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Price uncertainty and corporate value

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Abstract

This study examines the sensitivity of equity values of oil producers to changes in the uncertainty of future oil prices. We document that this sensitivity is negatively correlated with a firm's debt ratio and its production costs. These results indicate that companies that are more likely to experience financial distress or underinvestment from low cash flows are adversely affected by increases in the uncertainty of future cash flows. We conclude that corporate risk management can increase shareholder value by reducing the expected costs of financial distress and underinvestment. © 2002 Elsevier Science B.V. All rights reserved.

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1. Introduction

Financial theory suggests that corporate risk management can benefit shareholders. In particular, risk management can increase shareholder value by reducing cash flow uncertainty, and thus, the expected costs of financial distress and underinvestment.[1] These market imperfection costs arise when a company's cash flow falls below the level necessary to meet outstanding financial obligations or make value-maximizing capital investments.

In this study, we conduct empirical tests of the theory that shareholders of financially constrained firms can benefit from corporate risk management. Specifically, we analyze

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[1] See, for example, Smith and Stulz (1985), Shapiro and Titman (1986), Lessard (1990), Bessembinder (1991), Froot et al. (1993), Demarzo and Duffie (1995), and Mello and Parsons (2000).

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how the equity values of oil producers respond to changes in the uncertainty of future oil prices. This focus on oil price uncertainty allows us to directly test whether the sensitivity of a firm's value to changes in the degree of cash flow uncertainty is related to the likelihood that the firm will face costly market imperfections such as financial distress and underinvestment.

The oil industry provides an ideal setting to test the effects of price uncertainty on corporate value for several reasons. First, all oil producers are exposed to a common risk factor—the volatility of oil prices. Because options on oil futures are actively traded on the New York Mercantile Exchange, we can construct a forward-looking measure of oil price uncertainty by determining the implied volatility of these options.

Second, the debt ratios and production costs of oil producers differ significantly in the cross-section. We use these variables as a proxy for the expected costs from market imperfections (financial distress and underinvestment) arising from cash shortfalls. All else equal, the likelihood that a company will incur these costs is increasing in its debt ratio and its production costs. Mello and Parsons (2000) capture this logic in their model and conclude that "the firm should hedge more as its leverage increases or its margins decline" (p. 150). The cross-sectional variability in debt ratios and production costs for our sample of oil producers enables us to directly test this argument as well as similar market imperfection based arguments for corporate risk management, particularly, those of Smith and Stulz (1985) and Froot et al. (1993).

Third, oil producers provide reserve data that enable us to control for a significant portion of the real options that they possess. Because oil producers have the option, but not an obligation to produce their reserves, financial theory suggests that the value of their reserves should *increase* with price uncertainty. Thus, our cross-sectional tests include measures of oil reserves to control for this relation so that we can focus specifically on testing risk management theories that suggest that cash flow uncertainty can adversely affect the value of some corporations.

Finally, we have data on the extent of hedging activities for each of our sample firms. Because hedging can alter the relation between price uncertainty and a corporation's value, including the extent of hedging in our analysis may be necessary to determine how other characteristics of a company's operations affect the relation between price uncertainty and its value. Although all oil producers are exposed to oil price risk, we find that the hedging activities of oil firms vary significantly in the cross-section.

We conduct our empirical tests on a sample of 68 oil producers for the period 1992 to 1994. First, we regress the daily stock returns of these firms against the returns on a market index, returns on oil prices, and changes in the implied volatility of options on oil futures. The median volatility beta is -0.006 and the mean volatility beta is -0.008. The volatility betas vary significantly across the sample firms, ranging from -0.37 to 0.28.

We then use a combination of univariate and multivariate tests to determine whether volatility betas vary across firms according to their characteristics as predicted by risk management theory. The results from these tests show that firms with greater debt ratios and firms with higher production costs are adversely affected by increases in price uncertainty. For example, in our univariate tests we find that the mean and median volatility betas are significantly negative for companies with debt ratios in the upper quartile of the sample but are not significantly different from zero for companies in the other quartiles. Similarly, the mean and median volatility betas of the quartile of firms with the highest production costs are significantly less than the volatility betas of the quartile of firms with the lowest production costs. This negative association between volatility betas and debt ratios and also between volatility betas and production costs holds in the multivariate tests in which we account for a variety of other firm-specific characteristics, including size, the extent of oil production, the degree of real options, and hedging.

Overall, our findings indicate that capital markets incorporate the anticipated costs from cash flow variability into stock prices. These findings also support Smith and Stulz (1985), Froot et al. (1993), and Mello and Parsons (2000), who suggest that the benefits that shareholders realize from reducing cash flow variability by managing risks are associated with the likelihood that the firm will encounter underinvestment or bankruptcy.

Our results complement and extend the findings of other recent corporate risk management studies. Specifically, several recent studies, including Geczy et al. (1997), Haushalter (2000), and Graham and Rogers (2000), show that companies that are more likely to face market imperfections manage risks more extensively. Our results indicate that these are the types of companies that can realize the greatest benefits from reducing cash flow uncertainty. Therefore, in a broad sense, observed risk management policies are consistent with shareholder value maximization. Moreover, Minton and Schrand (1999) document that companies with more cash flow variation have lower levels of investment and higher costs associated with external capital. They conclude that cash flow volatility can lead companies to underinvest. Our results show that equity values reflect this potential underinvestment.

The remainder of the paper proceeds as follows. The next section discusses related literature. Section 3 describes the sample and provides descriptive statistics. Section 4 details the estimation of the volatility betas. Section 5 presents the cross-sectional regression results, and Section 6 summarizes and concludes.

2. The relation between price uncertainty and corporate value

Several recent studies document a relation between stock returns and factors other than overall market returns. This is particularly true for commodity-producing firms, whose stock prices are ultimately associated with changes in the price of the underlying commodity. For example, Tufano (1998) and Blose and Shieh (1995) document positive relations between the value of gold mining firms and gold prices. Similarly, Strong (1991) documents a positive relation between stock prices of oil companies and changes in oil prices. The implications from these studies are straightforward—changes in commodity price levels lead investors to change their perceptions of future cash flows, and, thus, the value of firms' assets.

We take a slightly different approach in that we focus on whether *uncertainty* regarding future commodity prices affects the value of oil producers. Exploring this relation enables us to test the prediction of corporate risk management theory that informational asymmetries can lead to capital market imperfections such as underinvestment and financial distress to the extent that a firm's value can be negatively affected by cash flow uncertainty. According to the theory, managing risks can increase a firm's value by reducing the likelihood that a company will encounter the costs stemming from these market imperfections.

Fig. 1 illustrates how increased cash flow uncertainty can trigger market imperfections that adversely affect corporate value. D1 and D2 represent two cash flow distributions with the same expected cash flow, but different levels of cash flow uncertainty. With distribution D1, the firm is always able to fully fund all investments and cover outstanding financial obligations. With distribution D2, there is a reasonable probability that the firm will encounter a cash shortfall and not be able to fully fund all investments and also cover outstanding financial obligations. The lower part of the figure shows the corresponding effects on the firm's value. If the underlying cash flow uncertainty is not large enough to include scenarios in which the firm would encounter a cash flow shortfall, as is the case with cash flow distribution D1, the firm's value is not diminished by capital market imperfections. However, as uncertainty is increased, as is the case with distribution D2, a

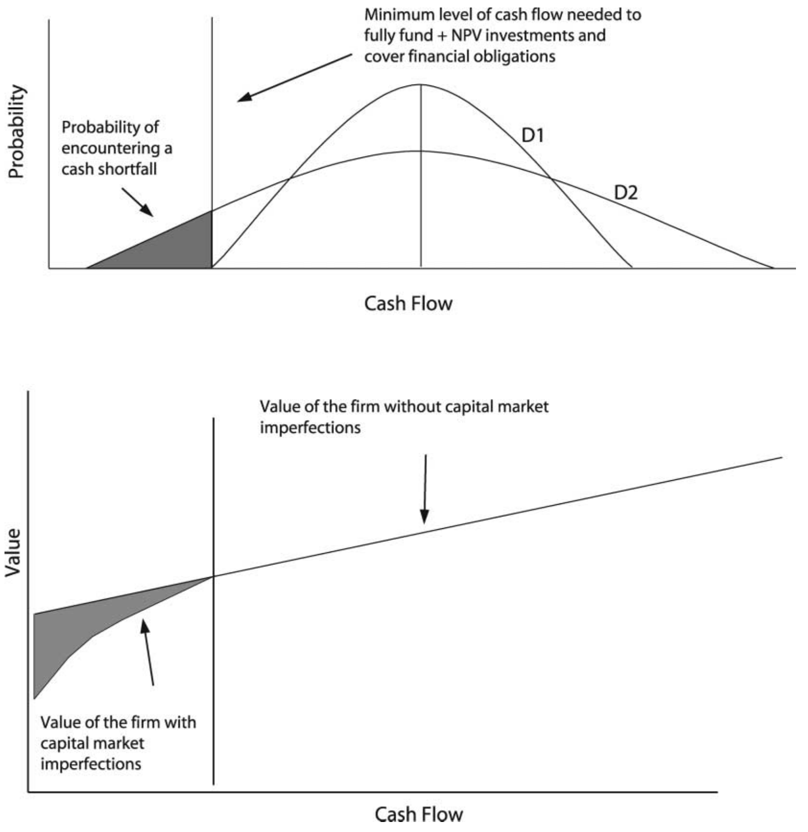

Fig. 1. Cash flows uncertainty and corporate value. The figure illustrates the relation between cash flow uncertainty and corporate value in the face of market imperfection costs from cash shortfalls. D1 and D2 represent two cash flow distributions with the same expected cash flow but different standard deviations. Because the probability of a cash shortfall is positive only for D2, the expected value for D2 is lower than that for D1 if there are capital market imperfections.

portion of the firm's value is eroded due to the expected costs of capital market imperfections. Thus, capital market imperfections cause the relation between a company's cash flows and its value to be concave. In such cases, reducing cash flow variability can increase corporate value.

The point at which a company encounters a cash shortfall varies across firms according to firm-specific characteristics. For many firms, in particular those with stable cash flows, minimal financial obligations, and therefore significant financial flexibility, the expected costs of underinvestment and financial distress are trivial. However, firms with higher levels of financial leverage, and therefore decreased financial flexibility, face a greater likelihood of encountering the costs of market imperfections. Thus, the loss in shareholder value from a given increase in price uncertainty is predicted to increase with the degree of the firm's financial leverage.

Production costs have a similar effect as financial leverage on the relation between cash flows and a firm's market value. All else equal, firms with higher production costs are more likely to encounter market imperfections as oil prices drop. The loss in shareholder value from a given increase in price uncertainty is predicted to increase with the level of the firm's production costs.

Real options theory asserts that many companies possess assets that should be valued similarly to financial options (for example, see Brennan and Schwartz, 1985; Pindyck, 1991). Unlike the discounted cash flow approach to valuation, an options-based approach captures important features of investment opportunities such as the ability to adjust operations as market conditions change. The insight of the real options approach is that, all else equal, the value of the real options a firm holds increases with the uncertainty of future cash flows. As we noted earlier, we have measures of the extent of oil reserves for our sample firms and include them in our multivariate analysis to control for this characteristic of their operations.

3. Sample

We examine the relation between oil price uncertainty and the value of 68 oil producers for the years 1992, 1993, and 1994. These firms met the following requirements. First, their primary source of revenue is oil and gas production (SIC code of 1311). Next, all firms are required to have a stock price above three dollars and their stocks are required to be actively traded for each year of the sample period. We define actively traded as being traded on at least 50% of the trading days in the year. We impose these requirements to mitigate any biases associated with low-priced and/or thinly traded stocks.

A final requirement is that the firm must provide information on the extent to which it hedged production against price risk. Current accounting standards do not require firms to disclose their commodity derivative positions. Therefore, the sample consists of firms that either voluntarily provided information on their risk management practices in financial statements, or did so by completing a survey.[2]

[2] A detailed description of the hedging data is provided in Haushalter (2000).

Table 1
Descriptive statistics

Descriptive statistics for 155 firm-year observations (40 in 1992, 59 in 1993, 56 in 1994) on 68 oil and gas producers. *Market value of assets* is defined as the sum of the book value of debt and the market value of equity (in millions). *Fraction of revenues from oil* is defined as revenues from oil sales scaled by total revenues. *Fraction of developed oil reserves* is the fraction of the firm's total oil reserves that is developed. *Production cost* is the cost of production per barrel of oil equivalent. *Fraction of oil production hedged* is the fraction of annual production that is hedged against price fluctuations using derivatives, fixed price agreements, and volumetric production payments. *Debt ratio* is total debt scaled by the sum of the book value of debt and the market value of equity.

	Mean	Median	Quartile 1	Quartile 3
Market value of assets	2055	357	131	1976
Fraction of revenues from oil	32%	30%	11%	50%
Fraction of developed oil reserves	73%	78%	63%	89%
Production cost	4.31	4.14	3.36	5.30
Fraction of oil production hedged	8.4%	0	0	9%
Debt ratio	41%	42%	27%	54%

In addition to the hedging data, we also gather data relating to these oil producers' operating and financial characteristics. We get data on oil producers' oil reserves, production, and production costs from their 1994 financial statements. Data regarding their financial characteristics are taken from *Compustat*, and stock return data are obtained from *CRSP*. The resulting sample for which we have the data required for our cross-sectional tests consists of 155 firm-year observations (40 in 1992, 59 in 1993, and 56 in 1994), comprising 68 different oil-producing companies.

Table 1 provides descriptive statistics for the sample. The sample firms exhibit a great deal of variation in their size and in their financing mix. The typical firm's size, as measured by the market value of assets, is US$357 million. A quarter of the firms have US$131 million or less in assets while another quarter have US$1976 million or more. In terms of financing, the average ratio of total debt to the market value of equity plus total debt is 41%. This debt ratio ranges from 27% at the 25th percentile to 54% at the 75th percentile. The typical firm generates approximately 1/3 of its revenue from oil production.

We find that 45.5% of the firms in the sample hedged production for at least one year during this period. We define the extent of oil production hedged as the ratio of the number barrels of oil hedged against price fluctuations to total oil production. As is shown in Table 1, the mean fraction of oil production hedged by all firms during the sample period is 8.4% and the median is 0%. Of the firm-years during which oil production is hedged, the average fraction hedged is 26%, the median is 20%, and the maximum is 100%.

4. Volatility betas

4.1. Estimating oil price uncertainty

We measure the degree of uncertainty surrounding future oil prices by calculating the implied volatilities of the nearest-the-money options on oil futures. We have chosen this approach because extant empirical research suggests that nearest-the-money options provide the best estimates of future price volatility (Beckers, 1981; Genmill, 1986). Moreover, the use of implied volatilities in this context provides a daily series of volatility estimates that correspond with the daily series of market values.

The futures options and futures contract data come from NYMEX. We use this information and Black's futures model (Black, 1976) to infer implied volatilities. Black's model assumes that the futures price, F, follows geometric Brownian motion: $dF=\mu F dt+\sigma dz$, where μ is the expected growth rate in F, σ is the volatility, and dz is a Wiener process. Under these assumptions, the theoretical call price should be:

$$c = e^{-rt}[FN(d_1) - XN(d_2)],$$

where $d_1=(\ln(F/X)+(\sigma^2/2)t)/\sigma\sqrt{t}$; $d_2=d_1-\sigma\sqrt{t}$; $r=$ a continuously compounded rate of interest; $t=$ time to maturity (in years); and $X=$ the option's strike price.

In this framework, we start with a volatility parameter (σ) of 0.0001 and iterate upward until the theoretical call price equals the observed call price. The value of σ at this point represents the option's implied volatility. We then create our series of daily implied volatilities based on the nearest-the-money options on futures that most closely approximate 3 months until maturity.[3]

We focus on the changes in implied volatility of options with 3-month maturities instead of options with longer-term maturities primarily due to data limitations. Specifically, there are relatively few options on oil futures with maturities longer than 3 months, and the majority of these longer-term options have such low trading activity that their use would be impractical. To the extent that it is theoretically optimal to employ longer-term maturities, using 3-month maturities may weaken, but not completely dissolve, our results given the reasonable assumption that the implied volatilities across maturities are correlated.[4] Moreover, anecdotal evidence shows that relatively short-term swings in prices can have a substantial impact on a company's financial welfare, particularly one that is highly levered. Continental Airlines offers such an example. In less than 3 months after Iraq invaded Kuwait, soaring fuel prices propelled Continental Airlines into financial distress. Continental's debt ratio was more than twice the industry average. Exactly 4 months after this invasion, Continental filed for bankruptcy.[5]

[3] On days in which we switch from a shorter-term option to a longer-term option because the longer-term option becomes the one that most closely approximates a 3-month option, we estimate the change in implied volatility as the change in the implied volatility of the longer-term contract. For example, suppose that on day t+1, the option contract with the maturity closest to 3 months has an actual maturity of 2.5 months (contract A), while on day t+1, the option contract with the maturity closest to 3 months has a maturity of 3.5 months (contract B). The change in implied volatility on day t+1 would be calculated as the difference in the implied volatility of contract B between day t and day t+1.

[4] We find some evidence that implied volatilities of options with different maturities are relatively highly correlated. The correlation between the daily implied volatilities of nearest-the-money options on oil futures with 1 and 3 months to maturity for the sample period was 0.974. However, we are not able to examine the correlation of these options with options with a longer time to maturity because longer-term options are thinly traded.

[5] For a further description of this episode, see "A gulf war casualty: Continental Airlines" in Smithson (1998).

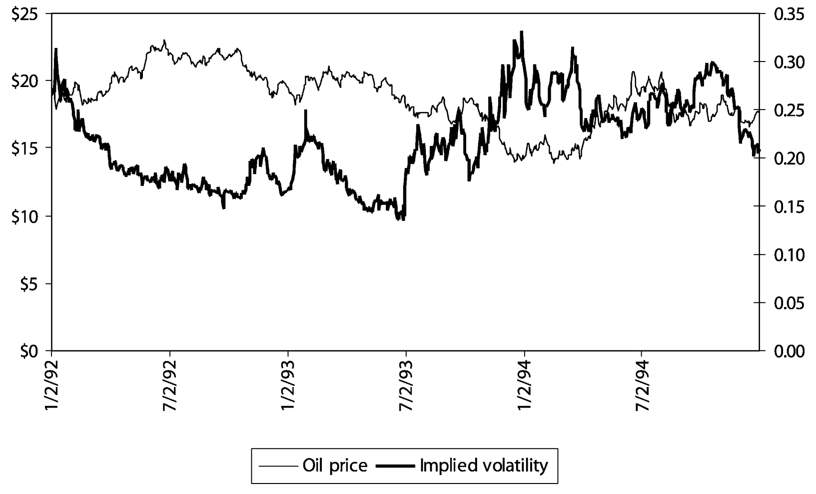

Fig. 2. Prices for West Texas intermediate crude oil and the implied volatilities for 3-month futures options for the period 1992–1994.

Fig. 2 shows the level of oil prices and implied volatilities calculated based on 3-month futures options on light, sweet crude for the period spanning 1992 to 1994. As is evident in the figure, oil prices over the sample period fluctuated between US$15 and US$25, whereas implied volatilities (calculated on a daily basis) varied between approximately 15% and 35% per year.

4.2. Estimating volatility betas

We estimate the sensitivity of the daily stock returns of our sample firms to changes in implied volatility by extending the multifactor market model used by Jorion (1990) and Tufano (1998). In particular, we estimate the following market model for each firm in the sample:

$$R_{jt} = a + \beta_1 R_{\mathrm{Mt}} + \beta_2 R_{\mathrm{OPt}} + \beta_3 R_{\mathrm{OVt}}$$

where R_{jt} is the return on company j's stock on day t, R_{Mt} is the return on the CRSP value-weighted index, R_{OPt} is the percentage change in oil prices, and R_{OVt} is the change in the implied volatility on future oil prices. Because our objective is to isolate the effect of changes in price uncertainty on a firm's value, we include the change in oil prices to control for any change in a firm's value that is attributable to a change in the price of oil.[6] We refer to β_1, β_2, and β_3 estimates from these regressions as the market beta, oil beta, and volatility beta.

[6] The correlation between changes in prices and changes in implied volatility over the period analyzed in this study is −0.26.

Table 2
Regressions of oil producers' stock returns
This table presents mean and median Dimson-adjusted beta estimates for 155 firm-year observations on 68 oil and gas producers. The betas are based on the following multifactor market model:

$$R_{jt} = a + \beta_1 R_{\mathrm{Mt}} + \beta_2 R_{\mathrm{OPt}} + \beta_3 R_{\mathrm{OVt}}$$

where R_{jt} is the return on company j's stock on day t, R_{Mt} is the return on the CRSP value-weighted index, R_{OPt} is the percentage change in oil prices, and R_{OVt} is the percentage change in the implied volatility of options on future oil prices. The Dimson-adjusted estimates are calculated using the procedure described by Dimson (1979) and later modified by Fowler and Rorke (1983). The implied volatility is estimated using 3-month futures options.

	β_1 (market beta)	β_2 (oil price beta)	β_3 (implied volatility beta)
Mean (p-value)	0.668 (0.001)	0.216 (0.001)	−0.008 (0.341)
Median (p-value)	0.667 (0.001)	0.208 (0.001)	−0.006 (0.390)

Because we use daily data to estimate the market model, traditional OLS beta estimates may suffer from infrequent or thin trading of either the stock or the oil options. To alleviate this potential problem, we estimate betas using the approach suggested by Dimson (1979) and modified by Fowler and Rorke (1983), which incorporates leads and lags for the independent variables. The estimates we report and utilize throughout our analysis are based on one lead and one lag.[7]

We estimate the market model for each sample firm for each of the years 1992, 1993, and 1994. We present the aggregate model estimates in Table 2. The average market beta estimate (β_1) is 0.668, whereas the average oil price beta (β_2) is 0.216. Consequently, a 10% increase in oil prices triggers roughly a 2% stock price increase for the typical oil producer in our sample. In comparison, Strong (1991) reports an average oil beta of 0.27 for 25 major oil companies between 1975 and 1987. Our oil beta estimates are significantly lower than the "gold beta" estimates of roughly two reported in Tufano (1998), indicating that gold prices have a much larger effect on the equity value of gold firms than oil prices have on the equity value of oil producers.

The mean of the estimated volatility betas (β_3) is −0.008 and the median is −0.006, neither of which statistically differs from zero.[8] However, this should not be interpreted to imply that oil producers are unaffected by oil price uncertainty. Instead, some oil producers, specifically, firms with financial flexibility and larger quantities of valuable oil reserves, should be positively affected by increased oil price uncertainty. In contrast, firms that are financially constrained to the extent that greater oil price uncertainty increases the likelihood that they will experience financial distress or underinvestment, should be negatively affected by heightened uncertainty. This suggests that firm-specific attributes, such as leverage, operating margins, and the size and quality of the producer's oil reserves will play an important role in determining the nature of the firm's exposure to oil price uncertainty. Consistent with this argument, we document significant variation in the volatility beta. As

[7] We also estimated betas using additional lead and lag terms. However, we present the results based on one lead and one lag only because we found that additional terms did not produce significant changes in the overall beta estimates, but overall noise was likely larger.

[8] We also estimate these volatility beta regressions using weekly data. However, the betas estimated using weekly data are not statistically different from the betas estimated using daily data that we present here.

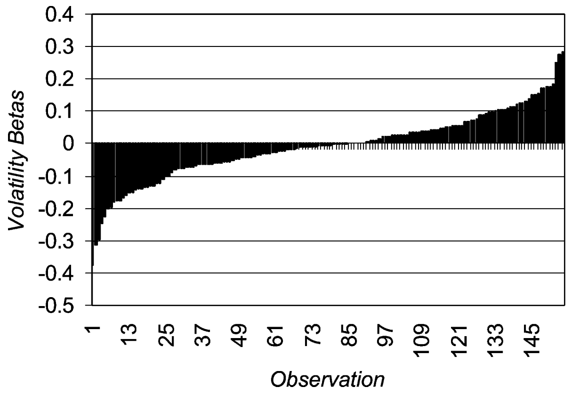

Fig. 3. Distribution of oil volatility betas. This figure plots the estimated volatility betas of 68 oil producers for the period of 1992 to 1994 (155 firm-years). These betas are estimated using the regressions described in Table 2.

is shown in Fig. 3, the volatility beta estimates range from −0.37 to +0.28. In the next section, we show that the variation in the volatility beta is systematically associated with firm-specific attributes in manners that are predicted in the financial literature.

5. Analysis of the volatility beta

5.1. Univariate analysis

Our univariate analysis focuses on the relation between the volatility beta and our two proxies for the likelihood of a company facing market imperfections: debt ratios and production costs. In Panel A of Table 3, firms are sorted into quartiles according to their debt ratio. The debt ratio is defined as ratio of total debt (book value) to the sum of the book value of debt and the market value of equity.

In Panel B of Table 3, firms are sorted into quartiles according to their abnormal production costs. The production cost data for our sample firms are expressed as costs per barrel of oil equivalent.[9] We use abnormal production costs because per barrel of oil equivalent production costs tend to be greater for producers with higher proportions of oil operations. Thus, a raw, unadjusted production cost measure may reflect the firm's production mix (oil vs. gas) rather than whether the firm is a low cost or a high cost producer. To remove this possible bias, we calculate abnormal production costs using a two-step process. First, we regress production costs per barrel of oil equivalent against the ratio of the fraction of revenues from oil production to the fraction of revenues from both oil and gas production. Next, we calculate the difference between the actual production costs and the production costs predicted by the estimated regression coefficients. We define this difference as the abnormal production costs. As discussed above, all else equal,

[9] Oil and gas companies typically quote production in *Barrels of Oil Equivalent* (BOE). Naturally, one barrel of oil=1 BOE. With regard to natural gas production, 6 thousand cubic feet (Mcf) of gas is counted as one BOE.

Table 3
Volatility betas, debt ratios and production costs
The data consists of 155 firm-year observations (40 in 1992, 59 in 1993, and 56 in 1994) on 68 oil and gas producers. *Debt ratio* is total debt scaled by the sum of the book value of debt and the market value of equity. The volatility betas are described in Table 2. For each quartile, we also report p-values for difference from 4th quartile. These probability values are from tests of whether the mean or median volatility beta of the quartile are statistically different from the mean and median volatility beta of the firms with a debt ratio or production cost that places them in 4th quartile of the sample. For Panel A, observations are distributed into quartiles according to the debt ratio. For Panel B, observations are distributed into quartiles according to the abnormal production costs. *Abnormal production cost* is the production costs per barrel of oil equivalent minus the predicted production cost from a regression where the independent variable is (fraction of oil revenues/(fraction of oil revenues+fraction of gas revenues)).

	1st Quartile		2nd Quartile		3rd Quartile		4th Quartile	
	Mean	Median	Mean	Median	Mean	Median	Mean	Median
Panel A: Volatility betas for quartiles based on debt ratios								
Debt ratio	0.17	0.17	0.36	0.37	0.46	0.46	0.64	0.63
Volatility beta	0.03	0.01	0.00	−0.00	−0.02	−0.01	−0.04**	−0.04**
p-Values for difference from 4th Quartile	0.01	0.01	0.08	0.05	0.44	0.17	NA	NA
Fraction with beta > 0	0.615		0.487		0.447		0.282	
Panel B: Volatility betas for quartiles based on abnormal production costs								
Abnormal production costs	−1.54	−1.41	−0.34	−0.37	0.38	0.37	1.46	1.24
Volatility beta	0.03*	0.01	−0.02	−0.02	−0.02	−0.01	−0.02	−0.00
p-Values for difference from 4th Quartile	0.06	0.09	0.74	0.78	0.83	0.87	NA	NA
Fraction with beta>0	0.538		0.384		0.447		0.462	

* Indicate that the value for the volatility beta is significantly different from zero at the 10% levels.
** Indicate that the value for the volatility beta is significantly different from zero at the 5% levels.

firms with greater production costs should be more adversely affected by an increase in price uncertainty. As a result, the abnormal production cost variable is predicted to be negatively associated with the volatility beta.

Table 3, Panel A shows a negative relation between debt ratios and volatility betas. The mean and the median volatility beta for companies with a debt ratio in the top quartile of the sample are both −0.04. Both of these values are significantly less than zero (p-value<0.05). Neither the mean nor the median volatility beta is significantly different from zero in any of the other quartiles. We also examine the differences in volatility betas between firms that have a debt ratio in the highest quartile of the sample and other firms. We find that both the mean and the median volatility beta of the firms with a debt ratio in the top quarter of the sample is less than the volatility beta of companies with a debt ratio in the first quartile (p-value<0.05) and the second quartile (p-value<0.10) of the sample.

We also tabulate the fraction of firms in each quartile that have volatility betas greater than zero. We find that 61.5% of the firms in the low leverage quartile have positive volatility betas. By comparison, only 28.2% of the firms in the high leverage quartile have a positive volatility beta.

In order to convey the economic significance of these figures, we calculated how the value of an oil producer with a debt ratio in the top quartile of the sample would be affected by a one standard deviation change in the implied volatility of oil prices. During the sample period, the standard deviation in implied volatility was roughly 4.4%. For companies with debt ratios in the top quartile of sample, a one standard deviation increase in implied volatility would result in a median decrease in firm value of approximately −US$693,850. Overall, these results are consistent with the notion that, for companies with greater leverage, an increase in price uncertainty can have a negative effect on shareholder value. Whether this adverse effect justifies firms taking steps to reduce uncertainty depends on the cost and effectiveness of a risk management program.

The relation between the volatility beta and abnormal production costs is less pronounced than the relation between the volatility beta and the debt ratio. Panel B of Table 3 shows that the mean volatility beta for the firms in the first quartile is significantly greater than zero at the 10% level. The volatility betas do not significantly differ from zero in the remaining three quartiles. Also in this table, we report results in which we compare the volatility betas of firms with abnormal production costs in the highest quartile of our sample (i.e., companies with high production costs) to the volatility betas of the other

Table 4
Multivariate regressions of volatility betas

This table presents the results from multivariate regressions of oil volatility beta estimates against independent variables. All regressions are estimated using a random-effects model. Table 2 contains the average volatility beta estimates. Independent variables are defined as follows: *Fraction of revenues from oil* is oil revenues scaled by total revenues. *Abnormal production cost* is the production costs per barrel of oil equivalent minus the predicted production cost from a regression where the independent variable is (fraction of oil revenues/(fraction of oil revenues+fraction of gas revenues)). The *debt ratio* is calculated as total debt scaled by the book value of debt plus the market value of equity. *Proven reserves/MVA* represents the total of the firm's proven reserves (both developed and undeveloped) in thousands of barrels divided by the market value of assets. *Fraction of reserves that is developed* is developed reserves expressed as a percentage of proven reserves. *Fraction of oil production hedged* is the fraction of annual oil production hedged against price fluctuations. *p*-Values are in parentheses.

	Dependent variable is β_3 implied volatility beta		
	(i)	(ii)	(iii)
Intercept	0.076 (0.095)	−0.018 (0.724)	−0.018 (0.716)
Natural logarithm of assets (market value)	−0.002 (0.716)	0.001 (0.891)	0.001 (0.859)
Fraction of revenues from oil	−0.028 (0.534)	−0.024 (0.619)	−0.025 (0.610)
Abnormal production cost	−0.022 (0.003)	−0.014 (0.039)	−0.014 (0.041)
Debt ratio	−0.153 (0.009)	−0.157 (0.002)	−0.160 (0.002)
Proven reserves/MVA (coefficient × 100)		0.002 (0.946)	0.002 (0.943)
Fraction of reserves that are developed		0.104 (0.008)	0.104 (0.008)
Fraction of oil production hedged			0.009 (0.850)
R^2	0.117	0.142	0.142
Number of observations	155	152	152

firms. We find that both the mean and the median volatility betas are significantly lower for the high cost firms than they are for the low cost firms (i.e., companies with abnormal production costs in the first quartile). We shed additional light on the strength of these relations in the multivariate analysis that follows.

5.2. Multivariate analysis

We present the results of our multivariate tests in Table 4. Because our data contain both cross-sectional and time series observations, the assumptions underlying traditional OLS regressions may not hold. As a result, we estimate our regressions using a random-effects model.[10] The dependent variable for all of these regressions in Table 4 is the volatility beta. Additionally, all regression models include the natural log of assets to control for size and the fraction of total revenues from oil to control for the portion of the firms operations allocated to oil production.

In all three models presented in Table 4, the coefficients on debt ratio and production costs are significantly negative (p-value<0.05).[11] These results are consistent with the theoretical arguments for risk management, particularly Smith and Stulz (1985), Froot et al. (1993), and Mello and Parsons (2000). Specifically, all else equal, higher leverage and higher production costs (i.e., lower margins), both of which increase the likelihood that the firm will encounter costly market imperfections, prompt a decline in firm value when oil price uncertainty is increased. Thus, the potential benefits shareholders realize from corporate hedging increase with the likelihood that the firm incurs costs resulting from capital market imperfections.

As discussed earlier, real option theory indicates that the value of a firm's oil reserves should increase with uncertainty surrounding future oil prices. Regression models (ii) and (iii) in Table 4 control for the quantity and quality of the oil reserves held by our sample firms using two measures. First, we capture the relative size of the oil reserves of each firm by including the ratio of proven reserves to the market value of assets. Proven reserves are the sum of reported levels of both developed and undeveloped reserves. Second, we include the fraction of the reserves that is developed. Because oil producers are more likely to develop their low-cost reserves first, all else equal, developed reserves should be of higher quality. Moreover, the greater the fraction of a producer's reserves that is developed, the easier it is for the producer to increase production to take advantage of price increases. For these reasons, we expect that the value of developed reserves is more sensitive to changes in oil price uncertainty than is the value of undeveloped reserves, which often involve significant sources of uncertainty (quality, etc.) outside of expectations about future oil prices.

The results in models (ii) and (iii) show a positive association between the fraction of the reserves that is developed and changes in price uncertainty. Thus, consistent with real

[10] We use a random-effects model rather than a fixed-effects model based on the results of the Hausman specification test. See Chapter 14 of Greene (1997) for a further discussion of these models and the Hausman test. We do, however, obtain similar results using OLS regressions.

[11] We find similar results if we utilize the raw production cost per barrel of oil equivalent figures instead of the abnormal production cost measure.

options theory, ceteris paribus, the value of an oil producer increases with price uncertainty when a greater proportion of its reserves is developed. More importantly though for the focus of our study, the coefficients on the debt ratio and abnormal production costs remain statistically significant when we control for these real option characteristics of the sample firms.

Regression model (iii) also includes the fraction of production hedged as an independent variable. In addition to serving as a control, this variable offers insights into the effect of the hedging activities on the sensitivity of an oil producer's value to changes in the uncertainty of future oil prices. If our sample firms manage risk effectively using hedging strategies, there should be a positive relation between the extent of hedging variable and the volatility beta. This prediction is based on the notion that only those firms that are financially constrained should hedge, and for such firms, hedging should reduce the probability that an increase in oil price uncertainty will lead to costly cash shortfall.

The coefficient on this hedging measure does not significantly differ from zero and the coefficients on the debt ratio and production costs remain negative. This suggests that, on average, the hedging activities of oil producers do not materially affect their stock's sensitivity to changes in oil price uncertainty. One possible explanation for this result is that oil producers often hedge using short-term financial instruments. In Table 5, we present the types of financial instruments the oil producers in our sample used in 1994 to hedge against oil and gas price volatility. Although the average maturities of these instruments are not shown, these types of instruments generally mature in less than a year. Stulz (1996) contends that short-term hedging instruments, which are used by most companies, including those in our sample, tend to affect a small portion of a company's value. Therefore, he argues that the use of short-term hedging instruments does not materially affect the variability of a company's value.

Another possibility is that the market does not fully recognize the variation in the hedging activities of our sample firms. As we noted earlier, at the time when the data on hedging were collected, companies were not required to disclose information on their hedging activities. As a result, many companies, including some that we found to hedge quite extensively, provided little, if any indication of the extent of their risk management

Table 5
Financial hedging instruments used by oil producers
This table presents the types of financial instruments reported as used by the subset of oil and gas producers that hedged at least some portion of their oil production. The financial instruments are not mutually exclusive, not exclusive to the firm's oil production, and reflect the hedging mix of the sample firms reported for the year 1994. Fixed price contracts and volumetric production payments are used almost exclusively by these firms to hedge natural gas production. The options category contains collars and floors/puts.

Financial instrument	Fraction indicating use (%)
Options	34
Swaps	60
Fixed price contracts	34
Futures or forwards	52
Volumetric production payments	8

activities in their financial statements. A common reason offered by companies for this lack of disclosure is that providing these data would hurt their competitiveness in the oil industry. This indicates that some companies view the costs of providing data on hedging to be greater than potential rewards they expect from the financial markets for hedging.

A third potential explanation for the insignificance of the hedging variable is that our sample potentially includes firms that are hedging for which hedging accomplishes very little. In particular, in cases in which underinvestment and financial distress is not a material concern, it is unlikely that reducing the uncertainty on cash flows will have a positive effect on the firm's value. In these cases, the benefits that shareholders realize from hedging, if any, are not clear.[12] This interpretation is consistent with Mello and Parsons (2000) who point out that because all hedges are fairly priced, hedging changes the pattern of a firm's future cash flows, but not the value of a financially unconstrained firm.

6. Summary and conclusion

This study investigates the relation between the value of oil producers and the degree of uncertainty around future oil prices. The primary objective is to provide empirical tests of risk management theories and, thus, provide a better understanding of when corporate risk management can increase shareholder value.

Our empirical tests show that the sensitivity of an oil producer's value to changes in oil price uncertainty is related to proxies for the likelihood that the producer will encounter costly market imperfections, such as financial distress and underinvestment. Specifically, the value of producers with less financial flexibility (higher financial leverage and/or higher production costs) is inversely related to a change in the degree of uncertainty around future prices. These results are robust when we control for other important characteristics of our sample firms, including size, the fraction of revenues from oil production, and the extent of their real options. We conclude that by reducing the expected costs from these market imperfections, corporate risk management can increase shareholder value.

The results also indicate that not all firms benefit from reducing price uncertainty. Specifically, we find little evidence to indicate that firms with little or no debt are adversely affected by changes in price uncertainty. For firms such as these, for which the expected costs from these market imperfections are likely immaterial, the benefits that shareholders realize from hedging are not clear. Therefore, while our results show that effective risk management can potentially increase shareholder value for some firms, they also imply that for others, hedging accomplishes very little.

[12] As an example, a financially unconstrained oil producer with a significant amount of its value residing in its oil reserves (and thus, in assets with real option characteristics) may *decrease* its value through hedging, even if the hedging is costless, because reducing cash flow variability reduces the value of real options. For such a firm, the coefficient on the hedging variable would be negative, indicating that hedging mitigates the positive relationship between oil price uncertainty and the firm's value.

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