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Uncertainty, Capital Investment, and Risk Management

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Abstract. We use forward-looking and exogenous measures of output price uncertainty to examine the effect of price uncertainty on firm-level capital investment, risk management, and debt issuance. The effects of uncertainty vary significantly by firm size. When faced with high price uncertainty, large firms increase their hedging intensity but do not lower capital investment or debt issuance. In contrast, small firms do not adjust their hedging intensity but significantly lower capital expenditure and debt issuance even after controlling for investment demand. Moreover, the negative effect of uncertainty on capital investment is significantly weaker for firms that hedge their output price risk. Our analysis highlights that, in the presence of financial frictions, high price uncertainty has significant dampening effects on capital investment of small firms by exacerbating their financial constraints, and that this negative effect is amplified by firm-level constraints on ability to hedge risk exposures.

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Keywords: uncertainty • capital investment • hedging • real options • financial frictions

1. Introduction

Uncertainty is a major factor in the capital investment and financing decisions of firms, as seen repeatedly in surveys of financial managers (Graham and Harvey 2001). Indeed, the effects of uncertainty on firm-level investment and financing policies have been of longstanding concern in finance and economics (Keynes 1936 and Myers 1977). Consistent with the prominent role of uncertainty in corporate decisions, the literature shows that managers attempt to hedge or manage financial risk in a variety of ways (Campello et al. 2011). Yet there is scarce empirical evidence regarding the causative effects of uncertainty on corporate policies and the potentially mitigating role of hedging. Although there is some evidence that uncertainty lowers capital investment, many important questions remain unanswered. Does risk management moderate the effect of uncertainty on capital investment, and how does risk management itself vary with uncertainty? Does uncertainty exacerbate financial frictions and affect firms' ability to raise new financing? Are the effects of uncertainty heterogeneous across firms, and, if so, what are the important drivers of this heterogeneity?

We address these questions by focusing on the U.S. upstream oil and gas (O&G) sector, which offers us many advantages. First, we are able to obtain forward-looking and long-term measures of output price uncertainty for our sample firms derived from options on crude oil futures. Being derived from the market-clearing options prices over time, our uncertainty measures reflect the dynamically evolving and forward-looking price uncertainty assessments of the heterogeneous agents that trade in futures markets (Singleton 2013). Importantly, most analysts agree that, unlike the national oil companies of the major oil-producing countries and the large integrated firms with downstream and midstream refining operations (e.g., Chevron, ExxonMobil, and Royal Dutch Shell), independent firms in the U.S. upstream O&G sector act as price-takers in the world crude markets.[1] Thus, our uncertainty measures can be treated as exogenous to the decisions of individual firms, which greatly aids identification. Second, because we have a homogeneous set of firms that operate in the same product market and are exposed to the same price uncertainty, we are able to create a measure of hedging intensity at the firm-quarter level that quantifies the fraction of risk exposure hedged by the firm.[2] Finally, the O&G sector is particularly well suited for this study because firms in this sector make large and irreversible capital investments in the face of considerable uncertainty (Arbogast and Kumar 2013), which makes risk management central to their decision making.

We find that, on average, output price uncertainty has a statistically and economically significant negative effect on capital expenditure, but it has a significant positive effect on hedging intensity. Strikingly, these unconditional average effects of price uncertainty on capital investment and hedging mask substantial heterogeneity in the data. In particular, firms in the highest size quartile ("large" firms) increase their hedging intensity but do not lower their capital expenditure when faced with high price uncertainty. On the other hand, small firms do not vary their hedging intensity but lower their capital expenditure when faced with high price uncertainty. Moreover, hedging affects the sensitivity of capital expenditure to price uncertainty: after controlling for the endogeneity of the hedging decision, we find that the negative effect of price uncertainty on capital expenditure is significantly larger among firms that choose not to hedge during that quarter.

What is the channel through which hedging affects the investment–uncertainty relationship? The extant literature shows that debt market constraints have a negative effect on investment (see Whited 1992, Almeida and Campello 2007, Nini et al. 2012) and that hedging can alleviate debt market constraints (Campello et al. 2011). However, the literature has only recently begun to explore whether high uncertainty exacerbates debt financing costs (see Section 2.2). If so, that can explain both the negative effect of price uncertainty on capital expenditure (independent of the real option channel), and why hedging will moderate this effect. We thus examine how price uncertainty affects net debt issuance, after controlling for firms' demand for debt. Consistent with the idea that price uncertainty exacerbates debt market frictions, we find that small firms significantly lower their debt issuance when faced with high price uncertainty (controlling for the demand for debt), whereas large firms do not. Moreover, the negative effect of price uncertainty on debt issuance is confined to firms that choose not to hedge during that quarter.

Past literature has highlighted that small firms and financially constrained firms are less likely to hedge their risk exposures (see Haushalter 2000, Kumar and Rabinovitch 2013, Rampini et al. 2014), which may be due to economies of scale in hedging and firm-level collateral constraints (Rampini and Viswanathan 2010). Our analysis shows that there is also a size effect in how firms vary their hedging with price uncertainty: large firms respond to high price uncertainty by increasing their hedging intensity, whereas small firms do not. This is likely due to institutional features of the O&G sector and incompleteness in the exchange-traded derivatives market, which makes it onerous for small firms to vary their hedging intensity with price uncertainty.

An important contribution of our paper is thus to highlight that, in the presence of financial frictions, the negative effect of price uncertainty on capital investment may be amplified by firm-level constraints on ability to hedge risk exposures. This is somewhat distinct from the classic real options argument that even unconstrained firms will optimally lower their capital investment when faced with high price uncertainty, because high uncertainty increases the value of the option to delay investment (McDonald and Siegel 1986 and Dixit and Pindyck 1994). As per the classic real options argument, the effects of price uncertainty should be fairly homogeneous across technologically similar firms, and hedging should not have any effect on the investment–uncertainty relationship.

The average negative effect of uncertainty on firm-level capital investment is consistent with the industry-level evidence in Kellogg (2014), who uses data on oil drilling in Texas and a forward-looking measure of price uncertainty similar to ours.[3] Despite this similarity, there are important differences between our paper and that of Kellogg (2014). To our knowledge, ours is the first study to empirically examine the joint effects of uncertainty on capital investment and hedging and how hedging may moderate the negative effect of price uncertainty on capital expenditure. We show that the negative relationship between capital expenditure and price uncertainty is essentially a small-firm phenomenon. On the other hand, large firms increase their hedging intensity when faced with high price uncertainty but do not lower their capital expenditure. Moreover, our analysis is based on aggregate capital expenditure instead of the number of wells drilled, while controlling for important firm-level determinants of capital expenditure, such as Q.

2. Theoretical and Institutional Backgrounds

In this section, we build on the theoretical literature to generate empirical hypotheses regarding the effects of output price uncertainty on capital investment and risk management.

2.1. Real Options, Uncertainty, and Capital Investment

A large body of literature argues that the interaction of capital irreversibility and uncertainty generates a real option of delaying investment and awaiting the resolution of uncertainty (e.g., see McDonald and Siegel 1986, Dixit and Pindyck 1994). As the value of the option to wait increases with uncertainty, this literature predicts that higher uncertainty will, ceteris paribus, dampen capital investment. However, the effects of uncertainty on investment in the presence of capital adjustment costs are complex, since the firm also faces increased expected expansion (or option exercise) costs by delaying investment. With competitive product markets (i.e., high price elasticity of demand), the expansion cost effect can dilute (if not neutralize) the real option motivation for delay (Caballero 1991). In the upstream O&G sector, there are nontrivial expansion costs, especially for larger and more technologically intensive projects, and firms are typically price-takers (as we argued in the introduction). Hence, the empirical resolution of the uncertainty–investment relationship in our sample is of substantial interest.

It is also noteworthy that there is no role for hedging or risk management in canonical real options models, because they ignore financial frictions.

2.2. Financial Frictions, Risk Management, and the Effects of Uncertainty

The existing literature in finance shows that financial frictions affect the real investment decisions of firms (e.g., see Whited 1992, Almeida and Campello 2007, Nini et al. 2012). Financial frictions also generate incentives for firms to undertake risk management or hedging in order to mitigate costs of financial distress and to lower external financing costs (Smith and Stulz 1985, Froot et al. 1993).[4]

Recent literature shows conceptually and empirically that uncertainty aggravates financial constraints by raising debt costs, which in turn reduces investment (Gilchrist et al. 2014, Kumar and Yerramilli 2017).[5] That is, financially constrained firms may be forced to cut their capital investment because of their inability to raise sufficient debt capital. Therefore, we expect the negative effect of price uncertainty on capital investment to be stronger for more financially constrained firms because they are more likely to be affected by debt market frictions. Moreover, if uncertainty aggravates financial frictions, then it is logical to expect that price uncertainty should have a positive effect on hedging intensity. However, to our knowledge, the literature has not examined empirically the joint effects of uncertainty on capital investment and hedging and how hedging may moderate the negative effect of price uncertainty on capital expenditure.

The effect of financial constraints on the uncertainty–investment relationship and the effect of uncertainty on risk management are more complex when real options and financial frictions coexist. Kumar and Yerramilli (2017) predict that the negative effect of uncertainty on capital investment should be stronger for financially constrained firms, which will lower their capacity in a bid to minimize ex post costs of financial distress. However, Boyle and Guthrie (2003) argue that the threat of future financing constraints may actually induce financially constrained firms to accelerate investment, thus weakening the real options effect. With regard to hedging and uncertainty, Adam et al. (2007) argue that firms with valuable real options may prefer to maintain exposure to price uncertainty and may actually hedge less as price uncertainty increases. Meanwhile, Rampini et al. (2014) emphasize tradeoff between investment and risk management due to collateral constraints and predict that financially constrained firms should hedge less, but not necessarily reduce their investment. Given these ambiguous predictions, the empirical resolution of these issues is of substantial interest, in particular the impact of price uncertainty on the joint investment and hedging decisions of the firm.

2.3. Fixed Costs and Hedging: The Role of Firm Size

The literature highlights that firm size has a significant effect on corporate policies (Graham and Harvey 2001). In particular, the positive association between hedging and firm size is well known in the risk management literature (Nance et al. 1993, Haushalter 2000, Kumar and Rabinovitch 2013). Although standard intuition may suggest that small firms should have greater incentives to hedge, the positive size–hedging relationship is typically attributed to economies of scale because of the fixed costs of setting up risk management operations and employing specialist risk managers (Booth et al. 1984, Block and Gallagher 1986, Dolde 1993) and quantity discounts in derivatives markets (Nance et al. 1993). Moreover, to the extent that small firms are likely to be more financially constrained, this evidence is also consistent with the argument in Rampini and Viswanathan (2010) and Rampini et al. (2014) that collateral constraints restrict hedging.

Institutional features of the O&G industry and incompleteness in the exchange-traded derivatives markets may also affect how small and large firms differ in their hedging decisions, and how they vary hedging in response to price uncertainty. Historically, exchange-traded derivatives have had relatively short horizons, which makes it hard for upstream O&G firms to hedge their risk exposures over long durations commensurate with the production horizons of their oil fields.[6] Moreover, because wellhead prices depend on the sulfur content and other characteristics of crude oil, finding perfect hedges on the standardized, benchmark oil indices traded on exchanges is not generally feasible. Finally, because exchange-traded O&G futures are typically physically delivered, their standardized sizes imply that producers are not generally not able to precisely hedge their anticipated production.

Consequently, a substantial portion of hedging in the O&G industry occurs through customized over-the-counter (OTC) derivative contracts intermediated through specialist brokers and banks (see Meyer 2012). Because of their customization, OTC derivative contracts are typically bilateral, nontransferable, and settled without a third party, such as an exchange or central clearinghouse (McMahon 2010). The absence of central clearing, along with the customization, generally makes OTC oil and gas contracts highly illiquid with a significant counterparty credit risk (Pirrong 2011). In particular, because counterparty risk tends to rise as commodity prices fall, OTC hedge positions can not be easily "scaled up" in such price environments. More generally, raising hedging intensity requires that a producer be able to find counterparties who are willing to accept the typically unique aspects of the producer's risk management needs.

Hence, varying hedging intensity with price uncertainty imposes significant search costs and requires specialized, full-time, and experienced risk managers to execute (Dolde 1993). Absorbing these fixed skilled labor costs is generally uneconomical for all but the larger O&G firms. For example, in our sample of 126 firms (see Section 3), only 10 firms report having a board risk management committee. Moreover, and strikingly, 10% of small firms (i.e., those in the bottom three size quartiles) do not even have a separate chief financial officer (CFO), and the chief executive officer (CEO) also acts as CFO. (The corresponding number for firms in the lowest size quartile is 58%.) This evidence suggests that small firms are unlikely to be able to afford sophisticated risk management operations.

In light of this, we expect the positive effect of price uncertainty on hedging to be stronger for large firms, which are more likely to have sophisticated risk management operations. Consequently, because hedging lowers firms' effective exposure to price uncertainty and mitigates financial frictions, we expect the negative effect of price uncertainty on capital investment to be weaker for large firms.

3. Sample Construction and Key Variables

3.1. Data Sources

We collect daily data for all options and futures on crude oil between January 2, 1990, and March 31, 2013, from the Commodity Research Bureau. The futures and options on crude oil are among the most liquid across all commodities. The data contain information on a large cross section of option contracts with varying maturities and strike prices, which allows for accurate computation of forward-looking measures of risk-neutral implied volatility. The average maturity of the option contracts in our sample increases substantially, from 100 days in 1990 to 343 days in 2012. The maximum available maturity has also increased over the years, from 369 days in 1990 to 1,780 days in 2012. The average *moneyness* of option contracts (i.e., the ratio of strike to the underlying futures price) in our sample is 54%, and the average maximum moneyness is 162%. We use these data to compute model-free risk-neutral volatility.

We obtain firm financial information from the Compustat Quarterly files. As explained in the introduction, our analysis is focused on U.S. firms in the upstream oil and gas sector.[7] Compustat provides information on four different industry classification codes for each firm: North American Industry Classification System (NAICS), Standard Industrial Classification (SIC), S&P Industry Sector Code (SPCINDCD), and the Global Industry Classification Sector Code (GSECTOR). We require all four codes to match before we classify a firm as belonging to the upstream oil and gas sector. Specifically, we require that the firm's NAICS code must equal 211111 ("Crude Petroleum and Natural Gas Extraction"), its SIC code must equal 1311 ("Crude Petroleum and Natural Gas"), its SPCINDCD must equal 380 ("Oil and Gas (Exploration and Production)"), and its GSECTOR must equal 10 ("Energy"). Further, we require that our sample firms have least 8 quarters of financial information; our qualitative results are unchanged even if we include firms with fewer than 8 quarters of financial information. There are 197 firms that meet these requirements and their names are listed at the end of the Internet appendix.

We hand-collect information on hedging activities of our sample firms from their 10-Q filings with the SEC. We are able to collect this information for the post-1995 period and for 126 firms in our sample. For this subsample, we have firm-level data on total volume of crude oil production and the quantity of crude oil that is hedged on a quarterly basis.

3.2. Key Variables

Our investment and hedging measures are defined at the quarterly level. We measure capital investment using the firms' capital expenditure (*CAPEX*) scaled by net property, plant and equipment (PP&E) outstanding at the end of the previous fiscal quarter. (We obtain qualitatively similar results if we scale with lagged assets instead of lagged net PP&E.)[8] For the subsample of firms for which we have hedging data, we create a *Hedging Intensity* measure to denote the proportion of the firm's crude oil production during the quarter that the firm has hedged. We provide more details regarding the construction of these and all other variables in the appendix.

Our key independent variable of interest is *Price Uncertainty*, which serves as a forward-looking measure of oil price volatility at the one-year horizon. We compute this as the option-implied volatility, using the method proposed by Bakshi et al. (2003), estimated from options on crude oil futures with maturity of approximately one year. The detailed steps for the construction of this variable are outlined in Section (1) of the Internet appendix.

We use the price of crude oil futures (*Futures Price*) to proxy for investment demand as well as drilling and operating costs and to differentiate the effect of price uncertainty from that of changes in the first moment. Firms' policies may also be affected by a host of macroeconomic factors, such as return on the market portfolio (*S&P500 Return*), return on oil futures (*Oil Return*), stock market volatility (*VIX*), term spread (i.e., difference in yields between 10-year and three-month

U.S. Treasury bonds), and credit spread (i.e., difference in yields between BBB-rated and AAA-rated corporate bonds). Instead of including such a large number of highly correlated macroeconomic variables in the regression, we use principal component analysis (PCA) to extract the first and second principal component, denoted *Macro* 1*st PC* and *Macro* 2*nd PC*, which together account for 98% of the variation in these variables.[9] We use *Macro* 1*st PC* and *Macro* 2*nd PC* as time-varying proxies of financial frictions because they are likely to be positively related to firms' cost of capital. The first principal component loads heavily on term spread and the second principal component loads heavily on credit spread.

4. Descriptive Statistics and Preliminary Results

4.1. Summary Statistics

We assemble a panel data set for 197 nonintegrated exploration and production (E&P) firms that are listed in the Internet appendix. The nonintegrated E&P firms are not involved in downstream segments like refining and marketing and, therefore, derive most of their cash flows from production of crude oil and natural gas. Being nonintegrated, these firms are not diversified through their physical or real assets and hence have incentives for risk management through financial contracts (see Kumar and Rabinovitch 2013). The panel comprises one observation for each firm-fiscal quarter ("firm-quarter") combination during 2Q1990–1Q2013. We match the oil price measures and other market measures with the quarterly panel data using the calendar dates corresponding to each observation in the data. For each firm-quarter, we extract the average oil volatility, average oil price, average VIX, quarterly return on one-year crude oil future, and quarterly return on the S&P 500 index over the calendar quarter corresponding to the firm's fiscal quarter. We use contemporaneous market measures because these are available on a daily basis to corporate managers and, hence, may have a contemporaneous effect on firms' investment decisions. We verify that our qualitative results are the same even if we use lagged market measures.

We summarize our panel data set in Table 1.[10] The size distribution of firms in the upstream O&G sector is highly skewed, with the average firm being six times as large as the median firm in terms of the book value of total assets. Given the skewness of the size distribution, we use the natural logarithm of the book value of total assets (*Size*) as a proxy for firm size in all our empirical specifications. The summary statistics on *Rated* and *Investment Grade* indicate that 37.4% of the firms in our sample have a long-term credit rating and that 35.8% of the firms have an investment-grade rating (i.e., an S&P rating of BBB− or better). Interestingly, 7.5% of the firms in our sample do not have a separate chief financial officer (CFO), because the chief executive officer (CEO) also serves as the CFO in these firms. The skewness in the distribution of CFO compensation and CEO compensation mirrors the skewness in the distribution of size.

There is significant cross-sectional variation in capital expenditure across firm-quarters. While the median firm's quarterly *CAPEX* is 6.2% (as a fraction of its lagged PP&E), the 25th- and 75th-percentile values of *CAPEX* are 3.4% and 10.5%, respectively. We also verify that there is significant within-firm variation in capital expenditure: in untabulated statistics, the mean (median) value of within-firm standard deviation in *CAPEX* is 0.074 (0.070), which is large compared to the mean (median) *CAPEX*.

The summary statistics on *Hedging Intensity* indicate that the average (median) firm hedges 29.6% (20.8%) of its oil production. There is substantial cross-sectional variation in hedging activity across firm-quarters, as indicated by the 25th- and 75th-percentile values of 0 and 0.533, respectively; that is, more than one-fourth of the firm-quarter observations in our sample do not involve any hedging, whereas at the other extreme, one-fourth of the firm-quarter observations feature firms that hedge more than half their output. However, unlike capital expenditure, there seems to be less within-firm variation in hedging intensity: in untabulated statistics, the mean (median) value of within-firm standard deviation in *Hedging Intensity* is 0.176 (0.198), which is small relative to the mean (median) *Hedging Intensity* of 0.296 (0.208).

The summary statistics on *Price Uncertainty* indicate that our main measure of output price uncertainty is not highly skewed and does not suffer from the presence of outliers. We use the price of the crude oil futures contract with maturity closest to one year as a proxy for crude oil price (*Futures Price*). During our sample period, *Futures Price* has varied between approximately \$13 per barrel and \$146 per barrel.

Next, we examine how the key firm characteristics vary by firm size. Accordingly, for each quarter, we classify firms into four quartiles by firm size and define the dummy variable *Large* to identify firms that are in the highest size quartile; hence, *Large* = 0 identifies small firms that are in the bottom three size quartiles. We present a univariate comparison of firm characteristics across small firms (*Large* = 0) and large firms (*Large* = 1) in panel B of Table 1; the last column lists the *p*-value of the difference in mean or median values. It is evident by comparing the mean and median values of total assets across the two columns that firms classified as large are an order of magnitude larger than firms classified as small. As expected, credit rating and executive compensation are highly positively correlated with size. Even then, it is striking that only 17.8% of

Table 1. Descriptive Statistics

Panel A: Summary statistics

	Mean	Median	Std. dev.	p25	p75	*N*
Firm characteristics (COMPUSTAT)						
Assets (in $ million)	2,073.209	251.132	6,159.437	47.179	1,157.682	6,151
Size	5.476	5.526	2.263	3.854	7.054	6,151
Profit	0.086	0.079	0.102	0.035	0.144	4,825
Leverage	0.286	0.279	0.211	0.114	0.421	6,151
Q	1.782	1.517	1.030	1.138	2.075	6,023
Cash	0.072	0.026	0.111	0.008	0.078	6,142
Cash Flow	0.034	0.041	0.070	0.020	0.064	6,064
Sales	0.128	0.102	0.095	0.072	0.150	6,149
Dividends	0.367	0.000	0.482	0.000	1.000	6,074
Rated	0.374	0.000	0.484	0.000	1.000	6,151
Investment Grade	0.358	0.000	0.480	0.000	1.000	6,151
No Separate CFO	0.075	0.000	0.263	0.000	0.000	4,166
CEO Pay (in $ '000)	1,139.438	558.845	2,917.760	248.320	1,138.707	4,124
CFO Pay (in $ '000)	458.374	330.718	484.586	161.000	625.840	3,800
CAPEX	0.086	0.062	0.088	0.034	0.105	6,068
ΔNet Debt	0.014	0.006	0.103	−0.021	0.041	6,000
Oil production and hedging						
Oil Production ('000 bbl)	1,717.775	280.428	4,054.209	57.000	1,482.000	4,019
Oil Hedged ('000 bbl)	546.993	30.000	1,422.903	0.000	355.000	3,583
Hedging Intensity	0.296	0.208	0.318	0.000	0.533	3,346
Oil market characteristics						
Futures Price	39.352	24.398	28.594	18.892	64.115	6,151
Oil Return	0.025	0.012	0.119	−0.035	0.088	6,151
6-month Price Uncertainty	0.321	0.319	0.083	0.270	0.369	6,151
Price Uncertainty	0.274	0.280	0.074	0.206	0.326	6,151

Panel B: Firm characteristics by size

	Large = 0	*Large* = 1	*p*-value of difference
Assets (in $ million)			
Mean	393.7	7,106.2	
Median	115.2	2,677.5	
Investment Grade	0.178	0.899	0.000
No Separate CFO	0.100	0.002	0.000
CEO Pay (in $ '000)			
Mean	632.2	2,585.4	0.000
Median	385.5	1,622.9	0.000
CFO Pay (in $ '000)			
Mean	329.4	786.2	0.000
Median	240.4	634.9	0.000
CAPEX	0.091	0.071	0.000
Hedging Intensity	0.267	0.378	0.000
ΔNet Debt	0.015	0.011	0.075
Q	1.809	1.704	0.001
Profit	0.081	0.101	0.000
Leverage	0.264	0.349	0.000

Notes. Panel A presents summary statistics for the key variables in our panel data. Panel B presents a univariate comparison of firm characteristics between small firms (*Large* = 0) and large firms (*Large* = 1). All variables are defined in the appendix. The panel data have one observation for each firm-quarter pair, span the period 2Q1990–1Q2013, and include the 197 firms listed in the Internet appendix.

small firms have an investment-grade rating, and 10% of these firms do not even have a separate CFO. The CFO compensation statistics indicate that only large firms are likely to be able to hire sophisticated CFOs and risk managers. Large firms also have significantly lower rates of capital expenditure and debt issuance, but they have significantly higher hedging intensity compared to small firms.[11]

4.2. Correlations Among Key Variables

In Table 2, we report the pairwise correlations among the key variables in our panel. Panel A shows that *Price Uncertainty* is highly positively correlated with *Futures Price* and the two macroeconomic factors, *Macro* 1*st PC* and *Macro* 2*nd PC*. The high correlation between the oil factors and the macro factors is not surprising and does not imply that oil price uncertainty is simply serving as

Table 2. Correlations

Panel A: Price uncertainty and other market characteristics

	Price Uncertainty	*Futures Price*	*Macro 1st PC*	*Macro 2nd PC*
Price Uncertainty	1.000			
Futures Price	0.601*	1.000		
Macro 1st PC	0.526*	0.215*	1.000	
Macro 2nd PC	0.578*	0.403*	−0.000	1.000

Panel B: Investment, hedging, and price uncertainty

	CAPEX	*Hedging Intensity*	*ΔNet Debt*
CAPEX	1.000		
Hedging intensity	−0.064*	1.000	
ΔNet Debt	0.433*	−0.006	1.000
Price Uncertainty	−0.067*	0.142*	−0.069*
Futures Price	0.022*	0.167*	−0.026*
Macro 1st PC	−0.121*	0.096*	−0.053*
Macro 2nd PC	−0.018	0.050*	−0.005
Size	−0.065*	0.359*	−0.002
Leverage	−0.091*	0.283*	−0.039*
Q	0.208*	−0.140*	0.030*
Rated	−0.052*	0.257*	0.017
Cash	0.172*	−0.280*	0.054*
Cash Flow	0.063*	−0.011	−0.055*
Sales	0.094*	−0.227*	−0.048*
Dividends	−0.057*	0.023	0.017

Notes. This table presents pairwise correlations between the key variables in our panel data. Panel A lists the pairwise correlations between price uncertainty, futures price, and the macroeconomic factors. Panel B lists the pairwise correlations between firm-level outcome variables (capital expenditure, hedging, and net debt issuance), price uncertainty, and the macroeconomic factors. All variables are defined in the appendix.

*Denotes statistical significance at the 10% level.

a proxy for time-series variation in the macro variables. The causality could very well be the other way around, because oil is one of the most important commodities and a key input to most nonoil firms. Indeed, recent research in asset pricing shows that oil risk factors are important in explaining the movement of asset prices and economic fundamentals (e.g., see Chiang et al. 2015). Nonetheless, these high correlations raise potential econometric concerns for our multivariate analysis, which we address in Section 5 below.

The pairwise correlations in panel B of Table 2 suggest that O&G firms lower their capital expenditure and increase hedging intensity when oil price uncertainty is high. On the other hand, they increase both capital expenditure and hedging intensity when the crude oil futures price is high. Of course, these are simple pairwise correlations that do not control for other important determinants of investment and hedging decisions. We next proceed to the multivariate analysis, where we are able to control for key determinants of investment and hedging activity.

5. Main Empirical Results

To examine how output price uncertainty affects firm-level capital investment and hedging activity, we estimate panel regressions of the form

$$Y_{j,t} = \alpha + \beta \times Price\_Uncertainty_t + \boldsymbol{\gamma} X_{j,t-1} + \boldsymbol{\lambda} X_{m,t} + \mu_j + \epsilon_{j,t}. \quad (1)$$

Here, $Y_{j,t}$ is either *CAPEX* or *Hedging Intensity* for firm j in fiscal quarter t. The main independent variable of interest is *Price Uncertainty*, which serves as a proxy for expected oil volatility one year into the future. The regression spans the time period 4Q1994–1Q2013 because *Price Uncertainty* is available beginning only in November 1994. We control for important firm characteristics ($X_{j,t-1}$) and market and macroeconomic characteristics ($X_{m,t}$) that can affect capital investment and hedging activity.[12]

As per the Q theory of investment, a key determinant of investment is the firm's Q, defined as the ratio of the firm's market value to the replacement cost of its existing capital stock. Following standard practice in the literature, we use the book values of firms' assets as proxies for their replacement values, and we compute Q by dividing the sum of market value of equity and the book value of interest-bearing debt with the sum of the book values of equity and interest-bearing debt. We also control for the following additional firm characteristics, which may affect capital investment and hedging activity: *Size*; *Leverage*, which is the ratio of long-term debt to assets; cash flow position using *Cash Flow*, which is the ratio of the sum of net income before extraordinary items and depreciation and amortization to net property, plant, and equipment (PP&E); *Sales*, which is defined as the ratio of sales to net PP&E and serves as a control for certain omitted aspects of the "true" Q or cash flows (Fazzari and Petersen 1993); cash position using *Cash*, which is the ratio of cash and equivalents to total assets; *Rated*, which is a dummy variable that identifies if the firm has a long-term credit rating; and *Dividends*, which is a dummy variable that identifies if the firm pays any dividends to its common shareholders.

Capital investment and hedging activity in a cyclical industry like oil and gas are also likely to be affected by the price of crude oil futures and other macroeconomic factors. Therefore, it is important to control the regression for *Futures Price*, *Macro 1st PC*, and *Macro 2nd PC*. A potential econometric concern with the inclusion of these controls is that they have relatively high correlation with each other and with oil price uncertainty (see panel A of Table 2). Therefore, we estimate the regressions with and without these macro controls to underline the robustness of our results. We also conduct several robustness tests, which we describe in Section 5.1, and we report detailed results in the Internet appendix.

The key identifying assumption underlying our analysis is that *Price Uncertainty* may be treated as exogenous conditional on the covariates. This is a reasonable assumption because U.S. firms in the upstream O&G sector were marginal players in the global crude oil markets during our sample period and did not have the market power, either individually or collectively, to affect global crude oil prices. For our purposes, *Price Uncertainty* could not have been affected by the past or present policies of any firm in our sample. Moreover, after controlling for the price of crude oil futures and the two macroeconomic factors, we are confident that the residual in regression (1) is uncorrelated with *Price Uncertainty*. Nonetheless, we use the method proposed in Oster (2016) to estimate unbiased effects of *Price Uncertainty*.

5.1. Capital Investment and Price Uncertainty

To examine how output price uncertainty affects capital investment, we estimate the panel regression (1) with *CAPEX* as the dependent variable. The results of our estimation are reported in Table 3. The standard errors in all specifications are robust to heteroskedasticity and are clustered by quarter. We obtain qualitatively similar results if we cluster at the firm level.

Panel A of Table 3 shows the results of estimation on the entire sample of firms. In column (1), we include all firm level controls but omit *Futures Price* and the market/macro variables. We also include fiscal quarter dummies to control for any variation in capital expenditure across the four fiscal quarters in all estimations. The negative and significant coefficient on *Price Uncertainty* indicates that firms decrease their capital expenditure when price uncertainty is high. This effect is also economically significant: an increase in *Price Uncertainty* from its 25th-percentile to 75th-percentile level (an increase of 0.12) is associated with a decrease in *CAPEX* of 1.24%, which represents a 14.4% (20.0%) decrease in *CAPEX* relative to its mean (median) value of 8.6% (6.2%).

We introduce *Futures Price* as an additional control in column (2) of Table 3, and the two macro factors

Table 3. Capital Investment and Price Uncertainty

Panel A: Capital investment and price uncertainty (all firms)

	Dependent variable: *CAPEX*			
	(1)	(2)	(3)	(4)
Price Uncertainty	−0.103***	−0.131***	−0.089**	−0.093**
	(0.025)	(0.031)	(0.042)	(0.041)
Size	0.366	−0.272	−0.198	−4.685*
	(1.012)	(1.004)	(1.007)	(2.718)
Leverage	−0.008	−0.006	−0.007	−0.039***
	(0.006)	(0.007)	(0.007)	(0.009)
Q	0.016***	0.016***	0.015***	0.017***
	(0.001)	(0.001)	(0.001)	(0.002)
Rated	0.003	0.004	0.004	0.015**
	(0.004)	(0.004)	(0.004)	(0.006)
Dividends	−0.007***	−0.006***	−0.006***	0.007
	(0.002)	(0.002)	(0.002)	(0.004)
Cash	0.099***	0.097***	0.098***	0.207***
	(0.017)	(0.017)	(0.017)	(0.025)
Cash Flow	0.074***	0.072***	0.072***	0.040*
	(0.023)	(0.023)	(0.022)	(0.022)
Sales	0.009	0.011	0.008	0.061**
	(0.016)	(0.016)	(0.016)	(0.024)
Futures Price/1,000		0.142**	0.119*	0.137
		(0.065)	(0.064)	(0.084)
Macro 1st PC			−0.005***	−0.004**
			(0.002)	(0.001)
Macro 2nd PC			0.002	0.003
			(0.005)	(0.004)
Constant	0.074***	0.079***	0.069***	0.076***
	(0.008)	(0.008)	(0.011)	(0.014)
Observations	5,799	5,799	5,799	5,799
R^2	0.079	0.080	0.083	0.221
Fiscal quarter dummies	Yes	Yes	Yes	Yes
Firm fixed effects	No	No	No	Yes

Table 3. (Continued)

Panel B: Variation by firm size

	Dependent variable: *CAPEX*					
	Large = 0 (1)	*Large* = 1 (2)	*Large* = 0 (3)	*Large* = 1 (4)	*Large* = 0 (5)	*Large* = 1 (6)
Price Uncertainty	−0.173***	0.017	−0.177***	−0.012	−0.126***	0.001
	(0.028)	(0.031)	(0.033)	(0.033)	(0.045)	(0.045)
Futures Price/1,000			0.020	0.251***	−0.004	0.234***
			(0.079)	(0.061)	(0.076)	(0.063)
Macro 1st PC					−0.006***	−0.002
					(0.002)	(0.002)
Macro 2nd PC					0.002	0.002
					(0.005)	(0.004)
χ^2 (difference)	48.71	—	28.62	—	11.59	—
p-value (difference)	0.000	—	0.000	—	0.001	—
Observations	4,308	1,491	4,308	1,491	4,308	1,491
R^2	0.085	0.098	0.085	0.105	0.089	0.107
All controls	Yes	Yes	Yes	Yes	Yes	Yes

Notes. This table reports the results of panel regressions that examine the relationship between firm-level capital investment (*CAPEX*) and *Price Uncertainty*. We estimate variants of the regression

$$CAPEX_{j,t} = \alpha + \beta \times Price\ Uncertainty + \gamma X_{j,t-1} + \lambda X_{m,t} + \varepsilon_{j,t}.$$

We estimate the above regression on a panel that has one observation for each firm-fiscal quarter pair and spans the period 4Q1994–1Q2013. We estimate the regression on the entire sample in panel A. In panel B, we estimate the regression in columns (1), (2), and (3) of panel A separately for small firms (*Large* = 0) and large firms (*Large* = 1). We employ the full set of controls in panel B but suppress these coefficients to conserve space. All variables are defined in the appendix. Standard errors (reported in parentheses) are robust to heteroskedasticity and are clustered by quarter.

***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

as additional controls in column (3). As expected, the coefficient on *Futures Price* is positive and significant, indicating that upstream O&G firms undertake larger capital expenditure when the one-year future price of crude oil is high. Notably, price uncertainty continues to have a statistically and economically significant negative effect on capital investment even after controlling for crude oil prices and time-varying proxies for financial frictions. Also, the magnitude of the coefficient on price uncertainty is similar between column (1) and column (3). Finally, in column (4) we include firm fixed effects to examine the relationship between within-firm variation in capital expenditure and price uncertainty and find results very similar to the baseline regression in column (1).[13]

Overall, the results in panel A of Table 3 indicate that, on average, firms lower their capital expenditure significantly—both in statistical and economic terms—when faced with high output price uncertainty.

In panel B of Table 3, we examine how the effect of price uncertainty on capital expenditure varies by firm size. Accordingly, we estimate the regression (1) separately for small firms (*Large* = 0) and large firms (*Large* = 1), after controlling for all the determinants of capital expenditure from panel A. This ensures that any differences in the response to *Price Uncertainty* across the two subgroups are driven only by differences in size, rather than by differences in investment opportunities or other firm characteristics. The empirical specification and control variables are the same as those in columns (1)–(3) of panel A, but we suppress the coefficients on firm-level control variables to conserve space.

The striking finding from columns (1) and (2) of panel B of Table 3 is that there is no negative effect of price uncertainty on capital expenditure for large firms.[14] As can be seen, the coefficient on *Price Uncertainty* is negative and significant only for the subgroup of small firms in column (1), and the difference in coefficients between columns (1) and (2) is highly significant. This differential effect of price uncertainty on capital expenditure for small versus large firms is robust to controlling for crude oil prices (columns (3) and (4)) and other macroeconomic factors (columns (5) and (6)).

Overall, the results in panel B of Table 3 indicate that the negative relationship between capital expenditure and price uncertainty is essentially a small firm phenomenon and is absent among large firms. One possible explanation for this size effect is that large firms are able to increase their risk management in uncertain environments to protect their investment programs, whereas small firms are unable to do so. To test this conjecture, we examine the effect of price uncertainty on firm-level hedging policies in Section 5.2 below following a brief description of the robustness of our *CAPEX* results.

5.1.1. Robustness Tests. We conduct several additional robustness tests, which we report in Table IA-1 of the Internet appendix to conserve space in the paper. In panel A, we show that our results are similar if we include all the macroeconomic variables individually instead of the macro principal components and that our results are robust to a purged residuals regression specification (see Clerides et al. 1998). In panel B, we show that our results are robust to a first-differences specification. Since the first-differences specification relies on "shocks" to the macroeconomic variables instead of their levels, high correlation among macro variables is no longer a concern. In panel C, we obtain a time series of covariate-adjusted average capital expenditure and show that it has a negative relationship with price uncertainty. In panel D, we show that the negative effect of price uncertainty on capital expenditure holds for all levels of crude oil futures price. Finally, in panel E, we show that the negative relationship between capital expenditure and price uncertainty is robust to a variety of alternative specifications, such as a fixed effects model with autocorrelated errors, a panel generalized method of moments (GMM) specification, and a linear errors-in-variables specification.

5.2. Hedging and Price Uncertainty

To examine how output price uncertainty affects firm-level risk management policies, we estimate panel regression (1) with *Hedging Intensity* as the dependent variable.[15] The results of our estimation are presented in Table 4.

In panel A, we estimate the regression on our entire sample of firms. In column (1), we utilize the full set of firm-level control variables that we used in the *CAPEX* regression in Table 3. The positive and significant coefficient on *Price Uncertainty* indicates that, on average, firms hedge more when faced with higher output price uncertainty. The effect is also economically significant: the coefficient estimate in column (2) suggests that an increase in *Price Uncertainty* from its 25th- to 75th-percentile level (an increase of 0.12) is associated with a 4.7% increase in *Hedging Intensity*, which represents a 15.9% (22.6%) increase relative to its mean (median) value of 29.6% (20.8%).

The coefficients on firm-specific controls are consistent with the risk management literature. Size has a strong positive effect on hedging intensity. Ceteris paribus, firms use hedging intensity to reduce debt contracting costs, as seen by the significant positive coefficient for leverage and the negative coefficients for cash holdings, dividend payout, sales, and the presence of a credit rating.

The positive effect of price uncertainty on hedging intensity is robust to controlling for the futures price of crude oil (column (2) of Table 4) and other macroeconomic factors (column (3)). The results in column (2) also indicate that on average hedging intensity is significantly positively related to the futures price of crude oil, as hedging firms attempt to capture higher prices for their output.

In column (4) of Table 4, we introduce firm fixed effects in addition to the time-varying control variables. Note that the coefficient on *Price Uncertainty* becomes insignificant, whereas the coefficient on *Futures Price* continues to be positive and significant. Therefore, most of the within-firm variation in hedging intensity seems to be driven by futures price of oil, rather than by oil price uncertainty. We also note that, compared to capital expenditure, there is very little within-firm variation in hedging intensity in the first place. For instance, in unreported tests, we find that firm dummies (or fixed effects) alone can explain 55% of the R^2 in hedging intensity, whereas they explain only 12.5% of the variation in capital expenditure. Thus, hedging policies of firms seem to be very rigid, on average, compared to capital expenditure policies. Moreover, hedging seems to be much more stickier among small firms compared to large firms. For instance, the average change in hedging intensity relative to the previous quarter (i.e., Δ*Hedging Intensity*) is only 0.068% among small firms versus 0.78% among large firms.

In panel B Table 4, we estimate the regression specifications from panel A separately for small firms (*Large* = 0) and large firms (*Large* = 1) in order to understand how the effect of price uncertainty on hedging varies by firm size. The striking finding from panel B is that the positive relationship between hedging intensity and price uncertainty is entirely driven by large firms. Recall that these are the same firms that do not lower their capital expenditure when faced with high price uncertainty (panel B of Table 3). By contrast, small firms do not vary their hedging intensity significantly with price uncertainty, although, as we saw in panel B of Table 3, the same group of firms lowers its capital expenditure significantly when price uncertainty is high.

The invariance of hedging intensity to price uncertainty in small firms is of substantial interest. We note that this result is not driven by firms that do not hedge at all. Rather, as we argued in Section 2, this result may be explained by the institutional features of the O&G industry where most of the hedging occurs through customized and highly illiquid over-the-counter contracts, making it difficult for small firms to adjust their hedging intensity to price uncertainty.

5.3. Effect of Hedging on the Investment–Uncertainty Relationship

Taken together, the results in Tables 3 and 4 suggest that hedging policies may affect how firms' capital

Table 4. Hedging Intensity and Price Uncertainty

Panel A: Hedging intensity and price uncertainty (all firms)

	Dependent variable: *Hedging Intensity*			
	(1)	(2)	(3)	(4)
Price Uncertainty	0.391***	0.226*	0.430**	0.021
	(0.131)	(0.128)	(0.169)	(0.163)
Size	53.487***	48.644***	49.060***	60.920***
	(3.277)	(3.017)	(3.052)	(7.962)
Leverage	0.292***	0.304***	0.303***	0.121***
	(0.035)	(0.034)	(0.034)	(0.030)
Q	−0.014***	−0.019***	−0.020***	0.000
	(0.004)	(0.004)	(0.004)	(0.004)
Rated	−0.068***	−0.065***	−0.065***	−0.054***
	(0.009)	(0.010)	(0.010)	(0.018)
Dividends	−0.061***	−0.055***	−0.056***	0.004
	(0.009)	(0.009)	(0.009)	(0.013)
Cash	−0.226***	−0.242***	−0.246***	−0.139**
	(0.040)	(0.040)	(0.040)	(0.062)
Cash Flow	0.207**	0.200**	0.163**	0.070
	(0.083)	(0.076)	(0.072)	(0.074)
Sales	−0.392***	−0.372***	−0.366***	0.086
	(0.069)	(0.068)	(0.068)	(0.114)
Futures Price/1,000		0.801***	0.813***	0.807***
		(0.205)	(0.223)	(0.284)
Macro 1st PC			−0.003	0.007
			(0.007)	(0.006)
Macro 2nd PC			−0.053***	−0.023*
			(0.016)	(0.013)
Constant	−0.090**	−0.051	−0.107**	−0.128**
	(0.040)	(0.037)	(0.045)	(0.049)
Observations	3,259	3,259	3,259	3,259
R^2	0.211	0.214	0.217	0.584
Firm fixed effects	No	No	No	Yes

investment responds to price uncertainty. Of course, both capital investment and hedging are endogenous and vary with price uncertainty, which makes it hard to characterize the effect of hedging on the sensitivity of capital investment to price uncertainty.

In this section, we employ a switching regression model with endogenous switching (Maddala 1983) to examine how the sensitivity of capital expenditure to price uncertainty varies between firms that hedged at least some of their oil production during the quarter and those that did not, after adjusting for the endogeneity of the decision to hedge or not. We define the dummy variable *Hedger* to identify firms that hedged at least some of their oil production during the quarter; i.e., *Hedger* = 1 identifies firms with *Hedging Intensity* > 0, whereas *Hedger* = 0 identifies firms with *Hedging Intensity* = 0.

In the first stage of the model, we estimate a probit regression with *Hedger* as the dependent variable, and use the serial correlation of taxable income ($\rho(TI)$) as a tax-based instrument for hedging (see Graham and Smith 1999). For each firm in our sample, we estimate $\rho(TI)$ each year using the firm's entire history to that point. The argument is that, given the convexity of tax schedules, a firm's expected tax benefit from hedging is likely to be higher if its taxable income exhibits more negative serial correlation so that the firm is more likely to shift between profits and losses (see page 2,256 of Graham and Smith 1999 for more details).[16] By this logic, we expect a negative relationship between $\rho(TI)$ and *Hedger*. At the same time, there is no reason to believe that $\rho(TI)$ affects the firm's current capital expenditure. Hence, we feel confident that $\rho(TI)$ satisfies the exclusion restriction.

In the second stage of the model, we estimate two outcome equations with *CAPEX* as the dependent variable, separately for firms that hedged (*Hedger* = 1) and for firms that did not hedge (*Hedger* = 0), after augmenting each equation using the inverse Mills ratio estimated from the first-stage probit regression. The results of our estimation are presented in Table 5. We include the full set of control variables in both the first-stage selection equation and the second-stage outcome equations but suppress these coefficients to conserve space.

Table 4. (Continued)

Panel B: Variation by firm size

	Dependent variable: *Hedging Intensity*					
	Large = 0 (1)	*Large* = 1 (2)	*Large* = 0 (3)	*Large* = 1 (4)	*Large* = 0 (5)	*Large* = 1 (6)
Price Uncertainty	0.031	1.028***	0.030	0.665***	0.256	0.580**
	(0.122)	(0.206)	(0.129)	(0.181)	(0.164)	(0.256)
Futures Price/1,000			0.006	3.915***	0.011	4.116***
			(0.185)	(0.625)	(0.201)	(0.642)
Macro 1st PC					−0.004	0.015
					(0.007)	(0.009)
Macro 2nd PC					−0.056***	−0.024
					(0.018)	(0.027)
χ^2 (difference)	31.42	—	13.89	—	2.74	—
p-value (difference)	0.000	—	0.000	—	0.098	—
Observations	2,408	851	2,408	851	2,408	851
R^2	0.212	0.216	0.212	0.273	0.215	0.277
All controls	Yes	Yes	Yes	Yes	Yes	Yes

Notes. This table reports the results of panel regressions that examine the relationship between *Hedging Intensity* and *Price Uncertainty*. We estimate the regression

$$Hedging\_\ Intensity_{j,t} = \alpha + \beta \times Price\ Uncertainty + \gamma X_{j,t-1} + \lambda X_{m,t} + \varepsilon_{j,t}.$$

We estimate this regression on a panel that has one observation for each firm-fiscal quarter pair, spans the period 1Q1995–1Q2013, and includes the 126 firms for which we are able to obtain information on hedging intensity from their SEC filings. We estimate the regression on the entire sample in panel A. In panel B, we estimate the regression in columns (1), (2), and (3) of panel A separately for small firms (*Large* = 0) and large firms (*Large* = 1). We employ the full set of controls in panel B but suppress these coefficients to conserve space. All variables are defined in the appendix. Standard errors (reported in parentheses) are robust to heteroskedasticity and are clustered by quarter.

***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

We estimate the model on our entire sample in columns (1)–(3) of Table 5. The results show a marked distinction between the effects of price uncertainty on the capital investment of firms that hedged versus those that did not. Although the coefficient on *Price Uncertainty* is negative for both firms that hedged (column (2)) and those that did not (column (3)), the coefficient is much more economically and statistically significant among the subgroup of firms that chose not to hedge their exposure to price uncertainty. Moreover, the results of the χ^2 test indicate that the difference in coefficients on *Price Uncertainty* between the two subgroups is statistically significant at the 10% level. The results of the first-stage probit regression in column (1) indicate that $\rho(TI)$ is a strong instrument for hedging. The insignificant coefficients on inverse Mills ratio in columns (2) and (3) indicate that any omitted factors that affect the firms' hedging decision do not have a significant effect on capital expenditure.

Next, we estimate the switching regression separately for small firms (*Large* = 0) and large firms (*Large* = 1) but suppress the results of the first-stage probit regressions in both cases to conserve space. We present the results of the second-stage regressions for small firms in columns (4) and (5) and for large firms in columns (6) and (7) of Table 5. As can be seen from columns (4) and (5), among small firms, the negative effect of price uncertainty on capital expenditure seems to be larger among firms that chose not to hedge, although the difference between coefficients on *Price Uncertainty* narrowly misses statistical significance at the 10% level (the p-value of the difference is 0.11). On the other hand, we fail to detect any effect of hedging on the *CAPEX*–uncertainty relationship among large firms. This may be because large firms face less severe financing constraints, regardless of whether they hedge or not. Alternatively, this result may reflect the limited statistical power of the test given that there are only 150 nonhedger firm-quarter observations among the subgroup of large firms.

5.4. Price Uncertainty, Debt Market Frictions, and Hedging

What is the channel through which hedging moderates the negative effect of price uncertainty on capital investment? One possibility is that price uncertainty exacerbates debt market frictions, which can be mitigated through hedging. Indeed, a large body of literature in finance shows that debt market constraints have a negative effect on capital investment (Whited 1992, Almeida and Campello 2007, and Nini et al. 2012), and that hedging can alleviate debt market constraints (Campello et al. 2011). However, the literature has not specifically examined if uncertainty exacerbates debt market frictions. If we can show that price uncertainty

Table 5. Effect of Hedging on the *CAPEX–Price Uncertainty* Relationship

	Switching regression model						
	All firms			*Large* = 0		*Large* = 1	
	Hedger	*CAPEX*	*CAPEX*	*CAPEX*	*CAPEX*	*CAPEX*	*CAPEX*
		Hedger = 1	*Hedger* = 0	*Hedger* = 1	*Hedger* = 0	*Hedger* = 1	*Hedger* = 0
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Price Uncertainty	1.272***	−0.060*	−0.139***	−0.115***	−0.194***	−0.003	0.008
	(0.423)	(0.030)	(0.044)	(0.038)	(0.046)	(0.034)	(0.048)
ρ(TI)	−0.225***						
	(0.062)						
Inverse Mills Ratio		−0.025	0.013	−0.068**	0.026	0.063**	0.006
		(0.020)	(0.024)	(0.030)	(0.030)	(0.024)	(0.011)
χ^2 (difference)		3.06		2.55		0.23	
p-value (difference)		0.080		0.110		0.629	
Specification	probit	OLS	OLS	OLS	OLS	OLS	OLS
Observations	3,201	1,950	1,236	1,255	1,085	695	151
R^2		0.141	0.081	0.142	0.090	0.176	0.440
Pseudo R^2	0.289						

Notes. This table presents the results of a switching regression model with endogenous switching, to further understanding of how the relationship between *CAPEX* and *Price Uncertainty* varies between firms that hedged (*Hedger* = 1) and those that did not hedge (*Hedger*= 0) any of their oil production during the quarter. We estimate the model on the entire sample in columns (1)–(3). In the first stage, we estimate a probit regression with *Hedger* as the dependent variable, and ρ(TI) as the instrument for hedging (column (1)). In the second stage, we estimate two outcome equations with *CAPEX* as the dependent variable, separately for firms that hedged (column (2)) and for firms that did not hedge (column (3)) any of their oil production during the quarter. We employ the full set of controls but suppress these coefficients to conserve space. We also estimate the model separately for small firms (*Large* = 0) and large firms (*Large* = 1) but suppress the results of the first-stage regressions in both cases to conserve space. We present the results of the second-stage regressions for small firms in columns (4) and (5) and for large firms in columns (6) and (7). All variables are defined in the appendix. Standard errors (reported in parentheses) are robust to heteroskedasticity and are clustered by quarter. OLS, ordinary least squares.

***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

exacerbates debt market frictions, that can potentially explain why the effects of price uncertainty vary by firm size and hedging policies.

To this end, we examine the effect of price uncertainty on net debt issuance by firms, and how this effect varies with firm size and hedging activity. accordingly, we estimate regression (1) with Δ*Net Debt* as the dependent variable, which denotes the change in net debt (i.e., total debt minus cash and equivalents) from the previous quarter scaled by lagged assets. If output price uncertainty exacerbates debt market frictions, then we expect a negative relationship between debt issuance and price uncertainty, especially for small firms that are more likely to be affected by debt market frictions.

The empirical challenge in this investigation is to differentiate between firms' supply of credit and demand for credit. That is, net debt issuance may be lower either because the firm is unable to raise debt (supply effect) or because the firm is undertaking less capital expenditure and, hence, does not need to raise debt (demand effect). Therefore, to partially control for the firm's demand for credit, we use *Industry CAPEX*, defined as the median value of *CAPEX* across all sample firms over the same calendar quarter, as a proxy for investment opportunities in the sector. The results of our estimation are presented in Table 6.

The results in panel A of Table 6 indicate that firms lower their net debt issuance when price uncertainty is high, which is consistent with both the static "trade-off" model of capital structure (Kraus and Litzenberger 1973) and dynamic structural models that consider investment and capital structure decisions (see Strebulaev and Whited 2011 for a survey). This result is also robust to controlling for the effect of oil futures price and macroeconomic factors (column (2)) and the inclusion of firm fixed effects (column (3)). The positive coefficient on *Industry CAPEX* indicates that firms issue more debt when investment demand is high. Examining debt issuance and cash accumulation separately, we find that price uncertainty has a significant negative effect on debt issuance (column (4)) but no significant positive effect on cash accumulation (column (5)).

In panel B of Table 6, we examine the effect of price uncertainty on debt issuance separately for small firms (*Large* = 0) and large firms (*Large* = 1). As can be seen, the negative effect of price uncertainty on net debt issuance is essentially a small firm phenomenon and is absent among large firms.[17]

In panel C of Table 6, we use the switching regression model with endogenous switching to examine how the

Table 6. Net Debt Issuance and Price Uncertainty

Panel A: Net debt issuance and price uncertainty (all firms)

	Δ*Net Debt* (1)	Δ*Net Debt* (2)	Δ*Net Debt* (3)	Δ*Debt* (4)	Δ*Cash* (5)
Price Uncertainty	−0.096***	−0.134***	−0.133***	−0.077***	0.015
	(0.026)	(0.041)	(0.047)	(0.018)	(0.012)
Industry CAPEX	0.466***	0.615***	0.510***	0.430***	−0.027
	(0.109)	(0.135)	(0.147)	(0.086)	(0.047)
Size	−0.679	−0.346	−5.843**	−2.702***	−1.811***
	(1.027)	(0.957)	(2.673)	(0.804)	(0.411)
Rated	0.006*	0.006	0.006	0.010***	0.004***
	(0.004)	(0.004)	(0.007)	(0.004)	(0.001)
Tangibility	−0.001	−0.002	−0.063***	0.029***	0.024***
	(0.010)	(0.010)	(0.016)	(0.007)	(0.006)
Profitability	−0.026	−0.027	0.006	−0.014	0.017**
	(0.018)	(0.018)	(0.019)	(0.015)	(0.007)
Q	0.002	0.002	0.003	0.002**	0.001
	(0.001)	(0.001)	(0.002)	(0.001)	(0.001)
Futures Price/1,000		−0.147*	−0.036		
		(0.082)	(0.105)		
Macro 1st PC		0.003	0.004*		
		(0.002)	(0.002)		
Macro 2nd PC		0.016***	0.018***		
		(0.004)	(0.004)		
Constant	0.011	0.017	0.094***	−0.005	−0.013**
	(0.012)	(0.015)	(0.018)	(0.008)	(0.006)
Observations	5,842	5,842	5,842	5,842	5,977
R^2	0.012	0.014	0.057	0.017	0.012
Firm fixed effects	No	No	Yes	No	No

Panel B: Variation by firm size

	Dependent variable: Δ*Net Debt*					
	Large = 0 (1)	*Large* = 1 (2)	*Large* = 0 (3)	*Large* = 1 (4)	*Large* = 0 (5)	*Large* = 1 (6)
Price Uncertainty	−0.146***	0.017	−0.105***	0.023	−0.190***	0.015
	(0.031)	(0.035)	(0.038)	(0.044)	(0.044)	(0.056)
Industry CAPEX	0.429***	0.444***	0.551***	0.467**	0.635***	0.510**
	(0.128)	(0.135)	(0.160)	(0.180)	(0.144)	(0.195)
Futures Price/1,000			−0.201**	−0.037	−0.229***	−0.043
			(0.095)	(0.133)	(0.086)	(0.133)
Macro 1st PC					0.004*	0.001
					(0.002)	(0.002)
Macro 2nd PC					0.021***	−0.000
					(0.004)	(0.006)
χ^2 (difference)	20.29	—	8.63	—	17.25	—
p-value (difference)	0.000	—	0.003	—	0.000	—
Observations	4,349	1,493	4,349	1,493	4,349	1,493
R^2	0.016	0.013	0.018	0.013	0.020	0.013
All controls	Yes	Yes	Yes	Yes	Yes	Yes

effect of price uncertainty on net debt issuance varies between hedgers and nonhedgers. We first estimate this model on our entire sample of firms, the results of which are presented in columns (1)–(3). As can be seen, the negative effect of price uncertainty on Δ*Net Debt* is confined entirely to nonhedging firms, and the difference in coefficients on *Price Uncertainty* between columns (2) and (3) is statistically significant at the 5% level.

Next, we estimate the switching regression model separately for small firms (*Large* = 0) and large firms (*Large* = 1) but suppress the results of the first-stage

Table 6. (Continued)

Panel C: Switching regression model							
	All firms			*Large* = 0		*Large* = 1	
	Hedger	*ΔNet Debt*	*ΔNet Debt*	*ΔNet Debt*	*ΔNet Debt*	*ΔNet Debt*	*ΔNet Debt*
		Hedger = 1	*Hedger* = 0	*Hedger* = 1	*Hedger* = 0	*Hedger* = 1	*Hedger* = 0
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Price Uncertainty	1.272***	0.019	−0.117**	−0.009	−0.181***	0.041	0.088
	(0.423)	(0.038)	(0.052)	(0.052)	(0.061)	(0.044)	(0.162)
ρ(TI)	−0.225***						
	(0.062)						
Inverse Mills Ratio		0.036**	0.032**	0.056***	0.044**	0.055**	0.032*
		(0.015)	(0.015)	(0.018)	(0.017)	(0.023)	(0.016)
χ^2 (difference)		5.05		5.24		0.09	
p-value (difference)		0.025		0.022		0.769	
Specification	Probit	OLS	OLS	OLS	OLS	OLS	OLS
Observations	3,201	1,930	1,216	1,236	1,065	694	151
R^2		0.032	0.022	0.039	0.035	0.039	0.025
Pseudo R^2	0.289						

Notes. This table reports the results of panel regressions that examine the relationship between firm-level net debt issuance and oil *Price Uncertainty*. We estimate variants of the regression

$$Y_{j,t} = \alpha + \beta \times Price\ Uncertainty + \gamma X_{j,t-1} + \lambda X_{m,t} + \varepsilon_{j,t}.$$

We estimate this regression on a panel that has one observation for each firm-fiscal quarter pair and spans the period 4Q1994–1Q2013. In panel A, we estimate the regression on the entire sample. The dependent variable is *ΔNet Debt* in columns (1)–(3), *ΔDebt* in column (4), and *ΔCash* in column (5). In panel B, we estimate the regression in columns (1)–(3) of panel A separately for small firms (*Large* = 0) and large firms (*Large* = 1). We employ the full set of controls in panel B but suppress these coefficients to conserve space. In panel C, we estimate a switching regression model with endogenous switching using *ΔNet Debt* as the dependent variable. We first estimate the model on the entire sample, where we report the results of the first-stage probit regression with *Hedger* as the dependent variable in column (1), and the results of the two outcome equations with *ΔNet Debt* as the dependent variable for firms that hedged (column (2)) and for firms that did not hedge (column (3)). Next, we estimate this model separately for small firms (*Large* = 0) and large firms (*Large* = 1) but suppress the results of the first stage regressions in both cases to conserve space. We present the results of the second-stage regressions for small firms in columns (4) and (5) and for large firms in columns (6) and (7). All variables are defined in the appendix. Standard errors (reported in parentheses) are robust to heteroskedasticity, and are clustered by quarter. OLS, ordinary least squares.

***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

probit regressions in both cases to conserve space. We present the results of the second-stage regressions for small firms in columns (4) and (5) and for large firms in columns (6) and (7). The results in columns (4) and (5) indicate that, among small firms, the negative effect of price uncertainty on *ΔNet Debt* is confined entirely to nonhedging firms, and the difference in coefficients on *Price Uncertainty* between the two columns is statistically significant at the 5% level. However, among large firms, price uncertainty has no effect on *ΔNet Debt*, regardless of hedging.

Overall, the results in Table 6 suggest that, on average, firms face more severe debt market constraints when price uncertainty is high. However, the results in panels B and C, respectively, show that large firms and firms that hedge do not face this problem.

6. Conclusion

In this paper, we use the U.S. upstream oil and gas sector as a laboratory to examine the causative effect of output price uncertainty on firm-level capital investment, risk management, and debt issuance. We use options on crude oil futures to derive a forward-looking and exogenous measure of price uncertainty. We find that the effects of uncertainty vary significantly by firm size. When faced with high price uncertainty, large firms increase their hedging intensity but do not lower capital expenditure or debt issuance. On the other hand, small firms do not adjust their hedging intensity but significantly lower capital expenditure and debt issuance even after controlling for investment demand. Moreover, the negative effect of uncertainty on capital investment is significantly weaker for firms that hedge their output price risk. Our analysis highlights that, in the presence of financial frictions, high price uncertainty has significant dampening effects on capital investment of small firms by exacerbating their financial constraints, and that this negative effect is amplified by firm-level constraints on the ability to hedge risk exposures.

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Appendix. Definitions of Variables

Firm-Level Variables

We indicate the corresponding Compustat Quarterly variable names in quotes within parentheses.

- *Size*: Natural logarithm of total assets ("atq").
- *Leverage*: Ratio of long-term debt ("dltt") to total assets ("atq").
- *Q*: Ratio of the sum of the market value of equity (i.e., "prccq" × "cshoq") and the book value of interest-bearing debt (i.e., "dltt" + "dlc") to the sum of book values of equity and interest-bearing debt (i.e., "seqq" + "dltt" + "dlc").
- *Cash Flow*: Ratio of the sum of net income before extraordinary items ("ibq") and depreciation and amortization ("dpq") to the net property, plant, and equipment ("ppentq").
- *Cash*: Ratio of cash and equivalents ("cheq") to total assets ("atq").
- *Sales*: Ratio of net sales ("saleq") to the net property, plant, and equipment ("ppentq").
- *Dividends*: A dummy variable that indicates whether the firm paid any dividends to its common shareholders.
- *CAPEX*: Capital expenditure during the current fiscal quarter scaled by net property, plant, and equipment at the beginning of the quarter (i.e., lagged "ppentq"). Compustat provides the variable "capxy," which denotes the firm's capital expenditure for the year to date. Hence, capital expenditure during the fiscal quarter equals "capxy" for the first fiscal quarter, and "capxy" minus lagged "capxy" for the second, third, and fourth fiscal quarters.
- *Large*: A dummy variable that identifies firms that are in the top quartile by *Size* during the given quarter.
- *Rated*: A dummy variable that identifies firms with a long-term credit rating from S&P.
- *Investment Grade*: A dummy variable that identifies firms with an S&P long-term credit rating of BBB− or better. *Investment Grade* = 0 for firms that are either unrated or whose credit rating is worse than BBB−.
- *Hedging Intensity*: Ratio of the number of barrels of oil hedged and the number of barrels of total oil production. The measure is computed for each fiscal quarter using the data obtained from 10-Q filings of a firm.
- $\rho(TI)$: First-order autocorrelation for pretax earnings of a firm. The measure is computed if we have at least four data points to compute the autocorrelation. For each year, the autocorrelation is computed using an expanding window size; i.e., the number of data points increases as the firm grows older.
- Δ*Net Debt*: Change in net debt (i.e., total debt minus cash and equivalents) from the previous quarter scaled by lagged assets.
- Δ*Debt*: Change in total debt from the previous quarter scaled by lagged assets.
- Δ*Cash*: Change in cash and equivalents from the previous quarter scaled by lagged assets.
- *Profit*: Ratio of earnings before taxes ("piy") to total assets ("atq").
- *No Separate CFO*: A dummy variable that identifies firms that do not have a separate chief financial officer (CFO).

Oil Price and Stock Market Measures

- *Price Uncertainty* and 6-*month Price Uncertainty* denote the model-free risk-neutral volatility at 365-day maturity and 180-day maturity, respectively, estimated using options on crude oil futures.
- *Futures Price*: Price of the crude oil futures contract closest to one-year maturity.
- *Oil Return*: The three-month rate of change in *Futures Price*.
- *S&P*500 *Return*: Three-month return on the S&P 500 Index, adjusted for dividend payout.
- *VIX*: A commonly used proxy for the volatility of the S&P 500 Index, 30 days forward.

Endnotes

[1] To reinforce this point, consider Apache Corporation, which is the largest firm in our sample. In 2012, Apache's annual crude oil production was 129 million barrels (bbl), a small fraction of the total U.S. production of approximately 2.4 billion bbl and minuscule in comparison to the total world production of 27 billion bbl. It is clear from this example that even the largest firm in our sample is unlikely to affect crude oil prices through its investment decisions.

[2] In most other industries, it would be infeasible to create such a measure of hedging intensity because it is not easy to measure risk exposures, and detailed hedging data at the firm level are not readily available. With the exception of a few papers that focus on commodity industries (e.g., see Haushalter 2000, Jin and Jorion 2006, Kumar and Rabinovitch 2013), most papers in the hedging literature measure hedging activity using either hedging dummies and/or the notional value of derivative contracts (e.g., see Purnanandam 2008, Campello et al. 2011).

[3] A larger literature examines the relationship between corporate investment and other forms of uncertainty (i.e., other than output price uncertainty), such as economic policy uncertainty (Baker et al. 2016), option-implied equity volatility (Stein and Stone 2013), and stock market volatility or VIX (Bloom et al. 2007, Bloom 2009).

[4] Campello et al. (2011) and Kumar and Rabinovitch (2013) provide empirical evidence that hedging indeed mitigates financial constraints and lowers borrowing costs.

[5] Gilchrist et al. (2014) provide micro- and macrolevel evidence that increases in uncertainty raise credit spreads, thereby dampening investment. In a model with endogenous costs of default, Kumar and Yerramilli (2017) show that an increase in output price uncertainty raises firms' cost of debt financing.

[6] For example, the trading horizons of the most liquid crude oil futures on the Chicago Mercantile Exchange (CME) and the Intercontinental Exchange (ICE), the two largest platforms for exchange-traded derivatives in oil, do not exceed nine years (and markets are typically quite thin beyond five years). The effective hedging horizons are, therefore, often shorter than the production horizons of oil wells.

[7] We classify a firm as U.S.-based by applying the following criteria. First, we check for U.S. incorporation by verifying that the firm's *FIC* variable in Compustat is set to "USA." Next, we verify that the main stock exchange on which the firm trades (*EXCHG* variable in Compustat) is a U.S. exchange, which corresponds to the condition $11 \leq EXCHG \leq 18$. Finally, we check that the firm's *STATE* is within the United States.

[8] Firms in the O&G sector do not report any research and development (R&D) expenditures. Although they constantly explore for new oil and gas sources, drilling of exploratory wells is classified as capital expenditure and not as an R&D expenditure.

[9] We show that the results are similar if we include all the macroeconomic variables individually, instead of the macro principal components (see panel A of Table IA-1 in the Internet appendix).

[10] To mitigate the effect of outliers, we winsorize all firm financial ratios other than *Leverage* and *Hedging Intensity* at the 1% level in both tails. We winsorize *Leverage* and *Hedging Intensity* at the 1% level in the right tail only.

[11] In unreported tests, we find similar differences between investment-grade firms and non-investment-grade firms (i.e., firms that are either unrated or have an S&P rating worse than BBB−), which is not surprising, given the evidence in this panel that large firms are also significantly more likely to have an investment-grade rating.

[12] To account for the joint determination of capital investment and hedging intensity decisions at the firm level, we also estimate a system of simultaneous equations approach to examine the simultaneous impact of *Price Uncertainty* on *CAPEX* and *Hedging Intensity*. We report these in Table IA-2 of the Internet appendix and show that our qualitative results are unchanged.

[13] Oster (2016) proposes a method to estimate the unbiased treatment effect by examining the changes in the β coefficients and R^2 between an uncontrolled regression specification and a regression specification with a full set of observable control variables. In our setting, an uncontrolled regression with *Price Uncertainty* as the only regressor generates a β of −0.088 with an R^2 of 0.0056. Comparing these numbers with the regression in column (4) with the full set of controls and firm fixed effects, and applying the procedure described in Oster (2016) yields an unbiased coefficient estimate of −0.100 on *Price Uncertainty*. Instead, if we compare against the specification in column (3) of Table 3 without firm fixed effects, then we obtain an unbiased coefficient estimate of −0.091 on *Price Uncertainty*. These estimates provide confirmation that the negative effect of *Price Uncertainty* on *CAPEX* is robust to omitted variable bias.

[14] In unreported tests, we find similar results when we estimate the regression separately for each of the four size quartiles. Specifically, we find that price uncertainty has a significant negative effect on capital expenditure for firms in each of the three bottom size quartiles but no effect for firms in the largest size quartile.

[15] As *Hedging Intensity* is clearly censored below at 0, we verify that our results are robust to a Tobit specification.

[16] Campello et al. (2011) use a similar approach with tax-based instruments to model the endogeneity of firms' hedging decisions. More generally, Graham and Smith (1999) define *Tax Convexity* to denote the tax benefits of hedging (specifically, the tax savings from a 5% reduction in volatility of taxable income) and relate it to firm-specific characteristics such as volatility and serial correlation of taxable income, net operating loss (NOL) carry-forwards, and investment tax credits. We choose to be agnostic about the actual shape of the *Tax Convexity* function in the upstream O&G sector because the coefficient estimates provided in Graham and Smith (1999) to compute *Tax Convexity* are based on regressions on a pooled sample of firm-year observations across all industries. Moreover, we are less confident that the volatility of taxable income satisfies the exclusion restriction with respect to *CAPEX*. Also, none of our sample firms report any investment tax credit on their balance sheets. Therefore, we use only $\rho(TI)$ as an instrument for hedging intensity, although our qualitative results are similar if we use all the explanatory variables in Graham and Smith (1999) as instruments.

[17] We also use a system of simultaneous equations approach to examine the joint effect of price uncertainty on Δ*Net Debt* and *Hedging Intensity*. The results reported in Table IA-3 of the Internet appendix are consistent with the findings in panels A and B of Table 6.

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