,304	1,304
R−Squared	0.2478	0.2291	0.2484	0.2452	0.3320	0.3491	0.1181	0.1501
Number of firms	101	101	89	89	36	39	80	80
Rho	0.4715	0.5144	0.5534	0.5665	0.5629	0.5674	0.5095	0.5118
Sigma of random effects	0.7335	0.7781	0.9771	0.9795	0.6722	0.6575	0.8021	0.7834
Sigma of error terms	0.7765	0.7560	0.8778	0.8569	0.5924	0.5741	0.7869	0.7652
AIC	5265.302	5380.268	3994.228	3919.184	684.488	662.315	3006.966	2935.05
BIC	5351.385	5472.800	4074.706	4005.027	744.209	726.139	3084.564	3017.821

This table provides the results of the fixed effects regressions for the determinants of remaining maturity for the oil hedging portfolio, swap contracts, put options, and costless collars, respectively. For each firm–quarter with oil hedging activity, this maturity is determined by taking the maximum horizon of hedging without weighting by the hedged quantity. All the variables are defined in Table 1. Independent variables related to oil producer characteristics (leverage ratio and its squared value, distress costs, oil production risk, debt maturity, oil reserves' life, firm size, gas hedging ratio, gas reserves, gas production risk), and oil and gas market conditions (oil spot price and its squared value, oil volatility, gas spot price, and gas volatility) are included in lagged values (first lag).The inverse Mills ratio is from the first–step Heckman regression (Table A.1). Heteroskedasticity–consistent standard errors clustered at the firm level are reported in parentheses. The superscripts ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

Table A.3: Determinants of the early termination of hedging contracts—Alternative specification for the remaining maturity

Variables	(1) Swap Contracts	(2) Swap Contracts	(3) Put Options	(4) Put Options	(5) Costless Collars	(6) Costless Collars
Leverage	-4.5693**	-5.0008***	-1.6812	-0.4433	6.4126	5.1647
	(1.918)	(1.901)	(3.550)	(4.035)	(3.944)	(3.362)
Leverage Squared	2.9672**	3.0707**	0.9361	0.0021	-4.3693	-3.4904
	(1.185)	(1.215)	(3.621)	(3.941)	(3.342)	(2.702)
Distress Costs	-0.0931	-0.0928	0.0073	0.0070	-0.0607	-0.0683
	(0.065)	(0.070)	(0.029)	(0.028)	(0.045)	(0.044)
Oil Spot Price		-0.0423*		-0.0125		-0.0906***
		(0.024)		(0.049)		(0.025)
Spot Squared		0.0001		0.0002		0.0005***
		(0.000)		(0.000)		(0.000)
Oil Volatility	0.0876		0.1483**		0.0050	
	(0.056)		(0.068)		(0.084)	
Remaining Maturity	-0.2852		-0.7262**		-0.5233**	
	(0.195)		(0.334)		(0.209)	
Moneyness Indicator		-0.3384**		-0.0025		-0.1064
		(0.159)		(0.320)		(0.158)
Oil Production Risk	-2.6918**	-2.7317**	0.4118	0.4191	-0.1935	-0.4532
	(1.264)	(1.317)	(1.124)	(1.154)	(0.833)	(0.843)
Debt Maturity	-0.0010	0.0032	-0.2643**	-0.2444**	0.0011	0.0746
	(0.100)	(0.105)	(0.126)	(0.110)	(0.083)	(0.099)
Oil Reserves Life	0.0149	-0.0021	-0.1192	-0.1410**	0.0131	0.0028
	(0.024)	(0.029)	(0.077)	(0.071)	(0.023)	(0.035)
Firm Size	-0.0745	0.1955	-1.0116***	-0.9979***	0.0458	0.3360
	(0.246)	(0.345)	(0.249)	(0.349)	(0.246)	(0.264)
Gas Hedge Ratio	-6.9665***	-5.9258**	0.7548	-0.8931	-2.4342	-1.3428
	(2.519)	(2.665)	(5.665)	(6.840)	(2.922)	(2.394)
Gas Spot Price	-0.1382	-0.0246	0.0914	-0.0369	-0.0490	0.0638
	(0.092)	(0.095)	(0.139)	(0.168)	(0.079)	(0.081)
Gas Volatility	-0.5012	-0.4432	0.0233	0.2703	0.3363	0.3459
	(0.479)	(0.479)	(0.532)	(0.687)	(0.307)	(0.333)
Gas Reserves	0.1469	-0.1025	0.8720**	0.7934*	-0.2575	-0.4526**
	(0.248)	(0.321)	(0.380)	(0.411)	(0.212)	(0.227)
Gas Production Risk	0.2378	-0.0110	-3.2758**	-3.5351**	-1.2555	-1.0409
	(1.001)	(0.897)	(1.336)	(1.463)	(0.950)	(1.011)
Constant	-0.4326	0.1445	1.6581	2.0131	-3.5588**	-2.5637
	(1.095)	(1.310)	(1.324)	(1.541)	(1.449)	(1.601)
Observations	1,654	1,654	430	430	1,389	1,389
Number of firms	89	89	40	40	80	80
Log Likelihood	-205.6486	-203.5725	-72.2952	-73.4411	-192.5772	-186.7756
AIC	443.2971	441.1449	176.5903	180.8822	417.1543	407.5511
BIC	529.8723	533.1311	241.6109	249.9665	500.9357	496.5689

This table provides the results of random effects logit regressions of the determinants of the early termination of swap contracts, put options, and costless collars, respectively. The dependent variable is a dummy variable that takes the value of one when there is an early termination of the hedging contract and zero otherwise. The remaining maturity is calculated without weighting by the hedged quantities. All the variables are defined in Table 1. Independent variables related to oil producer characteristics (leverage ratio and its squared value, distress costs, oil production risk, debt maturity, oil reserves' life, firm size, gas hedging ratio, gas reserves, gas production risk), oil and gas market conditions (oil spot price and its squared value, oil volatility, gas spot price, and gas volatility), and hedging contract features (moneyness indicator and remaining maturity) are included in lagged values (first lag). Heteroskedasticity–consistent standard errors clustered at the firm level are reported in parentheses. The superscripts ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

Table A.4: First–step of the essential heterogeneity models

Variables	(1) Maturity Choice
⊿ Kilian index	-0.7468***
	(0.277)
ROA	0.4246
	(0.577)
Investment Opportunities	1.0404***
	(0.271)
Leverage	0.4672**
	(0.211)
Liquidity	-0.1295**
	(0.057)
Dividend Payout	-0.0789
	(0.104)
Oil Reserves	0.3507***
	(0.036)
Inst Ownership	-0.0385
	(0.177)
Geo Diversification	0.3677*
	(0.206)
Oil Volatility	-0.0399
	(0.027)
Oil Spot Price	0.0289***
	(0.003)
Oil Production Risk	0.2114
	(0.219)
Gas Hedge Ratio	7.4881***
	(0.575)
Gas Spot Price	-0.0326
	(0.025)
Gas Volatility	0.2508***
	(0.085)
Gas Reserve	-0.14510***
	(0.035)
Gas Production Risk	0.3390
	(0.214)
Inverse Mills Ratio	0.6845***
	(0.244)
2008	-1.2263***
	(0.192)
2009	0.4301**
	(0.217)
Constant	-3.2355***
	(0.425)
Observations	1,614
R–Squared	0.3547

This table provides the results of the probit regressions corresponding to the first–step of the essential heterogeneity models related to the oil hedging maturity choice. The dependent variable is Maturity choice, which takes the value of one if the oil producer has a long–term oil hedging position and zero if it has a short–term oil hedging position. Short–term hedging maturities are below the 33rd percentile, which corresponds to one year ahead, and long–term hedging maturities exceed the 67th percentile, which corresponds to 1.33 years ahead. The instrument for oil hedging maturity is the changes in the Kilian index. All the variables are defined in Table 1. Independent variables related to oil producer characteristics (ROA, investment opportunities, leverage ratio, liquidity, dividend payout, oil reserves, institutional ownership, geographical diversification, oil production risk, gas hedge ratio, gas reserves, and gas production risk), and oil and gas market conditions (oil spot price, gas spot price, oil volatility, and gas volatility) are included in lagged values (first lag). The inverse Mills ratio is from the first–step Heckman regression (Table A.1). Standard errors are reported in parentheses. The superscripts ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

Table A.5: Estimated MTEs

(1) U_p	(2) Tobin's q	(3) U_p	(4) Tobin's q	(5) U_p	(6) Tobin's q	(7) U_p	(8) Tobin's q
u1	-0.5159	u26	-0.0020	u51	0.2020	u76	0.4100***
	(0.739)		(0.340)		(0.197)		(0.124)
u2	-0.4327	u27	0.0073	u52	0.2097	u77	0.4200***
	(0.673)		(0.333)		(0.192)		(0.125)
u3	-0.3799	u28	0.0164	u53	0.2174	u78	0.4302***
	(0.632)		(0.326)		(0.187)		(0.126)
u4	-0.3401	u29	0.0254	u54	0.2250	u79	0.4406***
	(0.601)		(0.320)		(0.183)		(0.128)
u5	-0.3078	u30	0.0343	u55	0.2328	u80	0.4514***
	(0.575)		(0.313)		(0.178)		(0.131)
u6	-0.2803	u31	0.0430	u56	0.2405	u81	0.4624***
	(0.554)		(0.307)		(0.174)		(0.135)
u7	-0.2562	u32	0.0516	u57	0.2482	u82	0.4739***
	(0.535)		(0.301)		(0.170)		(0.139)
u8	-0.2346	u33	0.0601	u58	0.2560	u83	0.4857***
	(0.518)		(0.294)		(0.165)		(0.143)
u9	-0.2150	u34	0.0684	u59	0.2639	u84	0.4980***
	(0.503)		(0.288)		(0.161)		(0.148)
u10	-0.1969	u35	0.0767	u60	0.2717*	u85	0.5108***
	(0.489)		(0.282)		(0.157)		(0.154)
u11	-0.1801	u36	0.0849	u61	0.2797*	u86	0.5242***
	(0.476)		(0.276)		(0.153)		(0.161)
u12	-0.1644	u37	0.0931	u62	0.2877*	u87	0.5383***
	(0.464)		(0.271)		(0.150)		(0.169)
u13	-0.1495	u38	0.1011	u63	0.2957**	u88	0.5531***
	(0.452)		(0.265)		(0.146)		(0.177)
u14	-0.1355	u39	0.1091	u64	0.3038**	u89	0.5689***
	(0.441)		(0.259)		(0.143)		(0.186)
u15	-0.1221	u40	0.1170	u65	0.3120**	u90	0.5857***
	(0.431)		(0.254)		(0.139)		(0.197)
u16	-0.1092	u41	0.1249	u66	0.3203**	u91	0.6037***
	(0.421)		(0.248)		(0.136)		(0.208)
u17	-0.0969	u42	0.1327	u67	0.3287**	u92	0.6234***
	(0.412)		(0.243)		(0.134)		(0.221)
u18	-0.0851	u43	0.1405	u68	0.3372**	u93	0.6450***
	(0.403)		(0.237)		(0.131)		(0.235)
u19	-0.0737	u44	0.1483	u69	0.3458***	u94	0.6691***
	(0.394)		(0.232)		(0.129)		(0.252)
u20	-0.0626	u45	0.1560	u70	0.3545***	u95	0.6966**
	(0.386)		(0.227)		(0.127)		(0.272)
u21	-0.0518	u46	0.1637	u71	0.3633***	u96	0.7289**
	(0.378)		(0.222)		(0.125)		(0.295)
u22	-0.0414	u47	0.1714	u72	0.3723***	u97	0.7686**
	(0.370)		(0.217)		(0.124)		(0.324)
u23	-0.0312	u48	0.1791	u73	0.3815***	u98	0.8214**
	(0.362)		(0.212)		(0.123)		(0.364)
u24	-0.0213	u49	0.1867	u74	0.3908***	u99	0.9047**
	(0.355)		(0.207)		(0.123)		(0.427)
u25	-0.0116	u50	0.1944	u75	0.4003***		
	(0.347)		(0.202)		(0.123)		

This table gives the estimated MTEs related to the choice of oil hedging maturity, long–term versus short–term. The MTEs are for firm value measured by the Tobin's q. U_p reflects different estimation points of the unobserved resistance to use long–term hedging maturity. The superscripts ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

B. Essential heterogeneity model

Practically, *essential heterogeneity* models usually begin with a Mincer–like equation (Mincer, 1974), as follows:

(B.1) $$y_{i,t} = \alpha + \beta \times d_{i,t} + \sum Control\ variables_{i,t-1} + u_{i,t},$$

where $y_{i,t}$ is the observed value of oil producer i at the end of quarter t and $d_{i,t}$ is the observed value of a dummy variable $D = (0,1)$ representing whether the oil producer i uses short (0) or long–term (1) hedging contracts at the end of quarter t. The control variables include the same set of observable covariates as presented previously, namely the return on assets, investment opportunities, quantity of oil reserves, oil production uncertainty, leverage ratio, liquidity, a dividend payout dummy, geographical diversification in oil production, institutional ownership, gas hedging ratio, gas reserves, and gas production uncertainty, oil and gas spot prices and volatilities, and a dummy variable for the years 2008 and 2009 respectively. The term $u_{i,t}$ is an individual–specific error term and β represents the average return from using long-term hedging contracts.

Two sources of bias could affect the estimates of β. The first is related to the standard problem of selection bias, when $d_{i,t}$ is correlated with $u_{i,t}$, but it should be resolved using IV methods, among others. The second source of bias occurs if the returns to using long-term hedging positions vary across oil producers (i.e., β is random), even after conditioning on observable characteristics leading to heterogeneous treatment effects. Moreover, oil producers make their hedging maturity choice (short–term versus long–term maturity) with at least partial knowledge of the *expected* idiosyncratic gains from this decision (i.e., β is correlated with D), leading to selection into treatment or sorting on the gain problem.

Heckman, Urzua, and Vytlacil (2006) developed an econometric methodology based on IVs to solve the problem of essential heterogeneity (i.e., β is correlated with D) in the estimation of MTEs. Their methodology is built on the generalized Roy model, which is an example of treatment effects models for economic policy evaluation. The generalized Roy model involves a joint estimation of an observed continuous outcome and its binary treatment, and is as follows. Let (Y_0, Y_1) be the potential outcomes observed under the counterfactual states of treatment (Y_1) and no treatment (Y_0); these outcomes are supposed to depend linearly upon observed characteristics X and unobservables (U_0, U_1), as follows:

(B.2) $$Y_1 = \alpha_1 + \kappa + \beta_1 X + U_1,$$

(B.3) $$Y_0 = \alpha_0 + \beta_0 X + U_0.$$

where κ is the benefit related to the treatment $D = 1$.

The selection process is represented by $I_D = \gamma Z - V$, which depends on the observed values of the Z variables and an unobservable disturbance term V. The selection process, related to whether short– or long–term hedging positions are used, is linked to the observed outcome through the latent variable I_D, which gives the dummy variable D representing the treatment status:

(B.4) $$D = \begin{cases} 1 \text{ if } I_D > 0, \\ 0 \text{ if } I_D \leq 0, \end{cases}$$

where the vector of the observed values of the Z variables includes IV variables Z_{IV} and all the components of X in the outcome equation. The variables Z_{IV} satisfy the following constraints: $\text{Cov}(Z_{IV}, U_0) = 0$, $\text{Cov}(Z_{IV}, U_1) = 0$, and $\gamma \neq 0$. Our candidate IV Z_{IV} is the change in the Kilian index. The unobservable set of (U_0, U_1, V) is assumed to be statistically independent of Z, given X. We must

first estimate the probability of participation in long-term horizon hedging maturities or the propensity score.

We can assume the joint normality of the unobservable components of the outcome and decision equations $(U_0, U_1, V) \sim N(0, \Sigma)$, where Σ is the variance–covariance matrix of the three unobservables, with $\sigma_{1V} = \text{Cov}(U_1, V)$ and $\sigma_{0V} = \text{Cov}(U_0, V)$. $\sigma_{VV} = 1$ following standard practice with the probit model. Under this parametric approach, the discrete choice model is a conventional probit with $V \sim N(0,1)$, where the propensity score is given by:

(B.5) $$P(z) = Pr(D = 1 | Z = z) = Pr(\gamma z > V) = \Phi(\gamma z),$$

with $\Phi(\cdot)$ as the cumulative distribution of a standard normal variable. The term $P(z)$, called the probability of participation or propensity score, denotes the selection probability of using long–term hedging maturity conditional on Z (i.e., $D = 1$). Therefore we can write:

(B.6) $$\Phi(\gamma Z) > \Phi(V) \Longleftrightarrow P(Z) > U_D$$

where $U_D = \Phi(V)$ and $P(Z) = \Phi(\gamma Z) = Pr(D = 1 | Z)$.

The term U_D is a uniformly distributed random variable between zero and one representing different quantiles of the unobserved component V in the selection process. These two quantities, $P(Z)$ and U_D, play a crucial role in essential heterogeneity models. The quantity $P(Z)$ could be interpreted as the probability of going into treatment and U_D is a measure of individual-specific resistance to undertake treatment or, alternatively, the propensity to not be treated. In our case, the higher the $P(Z)$, the more the oil producer is induced to use long–term hedging maturities because of Z. On the contrary, the higher the U_D, the greater the resistance of the oil producer to use long–term maturities due to a larger

unobserved component. $P(Z) = U_D$ is thus the margin of indifference for oil producers that are indifferent between long- and short–term hedging horizons.

The marginal treatment effects (MTEs) can be defined as follows:

(B.7) $\text{MTE}(X = x, U_D = u_D) = (\alpha_1 + \kappa - \alpha_0) + (\beta_1 - \beta_0)x + (\sigma_{1V} - \sigma_{0V})\Phi^{-1}(u_D).$

In our application, estimation of the parameters follows the parametric method proposed by Brave and Walstrum (2014) by using the *MARGTE* command (See also Heckman, Urzua, and Vytlacil (2006b) for a description of the different estimation techniques that allow the computation of treatment effects in the context of *essential heterogeneity* models). Under the assumption of joint normality, σ_{1V} and σ_{0V} are the coefficients of the inverse Mills ratios. They are estimated separately along with the other parameters of the two following equations:

(B.8) $$E(Y|X = x, D = 1, P(Z) = p) = \alpha_1 + \kappa + X\beta_1 + \sigma_{1V}\left(-\frac{\phi\left(\Phi^{-1}(p)\right)}{p}\right)$$

(B.9) $$E(Y|X = x, D = 0, P(Z) = p) = \alpha_0 + X\beta_0 + \sigma_{0V}\left(\frac{\phi\left(\Phi^{-1}(p)\right)}{1-p}\right)$$

to obtain the $\widehat{MTE}$ values, using the estimated propensity score:

$$\widehat{MTE}(X = x, U_D = u_D) = \widehat{\alpha_1 + \kappa} - \widehat{\alpha_0} + \left(\widehat{\beta_1} + \widehat{\beta_0}\right)x' + (\hat{\sigma}_{1V} - \hat{\sigma}_{0V})\Phi^{-1}(u_D).$$

Intuitively, how the MTE evolves over the range of U_D informs us about the heterogeneity in treatment effects among oil producers, that is, how the coefficient β is correlated with the treatment indicator D in Eq. (B.1). Equivalently, the estimated MTE shows how the increment in the marginal firm value by going from choice 0 to choice 1 varies with different quantiles of the unobserved component V in the choice equation. In our case, whether MTE increases or decreases with U_D tells us

whether the coefficient β in Eq. (B.1) is negatively or positively correlated with the latent tendency of using long–term contracts for oil hedging.