Determinants and real effects of joint hedging: An empirical analysis of US oil and gas producers

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Abstract

We study the intensity of joint hedging of oil and gas prices by US petroleum firms. We aim to explain the rationale for and find the determinants of joint hedging, as well as its impact on firm market value, performance, and riskiness. Joint hedging that takes into account the interdependence between risks should have a positive impact on firm value in the presence of multiple risks. We verify this theory in an innovative way, by testing the effects of hedging oil and gas prices simultaneously and by using an instrumental variable framework to attenuate the problem of endogeneity between firm value and risk management. We find evidence of higher market value, higher accounting performance, and lower riskiness for firms with a high propensity to jointly hedge their oil and gas production to a greater extent. We show that joint hedging dominates single-commodity hedging.

Keywords: Joint hedging, enterprise risk management, oil price, gas price, hedging intensity, bivariate probit, causality, firm value.

JEL codes: D81, C13, C23, C25, G23, G32.

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Abstract

We study the intensity of joint hedging of oil and gas prices by US oil and gas producers. We aim to explain the rationale for and find the determinants of joint hedging, as well as its impact on firm value, performance, and riskiness. Joint hedging that takes into account the interdependence between risks should have a positive impact on firm value in the presence of multiple risks. We verify this theory in an innovative way, by testing the effects of hedging oil and gas prices simultaneously and by using an instrumental variable framework to attenuate the problem of endogeneity between firm value and risk management. We find evidence of higher market value, higher accounting performance, and lower riskiness for firms with a high propensity to jointly hedge their oil and gas prices to a greater extent as compared to firms with the lowest hedging intensities. We also show that joint hedging dominates single-commodity hedging.

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Introduction

In the presence of friction in financial markets, risk management theory suggests that hedging may have a positive impact on non-financial firms by reducing cash flow and earnings volatility. Indeed, corporate managers often opt to hedge against different market- and industry-specific factors in the hopes of limiting the cost of risk and, hopefully, obtaining higher firm valuations.

Evidence in the corporate risk management literature suggests that the marginal benefits of hedging the firms' exposures exceed the marginal costs associated with it. Indeed, a study led by Bartram et al. (2009), spanning 48 countries and including over 7,000 non-financial firms, demonstrated that 54.3% of companies use derivatives to hedge against risks ranging from foreign-currency exposure to interest rate uncertainty. This suggests that managers do indeed see the value of hedging.

Firms producing oil and natural gas are intrinsically hedgers because they are subject to the risk of commodity prices, which can experience large drawdowns. Oil and natural gas prices fluctuate significantly in response to factors such as geopolitical instability and supply-and-demand shocks. Sometimes, the most profitable outcome for a firm is to halt production. This real option may have significant economic costs when oil and gas producing firms exercise the option to leave the oil or natural gas in the ground when market conditions are unfavorable. To protect their performance, other firms opt to hedge their production through financial assets to face future price uncertainty. Financial hedging, however, comes at a cost, and thus, corporate risk management must balance the costs and rewards to achieve the greatest firm value.

As such, we observe that oil and gas producers choose different levels of hedging based on discretionary factors such as management risk appetite, economic outlook, forecasted future production, market imperfections, and geographical location. Discrepancies in hedging behaviors have raised important research questions in the literature: What are the determinants of undertaking hedging? How do hedging decisions affect firm value? Which risk necessitates the highest level of hedging to maximize firm value? Should the company hedge in the short or the long run? Which hedging instruments are most appropriate? (Smith and Stulz, 1985; Tufano, 1996; Graham and Smith, 1999; Graham and Rogers, 2002; Carter et al., 2006; Mnasri et al., 2017; Dionne et al., 2018).

We explore a new question by analyzing the joint hedging decision of oil and gas prices in the US oil and gas industry, with quarterly data from 1998 to 2010: should producers hedge the price of both commodities at once, and if so, to what extent? First, we gauge the impact of firms' financial and operational characteristics, their managerial risk aversion, and the petroleum market's conditions on the hedging decisions of oil and gas producers. Second, we revisit the hedging premium issue, in an instrumental variable framework, to determine whether the decision to hedge commodity prices jointly has any causal effect on oil and gas producers. We apply the two-step methodology with a bivariate probit in the first step in order to reduce estimation bias in presence of potential essential heterogeneity between firms (Heckman et al., 2006). Third, we compare joint hedging to single-commodity hedging activities on firms' market value, performance, and risk. To our knowledge, the causal effect of a joint hedging decision on firm value has not yet been studied for any industry.[1]

[1] In short, we use 'firm value' for a firm's market value, performance, and risk; and 'performance' for its accounting performance. We should mention that our approach is suitable for the hedging of two commodity prices and two input prices, or one commodity price and one input price.

Several insights arise out of our study relating to both the determinants and the real implications of the joint decision about hedging intensities for oil and gas commodities. Our results show evidence of market timing in the hedging behavior of the managers of oil and gas producers, namely, a selective hedging behavior, as discussed in the corporate risk management literature, i.e., Adam et al., 2017; Sanda et al., 2013; Brown et al., 2006; Adam and Fernando., 2006. Intriguingly, hedging intensities for both oil and natural gas are simultaneously and oppositely impacted by the current level and the period-to-period variation in real global economic activity. The level and the variations in the real global economy are measured, respectively, by the level and changes in the Kilian Index, which we select as an instrumental variable. The period-to-period variations in the real global economy reflect the near-term market conditions for oil and natural gas; however, the current level of real global economy could indicate the expected long-term market conditions due to the mean-reversion behavior in economic and business cycles. Overall, managers appear to decrease their oil and gas hedging positions when real global economic activity is increasing from one quarter to the next, due to higher spot prices induced by a more vigorous demand for industrial commodities. Conversely, when the real global economy is at a higher level, managers tend to hedge oil and gas to greater extents, due to the expected reversal trend in the economy associated to a mean-reversion behavior. Furthermore, our results show that jointly hedging oil and gas to greater extents enhances the firm market value, increases accounting performance, as measured by the operating return on assets, and reduces the firm's total and specific risks.

Joint hedging may be related to enterprise risk management (ERM), but it is different in nature. Joint hedging is a risk management strategy for different assets or commodities, while ERM is a framework for risk management in an enterprise. Joint hedging can be implemented in a company without an ERM framework. Our test on the efficiency of joint hedging will be conducted without a control for ERM because we do not have this information. We suspect however that firms with an ERM framework would use joint hedging more often.[2]

1. Literature review and motivation

The empirical literature on joint hedging is recent. Liu et al. (2017) analyzed joint hedging in the oil industry and compared two joint hedging criteria: the second-order lower partial moment (LPM_2) approach of Fishburn (1977) and the mean variance (MV) approach. The LPM_2 approach is more closely related to portfolios' downside risk than to the symmetric MV approach. They found that LPM_2 is more effective than MV. They did not compare joint hedging to single-commodity hedging. Power and Vedenov (2010) analyzed joint hedging in the cattlemen hedging environment and found that hedging ratios are lower under the LPM_2 approach. Fei et al. (2021) is the only contribution that compares single hedging to joint hedging. It compares the relative effectiveness of joint hedging to single-commodity hedging, and shows that joint hedging always dominates single-commodity hedging with the LPM_2 measure of risk. The paper does not analyze the effect of joint hedging on firm value.

In this research, we are more concerned with the corporate literature on risk management, in which, to our knowledge, the effectiveness of joint hedging has not been studied. To compare the separate hedging of two commodity prices to the simultaneous hedging of two prices, we estimate multivariate econometric models under different hedging scenarios, and then compare the effect of the predicted probability of jointly hedging oil and gas, to a higher (lower) extent, on firm

[2] On the efficiency of ERM, see Kleffner et al. (2003), Liebenberg and Hoyt (2003), Hoyt and Liebenberg (2011), Eckles et al. (2014), Grace et al. (2014), and the survey of Gatzert and Martin (2015).

market value, performance, and risk. To reduce potential reverse causality between hedging and the different measures of firm value, we use the instrumental variable approach to estimate the equations of the joint decision on hedging intensity made by firms for their production of oil and gas. In this manner, we contribute to the literature on corporate hedging decisions by considering risk management with the hedging of two commodity risks simultaneously.

It is worth mentioning that the preceding theoretical and empirical research on corporate risk management has largely been built on a single-risk exposure environment. However, many non-financial firms have multi-risk exposure due to the nature of their operational activities. For example, natural resource companies producing multiple commodities are exposed to multiple risks, with interconnected market conditions requiring interlinked single-risk hedging strategies with mutual effects. Ignoring the connectedness between hedging decisions in a multi-risk environment, coupled with the endogeneity problem, might have led to contradictory and inconclusive results in the prior research as regards the motivations and real effects of corporate risk management, particularly for some production industries such as the petroleum and gold mining. A multidimensional framework is needed to better assess the joint hedging decisions of firms' managers. Froot et al. (1993) showed how taking into account the dependence between risks affects the optimal hedging decision of internal investment financing. However, they did not analyze the effect of joint hedging on firm value.

In our study, to gain a better understanding of the interactions in the joint decision-making process about hedging intensities for oil and gas, we need to look at the mechanisms that connect these commodities. Oil production ramps up with increased oil prices: since these firms have a real option on the extraction of oil and gas, it allows them to react to macroeconomic price trends by adjusting their production. As a result of increased oil production, gas production can also increase—in this case because the two resources are extracted from the same source in the ground. Thus, as oil production increases, naturally, the amount of gas extracted and produced may also increase as a by-product. To cement this relationship, we also explore the cointegration of oil and gas prices, which has been discussed at length in the literature. In a study focusing on the switching relationship between oil and gas prices, Brigida (2014) underscored the idea of price cointegration between oil and natural gas. We can synthesize both mechanisms as follows: a higher demand for oil, which results in higher oil prices, also increases the production of natural gas due to the associated gas production effect. Then, due to the cointegration of both prices, oil being higher over a long-time horizon means that gas prices also move upward, in tandem. Therefore, these mechanisms help explain why the hedging intensity for gas production decreases with an increased aggregate demand for oil. As oil prices soar, it drives oil production, which also increases gas production.

In the same vein, Jadidzadeh and Serletis (2017) investigated the effects of demand and supply shocks in the global crude oil market on the real price of natural gas in the US, using monthly data over the period 1976–2012 and a structural Vector AutoRegressive model. The authors try to answer the following question: Do natural gas prices in the United States react to crude oil price shocks? In sum, Jadidzadeh and Serletis (2017) showed that close to 45% of the variation in the real price of natural gas can be attributed to structural supply and aggregate demand shocks in the global crude oil market.

In fact, many studies (including Villar and Joutz, 2006; Brown and Yücel, 2008; Hartley et al., 2008; and Hartley and Medlock, 2014) have investigated whether the price of crude oil is an important determinant of the natural gas price. Using mostly cointegration models, these studies have revealed that the oil price largely drives the natural gas price, but that the reverse does not appear to occur, leading to a stable and asymmetric relationship between the two commodity prices. This significant stable relationship between the two series of prices is an additional motivation to analyze the joint decision to hedge both prices simultaneously.

1.1 Rationales for hedging

The main goal of risk management to increase firm value by reducing risk when there are market imperfections. The three main sources of market imperfections are the expected costs of financial distress, agency costs, and expected tax liabilities. Managers' risk behavior and corporate governance problems may also explain risk management.

1.1.1 Expected costs of financial distress

Financial distress can occur when the firm has volatile future cash flows and/or high financial leverage. In such circumstances, the generated cash flows are not sufficient to meet the payment commitments, and the firm may experience financial distress or default. Financial distress costs refer to the costs associated with default, not bankruptcy. These costs can be divided into two categories: direct costs, such as lawyer fees, consulting fees, and court-related expenses; and indirect costs incurred when a firm is under bankruptcy protection laws, such as reorganizational costs. Other indirect costs arise when stakeholders realize that the firm's default is imminent. These indirect costs consist of lost revenues, lost profits, restricted and more costly borrowing, and higher compensation for managers and employees because of the higher probability of unemployment. Both these categories of costs are directly reflected in a firm's valuation. The goal of an efficient risk management strategy is to maintain these expected costs at an optimal level, while taking into consideration the cost of hedging instruments. Smith and Stulz (1985) show that hedging with financial derivatives reduces the expected default costs by reducing the variability of cash flow to the point where default risk is at its minimum, and hence, it increases the current market value of the firm.

1.1.2 Expected tax payments

The tax argument for corporate hedging has been analyzed by Mayers and Smith (1982), Smith and Stulz (1985), and Graham and Smith (1999), among others. This last paper shows that, in the presence of a convex tax function, hedging reduces the variability of pre-tax firm values and reduces the expected corporate tax liability. Moreover, the presence of tax preference items (i.e., tax loss carryforwards, foreign tax credits, and investment tax credits) may extend the convex region. Then, if the cost of the hedge is not too large, corporate risk management increases the expected post-tax firm value.

1.1.3 Agency costs and investment financing

Hedging can enhance firm value through better coordination between investment and financing policies in the presence of market imperfections and particularly asymmetric information between firms and banks. Internally generated cash flows vary significantly; thus, firms may face cash shortages with respect to programmed investment projects. Consequently, the firm is obliged to bypass profitable projects or to raise more costly external funding due to market imperfections.

Myers (1977) showed that firms with outstanding risky debts will pass up positive net-present-value projects when the profits from value-increasing projects are more likely to accrue to bondholders than to shareholders. Mayers and Smith (1982 and 1987) demonstrate that hedging, by financial derivatives or insurance contracts, can alleviate the underinvestment problem by reducing the probability of default and by increasing the states of the world where the shareholders are residual owners of the firm. Froot et al. (1993) point out that, under asymmetric information, the external financial costs of investment are much higher than the internal ones and firms have incentives to risk-manage to coordinate internal funding and planned investments.

Morellec and Smith (2007) provide further insight into the principal-agent problem by showing that the firm's hedging policy is driven not only by the underinvestment problem arising from shareholder–debtholder conflicts but also by the overinvestment problem arising from shareholder–manager conflict. The overinvestment problem is due to the managerial tendency to overinvest because managers derive private benefits from the investment. Their analysis suggests that firms with fewer growth opportunities may be more likely to hedge to control the overinvestment incentives.

1.1.4 Managerial risk aversion

Shareholders hire managers because they have specialized resources that increase the firm's value. However, managers may not maximize the firm's value, and hence the shareholders' wealth, unless given proper incentives. Thus, managerial compensation should be designed in a way that the manager's expected utility depends on the distribution of the firm's payoffs. Knowing that hedging alters the distribution of the firm's value, the manager will make decisions about the hedging policy that meets their own risk preferences, either by hedging or not.

Stulz (1984) derived a theoretical model for optimal hedging policies for a firm facing foreign exchange risk. The model was derived under the assumption that managers maximize their expected lifetime utility. In this same setting, a subsequent seminal work (Smith and Stulz,1985) showed that if the manager's end-of-period utility is a concave function of the end-of-period firm value, then the optimal hedging policy involves completely insulating the firm's value from the underlying risks (if feasible). Accordingly, a manager owning a significant fraction of the firm's shares is likely to hold a well-diversified portfolio and, hence, has more incentive to hedge actively. Moreover, Smith and Stulz (1985) point out that if the manager's end-of-period utility is a convex function of the end-of-period firm value, then the manager has less incentive to eliminate the underlying risks. When the compensation package includes stock options, the manager's expected utility tends to be a convex function of the firm value.

Stulz (1996) acknowledged that firms with heavy managerial shareholding tend to hedge their price exposures more, because price volatility directly affects the manager's wealth. In addition, Stulz (1996) confirmed that one-sided payoffs from stock options motivate the manager to leave the price exposure unhedged, because the reduction in the firm's volatility makes the manager's options worthless.

1.1.5 Corporate governance

Dionne et al. (2019) test the effects of the independence and financial knowledge of directors on risk management and firm value in the gold mining industry. They use a hand collected database on directors' financial education, accounting background, and financial experience that allow them to measure the effect of financial knowledge on risk management activities. They show that directors' financial knowledge increases firm value through the risk management channel. This effect is strengthened by the independence of the directors on the board and on the audit committee. As a policy implication, their results suggest adding the experience and education dimensions to the 2002 Sarbanes–Oxley Act and New York Stock Exchange independence requirements for better governance.

1.2 Real implications of hedging

Mackay and Moeller (2006) contributed to the literature by deriving a model to estimate how valuable corporate risk management is for firms that choose to hedge. As such, they take a keen interest in the oil industry, assembling a sample of 34 oil refiners and regressing firm revenues and costs with input and output prices. The motivation behind this method was to demonstrate that hedging in the presence of non-linear revenues and costs relative to prices can create value for the firm. By accepting the tradeoff of incurring convex costs to hedge concave revenues for oil and gas firms, Mackay and Moeller (2006) obtained an increase in the firm's market value of 4%, using the Tobin's Q measure.

Jin and Jorion (2006) also attempted to shed light on the question by looking at 119 oil and gas producers in the US over a three-year period (1998–2001). The first step in their analysis consists of testing the stock-price and commodity-price sensitivities with respect to hedging intensity. Their results show a negative relationship between a firm's hedging and the market beta. Then, using the Tobin's Q measure, they found no evidence of any value effect of hedging in the oil and gas industry.

Gilje and Taillard (2017) considered the sudden drop of 51.9% in the relative effectiveness of West Texas Intermediate's (WTI) oil-based derivative contracts, used by Canadian light oil producers, during the first quarter of 2012 as an exogenous shock, to implement a quasi-natural experiment to measure the effect of financial hedging on firm value and to evaluate the importance of financial distress and underinvestment as channels through which hedging can affect firms. Their empirical design compares outcomes for Canadian light oil producers (treatment firms) to the otherwise similar US light oil producers (control firms), both before and after the basis risk shock, in a difference-in-differences framework. The authors used a treatment sample of 46 Canadian light oil producers and a control sample of 38 US oil producers, and they used the four quarters from Q1 2011 to Q4 2011 as the pre-event window, and the four quarters after the event from Q2 2012 to Q1 2013 as the post-event window. Overall, the Gilje and Taillard (2017) results reveal that Canadian oil producers, which have higher ex-ante exposure to financial distress (high financial leverage), actively sold assets, cut back on capital expenditures, and reduced debt following the basis risk shock. These findings provide direct empirical evidence that reducing the probability of financial distress and mitigating underinvestment are first-order reasons why firms hedge.

Dionne and Mnasri (2018) reconsidered the effect of hedging on firm value, by applying the marginal treatment effect methodology (MTE) of Carneiro et al. (2009) and Heckman et al. (2006), to better identify the firms with a greater causal effect. Using a sample of US firms in the oil industry, Dionne and Mnasri (2018) found evidence of a higher marginal market value for firms with a higher hedging propensity score. They also found evidence of a higher marginal risk reduction premium and a higher marginal accounting value for the same firms. These oil producers with higher propensity scores to hedge also have significant average treatment effects for firm financial value, idiosyncratic risk, and systematic risk. Finally, Mnasri et al. (2017) verified that non-linear hedging derivatives, such as options, are more efficient to reduce risk and increase firm value, while Dionne et al. (2018) showed that short-run hedging dominates long-run hedging.

Jankensgård and Moursli (2020) revisited the argument by Froot et al. (1993) that corporate hedging supports corporate investment when internal cash flows are volatile and external financing is costly. Using hand-collected data on cash flows from derivative positions in the oil and gas industry between 2000 and 2015, the authors found that, on average, an extra dollar in derivative cash flows translates into one more dollar in capital expenditure. Interestingly, during the industry recessions of 2009 and 2015, the median ratio of derivative cash flows to capital expenditure rose to 20% for hedging firms. These findings suggest that hedging plays a crucial role in sustaining planned investment when the cost of external financing demonstrably goes up.

Ferriani and Veronese (2022) relied on a new, hand-collected, detailed firm-level dataset of over 100 US oil producers between 2007 and 2016 to explore how hedging by oil producers relates to the amount of pledgeable collateral, as proxied by firms' oil net worth. Ferriani and Veronese (2022) found a strong positive link between net worth and hedging in the oil producing sector. These findings are robust to different model specifications as well as to different measures of net worth. Interestingly, the authors also found that firms experiencing larger negative collateral shocks are also the ones reducing their hedging activity to a greater extent.

2. Data and dependent variables: Construction and statistics

2.1 Data construction

The starting sample consists of quarterly data for 150 oil and gas producing firms between 1998 and 2010, amounting to a large panel of 6,326 firm-quarter observations.[3] The 150 firms were filtered with the following criteria: they needed to have a minimum of 5 years of oil and gas reserve data, have 10-K and 10-Q filings available on the EDGAR database, and have data available on Compustat and Bloomberg to provide more information on different variables. Quarterly data

[3] We discuss the robustness of our results with a more recent period of analysis in the Online Appendix.

about oil- and gas-hedging activities were hand-collected from 10-K and 10-Q reports. More details on the construction of this data are available in Mnasri et al. (2017) and Dionne et al. (2018).

2.2 Data description

Table A1, in the Appendix, gives details on the construction of the different variables related to the financial and operational characteristics of our sample firms. Table 1 summarizes the descriptive statistics of our starting pooled dataset of 6,326 firm-quarter observations. The operating gross margin for the 150 firms averages to 0.32, with a median of 0.63. This indicates an asymmetric earnings distribution, with a notably negative skewness. Use of leverage is prevalent in our firms of interest, with an average leverage ratio of 52%. Another interesting observation is the high level of liquidity that these firms have on hand, which translates to a high ability to honor their short-term liabilities, as evidenced by a quick ratio of 1.56, compared to an average quick ratio of 0.3 in 2019 for the oil and gas industry (CSI Market, 2019). More than a quarter of the firms sampled pay a dividend to their shareholders.

Table 1 – Descriptive statistics of the 150 firms' financial and operational characteristics

Variable	Obs	Mean	Median	1st quartile	3rd quartile	STD
Operating gross margin	6,097	0.32	0.63	0.38	0.78	2.60
Investment opportunities	6,295	0.13	0.06	0.04	0.11	2.33
Leverage ratio	6,044	0.52	0.52	0.34	0.66	0.29
Liquidity	6,069	1.56	0.28	0.08	0.85	5.33
Dividend payout	6,326	0.27	0.00	0.00	1.00	0.44
Oil reserves	6,326	277	8.01	0.95	53.35	1,278
Institutional ownership	6,326	0.34	0.22	0.00	0.69	0.35
Geographical diversification of oil production	6,326	0.12	0.00	0.00	0.00	0.27
Geographical diversification of gas production	6,326	0.08	0.00	0.00	0.00	0.23

Oil production risk	6,246	0.27	0.17	.08	0.34	0.30
Gas reserves	6,326	1,504	99	13	571	5,888
Gas production risk	6,222	0.27	0.18	.09	0.36	0.28
CEO ownership	6,028	0.04	0.00	0.00	0.00	0.02
Number of CEO options	6,326	174,386	0.00	0.00	120,000	681,759
Number of analysts	6,326	5.11	2.00	0.00	8.00	6.914
Price_Quantity correlation (oil)	6,228	0.114	0.199	-0.43	0.683	0.599
Price_Quantity correlation (gas)	6,216	0.075	0.056	-0.37	0.555	0.525

This table displays the summary statistics for the 150 firms sampled in the study. We can find the number of observations, the mean, the median, the lower quartile, the upper quartile, and the standard deviation of all relevant variables describing the sample. See Table A1 for further details on the construction of the variables.

This data also highlights important details about oil and gas production and reserves. For instance, oil reserves (including developed and undeveloped) amount to 277 million barrels per firm, while gas reserves amount to 1,504 billion cubic feet per firm. We notice a moderately low concentration of oil and gas activities and geographical diversification (on average), with Herfindahl indices of 0.12 and 0.08 for oil and for gas, respectively. However, the standard deviations of 0.27 and 0.23 indicate a high dispersion in the data in terms of industry concentration.

Finally, it is important to control for the sampled firms' manager characteristics to understand hedging behavior and extent. On average, managers hold 4% of the firms' stocks, and their stock option holdings equate to more than 174,000 units. These variables rely on distinguishing between highly risk-averse managers, who hedge their production to a large extent, and weakly risk-averse managers, with low oil and gas production hedging.

2.3 Hedging activities

Table 2 breaks down the sample of 6,326 firm-quarters into observations with and without gas and/or oil hedging. Oil and gas producers report hedging activities for 3,489 firm-quarters, accounting for almost 55% of the whole dataset. Of these 3,489 firm-quarters, 2,255 report hedging activities for both oil and gas simultaneously: almost 64.63% of the hedging subsample. Firm-quarters with only gas hedging account for 25.27% of the hedging subsample, with 882 observations. Finally, there are 352 firm-quarters with only oil hedging, or 10% of the hedging subsample. Remarkably, this breakdown of the hedging decisions reveals that petroleum companies tend to hedge oil and gas commodities simultaneously. In what follows, we analyze in depth the hedging behavior of the companies and particularly the joint decision about the hedging intensities for both commodities.

Table 2 – Distribution of the hedging decisions by number of firm-quarters

	Hedging activity: Firm-quarters		
	Oil hedgers	Non-oil hedgers	Total
Gas hedgers	2,255	882	3,137
Non-gas hedgers	352	2,837	3,189
Total	2,607	3,719	6,326

This table breaks down the total sample of 6,326 firm-quarters into observations with and without oil hedging and with and without gas hedging.

Next, we construct production-based hedging ratios by instrument[4] and by horizon for both oil and gas separately. Following Haushalter (2000), the oil (gas) hedging ratio for each fiscal year is calculated by dividing the hedged notional quantities by the predicted oil (gas) production quantities. We collect data relative to hedged notional quantities for each fiscal year from the current year to five years ahead. Oil (gas) production quantities are predicted for each fiscal year

[4] Table OA.1 in the Online Appendix reports a breakdown of the different types of derivative instruments used by the oil and gas hedgers in our sample.

based on the daily oil (gas) production realized in the current fiscal year. Subsequently, we calculate aggregated hedging ratios by horizon for oil and gas separately.

Table 3 and Table 4 report descriptive statistics for these hedging ratios by horizon for oil and for gas, respectively. Overall, these two tables indicate an average hedging ratio for the current fiscal year (i.e., HR0) of around 46% (51%) of the oil (gas) expected production. Hedging ratios for subsequent fiscal years are decreasing steadily across horizons in terms of extent and frequency.

Table 3 – Summary statistics for oil hedging ratios by horizon

Hedge ratio	Obs	Mean	Median	1st quartile	3rd quartile	STD
HR0	2587	46.070	44.564	24.315	63.889	27.876
HR1	1723	38.328	36.043	16.437	54.737	27.338
HR2	907	30.848	26.798	9.526	46.392	25.680
HR3	431	27.352	19.946	7.340	43.654	25.777
HR4	185	23.254	14.686	7.215	33.860	24.589
HR5	61	21.887	19.685	4.563	38.933	18.171

This table reports summary statistics for oil hedging ratios (HR) by horizon (from the current fiscal year, HR0, to five fiscal years ahead, HR5).

Table 4 – Summary statistics for gas hedging ratios by horizon

Hedge ratio	Obs	Mean	Median	1st quartile	3rd quartile	STD
HR0	3108	50.874	48.955	27.557	70.809	29.963
HR1	2295	37.617	30.912	14.441	54.947	29.416
HR2	1225	27.467	19.402	5.983	41.129	28.059
HR3	548	22.101	11.581	4.021	31.144	27.150
HR4	266	17.975	7.590	2.611	17.804	27.099
HR5	127	18.648	5.916	3.280	21.753	26.030

This table reports summary statistics for gas hedging ratios (HR) by horizon (from the current fiscal year, HR0, to five fiscal years ahead, HR5).

2.4 Dependent variables

Based on the hedging ratio for the current fiscal year, i.e., HR0, we construct binary variables to distinguish between firms that hedge to either greater or lesser extents. So, we assign a value of 0 for firms that rank below the 25th percentile in terms of the extent of their hedging for the current fiscal year (HR0) for oil and gas, respectively (low-hedging firms). Similarly, we assign a value of 1 to firms that rank above the 75th percentile of the sample in terms of hedging for oil and gas, respectively (high-hedging firms). These percentiles are chosen because they are wide and categorical enough to allow us to quantifiably distinguish between firms that hedge their oil or gas production to either a small or large extent. This helps us emphasize their defining characteristics. Also, by focusing on these two tranches, we reduce noise by filtering out firms that do not have a definitive stance (low or high) on hedging. These binary variables are used subsequently in a bivariate probit methodology with an instrumental variable. They help to reduce estimation bias in presence of essential heterogeneity between firms (Heckman et al, 2006).

We excluded firms that do not have any hedging activity, to retain consistency when assigning the low-hedging label to firms; it implies some level of positive hedging. Firms at zero hedging are very different from those at a small level of hedging. This discontinuity with a mass point at zero is still an open research question in the literature.

2.5 Univariate results

Table 5 reports tests for differences between the means and medians of the relevant firms' financial and operational characteristics by oil hedging intensity, as constructed previously, namely, the dummy variable measuring high or low oil-hedging intensity. Table 6 reports the same tests by gas hedging intensity. The means are compared by using a *t*-test assuming unequal variances; the medians are compared with a non-parametric Wilcoxon rank-sum Z-test.

The univariate analysis reveals considerable differences in the firms' characteristics relative to their hedging intensities. Tables 5 and 6 show that oil and gas producers with high-intensity hedging appear to have higher investment opportunities and higher financial constraints, that is to say, they have higher financial leverage, have lower cash reserves, and pay less dividends. These findings corroborate the conjecture that a financially constrained firm with high investment opportunities hedges more to avoid the underinvestment problem, as postulated by Mayers and Smith (1982) and Froot et al. (1993). Univariate results also show that oil and gas producers that hedge to a greater extent are less diversified geographically, have lower oil and gas reserves, and have higher production uncertainty. Moreover, the price-quantity correlation appears to be positively related to high-intensity hedging. These findings suggest that petroleum companies tend to hedge more when they have lower operational flexibility, as proxied by geographical diversification; higher additional unhedgeable risk, as measured by production uncertainty; and revenue volatility, because quantities and prices are moving in the same direction.

As regards managerial stockholding, the results are inconclusive. In fact, the mean and median comparison are not consistent across intensities of oil and gas hedging. Even though results show that managerial stockholding is, on average, higher for oil producers using high-intensity oil hedging, as was suggested by Smith and Stulz (1985) and Tufano (1996), the opposite appears to be the case for gas hedging intensities. The median comparison indicates that managerial option holding is greater for low-intensity hedgers, for both oil and gas, suggesting that risk-averse managers with higher option holdings will prefer less hedging, to increase the volatility of the firm's revenues due to the convexity of the options' payoff. This finding is in line with the conjecture made by Smith and Stulz (1985) and Tufano (1996), depending on the moneyness of the option contracts. Univariate tests also show that institutional ownership and the number of analysts are lower for users of higher hedge intensities, for oil and gas, indicating that petroleum firms tend to hedge more to lessen problems related to weak governance and information asymmetry. Finally, results indicate that petroleum firms are induced to hedge more when oil and gas price volatility is higher.

Table 5 – Firm's financial and operational characteristics by oil hedging intensity

	(1) High intensity			(2) Low intensity			(1) vs (2)
Variable	Obs	Mean	Median	Obs	Mean	Median	*t*-Stat Z-score
Operating gross margin	640	0.667	0.679	647	0.476	0.688	-0.938 0.175
Investment opportunities	635	0.099	0.062	647	0.079	0.059	-2.264** -0.430
Leverage	633	0.654	0.621	647	0.547	0.531	-8.593*** -10.338***
Liquidity	637	0.334	0.104	647	0.485	0.213	2.296** 8.021***
Dividend payout	647	0.279	0.000	647	0.518	1.000	9.006*** 8.740***
Oil reserves (in log)	647	3.488	3.457	647	4.106	4.287	6.198*** 5.405***
Institutional ownership	647	0.475	0.517	647	0.578	0.723	5.717*** 5.195***
Geographic diversification (oil)	647	0.048	0.000	647	0.225	0.000	13.770*** 12.409***
Oil production risk	647	0.259	0.167	647	0.197	0.138	-4.691*** -3.695***
Price_quantity correlation (oil)	647	0.177	0.282	647	0.097	0.165	-2.4563** -1.970**
Oil price volatility	646	4.031	2.808	647	3.554	2.674	-2.676*** -3.467***
Oil price basis	646	-0.007	0.008	647	-0.006	0.008	0.4532

							0.632
CEO % of stockholding	632	0.007	0.000	645	0.003	0.001	-2.282**
							2.825***
CEO number of options (×10000)	647	29.909	0.000	647	20.524	6.000	-1.553
							4.188***
Number of analysts	647	6.599	4.000	647	10.629	9.000	9.298***
							9.089***

This table reports the univariate analysis for the firm's financial and operational characteristics, and the condition of the oil market, by oil hedging intensity, i.e., high versus low intensity. See Table A1 for further details on the construction of the independent variables. The means (mean low – mean high) are compared by using a *t*-test assuming unequal variances; the medians (median low – median high) are compared by using a non-parametric Wilcoxon rank-sum Z-test.

Table 6 – Firm's financial and operational characteristics by gas hedging intensity

	(1)			(2)			(1) vs (2)
	High intensity			Low intensity			
Variables	Obs	Mean	Median	Obs	Mean	Median	*t*-Stat Z-score
Operating gross margin	769	0.441	0.654	776	0.506	0.714	0.363
							4.111***
Investment opportunities	775	0.106	0.062	777	0.088	0.059	-1.381
							0.001
Leverage	764	0.607	0.583	773	0.596	0.554	-0.906
							-2.362**
Liquidity	769	0.353	0.109	776	0.414	0.176	1.597
							5.527***
Dividend payout	777	0.295	0.000	777	0.480	0.000	7.633***
							7.496***
Gas reserves (in log)	777	5.693	5.812	774	6.339	6.179	7.334***
							12.746***
Institutional ownership	777	0.420	0.369	777	0.548	0.674	7.509***
							6.969***
Geographic diversification (gas)	777	0.013	0.000	777	0.110	0.000	12.827***
							9.787***
Gas production risk	777	0.263	0.183	777	0.200	0.141	-5.395***
							-4.856***
Price_quantity correlation (gas)	777	0.108	0.069	777	0.084	0.108	-0.943
							2.362**
Gas price volatility	776	0.806	0.543	777	0.715	0.468	-3.216***
							-11.223***
Gas price basis	776	0.154	0.125	777	0.112	0.094	-4.602***
							-6.343***
CEO % of stockholding	759	0.003	0.000	774	0.005	0.000	3.825***
							4.785***
CEO number of options (×10000)	777	15.264	0.000	777	26.721	4.373	3.166***
							5.327***
Number of analysts	777	6.651	4.000	777	9.651	8.000	7.829***

	8.060***

This table reports the univariate analysis for the firm's financial and operational characteristics, and the condition of the gas market, by gas hedging intensity: high versus low intensity. See Table A1 for further details on the construction of the independent variables. The means (mean low – mean high) are compared by using a *t*-test assuming unequal variances; the medians (median low – median high) are compared by using a non-parametric Wilcoxon rank-sum Z-test.

3. Joint decision-making about hedging intensity for oil and gas production

In this section, we focus our analysis on the joint decision about hedging intensities for oil and gas commodities. We retain a final subsample of 614 firm-quarter observations with a high or low simultaneous hedging intensity for oil and gas. Table 7 gives a breakdown of these hedging intensities and shows that oil and gas producers hedge both commodities to the same extent. In fact, a high joint hedging intensity for both commodities occurs in almost 41% of the firm-quarters, and a low joint hedging intensity is seen in 42% of the observations; different hedging intensities arise in almost 175 of the cases. Table 8 reports tests of differences between the means and medians of the final subsample for the regression analysis: 251 observations for high (1,1) and 258 observations for low (0,0), with few exceptions. The results are like those in Table 5 and Table 6, confirming the representativeness of the studied sample. Table OA.6 presents the statistics of firms with intermediate hedging intensity, namely, firms that are not designated to have either high or low joint hedging for both commodities. Table OA.6 shows significant differences, in terms of operational and financial characteristics, between intermediate hedgers and high or low hedgers.

Table 7 – Hedging intensity breakdown

	Oil hedging intensity		
Gas hedging intensity	High	Low	Total
High	251	54	305
Low	51	258	309
Total	302	312	614

This table breaks down the total subsample of 614 firm-quarters into observations with simultaneously high- or low-hedging intensity for oil and gas. High and low intensity are defined by the extent of hedging for the current fiscal year HR0. High intensity is above the 75th percentile of HR0, and low intensity is below the 25th percentile of HR0.

Table 8 – Financial and operational characteristics of firms with high and low joint hedging intensity

	(1) High intensity			(2) Low intensity			(1) vs (2)
Variables	Obs	Mean	Median	Obs	Mean	Median	*t*-Stat Z-score
Operating gross margin	246	0.963	0.687	258	0.579	0.724	-0.742 1.402
Investment opportunities	251	0.100	0.059	258	0.082	0.056	-0.973 -0.036
Leverage	244	0.636	0.603	258	0.564	0.533	-4.040*** -4.874***
Liquidity	247	0.218	0.087	258	0.477	0.223	4.563*** 6.494***
Dividend payout	251	0.382	0.000	258	0.628	1.000	5.700*** 5.532***
Institutional ownership	251	0.440	0.413	258	0.610	0.756	6.144*** 5.792***
CEO % of stockholding	242	0.002	0.000	256	0.003	0.000	2.128** 2.451**
CEO number of options (×10000)	251	18.261	0.000	258	24.926	4.000	0.777 2.422**
Number of analysts	251	6.984	4.000	258	13.407	13.000	8.763*** 8.265***
Oil reserves (in log)	251	3.300	3.346	258	4.752	4.908	9.325*** 8.701***
Gas reserves (in log)	251	5.923	5.828	258	6.989	7.509	7.376*** 6.743***
Geographic diversification (oil)	251	0.059	0.000	258	0.284	0.235	10.823*** 9.466***
Geographic diversification (gas)	251	0.019	0.000	258	0.179	0.000	10.329*** 9.508***
Oil production risk	251	0.298	0.199	258	0.184	0.130	-4.979*** -4.542***
Gas production risk	251	0.308	0.209	258	0.172	0.116	-6.381*** -6.770***

Price_quantity correlation (oil)	251	0.182	0.276	258	0.256	0.407	1.522 2.176**
Price_quantity correlation (gas)	251	0.164	0.192	258	0.069	0.057	-2.089** -1.844*
Oil price volatility	250	4.885	3.471	258	3.093	2.445	-6.266*** -6.601***
Gas price volatility	250	0.884	0.810	258	0.722	0.500	-3.267** -3.868***
Oil price basis	250	0.000	0.009	258	-0.016	-0.011	-2.669*** -2.064**
Gas price basis	250	0.136	0.094	258	0.125	0.094	-0.714 -0.219

This table reports the univariate analysis for the firm's financial and operational characteristics with high and low joint hedging intensity. See Table A1 for further details on the construction of the independent variables. The means (mean low – mean high) are compared by using a *t*-test assuming unequal variances; the medians (median low – median high) are compared by using a non-parametric Wilcoxon rank-sum Z-test.

3.1 Bivariate probit model

Firms producing both oil and natural gas are faced with the added challenge of needing to consider their hedging strategy for two commodities simultaneously. Indeed, firms only have limited resources to hedge their oil and gas production, and thus, must consider several factors before choosing whether or not to hedge. Some of these include the risk factors producers face.

By analyzing the hedging of both oil and gas simultaneously, we will gain a better understanding of the determinants for this hedging allocation. Thus, we will take the analysis further by studying this unique feature of oil and gas companies (as opposed to a single commodity). We will be using the bivariate probit model, which is a joint model for two binary outcomes that generalizes the index function model, from one latent variable to two latent variables, which may be correlated (Cameron and Trivedi, 2005).

Before we delve into the results of our analysis, we succinctly present this estimation method. A bivariate probit uses the same basic tenets in its construction as a univariate probit, but the difference, as the name implies, is that, in the regression model, we have two dependent variables (Y_1 and Y_2), which are simultaneously and jointly a function of the regressors.

Thus, due to the binary nature of the dependent variables, and the joint regression function, we have four different outcomes to analyze:

- Firms that hedge at a low intensity for both oil (Y_1) and gas (Y_2):

  ($Y_1 = 0$ and $Y_2 = 0$);

- Firms that hedge at a high intensity for both oil and gas:

  ($Y_1 = 1$ and $Y_2 = 1$);

- Firms that hedge at a high intensity for oil but a low intensity for gas:

  ($Y_1 = 1$ and $Y_2 = 0$);

- Firms that hedge at a low intensity for oil but a high intensity for gas:

  ($Y_1 = 0$ and $Y_2 = 1$).

The bivariate probit regression is the appropriate method in this instance because it will allow us to model the effects of the explanatory variables on the decision to hedge both oil and gas production, jointly and concurrently. Also, this model will help address any potential endogeneity between the decisions to hedge oil and gas, by accounting for correlations and relationships of unobserved terms and residuals.

For the unobserved latent variables Y_1^* and Y_2^* we specify the following equations:

$$Y_1^* = X_1^{'}\beta_1 + \varepsilon_1$$

$$Y_2^* = X_2^{'}\beta_2 + \varepsilon_2 \tag{1}$$

where X_1 and X_2 are vectors of explanatory variables.

The random disturbances ε_1 and ε_2 are jointly normal with mean zero, variance one, and correlation denoted as ρ:

$$\begin{Bmatrix} \varepsilon_1 \\ \varepsilon_2 \end{Bmatrix} \Big| X_1, X_2 \Big\} \sim N \begin{bmatrix} 0 \\ 0 \end{bmatrix} \begin{pmatrix} 1 & \rho \\ \rho & 1 \end{pmatrix}. \tag{2}$$

Thus, our observed dichotomous variables, denoted as Y_1 and Y_2, are specified using the latent variables as follows:

$$Y_1 = \begin{cases} 1 \; for \; Y_1^* > 0 \\ 0 \; otherwise \end{cases}$$

$$Y_2 = \begin{cases} 1 \; for \; Y_2^* > 0 \\ 0 \; otherwise. \end{cases}, \tag{3}$$

Finally, the probabilities for the different possible outcomes could be summarized for $i, j = 0$ or 1:

$$P(y_1 = i, y_2 = j) = \Phi\left(X_1'\beta_1, X_2'\beta_2, \rho\right) \tag{4}$$

where Φ is the joint normal distribution.

To estimate the bivariate probit coefficients, the maximum-likelihood estimation method is applied to obtain the model parameters. Using the latent variables described earlier, and our postulated equations, we can write the likelihood function as

$$L = \Pi \begin{Bmatrix} P\left(\varepsilon_1 > -X_1'\beta_1, \varepsilon_2 > -X_2'\beta_2\right) + P\left(\varepsilon_1 < -X_1'\beta_1, \varepsilon_2 > -X_2'\beta_2\right) \\ +P\left(\varepsilon_1 > -X_1'\beta_1, \varepsilon_2 < -X_2'\beta_2\right) + P\left(\varepsilon_1 < -X_1'\beta_1, \varepsilon_2 < -X_2'\beta_2\right) \end{Bmatrix}. \tag{5}$$

We then maximize the log-likelihood function to find the estimators for our bivariate probit regression coefficients.[5]

[5] We apply the biprobit function in Stata to estimate the bivariate model with seemingly unrelated regressions.

$$\ln L = \sum \left\{ \begin{matrix} ln\ \Phi(X_1'\beta_1, X_2'\beta_2, \rho) + ln\ \Phi(-X_1'\beta_1, X_2'\beta_2, -\rho) \\ +ln\ \Phi(X_1'\beta_1, -X_2'\beta_2, -\rho) + ln\ \Phi(-X_1'\beta_1, -X_2'\beta_2, \rho) \end{matrix} \right\}. \tag{6}$$

3.2 Instrumental variables

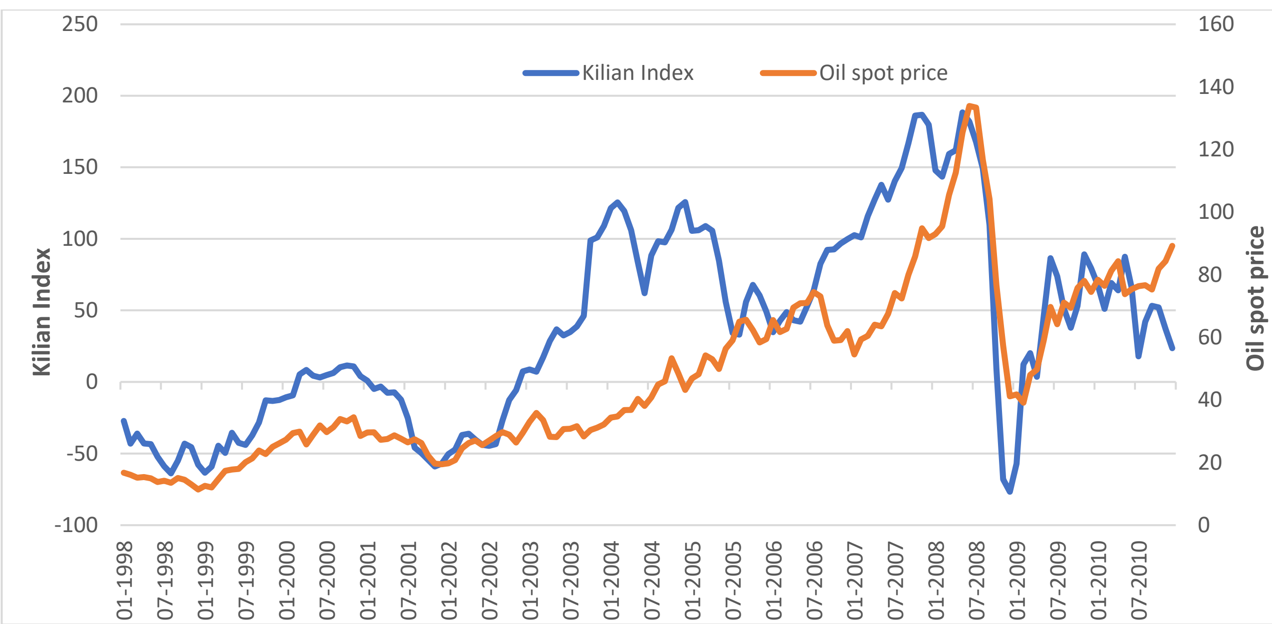
Measuring global real economic activity plays a crucial role in determining the aggregate demand for commodities. Energy commodities (namely, oil and gas) are even closely tied to the aggregate economic demand, due to the increasing globalization of commerce and the need to ship goods around the world. Kilian (2009) proposed the Kilian index as a non-lagging index of real economic activity, which approximates the average shipping costs.

The freight and shipping industry is strongly dictated by the supply of and demand for commodities. Indeed, if the aggregate demand experiences a surge, we can expect that shipping services will also experience a surge (and vice versa). Supply-and-demand pressures will also push shipping prices upward or downward. However, with advances in shipping technology and capacity, the supply line is driven outward, thereby decreasing prices. Since technology and capacity have continued to advance in recent years, as outlined by Hamilton (2019), real prices have declined constantly. Now, taking the growth of the GDP, the increase in shipping capacity, and advances in technology as trending over time, we can analyze the residuals from a time series regression of the real shipping costs as a proxy for the cyclicity of real economic output.

For our purposes, we choose the level and the change (i.e., the first difference) in the Kilian index as our two instrumental variables. We use the level of the Kilian index to discover the long-run relationship between real economic activity and the hedging intensity for the expected oil and gas production. By contrast, the change in the Kilian index makes it possible to grasp the effects of an instantaneous change in the real economic activity on hedging intensity, that is, the short-run relationship between hedging intensities and period-to-period fluctuations in real economic activity.[6]

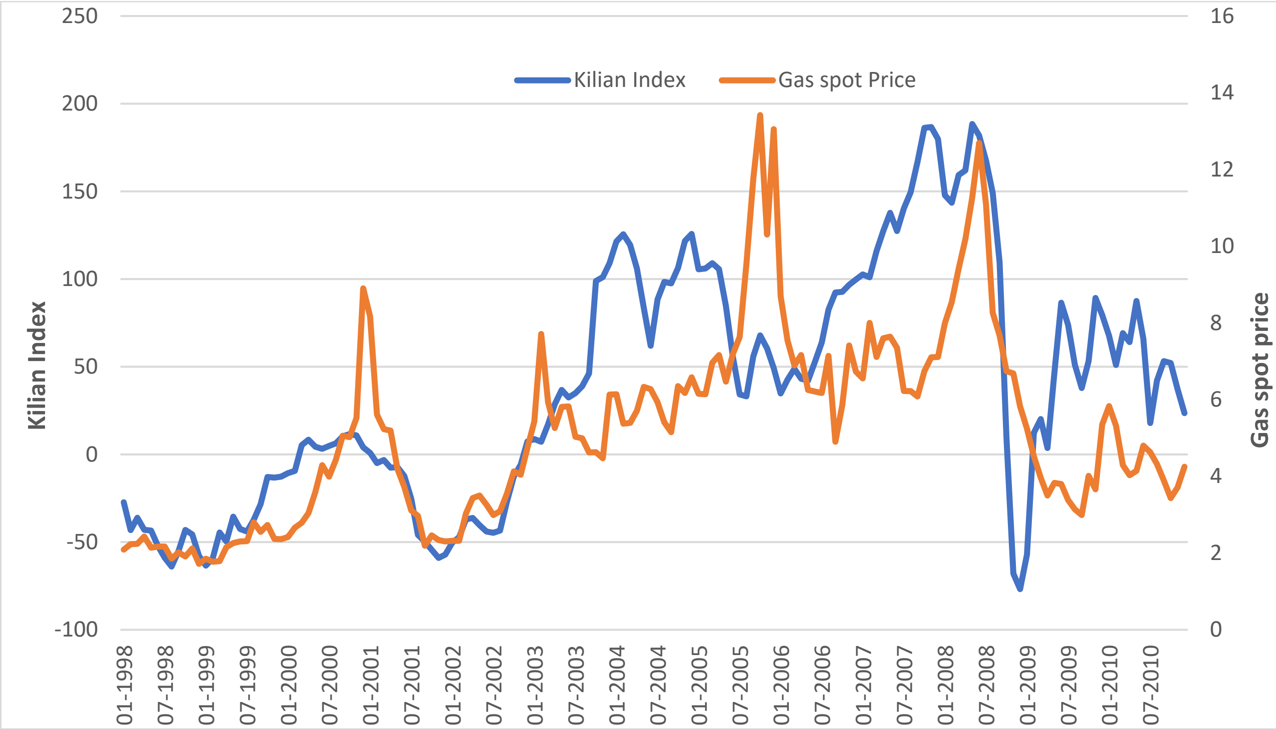
During our sample period, and on a monthly basis, the Kilian index has a correlation of about 76% with both the West Texas Intermediate (WTI) oil spot price and the NYMEX near-month crude oil futures price, and around 68% with both the Henry Hub Natural Gas spot price and the NYMEX near-month natural gas futures price. Figures 1 and 2 graphically show the temporal evolution of the Kilian index and the oil and gas spot prices. Overall, the resulting high-correlation coefficients reflect the high predictive power of the Kilian index for the prevalent spot prices and near-term future prices for crude oil and natural gas. Thus, the evolution of the Kilian index gives a clear vision of the oil and gas market and hedging conditions.

Figure 1: Kilian index versus the Cushing, OK WTI Spot Price ($/Barrel)



[6] We calculate the correlation between the Kilian index and its changes to verify the existence of any possible multicollinearity problem. This correlation appears to be relatively low, at around 12.5%.

Figure 2: Kilian index versus the Henry Hub Natural Gas spot price ($/Million Btu)



Our two instruments may capture the dynamic effects of market conditions on corporate hedging behavior. First, the current effect is induced by the actual (period-to-period) trend in real economic activity and is reflected by the change in the Kilian index. The second effect is more related to the expected turnaround or reversal of the trend in real economic activity, knowing its current magnitude, as illustrated by the level of the Kilian index. For example, we can have an actual increase from one quarter to the next but for a currently weak real economic activity, as reflected by a lower Kilian index. On the other hand, the real economic activity can decrease from one quarter to another while currently being at its highest level. These two dynamic effects could be concomitant or opposite, depending on how the firm's manager perceives them.

How the manager perceives and reacts to the current and expected market conditions, proxied by our two instruments, is sometimes referred to as selective hedging, active risk management, or manager market views, in the corporate risk management literature (Stulz, 1996). In fact, managers alter the timing and size of their derivative positions based on their market views. Alternatively, the period-to-period fluctuations in real economic activity, as proxied by the changes in the Kilian index, influence managers' near-term market views; and the level of real economic activity, as proxied by the level of the Kilian index, will impact long-term market views.[7]

4. Bivariate probit regression results

The results of the bivariate probit in Table 9 offer significant insight into the joint decision on a hedging intensity made by firms for their oil and gas production. First, we start by analyzing some statistics related to the estimation of the bivariate probit model, as given in the lower part of Table 9. These statistics reveal that the correlation coefficient of the residuals, i.e., rho, from the estimation of the two equations, is about 0.79, which is indeed highly statistically significant, as indicated by the *p*-value of the Wald test, suggesting that the bivariate probit model is more appropriate than the estimation of two separate univariate probit models. Moreover, the lower panel of Table 9 gives two additional log-likelihood values: the first corresponds to running the univariate probit model for the first equation (i.e., oil hedging intensity), and the second corresponds to running the univariate probit for the second model (i.e., gas hedging intensity). The joint log-likelihood is just the sum of these two log-likelihoods of the separate probits, and is given by the comparison log likelihood in the lower panel of Table 9. The comparison between the log-likelihoods indicates that the bivariate probit model fits the data better than the separate probits.

[7] Brown et al. (2006) examined the importance of managerial views by directly surveying managers about their risk management practices, and they found that managers' market views have a significant effect on hedge ratios for many firms. More importantly, the two most important factors impacting the hedge ratios are a long-term market view on gold prices and a near-term market view on gold prices.

Importantly, results concerning our two instrumental variables, namely, the level and the change in the Kilian index, as described above, show a negative and statistically highly significant coefficient for the change in the level index for both dependent dummy variables. This result suggests that oil and gas producers tend to jointly decrease the extent of their oil and gas hedging when real economic activity is increasing from period to period. In fact, increasing real economic activity induces a more vigorous demand for industrial commodities, and more specifically for crude oil and natural gas, and thus leads to higher current spot prices. Consequently, oil and gas producers have less need to hedge for the nearest-term when real economic activity is increasing in the short-run from period to period.

Intriguingly, our second instrument, the level of the Kilian index, has a positive and statistically significant coefficient. This suggests that when real economic activity is at its highest levels, petroleum companies tend to hedge their expected oil and gas production to a greater extent. At first glance, this seems counterintuitive. However, upon deeper scrutiny of the temporal evolution of the long-run Kilian index and the oil and gas spot prices, we can find plausible explanations. We estimate the stochastic diffusion processes for oil and gas prices, which appear to be mean-reverting.[8] The estimation reveals a long-run mean of \$43/barrel for WTI, with a daily volatility of \$1.70 and an average daily mean-reversion speed of about 1.55/1000, resulting in a half-life of

[8] We estimate the following simple discrete-time model of a mean-reverting process: $X_{t+1} = X_t + \kappa(\mu - X_t) + \varepsilon_{t+1}$, where X_t is the current value of the process at time t, μ is the long-run mean of the process, κ is the adjustment coefficient, and $\varepsilon_{t+1} \sim \mathbb{N}(0, \sigma_\varepsilon^2)$ is a random shock independent of X_t. This is just like estimating the following regression: $X_{t+1} - X_t = \kappa\mu - \kappa X_t + \varepsilon_{t+1}$. If the estimated slope coefficient $-\hat{\kappa}$ is positive, there is no mean-reversion. If $-\hat{\kappa}$ is negative, then $\hat{\kappa}$ is positive, indicating the presence of a mean-reversion process, conditional on its statistical significance. The estimation is done using daily spot prices for WTI crude oil and Henry Hub Natural Gas, as extracted from the US Energy Information Agency website. WTI crude oil daily prices are from January 1986 to April 2022, and Henry Hub Natural Gas daily prices are from January 1997 to April 2022. Estimations are available upon request. We repeat the same estimations during our sample period (1998–2010) and find evidence of the mean-reversion process for oil and gas spot prices. We also do the estimation using monthly observations and find similar results, however with a lower statistical significance for the WTI crude oil spot price.

445 days, i.e., the time to travel halfway from the current level to equilibrium (without accounting for daily volatility). The Henry Hub Natural Gas has a long-run mean of $4.31/MMBtu, with a daily volatility of $0.40 and an average daily mean-reversion speed of 1.53/100, giving it a half-life of 45 days without accounting for daily volatility.

Consequently, the positive significant coefficient for the level of the Kilian index could be explained by firm managers' selective hedging behavior. In fact, when oil and gas spot prices are highly induced by the higher real economic activity, firm managers have a bearish long-term market view, due to the mean-reverting behavior of spot prices, and they are inclined to hedge to a greater extent. On the other hand, when oil and gas spot prices are low, due to slower real economic activity, firm managers have a bullish long-term market view and hedge to a lesser extent. Brown et al. (2006) similarly found that, for the gold-mining industry, changes in hedge ratios are positively associated with changes in gold prices, suggesting that gold producers hedge more when gold prices increase and hedge less when gold prices decrease. Brown et al. (2006) mention that such a hedging strategy (i.e., selective hedging) could earn excess returns when gold prices are mean-reverting, and they found some evidence that gold prices do mean-revert, albeit very slowly during the 1978-1998 period.

Liquidity, the next variable of interest, has a negative and significant coefficient. This result suggests that the joint hedging intensity for oil and gas production tends to increase when liquidity reserves decrease. Thus, firms with a liquidity constraint prefer to hedge more because they are more exposed to a potential risk event, elevating their expected distress costs and prompting them to intensify their hedging activities. The coefficients for the geographical diversification of oil and of gas are negative and significant at the 10% and 1% threshold, respectively. This result suggests that geographical diversification is a determining factor considered by energy firms when making the joint decision to hedge their oil and their gas production. In fact, firms' propensity to hedge decreases as their production of oil and gas is more geographically diversified. An interpretation of this tendency is that a firm's overall hedging strategy relies on how geographically diverse their production is, because this diversification reduces firms' risk, making them less sensitive to price shocks, whereas firms whose production is geographically concentrated, which is inherently riskier, tend to hedge more to reduce their risk profile. Table 9 also shows that petroleum companies with a higher gas-production risk tend to increase the hedging intensity of their expected gas production more, probably to stabilize generated cash flows when produced gas quantities are more volatile.

Lastly and interestingly, the number of analysts following the firm is significantly negatively related to hedging intensity. Thus, it appears that firms with lower information asymmetry, due to higher analyst coverage, have less need to pursue aggressive hedging strategies. A managerial explanation was advanced by Breeden and Viswanathan (2016) and DeMarzo and Duffie (1991), who postulated that managers are inclined to engage in risk management to better communicate their skills to the labor market.

Table 9 – Bivariate probit regression for oil and gas hedging intensity

	(1)	(2)
Variable	Oil hedging intensity	Gas hedging intensity
Change in the Kilian index	-0.0052***	-0.0049***
	(0.001)	(0.001)
Level of the Kilian index	0.0063***	0.0051***
	(0.002)	(0.002)
Operating gross margin	0.0919	-0.0012
	(0.072)	(0.010)
Investment opportunities	0.4907	0.2361
	(0.463)	(0.290)

Variable	(1) Oil hedging intensity	(2) Gas hedging intensity
Leverage ratio	0.4209	-0.1180
	(0.538)	(0.530)
Liquidity ratio	-0.6590***	-0.7057***
	(0.250)	(0.213)
Dividend payout	-0.1830	-0.1292
	(0.273)	(0.286)
Oil (Gas) reserves (in log)	0.0871	0.2372*
	(0.067)	(0.128)
Institutional ownership	-0.3453	-0.4280
	(0.385)	(0.448)
Oil (Gas) geo diversification	-0.8085*	-2.4906***
	(0.456)	(0.821)
Oil (Gas) price volatility	0.0114	-0.1179
	(0.023)	(0.117)
Oil (Gas) basis	0.5870	-0.0968
	(1.131)	(0.319)
Oil (Gas) production risk	0.1186	0.8183**
	(0.444)	(0.377)
Price_Quantity correlation (oil/Gas)	0.0684	-0.0974
	(0.170)	(0.165)
CEO ownership	4.4636	-16.3198
	(15.885)	(18.169)
Number of CEO's options	0.0015	0.0017
	(0.002)	(0.002)
Number of analysts	-0.0561***	-0.0672***
	(0.021)	(0.023)
Constant	-0.0525	-0.4429
	(0.446)	(0.749)
Observations	578	
Log likelihood	-532.8504	
Number of firms	79	
Wald chi2	159.4170	
Significance	0.0000	
Rho	0.7919	
p-value of the Wald test of rho=0	0.0000	
Log likelihood for the first equation	-303.1192	
Log likelihood for the second equation	-293.5551	

	(1)	(2)
Variable	Oil hedging intensity	Gas hedging intensity
The comparison log likelihood	-596.6743	

This table shows the results of the seemingly unrelated bivariate probit regressions, which test the firms' *joint* decision about the extent of their hedging oil and gas production. Both dependent variables, oil hedging intensity and gas hedging intensity, are dummy variables taking the value of 1 for a high extent, i.e., higher than or equal to the 75th percentile, and taking the value of 0 for a low extent, i.e., equal to or lower than the 25th percentile. These percentiles are calculated based on HR0: the hedging ratio for the current fiscal year. The level and changes in the Kilian index are our two instrumental variables. Control variables related to the firm's financial and operational characteristics are included in lagged values (first lag). See Table A1 for further details on the construction of the control variables. Heteroskedasticity-consistent standard errors clustered at the firm level are reported in parentheses. The superscripts ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

The previous estimation of the bivariate probit helps to get predictions of conditional probabilities for hedging oil and gas at low or high intensities, as described below.

p00: determines the predicted probability that a firm in the sample has both a low hedging intensity for its oil production and a low hedging intensity for its natural gas production. We can denote this probability as follows:

$$Pr\left(y_{1j} = 0, y_{2j} = 0\right). \tag{7}$$

p11: determines the predicted probability that a firm in the sample has both a high hedging intensity for its oil production and a high hedging intensity for its natural gas production:

$$Pr\left(y_{1j} = 1, y_{2j} = 1\right). \tag{8}$$

p10: determines the predicted probability that a firm in the sample has a high hedging intensity for its oil production while having a low hedging intensity for its natural gas production:

$$Pr\left(y_{1j} = 1, y_{2j} = 0\right). \tag{9}$$

p01: determines the predicted probability that a firm in the sample has a low hedging intensity for its oil production while having a high hedging intensity for its natural gas production:

$$Pr(y_{1j} = 0, y_{2j} = 1). \tag{10}$$

These predicted probabilities will be employed to analyze the real effects of joint price hedging on firm value.

5. Real effects of joint price hedging

5.1 Estimation methodology

To estimate the real effects of the joint hedging of oil and gas, we regress various metrics related to firm market value, risk, and performance (dependent variables) on the predicted probabilities of hedging intensities (low versus high) for oil and gas, given by the bivariate probit estimation discussed in Section 4. Control variables pertaining to the firm's financial and operational characteristics and to oil and gas market conditions are included. The firm's market value is proxied by Tobin's Q (in log), measured by the ratio of the sum of the company's market value of equity, book value of debt, and book value of preferred shares to the book value of its assets. The firm's performance is proxied by i) the return on equity (ROE) and ii) the operating return on assets measured by the ratio of the quarterly EBIT scaled by total assets at the beginning of the quarter. The firm's risk profile is proxied using different variables: i) The firm's total risk is measured by the standard deviation of daily stock returns during each quarter. ii) The firm's systematic risk (i.e., market beta) measures the stock returns' sensitivity to the CRSP value-weighted portfolio estimated using the four factors of Fama and French (1993) and Carhart (1997) and the daily returns on the near-month WTI crude oil futures and the near-month natural gas futures in the NYMEX. The estimation is based on daily returns during each quarter in the sample. iii) The firm's specific risk is measured by the standard deviation of the residuals coming from the estimation of the factor model discussed previously.

5.2 Results of real effects

In this section, we run a variety of regressions. We regress the dependent variables based on firm metrics, namely, market valuation, performance, and risk, on the variables p11, p10, p00, and p01, detailed above. For the sake of conciseness, we focus our analysis on the two extreme situations, p11 and p00, indicating high joint hedging intensity and low joint hedging intensity, respectively, for both commodities. The real effects related to the two other predicted probabilities, p10 and p01, are discussed briefly below, and results are available in the Online Appendix.

5.2.1 Real effect of joint high intensities of oil and gas hedging

Table 10 summarizes the results of the first regression, in which we regress the firm's Tobin's Q, return on equity (ROE), operating return on assets (Op ROA), total risk, systematic risk, and idiosyncratic risk on the predicted probability p11 and control variables. The p11 denotes the predicted propensity to simultaneously hedge oil and gas to a larger extent. It is worth noticing that the interpretation of the results of Table 10 is from a comparison of companies with high-intensity hedging with companies with lower-intensity hedging.

Table 10 reveals a positive and statistically highly significant effect of the predicted probability p11, coming from the bivariate probit estimation, on the firm's Tobin's Q, with a value of 0.519, suggesting that an increase of 1% in the propensity to hedge both commodities at the highest extent will achieve an economically significant increase in the firm's value of 0.519%. This finding is consistent with the valuation premium for corporate hedging advocated by a large body of literature. Allayannis and Weston (2001) gave the first direct evidence of the positive relation between currency derivative usage (proxied by a dummy variable) and firm value (as defined by a natural logarithm of the firm's Tobin's Q) and showed that, for a sample of 720 non-financial firms, the market value of foreign-currency hedgers is 5% higher on average than that of non-hedgers. Carter et al. (2006) investigated the jet fuel hedging behavior of firms in the US airline industry in 1993–2003 and found an average hedging premium of 12%–16%, where they retained dummy variables to proxy for the existence of hedging activities. Bartram et al. (2009) explored the real effects of derivative use for a large sample of 6,888 non-financial firms from 47 countries during 2000–2001. Their evidence suggests that using derivatives is associated with a higher firm value. Pérez-Gonzalez and Yun (2013) exploited the introduction of weather derivatives in 1997 as a natural experiment for a sample of energy firms. They found evidence of positive effects of weather-derivative use on a firm's value, as measured by the market-to-book ratio.

Pertaining to the firm's return on equity, Table 10 shows a positive, but statistically insignificant, effect of high-intensity hedging for oil and gas. Remarkably, the results reveal a significant positive impact of the predicted probability of a high joint hedging on the operating return on assets. This finding gives evidence that oil and gas producers can improve their operational performance by highly hedging their oil and gas production. In fact, a 1% increase in the predicted probability of a high joint hedging for oil and gas production leads to an increase of about 0.13% in operational performance. Table 10 also indicates a statistically significant negative effect of high-intensity hedging for oil and gas on the firm's risk profile, that is, on the firm's total risk and idiosyncratic risk. Our results show that a 1% increase in the predicted probability of hedging oil and gas production to a greater extent will reduce the firm's total risk by almost 0.62% and decrease the firm’s specific risk by 0.03%. These findings corroborate previous findings in one stream of the related literature. Guay (1999) looked at a sample of 254 non-financial corporations that began using derivatives in the fiscal year 1991, and reported that new derivative users experience a statistically and economically significant 5% reduction in stock return volatility, as compared to a control sample of non-users. Using a sample of S&P 500 non-financial firms for 1993, Allayannis and Ofek (2001) found strong evidence that foreign-currency hedging reduces firms’ exchange-rate exposure. Bartram et al. (2011) found evidence that using derivatives reduces total risk. The impact of the firm’s systematic or market risk is positive but statistically insignificant. Our finding is in line with the results of Adam and Fernando (2006), who examined the outstanding gold derivative positions of a sample of 92 North American gold-mining firms for the period 1989–1999 and obtained that using derivatives translates into value gains for shareholders since there is no offsetting increase in the firm’s systematic risk.

Table 10 – Real effects of high joint hedging intensities for oil and gas

Variable	(1) Tobin's Q	(2) ROE	(3) Op ROA	(4) Firm risk	(5) Specific risk	(6) Market risk
p11	0.5194***	0.4412	0.1295***	-0.6240***	-0.0340***	0.3514
	(0.146)	(0.453)	(0.046)	(0.144)	(0.010)	(0.344)
Operating gross margin	-0.0018**	0.0004	-0.0002	0.0022***	0.0002***	-0.0013
	(0.001)	(0.002)	(0.000)	(0.001)	(0.000)	(0.002)
Investment opportunities	0.0160	-0.0771*	-0.0133*	-0.0178	-0.0022**	0.1284***
	(0.037)	(0.044)	(0.007)	(0.015)	(0.001)	(0.045)
Leverage ratio	-0.0040	0.0281	0.1787***	0.2676	0.0212*	0.2060
	(0.126)	(0.366)	(0.048)	(0.199)	(0.012)	(0.232)
Liquidity ratio	0.1033**	0.0646	0.0313***	-0.0453*	-0.0019	0.1015
	(0.043)	(0.045)	(0.007)	(0.025)	(0.002)	(0.083)
Dividend payout	0.0552	-0.0009	-0.0057	0.0194	0.0017	0.0779
	(0.083)	(0.068)	(0.012)	(0.041)	(0.002)	(0.099)
Oil reserves (in log)	-0.0496	0.0362	-0.0057	-0.0309	-0.0015	-0.0297
	(0.037)	(0.057)	(0.009)	(0.021)	(0.001)	(0.062)
Institutional ownership	0.1037	-0.0284	0.0029	-0.1889	-0.0170**	-0.2074
	(0.099)	(0.144)	(0.020)	(0.140)	(0.008)	(0.294)
Oil geographical diversification	0.0754	0.2589	0.0538*	-0.1254	-0.0056	-0.4808
	(0.090)	(0.223)	(0.030)	(0.173)	(0.011)	(0.344)
Gas geographical diversification	0.5102	0.2406	0.0861**	-0.7369**	-0.0365**	0.1260
	(0.321)	(0.299)	(0.038)	(0.366)	(0.017)	(0.635)
Oil price volatility	-0.0364***	-0.0227	-0.0057**	0.0517***	0.0019***	0.0087
	(0.006)	(0.015)	(0.003)	(0.007)	(0.000)	(0.012)
Oil basis	0.9322***	0.1732	0.1098**	-0.6722**	-0.0307*	-0.9790
	(0.248)	(0.290)	(0.053)	(0.291)	(0.016)	(0.751)
Oil production risk	-0.1333	-0.2382	0.0067	0.0409	0.0039	0.1161

Variable	(1) Tobin's Q	(2) ROE	(3) Op ROA	(4) Firm risk	(5) Specific risk	(6) Market risk
	(0.099)	(0.184)	(0.027)	(0.072)	(0.005)	(0.199)
Price_Quantity correlation (oil)	0.1253***	0.0513*	0.0089*	-0.0033	-0.0002	0.0528
	(0.046)	(0.029)	(0.005)	(0.039)	(0.002)	(0.094)
Gas basis	-0.0958	0.0110	-0.0438***	0.1616**	0.0069*	0.0515
	(0.067)	(0.084)	(0.015)	(0.067)	(0.004)	(0.159)
Gas price volatility	0.0388*	0.0246	0.0010	0.0843***	0.0025*	0.0875
	(0.022)	(0.032)	(0.005)	(0.027)	(0.001)	(0.056)
Gas reserves (in log)	0.0426	-0.0908**	-0.0130*	0.0693	0.0005	0.1679**
	(0.049)	(0.045)	(0.007)	(0.046)	(0.002)	(0.082)
Gas production risk	0.0389	0.0176	-0.0343	-0.0055	0.0023	0.0371
	(0.088)	(0.098)	(0.025)	(0.071)	(0.005)	(0.170)
Price_Quantity correlation (gas)	0.0200	-0.0119	-0.0002	0.0440	0.0005	0.1142*
	(0.044)	(0.026)	(0.007)	(0.037)	(0.002)	(0.066)
CEO ownership	-1.7303	3.2400	-0.5619	-1.0049	0.0831	-4.5854
	(3.096)	(3.136)	(0.888)	(2.547)	(0.130)	(4.006)
Number of CEO's options	0.0006*	-0.0004	-0.0000	0.0005	0.0000	0.0003
	(0.000)	(0.000)	(0.000)	(0.001)	(0.000)	(0.001)
Number of analysts	0.0121***	0.0106	0.0030***	-0.0138***	-0.0007**	0.0026
	(0.004)	(0.010)	(0.001)	(0.004)	(0.000)	(0.009)
Constant	-0.0900	0.1722	-0.0583	0.3161	0.0366**	-0.2776
	(0.233)	(0.203)	(0.044)	(0.258)	(0.015)	(0.504)
Observations	574	541	578	573	555	555
R-squared	0.2305	0.0600	0.1716	0.3322	0.2509	0.0552
Number of firms	79	76	79	78	75	75
F statistic	4.4934	4.4926	5.3844	15.4226	11.1116	3.5918
Rho	0.6254	0.4662	0.7572	0.7338	0.5813	0.4122

Variable	(1) Tobin's Q	(2) ROE	(3) Op ROA	(4) Firm risk	(5) Specific risk	(6) Market risk
Panel-level standard deviation	0.2789	0.3298	0.1108	0.3932	0.0148	0.5366
Standard deviation of epsilon_it	0.2159	0.3529	0.0627	0.2368	0.0126	0.6408

This table displays the results of the time series cross-sectional regressions with fixed effects when regressing the dependent variables (firm's Tobin's Q, ROE, operating ROA, total risk, systematic risk, and idiosyncratic risk) on the predicted probability *p11*, which corresponds to the probability of simultaneously high hedging intensities for both oil and gas production, coming from the bivariate probit estimation, and control variables related to the firm's financial and operational characteristics and to oil and gas market conditions. Control variables are included in lagged values (first lag). See Table A1 for further details on the construction of control variables. Heteroskedasticity-consistent standard errors clustered at the firm level are reported in parentheses. The superscripts ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

5.2.2 Real effect of joint low-intensity oil and gas hedging

Table 11 summarizes the results of the second regression, in which we regress the sample firms' Tobin's Q, return on equity (ROE), operating return on assets, total risk, systematic risk, and idiosyncratic risk on the predicted probability p00 and control variables. The p00 denotes the predicted propensity to simultaneously hedge oil and gas to a lower extent. It is worth noticing that the interpretation of the results of Table 11 is for companies with low-intensity hedging relative to companies with high-intensity hedging.

Table 11 shows that hedging at a lesser extent has the exact opposite real effects as hedging at a higher extent, which are mentioned in Table 10. In fact, Table 11 reveals a statistically and economically significant negative effect for the predicted propensity p00 on the firm's market valuation, with a coefficient of -0.68. This means that an increase of 1% in the predicted probability of being in the lower percentile for hedging reduces the firm's value by 0.68%. Table 11 also indicates that lower-intensity hedgers should have a notably lower operating return on assets, as compared to higher-intensity hedgers. These findings show that there will be an erosion in the shareholders' wealth for lower-intensity hedgers, as compared to more aggressive hedgers.

For firm riskiness, the results in Table 11 suggest that petroleum companies that are among the lower-quintile hedgers have experienced a higher risk profile, as compared to companies among the upper-quintile hedgers. A 1% increase in the predicted probability, p00, increases the firm's total risk by about 0.73% and 0.04% for the firm's specific risk. More firm risk, reflected by a more volatile share price, can erode shareholder value because it increases the probability of default and, consequently, its associated expected financial distress. The effect on the firm's systematic risk, measured by its market beta, is negative and statistically insignificant.

Table 11 – Real effects of low joint hedging intensities for oil and gas

Variable	(1) Tobin's Q	(2) ROE	(3) Op ROA	(4) Firm risk	(5) Specific risk	(6) Market risk
p00	-0.6818***	-0.2106	-0.1105***	0.7316***	0.0384***	-0.4554
	(0.150)	(0.258)	(0.040)	(0.178)	(0.011)	(0.288)
Operating gross margin	-0.0015*	0.0008	-0.0001	0.0017**	0.0001***	-0.0011
	(0.001)	(0.002)	(0.000)	(0.001)	(0.000)	(0.002)
Investment opportunities	0.0147	-0.0596*	-0.0107	-0.0205	-0.0024***	0.1277***
	(0.035)	(0.032)	(0.007)	(0.014)	(0.001)	(0.043)
Leverage ratio	-0.0040	0.0374	0.1786***	0.2668	0.0210*	0.2063
	(0.121)	(0.370)	(0.048)	(0.191)	(0.012)	(0.233)
Liquidity ratio	0.1400***	0.0505	0.0326***	-0.0781***	-0.0036*	0.1268
	(0.048)	(0.039)	(0.006)	(0.029)	(0.002)	(0.088)
Dividend payout	0.0659	-0.0174	-0.0071	0.0119	0.0013	0.0861
	(0.081)	(0.053)	(0.011)	(0.045)	(0.003)	(0.100)
Oil reserves (in log)	-0.0542	0.0470	-0.0045	-0.0289	-0.0015	-0.0324
	(0.036)	(0.049)	(0.008)	(0.023)	(0.001)	(0.062)
Institutional ownership	0.0859	-0.0185	0.0002	-0.1715	-0.0157**	-0.2256
	(0.089)	(0.141)	(0.020)	(0.133)	(0.008)	(0.295)
Oil geographical diversification	0.0399	0.2229	0.0457*	-0.0831	-0.0032	-0.5061
	(0.105)	(0.210)	(0.026)	(0.169)	(0.011)	(0.325)
Gas geographical diversification	0.4445	0.0938	0.0517*	-0.6321*	-0.0305**	0.0825
	(0.309)	(0.169)	(0.030)	(0.338)	(0.015)	(0.638)
Oil price volatility	-0.0373***	-0.0215	-0.0056**	0.0523***	0.0019***	0.0081
	(0.005)	(0.014)	(0.003)	(0.007)	(0.000)	(0.012)
Oil basis	0.9498***	0.0143	0.0810	-0.6440**	-0.0297*	-0.9556
	(0.239)	(0.350)	(0.049)	(0.294)	(0.016)	(0.707)
Oil production risk	-0.1345	-0.2176	0.0100	0.0383	0.0036	0.1175

Variable	(1) Tobin's Q	(2) ROE	(3) Op ROA	(4) Firm risk	(5) Specific risk	(6) Market risk
	(0.095)	(0.181)	(0.029)	(0.071)	(0.005)	(0.199)
Price_Quantity correlation (oil)	0.1043**	0.0565*	0.0076	0.0163	0.0008	0.0387
	(0.044)	(0.030)	(0.006)	(0.034)	(0.002)	(0.095)
Gas basis	-0.1000	0.0203	-0.0422***	0.1630**	0.0070*	0.0487
	(0.067)	(0.092)	(0.016)	(0.070)	(0.004)	(0.160)
Gas price volatility	0.0375	0.0276	0.0016	0.0846***	0.0025*	0.0870
	(0.023)	(0.033)	(0.005)	(0.027)	(0.001)	(0.057)
Gas reserves (in log)	0.0425	-0.0711*	-0.0099	0.0652	0.0004	0.1662**
	(0.049)	(0.038)	(0.008)	(0.044)	(0.002)	(0.080)
Gas production risk	0.0580	0.0592	-0.0254	-0.0341	0.0009	0.0492
	(0.088)	(0.083)	(0.023)	(0.073)	(0.005)	(0.171)
Price_Quantity correlation (gas)	0.0335	-0.0171	0.0003	0.0316	-0.0002	0.1236*
	(0.041)	(0.025)	(0.007)	(0.036)	(0.002)	(0.065)
CEO ownership	-2.5654	2.3807	-0.9007	0.1890	0.1426	-5.0351
	(3.230)	(2.823)	(0.965)	(2.854)	(0.146)	(3.862)
Number of CEO's options	0.0007**	-0.0002	0.0000	0.0003	-0.0000	0.0003
	(0.000)	(0.000)	(0.000)	(0.001)	(0.000)	(0.001)
Number of analysts	0.0147***	0.0075	0.0028**	-0.0157***	-0.0008**	0.0045
	(0.005)	(0.007)	(0.001)	(0.005)	(0.000)	(0.009)
Constant	0.3975	0.2869	0.0182	-0.2035	0.0087	0.0592
	(0.249)	(0.247)	(0.059)	(0.320)	(0.019)	(0.548)
Observations	574	541	578	573	555	555
R-squared	0.2504	0.0503	0.1597	0.3404	0.2576	0.0565
Number of firms	79	76	79	78	75	75
F statistic	5.5905	5.5290	4.8821	17.3708	12.5157	3.5119
Rho	0.6129	0.4482	0.7523	0.7343	0.5667	0.4187

Variable	(1) Tobin's Q	(2) ROE	(3) Op ROA	(4) Firm risk	(5) Specific risk	(6) Market risk
Panel-level standard deviation	0.2681	0.3197	0.1101	0.3913	0.0143	0.5435
Standard deviation of epsilon_it	0.2131	0.3547	0.0632	0.2353	0.0125	0.6404

This table displays the results of the time series cross-sectional regressions with fixed effects when regressing the dependent variables (firm's Tobin's Q, ROE, operating ROA, total risk, systematic risk, and idiosyncratic risk) on the predicted probability *p00*, which corresponds to the probability of simultaneously *low* hedging intensities for both oil and gas production, coming from the bivariate probit estimation, the control variables related to firm's financial and operational characteristics, and oil and gas market conditions. Control variables are included in lagged values (first lag). See Table A1 for further details on the construction of the control variables. Heteroskedasticity-consistent standard errors clustered at the firm level are reported in parentheses. The superscripts ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

Overall, the results conveyed by tables 10 and 11 are complementary and mutually confirmed. In fact, the summarized results converge with the conclusion that hedging to a greater extent in the oil and gas industry increases firm value and reduces firm riskiness, as compared to the firms with the lowest hedging intensities.

We estimate the same regression using the predicted probability that a firm in the sample has a high hedging intensity for its oil production while having a low hedging intensity for its natural gas production, that is, p10. Our results show coefficients for p10 with the same signs as in Table 10, but with no statistical significance. Results are reported in Table OA.2 in the Online Appendix. We also use the predicted probability that a firm in the sample has a low hedging intensity for its oil production while having a high hedging intensity for its natural gas production, that is, p01. We obtain coefficients for p01 with the same signs as in Table 11 and that are specifically significant for the operational ROA, total risk, and specific risk. Relevantly, it appears that our results in Table 11 are more driven by the extent of oil hedging than the extent of gas hedging. Results are reported in Table OA.3 in the Online Appendix.

5.3 The superiority of joint hedging

In this section, we investigate the relevance and the superiority of a joint hedging strategy to assess the real effects of hedging intensity on firm value over an estimation based on separate, single-risk exposures or a stand-alone framework. We do so by comparing the real effects reported in Table 10 using the predicted probability of a simultaneous high hedging intensity for both oil and gas, i.e., p11, coming from the bivariate probit regression and the real effects using a univariate probit estimation for the predicted probabilities of a high hedging intensity for oil and gas separately. Overall, Table OA.4 reports the estimations and shows that the stand-alone predicted probabilities of the univariate probit for oil hedging have a significant positive effect on the operating ROA and a significant negative effect on the total and specific risks. By itself, a predicted probability of high intensity for gas has insignificant effects on firm value and risk.

Furthermore, we calculate the joint predicted probability of having a high hedging intensity for both oil and gas simultaneously by multiplying the two predicted probabilities coming from the univariate probit estimation, that is, we are supposing that the correlation between the residuals of the two estimations is equal to zero.

Results are reported in Table OA.5 and reveal a significant positive impact on firm value and the operating return on assets, and a significant negative effect on the firm's total and specific risk. The positive effect on the firm's return on equity is insignificant. To go further, we gauge the economic magnitude of the real effects by comparing the coefficients reported in Table 10 for the predicted probabilities from the bivariate probit, i.e., p11, with the coefficients reported in Table AO.5 for the joint probabilities coming from the univariate probits assuming a zero correlation between residuals, as described previously. We examine whether these coefficients are statistically equal or different. Table 12 summarizes the coefficients from Table 10 and Table OA.5 beside the Wald test for the equality of estimated coefficients.

Table 12 – Comparison of the real effects

Variable	(1) Tobin's Q	(2) ROE	(3) Op ROA	(4) Firm risk	(5) Specific risk	(6) Market risk
Joint probability of high intensity from the bivariate probit (Table 10)	0.5194***	0.4412	0.1295***	-0.6240***	-0.0340***	0.3514
	(0.146)	(0.453)	(0.046)	(0.144)	(0.010)	(0.344)
Joint probability of high intensity from univariate probits (Table OA.5)	0.4379***	0.3636	0.1078**	-0.5682***	-0.0313***	0.2219
	(0.148)	(0.402)	(0.041)	(0.126)	(0.008)	(0.318)
Wald test with *H0*: coefficients are equal	10.51***	1.86	4.38**	2.26	1.63	3.04*

p-value	0.0012	0.1726	0.0364	0.1331	0.2023	0.0815

We use Stata's command *suest* allowing tests for intra-model and cross-model hypotheses by performing Wald tests of simple and composite linear hypotheses about the estimated parameters.

Interestingly, the Wald test reveals that the joint estimation considering the simultaneity between managerial hedging decisions in a multi-risk environment, that is, the bivariate probit, leads to an economically and statistically higher firm market value and operational performance, as compared to isolated estimations based on univariate probits.

To sum up, these findings reveal two interesting facts: i) using separate predicted probabilities can be misleading, by showing insignificant real effects on firm value of hedging-related choices and ii) by showing insignificant real effects related to gas hedging decisions; and iii) assuming a zero correlation between the decision process in a multi-risk exposure environment can induce economically smaller effects compared to a full joint framework considering the interactions of corporate hedging activities.

To further examine the appropriateness and relevance of the joint estimation of the manager's decision-making process regarding the extent of hedging for both commodities, i.e., oil and gas, we compare the predicted probabilities coming from the bivariate probit with real frequencies calculated from data documented in Table 7. Table 13 gives these observed frequencies (Observed) alongside the predicted probabilities from the bivariate probit estimation (Joint estimation). Remarkably, the joint estimation predicts probabilities that are very close to the observed decision frequencies, indicating that the bivariate probit captures very well the managers' simultaneous decisions about hedging intensities for oil and gas.

Table 13 – Observed frequencies and predicted probabilities for oil and gas hedging intensities

		Oil hedging intensity	
		High	Low
Gas hedging intensity			
High	Observed	40.88%	8.79%
	Joint estimation	39.24%	10.08%
	Independent	30.05%	19.27%
Low	Observed	8.31%	42.02%
	Joint estimation	9.27%	41.40%
	Independent	18.47%	32.21%

We further calculate the predicted probabilities for high hedging intensities for oil and gas separately, using univariate probit estimations assuming independent managerial choices.[9] We then calculate the predicted probabilities for the different combinations of hedging intensities for oil and gas, namely, high and/or low intensity for oil and gas. These independent predicted probabilities are shown in Table 13 (Independent). Interestingly, we observe that the univariate probit estimations fail to accurately predict the managerial decision process. In fact, the predicted probabilities, for either a simultaneously high or simultaneously low intensity for both commodities, are surprisingly underestimated. By contrast, the predicted probabilities for the combinations of high and low intensity for oil and gas are astonishingly overestimated—more than double the observed frequencies. Overall, these findings indicate that managerial decision-making about hedging intensities for oil and gas is a simultaneous process and that the interdependence between these decisions should be considered through a joint estimation framework to better capture managerial hedging behavior in a multi-risk environment.

[9] The dependent variable for each univariate probit is a dummy variable that takes the value of 1 when the oil (gas) hedging intensity is considered high (above the 75th percentile) and 0 when it is low (below the 25th percentile).

6. Conclusion

We revisit the real effects associated with corporate risk management by considering the joint hedging of two market risk exposures, namely, oil and gas price risk. We take a multidimensional approach by looking at the hedging question from different angles. We first analyze the joint decision to hedge both oil and natural gas prices simultaneously, using a bivariate probit panel regression. Then, we study the effects of the joint decision to hedge oil and gas production on the market's firm value, risk, and performance. We do our analysis in an instrumental variable framework to account for the endogeneity of the hedging decision.

We use an appropriate instrument for the need to hedge and to reflect managers' market views, that is, the Kilian index, which measures real global economic activity based on a short-term view of real shipping costs. We find that, jointly, hedging intensities for oil and natural gas decrease when real global economic activity is increasing from period to period, as proxied by changes in the Kilian index. Also, hedging intensities tend to be higher when the current level of real economic activity is high, as proxied by the level of the Kilian index. This raises some interesting implications for the timing of hedging and for managers' responses to changing real economic conditions. So, we can talk about managers' near-term and long-term market views, which appear to have opposite effects on the extent of hedging.

Armed with these two instruments (the level and the change in the Kilian index), we estimate a bivariate probit model and generate predicted probabilities for the joint decision about oil and gas hedging intensities. Then, in a second step, we test for a hedging premium by analyzing whether firm value is enhanced as a result of the hedging intensity for oil and gas. We regress market value, accounting performance, and risk measures on different combinations of hedging behavior. We find a positive relationship between firms that tend to hedge oil and gas simultaneously to a greater extent and their Tobin's Q and their operating return on assets. This implies that firms with a tendency to hedge more aggressively than their counterparts in the lower hedging quintiles enjoy a higher market valuation. Finally, we find evidence to suggest that firms with a high propensity to hedge to a larger extent face significantly lower riskiness, as compared to firms with low hedging intensities. Finally, we show that joint hedging dominates single-commodity hedging.

Hedging is a costly proposition, one that is still heavily debated in the literature; however, our paper lends credence to the claim that the benefits of joint hedging outweigh its costs and that it serves to increase firm value.

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Appendix

Table A1 – Variable definitions

Variable	Construction	Source
Operating gross margin	Measured by (Sales – Cost of goods sold)/Sales, for each quarter	Constructed manually
Investment opportunities	Quarterly capital expenditure, with a scale by net property, plant, and equipment at the beginning of the quarter	Compustat
Leverage ratio	Ratio of the book value of total debts to the total book value of assets	Compustat
Liquidity	Ratio of cash and cash equivalents to the book value of current liabilities	Constructed manually
Dividend payout	Dividends declared for the quarter (dummy variable)	Constructed manually
Oil reserves	The quantity (in millions of barrels) of the total proved developed and undeveloped oil reserves. This variable is disclosed annually. We repeat the same observation for the same fiscal year quarters. The raw value of this variable (in millions of barrels) is used in Table 1 (Descriptive Statistics). The logarithm transformation of this variable is used elsewhere.	10Ks and Bloomberg
Institutional ownership	Percentage of shares owned by institutional investors	Thomson Reuters
Geographical diversification of oil production	Constructed using $1-\sum_{i=1}^{N}\left(\frac{q_1}{q}\right)^2$, where q_1 represents the daily oil production in the *i* region (Latin America, North America, Middle East, Africa) while q is the total daily production of oil	Constructed manually
Geographical diversification of gas production	Constructed using $1-\sum_{i=1}^{N}\left(\frac{q_1}{q}\right)^2$ where q_1 represents the daily gas production in the *i* region (Latin America, North America, Middle East, Africa) while q is the total daily production of gas	Constructed manually
Oil price volatility	Historical volatility (in \$) measured with the standard deviation of oil daily spot prices during the quarter	Constructed manually

Oil basis	The oil basis is measured by the ratio of the average oil futures prices for exchange-traded futures for the next 12 months, divided by the oil spot price at the end of the quarter minus one. Spot price is measured by the Bloomberg West Texas Intermediate (WTI) - Cushing, Oklahoma. Spot and future oil prices are extracted from Bloomberg.	Constructed manually
Oil/Gas production risk	Coefficient of variation of daily oil (gas) production. This coefficient is calculated for each firm by using rolling windows of 12 quarterly observations. The daily oil (gas) production is disclosed annually. We repeat the same observation for the same fiscal year quarters.	Constructed manually, Bloomberg, 10K reports
Gas price volatility	Historical volatility (in $) measured with the standard deviation of gas daily spot prices during the quarter	Constructed manually
Gas basis	The gas basis is measured by the ratio of the average gas future prices for exchange-traded futures for the next 12 months divided by the gas spot price at the end of the quarter minus one. Gas spot price is measured by the Bloomberg Natural Gas Spot Price Index, which is a multi-region average of gas indices in the United States (Henry Hub, Gulf Coast, and others). Gas spot and futures prices are extracted from Bloomberg.	Constructed manually
Gas reserves	The quantity of the total proved developed and undeveloped gas reserves. This variable is disclosed annually. We repeat the same observation for the same fiscal year quarters. The raw value of this variable (in billions of cubic feet) is used in Table 1 (Descriptive Statistics). The logarithm transformation of this variable is used elsewhere.	10K reports and Bloomberg
Price–quantity correlation (oil/gas)	Correlation coefficient between daily oil (gas) production and oil (gas) spot prices. These correlation coefficients are calculated for each firm by using rolling windows of 12 quarterly observations.	Bloomberg and 10K reports
CEO ownership	Percentage ownership of the firm by its CEO	Thomson Reuters
CEO option holding	Number of options on company stock held at the end of the quarter by the CEO	Thomson Reuters
Number of analysts	Number of analysts following the firm, and subsequent issue earnings forecast for the quarter	I/B/E/S

Determinants and real effects of joint hedging: An empirical analysis of the U.S. oil and gas producers

Online appendix

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Table OA.1 – Derivative instruments used by oil and gas hedgers

	Gas hedging		Oil hedging	
Derivative instrument	Number of firm-quarters	Percentage of use	Number of firm-quarters	Percentage of use
Swap contracts	2255	45.58	1711	45.25
Put options	522	10.55	448	11.85
Costless collar	1840	37.19	1403	37.11
Forward or futures contract	161	3.25	105	2.78
3-ways collar	169	3.42	114	3.02
Total	4947	100	3781	100

The table reports the different type of financial instruments used by the sample firms that report non-zero oil and gas hedging activities in each firm-quarter observation. The values for each instrument indicate the number of firm-quarters and the fraction (in percentage) of use.

Table OA.2 – Real effects of joint high hedging intensity for oil and low hedging intensity for gas

Variable	(1) Tobin's Q	(2) ROE	(3) Op ROA	(4) Firm risk	(5) Specific risk	(6) Market risk
p10	0.8312	0.3886	0.1526	-0.9846*	-0.0372	0.6982
	(0.514)	(0.498)	(0.097)	(0.542)	(0.027)	(0.834)
Operating gross margin	-0.0016**	0.0007	-0.0001	0.0020**	0.0001***	-0.0013
	(0.001)	(0.002)	(0.000)	(0.001)	(0.000)	(0.002)
Investment opportunities	0.0515	-0.0479*	-0.0047	-0.0604***	-0.0045***	0.1526***
	(0.042)	(0.027)	(0.006)	(0.013)	(0.001)	(0.041)
Leverage ratio	-0.0388	0.0145	0.1722***	0.3087	0.0221*	0.1789
	(0.127)	(0.375)	(0.050)	(0.197)	(0.013)	(0.232)
Liquidity ratio	0.0616*	0.0310	0.0202***	0.0050	0.0011	0.0743
	(0.035)	(0.026)	(0.006)	(0.035)	(0.002)	(0.068)
Dividend payout	0.0363	-0.0264	-0.0119	0.0423	0.0030	0.0698
	(0.080)	(0.043)	(0.010)	(0.043)	(0.003)	(0.104)
Oil reserves (in log)	-0.0425	0.0490	-0.0030	-0.0397	-0.0021	-0.0299
	(0.040)	(0.046)	(0.008)	(0.034)	(0.002)	(0.073)
Institutional ownership	0.0745	-0.0218	-0.0024	-0.1545	-0.0170**	-0.2232
	(0.092)	(0.145)	(0.022)	(0.140)	(0.008)	(0.280)
Oil geographical diversification	0.1063	0.2464	0.0579*	-0.1614	-0.0066	-0.4472
	(0.101)	(0.204)	(0.030)	(0.119)	(0.008)	(0.367)
Gas geographical diversification	-0.1288	-0.1336	-0.0491	0.0244	-0.0020	-0.3704
	(0.264)	(0.191)	(0.050)	(0.229)	(0.014)	(0.619)
Oil price volatility	-0.0339***	-0.0207	-0.0051**	0.0487***	0.0017***	0.0104
	(0.006)	(0.014)	(0.002)	(0.007)	(0.000)	(0.011)
Oil basis	0.5208**	-0.1146	0.0105	-0.1787	-0.0049	-1.2646*
	(0.242)	(0.449)	(0.050)	(0.265)	(0.015)	(0.640)
Oil production risk	-0.1006	-0.2007	0.0154	0.0016	0.0020	0.1367
	(0.092)	(0.182)	(0.030)	(0.076)	(0.005)	(0.197)
Price_quantity correlation (oil)	0.1217***	0.0573*	0.0099*	0.0005	-0.0004	0.0457
	(0.045)	(0.029)	(0.006)	(0.033)	(0.001)	(0.085)
Gas basis	-0.0783	0.0247	-0.0387**	0.1404*	0.0059	0.0592
	(0.065)	(0.098)	(0.016)	(0.073)	(0.004)	(0.161)
Gas price volatility	0.0338	0.0233	0.0007	0.0901***	0.0027*	0.0811
	(0.023)	(0.032)	(0.005)	(0.027)	(0.001)	(0.063)

Variable	(1) Tobin's Q	(2) ROE	(3) Op ROA	(4) Firm risk	(5) Specific risk	(6) Market risk
Gas reserves (in log)	0.1099**	-0.0428	0.0017	-0.0110	-0.0035	0.2234**
	(0.055)	(0.049)	(0.010)	(0.044)	(0.002)	(0.088)
Gas production risk	0.1925*	0.1127	-0.0016	-0.1886*	-0.0052	0.1497
	(0.113)	(0.094)	(0.020)	(0.103)	(0.006)	(0.189)
Price_quantity correlation (gas)	0.0034	-0.0266	-0.0045	0.0638*	0.0015	0.1041
	(0.045)	(0.024)	(0.007)	(0.037)	(0.002)	(0.065)
CEO ownership	-7.0134	0.9895	-1.6849	5.2923	0.3884	-8.8958
	(4.899)	(3.348)	(1.134)	(4.398)	(0.236)	(5.830)
Number of CEO's options	0.0010***	-0.0001	0.0001	-0.0000	-0.0000	0.0006
	(0.000)	(0.000)	(0.000)	(0.001)	(0.000)	(0.001)
Number of analysts	0.0031	0.0036	0.0009	-0.0031	-0.0001	-0.0041
	(0.004)	(0.003)	(0.001)	(0.004)	(0.000)	(0.008)
Constant	-0.2696	0.0398	-0.0928	0.5298*	0.0471***	-0.4438
	(0.281)	(0.247)	(0.058)	(0.298)	(0.016)	(0.553)
Observations	574	541	578	573	555	555
R-squared	0.2023	0.0489	0.1449	0.3026	0.2097	0.0539
Number of firms	79	76	79	78	75	75
F statistic	3.9921	4.6344	3.3318	15.3633	15.0790	3.6571
Rho	0.6482	0.4441	0.7354	0.7167	0.5900	0.4134
Panel-level standard deviation	0.2984	0.3173	0.1063	0.3849	0.0155	0.5383
Standard deviation of epsilon_it	0.2198	0.3550	0.0638	0.2420	0.0129	0.6412

This table displays the results of the time series cross sectional regressions with fixed effects when regressing the dependent variables (firm's Tobin's Q, ROE, operating ROA, total risk, systematic risk, and idiosyncratic risk) on the predicted probability p10, which corresponds to the probability of a simultaneous high hedging intensity for oil and low hedging intensity for gas production coming from the bivariate probit estimation, and control variables related to firm's financial and operational characteristics, and oil and gas market conditions. Control variables are included in lagged values (first lag). See Table A.1 for more details on the construction of control variables. Heteroskedasticity-consistent standard errors clustered at the firm level are reported in parentheses. The superscripts ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

Table OA.3 – Real effects of joint low hedging intensity for oil and high hedging intensity for gas

Variable	(1) Tobin's Q	(2) ROE	(3) Op ROA	(4) Firm risk	(5) Specific risk	(6) Market risk
p01	-0.1285	-1.6475	-0.2751**	0.5658***	0.0264**	-0.1829
	(0.348)	(1.365)	(0.128)	(0.185)	(0.011)	(0.653)
Operating gross margin	-0.0014	-0.0012	-0.0004**	0.0022***	0.0001***	-0.0012
	(0.001)	(0.001)	(0.000)	(0.001)	(0.000)	(0.002)
Investment opportunities	0.0476	-0.0663*	-0.0076	-0.0516***	-0.0041***	0.1486***
	(0.044)	(0.039)	(0.006)	(0.013)	(0.001)	(0.040)
Leverage ratio	-0.0039	-0.0906	0.1671***	0.2895	0.0217	0.2063
	(0.133)	(0.379)	(0.050)	(0.210)	(0.013)	(0.234)
Liquidity ratio	0.0488	-0.0002	0.0135**	0.0272	0.0021	0.0621
	(0.030)	(0.029)	(0.006)	(0.035)	(0.002)	(0.065)
Dividend payout	0.0259	-0.0057	-0.0099	0.0492	0.0033	0.0604
	(0.083)	(0.060)	(0.011)	(0.039)	(0.002)	(0.101)
Oil reserves (in log)	-0.0291	0.0222	-0.0061	-0.0457	-0.0023	-0.0199
	(0.040)	(0.060)	(0.008)	(0.028)	(0.002)	(0.067)
Institutional ownership	0.1121	-0.0602	-0.0007	-0.1869	-0.0182**	-0.1930
	(0.100)	(0.159)	(0.021)	(0.145)	(0.008)	(0.288)
Oil geographical diversification	0.0614	0.4562	0.0849*	-0.1674	-0.0076	-0.4734
	(0.108)	(0.301)	(0.044)	(0.139)	(0.009)	(0.397)
Gas geographical diversification	0.2137	-0.3780	-0.0430	-0.2868	-0.0126	-0.1006
	(0.347)	(0.297)	(0.046)	(0.354)	(0.016)	(0.671)
Oil price volatility	-0.0334***	-0.0213	-0.0052**	0.0484***	0.0017***	0.0109
	(0.006)	(0.014)	(0.003)	(0.007)	(0.000)	(0.011)
Oil basis	0.5777**	-0.0292	0.0423	-0.2821	-0.0084	-1.2137*
	(0.250)	(0.344)	(0.053)	(0.277)	(0.015)	(0.638)
Oil production risk	-0.1038	-0.2102	0.0101	0.0095	0.0024	0.1330
	(0.095)	(0.187)	(0.026)	(0.077)	(0.005)	(0.195)
Price_Quantity correlation (oil)	0.1462***	0.0512*	0.0116**	-0.0241	-0.0013	0.0657
	(0.049)	(0.028)	(0.005)	(0.041)	(0.002)	(0.090)
Gas basis	-0.0737	0.0091	-0.0411**	0.1400**	0.0059	0.0629
	(0.065)	(0.088)	(0.016)	(0.069)	(0.004)	(0.159)
Gas price volatility	0.0452**	-0.0004	-0.0019	0.0844***	0.0025*	0.0893
	(0.021)	(0.028)	(0.006)	(0.026)	(0.001)	(0.056)

Variable	(1) Tobin's Q	(2) ROE	(3) Op ROA	(4) Firm risk	(5) Specific risk	(6) Market risk
Gas reserves (in log)	0.0786	-0.0141	0.0020	0.0149	-0.0027	0.1985**
	(0.057)	(0.055)	(0.008)	(0.046)	(0.002)	(0.089)
Gas production risk	0.1081	0.1418	-0.0044	-0.1106	-0.0027	0.0830
	(0.102)	(0.101)	(0.019)	(0.085)	(0.006)	(0.179)
Price_Quantity correlation (gas)	0.0015	-0.0468	-0.0073	0.0709*	0.0018	0.1015
	(0.046)	(0.033)	(0.008)	(0.037)	(0.002)	(0.063)
CEO ownership	-4.2129	-0.5376	-1.4886	2.5040	0.2925*	-6.6074
	(3.702)	(3.378)	(1.032)	(3.363)	(0.172)	(4.245)
Number of CEO's options	0.0009***	-0.0005	0.0000	0.0002	-0.0000	0.0005
	(0.000)	(0.000)	(0.000)	(0.001)	(0.000)	(0.001)
Number of analysts	0.0044	-0.0002	0.0006	-0.0036	-0.0001	-0.0032
	(0.005)	(0.003)	(0.001)	(0.003)	(0.000)	(0.008)
Constant	-0.1028	0.3105	-0.0330	0.2847	0.0376**	-0.2959
	(0.260)	(0.253)	(0.050)	(0.312)	(0.017)	(0.518)
Observations	574	541	578	573	555	555
R-squared	0.1908	0.0787	0.1670	0.2967	0.2074	0.0528
Number of firms	79	76	79	78	75	75
F statistic	3.8636	3.3530	4.3400	13.6624	13.7326	3.4031
Rho	0.6644	0.4747	0.7426	0.7225	0.6073	0.4085
Panel-level standard deviation	0.3115	0.3321	0.1069	0.3921	0.0161	0.5332
Standard deviation of epsilon_it	0.2214	0.3494	0.0629	0.2430	0.0129	0.6416

This table displays the results of the time series cross sectional regressions with fixed effects when regressing the dependent variables (firm's Tobin's Q, ROE, operating ROA, total risk, systematic risk, and idiosyncratic risk) on the predicted probability p01, which corresponds to the probability of a simultaneous low hedging intensity for oil and high hedging intensity for gas production coming from the bivariate probit estimation, and control variables related to firm's financial and operational characteristics, and oil and gas market conditions. Control variables are included in lagged values (first lag). See Table A.1 for more details on the construction of control variables. Heteroskedasticity-consistent standard errors clustered at the firm level are reported in parentheses. The superscripts ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

Table OA.4 – Real effects of univariate predicted probabilities of high intensity hedging for oil and gas

Variable	(1) Tobin's Q	(2) ROE	(3) Op ROA	(4) Firm risk	(5) Specific risk	(6) Market risk
Probability of high intensity hedging for oil	0.3822	1.1535	0.2219**	-0.7082***	-0.0307**	0.4031
	(0.334)	(0.990)	(0.096)	(0.249)	(0.014)	(0.477)
Probability of high intensity hedging for gas	0.2523	-1.0075	-0.1240	0.0452	-0.0063	-0.0033
	(0.331)	(0.854)	(0.095)	(0.307)	(0.018)	(0.627)
Operating gross margin	-0.0018*	-0.0011	-0.0005***	0.0027***	0.0002***	-0.0016
	(0.001)	(0.001)	(0.000)	(0.001)	(0.000)	(0.002)
Investment opportunities	0.0125	-0.0650	-0.0116	-0.0172	-0.0022**	0.1267***
	(0.035)	(0.043)	(0.008)	(0.016)	(0.001)	(0.045)
Leverage ratio	-0.0113	-0.1255	0.1630***	0.3062*	0.0226*	0.1814
	(0.131)	(0.392)	(0.046)	(0.184)	(0.012)	(0.224)
Liquidity ratio	0.1240***	0.0363	0.0288***	-0.0574**	-0.0027	0.1113
	(0.041)	(0.030)	(0.006)	(0.025)	(0.002)	(0.089)
Dividend payout	0.0643	0.0085	-0.0031	0.0061	0.0011	0.0872
	(0.083)	(0.072)	(0.011)	(0.044)	(0.003)	(0.098)
Oil reserves (in log)	-0.0563	0.0099	-0.0111	-0.0141	-0.0009	-0.0401
	(0.039)	(0.065)	(0.008)	(0.029)	(0.002)	(0.068)
Institutional ownership	0.0893	-0.0872	-0.0089	-0.1514	-0.0155**	-0.2296
	(0.089)	(0.175)	(0.023)	(0.136)	(0.008)	(0.296)
Oil geographical diversification	0.0756	0.4505	0.0869**	-0.1882	-0.0072	-0.4476
	(0.099)	(0.298)	(0.043)	(0.164)	(0.011)	(0.341)
Gas geographical diversification	0.4560	-0.6296	-0.0578	-0.4299	-0.0258*	-0.0297
	(0.333)	(0.521)	(0.072)	(0.284)	(0.015)	(0.796)
Oil price volatility	-0.0372***	-0.0230	-0.0058**	0.0525***	0.0020***	0.0080
	(0.006)	(0.015)	(0.003)	(0.007)	(0.000)	(0.012)

Variable	(1) Tobin's Q	(2) ROE	(3) Op ROA	(4) Firm risk	(5) Specific risk	(6) Market risk
Oil basis	0.9703***	-0.0323	0.0866*	-0.6647**	-0.0307*	-0.9699
	(0.242)	(0.345)	(0.049)	(0.297)	(0.016)	(0.752)
Oil production risk	-0.1367	-0.2141	0.0058	0.0420	0.0039	0.1140
	(0.097)	(0.185)	(0.026)	(0.071)	(0.005)	(0.201)
Price_Quantity correlation (oil)	0.1111**	0.0170	0.0021	0.0208	0.0009	0.0381
	(0.046)	(0.047)	(0.006)	(0.034)	(0.002)	(0.096)
Gas basis	-0.1009	0.0058	-0.0451***	0.1692**	0.0072*	0.0464
	(0.068)	(0.085)	(0.016)	(0.070)	(0.004)	(0.160)
Gas price volatility	0.0353	-0.0092	-0.0044	0.0975***	0.0030**	0.0799
	(0.024)	(0.031)	(0.006)	(0.027)	(0.001)	(0.061)
Gas reserves (in log)	0.0446	0.0053	0.0009	0.0409	-0.0004	0.1822*
	(0.056)	(0.070)	(0.010)	(0.047)	(0.003)	(0.100)
Gas production risk	0.0536	0.2167	0.0006	-0.0810	-0.0004	0.0776
	(0.119)	(0.139)	(0.020)	(0.070)	(0.005)	(0.204)
Price_Quantity correlation (gas)	0.0268	-0.0316	-0.0024	0.0428	0.0003	0.1156*
	(0.043)	(0.028)	(0.008)	(0.039)	(0.002)	(0.066)
CEO ownership	-2.2574	-2.4632	-1.6457	1.4054	0.1715	-5.8396
	(4.127)	(4.563)	(1.048)	(2.931)	(0.169)	(5.276)
Number of CEO's options	0.0006**	-0.0004	-0.0000	0.0005	0.0000	0.0003
	(0.000)	(0.000)	(0.000)	(0.001)	(0.000)	(0.001)
Number of analysts	0.0136**	0.0016	0.0019	-0.0129**	-0.0007**	0.0025
	(0.005)	(0.005)	(0.001)	(0.005)	(0.000)	(0.011)
Constant	-0.1828	0.0387	-0.0858*	0.4384*	0.0427***	-0.3474
	(0.235)	(0.227)	(0.047)	(0.245)	(0.014)	(0.514)
Observations	574	541	578	573	555	555
R-squared	0.2440	0.0741	0.1836	0.3440	0.2599	0.0563
Number of firms	79	76	79	78	75	75

Variable	(1) Tobin's Q	(2) ROE	(3) Op ROA	(4) Firm risk	(5) Specific risk	(6) Market risk
F statistic	4.8416	6.5522	6.9260	19.9469	10.7028	3.9743
Rho	0.6148	0.4585	0.7685	0.7376	0.5725	0.4159
Panel-level standard deviation	0.2706	0.3227	0.1136	0.3939	0.0145	0.5410
Standard deviation of epsilon_it	0.2142	0.3507	0.0624	0.2349	0.0125	0.6411

This table displays the results of the time series cross sectional regressions with fixed effects when regressing the dependent variables (firm's Tobin's Q, ROE, operating ROA, total risk, systematic risk, and idiosyncratic risk) on the predicted probabilities coming from a univariate probit estimation for a high intensity hedging for oil and gas separately, and control variables related to firm's financial and operational characteristics, and oil and gas market conditions. Control variables are included in lagged values (first lag). See Table A.1 for more details on the construction of control variables. Heteroskedasticity-consistent standard errors clustered at the firm level are reported in parentheses. The superscripts ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

Table OA.5 – Real effects of bivariate predicted probability of high intensity hedging for oil and gas simultaneously assuming a zero correlation

Variable	(1) Tobin's Q	(2) ROE	(3) Op ROA	(4) Firm risk	(5) Specific risk	(6) Market risk
Joint probability of high intensity hedging	0.4379***	0.3636	0.1078**	-0.5682***	-0.0313***	0.2219
	(0.148)	(0.402)	(0.041)	(0.126)	(0.008)	(0.318)
Operating gross margin	-0.0019**	0.0004	-0.0002	0.0023***	0.0002***	-0.0013
	(0.001)	(0.002)	(0.000)	(0.001)	(0.000)	(0.002)
Investment opportunities	0.0179	-0.0751*	-0.0127*	-0.0171	-0.0022**	0.1349***
	(0.038)	(0.043)	(0.007)	(0.014)	(0.001)	(0.044)
Leverage ratio	-0.0154	0.0191	0.1760***	0.2831	0.0219*	0.2045
	(0.128)	(0.365)	(0.048)	(0.200)	(0.012)	(0.233)
Liquidity ratio	0.0909**	0.0546	0.0281***	-0.0342	-0.0012	0.0855
	(0.042)	(0.038)	(0.007)	(0.027)	(0.002)	(0.080)
Dividend payout	0.0486	-0.0068	-0.0073	0.0249	0.0021	0.0695
	(0.083)	(0.064)	(0.011)	(0.040)	(0.002)	(0.100)
Oil reserves (in log)	-0.0428	0.0422	-0.0039	-0.0374*	-0.0018	-0.0233
	(0.037)	(0.054)	(0.008)	(0.022)	(0.001)	(0.063)
Institutional ownership	0.0953	-0.0338	0.0010	-0.1768	-0.0170**	-0.2019
	(0.098)	(0.149)	(0.020)	(0.141)	(0.008)	(0.293)
Oil geographical diversification	0.0680	0.2509	0.0518*	-0.1188	-0.0054	-0.4880
	(0.087)	(0.223)	(0.031)	(0.166)	(0.011)	(0.359)
Gas geographical diversification	0.4182	0.1581	0.0627*	-0.6433*	-0.0313*	0.0313
	(0.324)	(0.229)	(0.034)	(0.363)	(0.016)	(0.620)
Oil price volatility	-0.0359***	-0.0222	-0.0056**	0.0513***	0.0019***	0.0096
	(0.006)	(0.015)	(0.003)	(0.007)	(0.000)	(0.012)
Oil basis	0.8960***	0.1448	0.0996*	-0.6604**	-0.0297*	-1.0622
	(0.250)	(0.293)	(0.053)	(0.291)	(0.016)	(0.741)

Variable	(1) Tobin's Q	(2) ROE	(3) Op ROA	(4) Firm risk	(5) Specific risk	(6) Market risk
Oil production risk	-0.1381	-0.2389	0.0055	0.0501	0.0047	0.1168
	(0.102)	(0.185)	(0.027)	(0.074)	(0.005)	(0.200)
Price_Quantity correlation (oil)	0.1293***	0.0548*	0.0100**	-0.0064	-0.0003	0.0585
	(0.046)	(0.028)	(0.005)	(0.038)	(0.002)	(0.094)
Gas basis	-0.0926	0.0115	-0.0430***	0.1597**	0.0068*	0.0562
	(0.068)	(0.084)	(0.016)	(0.067)	(0.004)	(0.159)
Gas price volatility	0.0415*	0.0266	0.0017	0.0817***	0.0024*	0.0900
	(0.022)	(0.033)	(0.005)	(0.027)	(0.001)	(0.056)
Gas reserves (in log)	0.0425	-0.0891*	-0.0130*	0.0726	0.0005	0.1757**
	(0.049)	(0.046)	(0.008)	(0.047)	(0.002)	(0.082)
Gas production risk	0.0314	0.0115	-0.0361	0.0102	0.0033	0.0412
	(0.085)	(0.105)	(0.025)	(0.070)	(0.005)	(0.176)
Price_Quantity correlation (gas)	0.0146	-0.0166	-0.0015	0.0493	0.0008	0.1089
	(0.044)	(0.024)	(0.007)	(0.036)	(0.002)	(0.065)
CEO ownership	-2.1462	3.0179	-0.6714	-0.6883	0.1134	-5.3427
	(3.137)	(3.199)	(0.916)	(2.718)	(0.130)	(4.048)
Number of CEO's options	0.0006**	-0.0003	-0.0000	0.0005	0.0000	0.0004
	(0.000)	(0.000)	(0.000)	(0.001)	(0.000)	(0.001)
Number of analysts	0.0107**	0.0093	0.0027***	-0.0128***	-0.0006**	0.0004
	(0.004)	(0.009)	(0.001)	(0.004)	(0.000)	(0.009)
Constant	-0.0042	0.2344	-0.0374	0.2020	0.0314**	-0.2517
	(0.236)	(0.220)	(0.046)	(0.280)	(0.015)	(0.505)
Observations	574	541	578	573	555	555
R-squared	0.2234	0.0576	0.1656	0.3307	0.2500	0.0539
Number of firms	79	76	79	78	75	75
F statistic	4.2576	4.0980	5.0683	15.7446	10.9119	3.3875
Rho	0.6298	0.4640	0.7526	0.7355	0.5868	0.4099

Variable	(1) Tobin's Q	(2) ROE	(3) Op ROA	(4) Firm risk	(5) Specific risk	(6) Market risk
Panel-level standard deviation	0.2829	0.3288	0.1099	0.3953	0.0150	0.5344
Standard deviation of epsilon_it	0.2169	0.3534	0.0630	0.2371	0.0126	0.6412

This table displays the results of the time series cross sectional regressions with fixed effects when regressing the dependent variables (firm's Tobin's Q, ROE, operating ROA, total risk, systematic risk, and idiosyncratic risk) on the predicted probabilities of a high hedging intensity for oil and gas simultaneously. This joint predicted probability is the product of the two probabilities coming from a univariate probit estimation for a high intensity hedging for oil and gas separately assuming a zero correlation between residuals. Control variables related to firm's financial and operational characteristics, and oil and gas market conditions. Control variables are included in lagged values (first lag). See Table A.1 for more details on the construction of control variables. Heteroskedasticity-consistent standard errors clustered at the firm level are reported in parentheses. The superscripts ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

Table OA.6 – Financial and operational characteristics firms with intermediate-hedging intensity (Inter)

	Intermediate intensity			(High) vs. (Inter)	(Low) vs. (Inter)
Variables	Obs	Mean	Median	*t*-Stat Z–score	*t*-Stat Z–score
Operating gross margin	105	0.387	0.644	1.085	1.460
				1.356	2.538**
Investment opportunities	105	0.093	0.074	0.467	-0.685
				-1.642	-1.841*
Leverage	105	0.682	0.613	-1.447	-3.746***
				-0.828	-4.994***
Liquidity	105	0.248	0.132	-0.702	3.690***
				-1.368	3.485***
Dividend payout	105	0.304	0.000	1.423	5.953***
				1.391	5.589***
Institutional ownership	105	0.538	0.633	-2.654***	2.022**
				-2.491**	2.413**
CEO % of stockholding	105	0.005	0.001	-2.638***	-1.336
				-2.818***	-1.083
CEO number of options (×10000)	105	16.184	3.750	0.364	1.208
				-2.250**	-0.376
Number of analysts	105	8.152	7.000	-1.380	5.789***
				-1.954*	5.076***
Oil reserves (in log)	105	3.494	3.352	-1.153	6.656***
				-1.210	5.561***
Gas reserves (in log)	102	5.916	5.893	0.041	5.652***
				-0.304	5.198***
Geographic diversification (oil)	105	0.078	0.000	-0.820	7.351***
				-1.408	5.736***

Geographic diversification (gas)	105	0.040	0.000	-1.407	7.023***
				-1.244	5.691***
Oil production risk	105	0.253	0.167	1.497	-2.517**
				0.604	-2.963***
Gas production risk	105	0.225	0.175	3.476***	-2.627***
				1.609	-4.812***
Price_Quantity correlation (oil)	105	0.089	0.200	1.354	2.375**
				1.117	2.430**
Price_Quantity correlation (gas)	105	-0.011	0.019	3.168***	1.385
				3.250***	1.494
Oil price volatility	105	3.465	2.371	3.738***	-1.120
				3.971***	-0.930
Gas price volatility	105	0.754	0.543	2.087**	-0.519
				2.045**	-0.938
Oil price basis	105	0.008	0.025	-0.900	-2.843***
				-1.542	-2.902***
Gas price basis	105	0.201	0.165	-2.878***	-3.507***
				-3.327***	-3.797***

This table reports the univariate analysis for the firm's financial and operational characteristics with joint intermediate-hedging. Comparison of the means are made by using a *t*-test assuming unequal variances; the medians are compared by using a non-parametric Wilcoxon rank-sum Z-test.

Table OA.7 – Estimation results with spot prices correlation

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Specification 1		Specification 2		Specification 3		Specification 4	
Variable	Oil hedging intensity	Gas hedging intensity	Oil hedging intensity	Gas hedging intensity	Oil hedging intensity	Gas hedging intensity	Oil hedging intensity	Gas hedging intensity
Change in the Kilian Index	-0.0051***	-0.0046***	-0.0050***	-0.0041***	-0.0055***	-0.0047***	-0.0050***	-0.0041***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Level of the Kilian Index	0.0067***	0.0053***	0.0066***	0.0051***	0.0069***	0.0056***	0.0067***	0.0054***
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
Spot prices correlation	**0.2473***	**0.1528**	**0.2533****	**0.1500**				
	(0.138)	**(0.127)**	**(0.126)**	**(0.128)**				
Spot prices correlation × Proportion of oil revenues					**0.3537****	**0.2055**	**0.3243****	**0.2064**
					(0.143)	**(0.138)**	**(0.130)**	**(0.141)**
Proportion of oil revenues					0.2783	-0.7148	0.2728	-0.7003
					(0.414)	(0.561)	(0.414)	(0.567)
Operating Gross margin	0.0917	-0.0011	0.0708	0.0002	0.0731	-0.0004	0.0575	0.0016
	(0.071)	(0.010)	(0.069)	(0.010)	(0.067)	(0.011)	(0.065)	(0.012)
Investment opportunities	0.4342	0.2166	0.4449	0.2031	0.3877	0.2696	0.4214	0.2479
	(0.450)	(0.268)	(0.458)	(0.265)	(0.467)	(0.387)	(0.476)	(0.379)
Leverage ratio	0.4920	-0.0809	0.4577	-0.0739	0.5004	-0.1128	0.4410	-0.0988
	(0.548)	(0.535)	(0.547)	(0.541)	(0.560)	(0.537)	(0.555)	(0.546)
Liquidity ratio	-0.6463***	-0.6948***	-0.6408***	-0.6925***	-0.6831***	-0.6505***	-0.6683***	-0.6486***
	(0.250)	(0.216)	(0.249)	(0.215)	(0.249)	(0.216)	(0.248)	(0.214)
Dividend payout	-0.1709	-0.1210	-0.1592	-0.1157	-0.0561	-0.2032	-0.0544	-0.1936
	(0.277)	(0.290)	(0.280)	(0.291)	(0.336)	(0.315)	(0.339)	(0.314)
Oil (Gas) reserves (in log)	0.0866	0.2371*	0.0863	0.2370*	0.0732	0.1928	0.0764	0.1955
	(0.067)	(0.128)	(0.066)	(0.128)	(0.067)	(0.131)	(0.066)	(0.132)
Institutional ownership	-0.3712	-0.4421	-0.3496	-0.4761	-0.3164	-0.4947	-0.2979	-0.5357
	(0.385)	(0.450)	(0.383)	(0.451)	(0.387)	(0.432)	(0.383)	(0.433)
Oil (Gas) geo diversification	-0.8071*	-2.4940***	-0.8498*	-2.4345***	-0.7776*	-2.7679***	-0.8046*	-2.6998***
	(0.458)	(0.821)	(0.474)	(0.829)	(0.432)	(0.907)	(0.442)	(0.917)
Oil (Gas) price volatility	0.0031	-0.1171			-0.0150	-0.1444		
	(0.025)	(0.118)			(0.025)	(0.103)		
Oil (Gas) basis	0.7779	-0.0911			1.0697	-0.0690		
	(1.139)	(0.316)			(1.121)	(0.321)		
Oil (Gas) production risk	0.1259	0.8008**	0.1465	0.7575**	0.1561	0.8768**	0.1678	0.8450**
	(0.447)	(0.379)	(0.443)	(0.372)	(0.458)	(0.377)	(0.456)	(0.371)
Price_Qtity corr (oil/Gas)	0.0678	-0.1024	0.0808	-0.1005	-0.0021	-0.1193	0.0036	-0.1133
	(0.171)	(0.165)	(0.168)	(0.163)	(0.159)	(0.159)	(0.161)	(0.156)
CEO ownership	4.4376	-16.2782	2.3720	-14.9322	4.0674	-19.2560	2.6944	-17.6014

	(16.005)	(18.137)	(15.832)	(17.595)	(16.197)	(18.110)	(15.897)	(17.595)
Number of CEO's options	0.0013	0.0016	0.0014	0.0015	0.0017	0.0013	0.0017	0.0011
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
Number of analysts	-0.0569***	-0.0679***	-0.0554***	-0.0682***	-0.0590***	-0.0602***	-0.0582***	-0.0607***
	(0.021)	(0.023)	(0.021)	(0.023)	(0.022)	(0.021)	(0.022)	(0.021)
Constant	-0.1387	-0.5083	-0.1213	-0.5817	-0.3182	0.3620	-0.3465	0.2383
	(0.462)	(0.754)	(0.471)	(0.764)	(0.542)	(0.960)	(0.539)	(0.977)
Observations	578		578		572		572	
Log Likelihood	-531.1938		-532.5695		-514.1019		-515.9120	
Number of firms	79		79		79		79	
Wald chi2	168.5407		146.8028		183.6589		161.9193	
Significance	0.0000		0.0000		0.0000		0.0000	
Rho	0.7916		0.7984		0.8159		0.8174	
p-value of the Wald test of rho=0	0.0000		0.0000		0.0000		0.0000	

This table reports the results of the seemingly unrelated bivariate probit regressions, which test the firms' joint decision about the extent of their hedging oil and gas production. Both dependent variables, oil hedging intensity and gas hedging intensity, are dummy variables taking the value of 1 for a high extent, i.e., higher than or equal to the 75th percentile, and taking the value of 0 for a low extent, i.e., equal to or lower than the 25th percentile. These percentiles are calculated based on HR0: the hedging ratio for the current fiscal year. The level and changes in the Kilian index are our two instrumental variables. Beside the control variables related to the firm's financial and operational characteristics used in the previous tables, this table also includes the spot price correlation measuring the correlation between the daily spot prices for oil and gas during each quarter. The interaction of the spot price correlation with a variable measuring the proportion of firm revenues driven from oil sales, is also included. All control variables are included in lagged values (first lag). See Table A1 for further details on the construction of the control variables. Heteroskedasticity-consistent standard errors clustered at the firm level are reported in parentheses. The superscripts ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

Robustness of our results for more recent years

1. We run different specifications of the bivariate probit regression, including a new variable measuring the correlation between the daily spot prices for oil and gas during each quarter, namely, *Spot price correlation.*[1] We also have this correlation interact with a variable measuring the proportion of firm revenues driven from oil sales, to control for the structure of the firm's revenues.

   Interestingly, the results in Table OA.7 reveal that the correlation between oil and gas spot prices have a positive impact on the joint hedging intensity for oil and gas production. However, the coefficient is statistically significant at conventionnel levels for only oil hedging intensity. This result suggests that a higher correlation between oil and gas spot prices motivates petroleum producers to hedge their production to greater extents. In fact, a higher correlation between spot prices for the two commodities makes the firm revenues more volatile. Moreover, the significant positive effect on the oil hedging intensity could be explained by cross-hedging behavior by the producers. When oil and gas spot prices are more closely correlated, hedging oil price risk could be a substitute for hedging gas price risk.

2. We then turned to the analysis of the dynamics of oil and gas spot prices during our sample period and afterwards. We calculated the correlation between monthly spot oil and gas prices. The correlation is around 0.66 during our sample period. For the subsequent period (from January 2011 to April 2022), the correlation is around 0.64. The two correlations are very close, indicating that the dynamics of oil and gas spot prices are still relatively the same during and after our study

[1] We use the Cushing, OK WTI Spot Price FOB (Dollars per Barrel) for the oil spot prices and Henry Hub Natural Gas Spot Price (Dollars per Million Btu). Data is extracted from the web site of the U.S Energy Information Administration: https://www.eia.gov/.

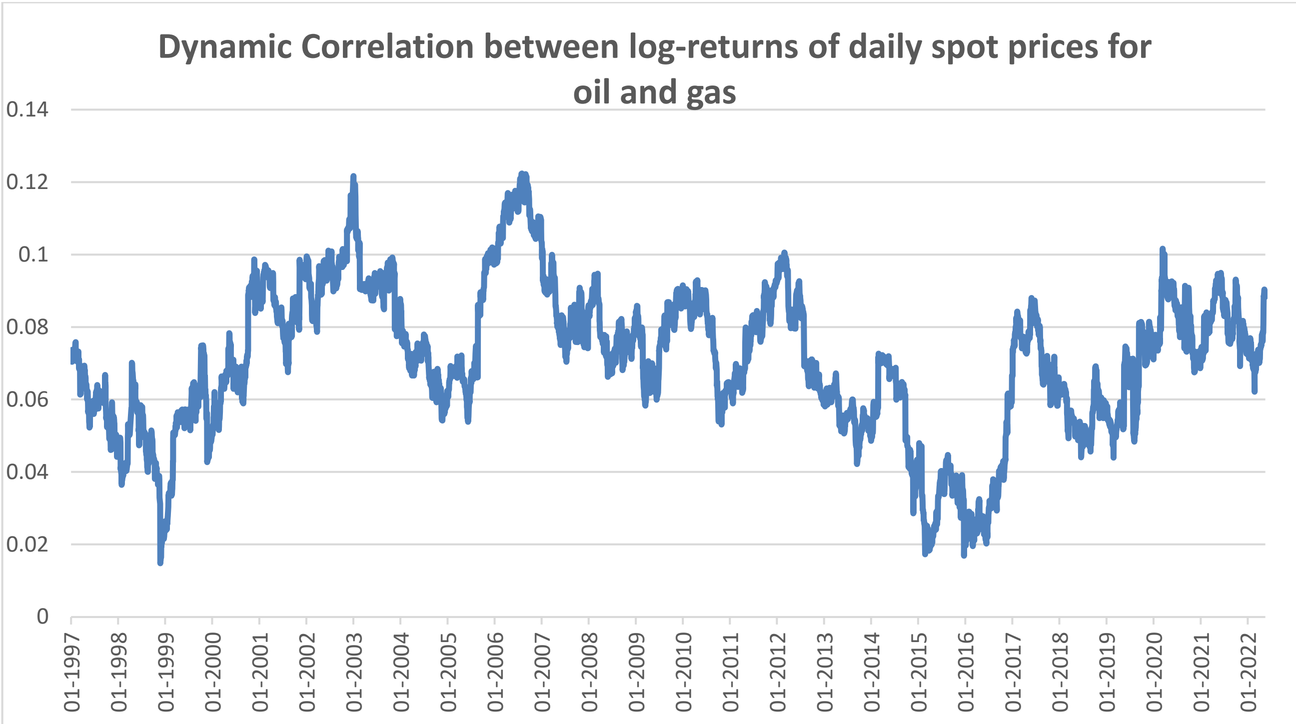
period. We recalculated the correlations using daily spot prices and also found very close values. The correlation is about 0.64 between daily prices during our sample period and around 0.58 during the period afterwards (2011–2022).

3. Going into greater detail to discover the dynamics between spot oil and gas prices, we estimated the time-varying correlation between the log-returns coming from the daily spot prices of the two commodities. We used a DCC-GARCH–style specification to model the dynamic conditional correlation between the log-returns. In short, we estimated the daily dynamic volatility of the log-returns using a non-linear GARCH-style model, namely NGARCH (1,1). After standardizing each daily return using its NGARCH standard deviation, we estimated the DCC-GARCH model for the two series, for the standardized returns of both commodities.

   The following plot in Figure OA.1 shows how this dynamic correlation evolved during all periods from 1997 to 2022. Overall, we observe that the dynamic correlation is oscillating around its long-run average of about 0.08. The lowest and highest values are, respectively, 0.02 and 0.12 during the entire period (1997–2022), suggesting that oil and gas spot prices keep evolving over time with the same dynamics.

In conclusion, we can presume that the results of our study are still valid nowadays, because oil and gas prices have evolved over time with the same dynamics since 1997.

Figure OA.1



Dynamic Correlation between log-returns of daily spot prices for oil and gas
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
01-1997
01-1998
01-1999
01-2000
01-2001
01-2002
01-2003
01-2004
01-2005
01-2006
01-2007
01-2008
01-2009
01-2010
01-2011
01-2012
01-2013
01-2014
01-2015
01-2016
01-2017
01-2018
01-2019
01-2020
01-2021
01-2022