Journal of Financial Stability 67 (2023) 101152

Contents lists available at ScienceDirect

Journal of Financial Stability

journal homepage: www.elsevier.com/locate/jfstabil

Promoting financial stability of oil producers: Operational vs. financial hedging☆

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ARTICLE INFO

JEL classification:
G30
G32
L1

Keywords:
Operational hedging
Financial hedging
Oil producer
Risk management

ABSTRACT

This paper investigates the effects of operational hedging on commodity price risks. It explores a novel type of operational hedging, i.e., the natural operational hedge position between upstream crude oil production and downstream activities in the supply chain. Using hand-collected data from 293 unique oil-producing firms, we find that operational hedging is sufficiently effective in reducing firms' exposure to oil-price risk. We also find an inverse relationship between operational and financial hedging, suggesting that they can substitute for each other.

1. Introduction

From the 2000s onward, crude oil markets have witnessed at least three shocks: the 2008 financial crisis, the 2014 oil glut, and the 2020 Russia-Saudi Arabia oil-price war, when the COVID-19 pandemic spread widely. As a result, the demand for oil products declined dramatically. The demand uncertainties severely damaged crude oil markets, which negatively affected the welfare of oil producers. As suggested by Singh (2020), the side effects from oil price shocks are likely to last longer in the current volatile international political and strategic environment, and this renders our questions: How can oil producers protect themselves from becoming victims of the turmoil of crude oil markets? At the corporate level, firms can manage such risk exposure by implementing financial hedging strategies, involving the use of financial derivatives to protect firm value. Previous studies have advanced our understanding of how financial hedging and firm value are intertwined.[1] Although the use of financial derivatives is effective in reducing the sensitivity of oil producers' stock prices to oil-price fluctuations, from empirical observation, the average financial hedge ratio is less than 20 % of their production (Jin and Jorion, 2006). As suggested by Guay and Kothari (2003), "corporate derivative use appears to be a small piece of non-financial firms' overall risk profile." A possible explanation is that the effectiveness of financial hedging is diminished when commodity price volatility is high (Laing et al., 2020). Another possibility is that firms implement techniques such as operational hedging activities to manage their risk exposure (Cachon, 2003). However, operational hedging has not been consistently described in the literature. As suggested by Treanor et al. (2014), each industry has its unique operational hedging strategies that are not necessarily comparable across industries. Cohen and Huchzermeier (1999) suggest that operational hedging can be viewed as the exercise of real options to anticipate and respond to changes in market conditions and represents a firm's ability to postpone its operational decision to adapt to the changing market (Ding, Dong and Kouvelis, 2007). Similar to this kind of operational flexibility, geographical diversification is discussed as another operational hedging strategy in a multinational context.[2] A key focus of this paper is a novel type of operational hedging, i.e., the natural hedging positions between simultaneous upstream crude oil production and downstream activities in the supply chain. To date, this form of operational hedging has not been studied in the literature.

☆ This work is supported by the National Science Foundation of China [Grant ID: 72272104].

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[1] Allayannis and Weston (2001), Jin and Jorion (2006), Gilje and Taillard (2017), among others, empirically test the relation between financial hedging and firm value. Haushalter (2000), Kumar and Rabinovitch (2013), among others, find evidence for explaining the rationales behind financial hedging.

[2] See Hommel (2003), Kim, Mathur and Nam (2006), Hutson and Laing (2014), and Laing et al. (2020).

https://doi.org/10.1016/j.jfs.2023.101152
Received 7 July 2022; Received in revised form 10 June 2023; Accepted 14 June 2023
Available online 16 June 2023
1572-3089/

Hull (2015) points out that a firm's position in the supply chain is important for hedging activities. In the oil-extraction industry, Standard Industry Code (SIC) 1311, some firms focus solely on upstream business activities while others engage in both upstream and midstream/downstream businesses.[3] The former can benefit from implementing short hedges. The latter firms' incentive for short hedging depends, however, on the nature of their downstream/midstream businesses, because some can arguably regulate the earning variation of oil producers instead of financial hedging. As a result, when a firm is involved with both upstream and downstream segments, its net exposure to oil-price risk is less than that of firms involved only with upstream businesses.

We construct our novel type of operational hedging to shed light on two research questions that remain unresolved: 1) Does operational hedging reduce firm risk exposure? and 2) What is the nature of the relationship between financial and operational hedging, and do they substitute for or complement each other? Although several papers have considered these research questions, their conclusions are mixed and most of the evidence considers diversification effects as operational hedging effects (Allayannis et al., 2001; Allayannis and Ofek, 2001; Kim et al., 2006; Hutson and Laing, 2014; Laing et al., 2020).

Our first research question concerns whether operational hedging activities can contribute to reducing a firm's exposure to oil-price risk. Following Jin and Jorion (2006), using the market model and the Fama-French 3-factor model, we examine whether operational hedging activities contribute to reducing the sensitivity of a firm's stock returns to oil-price movement (the beta risk). Our evidence indicates that operational hedging, compared to financial hedging, is more effective in reducing firms' exposure to oil-price risk.

Despite the benefits of operational hedging, however, less than 30 % of the observations in our sample contain operational hedging activities. Because entering a new business segment involves extra investment, asset purchases, or a merger-and-acquisition (M&A) process, it is costly for an upstream firm to step into the downstream segment (or to be vertically integrated). Therefore, we implement the propensity-score-matching (PSM) method to mitigate potential omitted-variable (or selection-bias) concerns,[4] and our results are robust.

Our second research question investigates the relationship between operational and financial hedging. Allayannis and Ofek (2001), Guay and Kothari (2003), Brown, Crabb and Haushalter (2006), Kim et al. (2006), and Hutson and Laing (2014) argue that multinational activities (operational hedging) and financial hedging are positively related. We extend their evidence by testing in the oil industry, which is homogeneous in the sense that product types are relatively standardized.[5] Following Allayannis and Ofek (2001), and Kim et al. (2006), we regress a firm's financial hedging activities on operational hedging activities, and characteristics of firm-related variables that measure financial-distress costs, and external-financing costs. Our analysis reveals a negative relationship between financial and operational hedging in the oil industry, which indicates that financial and operational hedging activities are substitutes for each other. We also use the PSM method to mitigate concerns regarding omitted variables, and the results are robust.

The contribution of our paper to the literature is threefold. First, we complement prior literature[6] by introducing a novel type of operational hedging, i.e., the natural operational hedging positions between upstream crude oil producers and downstream oil consumers. Second, the study increases our understanding of the relationship between operational hedging and commodity price risk. Using a homogeneous industry, the oil-producing sector, we provide evidence that operational hedging can mitigate firms' exposure to commodity price risks. Finally, our research fills a gap in the literature by providing unique evidence that financial and operational hedging are substitutes for each other.

The remainder of the paper is structured as follows. Section 2 reviews the literature and develops our hypotheses. Section 3 describes the sample and explains the variables. Section 4 describes our empirical strategies and results. Section 5 describes the robustness tests. Section 6 concludes the paper.

2. Literature and hypotheses

Our study builds on the financial risk-management literature. Many early studies have examined the hedging premium in general.[7] The literature also explores the incentives to hedge. For example, risk-management theories argue that financial hedging can increase firm value by reducing bankruptcy costs (Smith and Stulz, 1985; Mayers and Smith Jr, 1990), the underinvestment problem from costly external financing (Froot et al., 1993), and expected tax liabilities (Smith and Stulz, 1985).

Firms also engage in operational hedging activities (Cachon, 2003) to manage their risk exposure. Operational hedging is defined in the finance literature as the activities that reduce risk exposure by employing non-financial instruments, primarily through operational activities. Since operational hedging can be used for strictly value-enhancement purposes, operational actions are considered to be hedges only if they are employed to reduce risk exposure (Chowdhry and Howe, 1999; Hommel, 2003). Although it is difficult to identify and measure firms' operational hedging strategies, and the unique operational hedging strategies in each industry are not necessarily comparable to each other, real options and geographical diversification are the two major definitions thereof discussed in the literature.[8] Cohen and Huchzermeier (1999) suggest that operational hedging can be viewed as real options that a firm can exercise according to changing market conditions. Such options refer to a firm's capability to postpone its decision (Ding et al., 2007) to adapt to these changes. Boyabatli and Toktay (2004) suggest that geographical diversification (opening production facilities in different markets) can be viewed as an operational hedging strategy in the sense that it aligns the costs and revenues of a firm so that they are exposed to less financial risk. Compared with financial hedging, the operational flexibility created through either real options or geographical diversification and high levels of capital investment (such as opening a new production facility) is the main feature of an operational hedging strategy.

Even though operational hedging has been frequently discussed in the prior literature, empirical evidence that operational hedging activities are effective in managing various types of risk exposure is thin and inconclusive. For example, Allayannis and Ofek (2001) and Pantzalis et al. (2001) find that operational hedging leads to lower foreign exchange risk exposure for multinational corporations. In a similar vein, Kim et al. (2006), and Choi and Jiang (2009) conclude that operational hedging is effective in reducing risk exposure and that it also has value-adding effects. Examining the relation between multinational firms with greater geographic dispersion and their risk exposure by investigating the US oil and gas companies over the period 2000–2015, however, Laing et al. (2020) find no evidence that operational hedging is effective. For these studies, the operational hedging measurement is

[3] Appendix A lists our downstream/midstream businesses information, such as segment name and segment identifier (sid).

[4] See Cao et al. (2021), and Chen et al. (2021) for the PSM approach.

[5] The firms are heterogeneous in marginal costs and product qualities, but all produce petroleum-related goods.

[6] Most of the literature considers geographical diversification effects (see Allayannis et al., 2001; Choi and Jiang, 2009; Kim et al., 2006; Hutson and Stevenson, 2010; Jongen et al., 2012; Hutson and Laing, 2014; Laing et al., 2020) and real options effects (Tufano, 1998; Petersen and Thiagarajan, 2000) as operational hedging strategies.

[7] See Smith and Stulz (1985), Froot, Scharfstein and Stein (1993), Jin and Jorion (2006), among others.

[8] See Boyabatli and Toktay (2004).

defined as a firm's multinationality,[9] which captures diversification effects. Lim and Wang (2001) show that operational hedging, which is measured as corporate diversification, is more often useful for mitigating idiosyncratic risk.

In the commodity setting, very few studies have shed light on the important role of operational hedging since it is very difficult to identify and measure the real-option effect. In most cases, the data required to conduct operational hedging studies are not easily accessible. Tufano (1998) examines a gold-mining firm's real-option effect (using the range of costs to proxy for option flexibility) and finds that operational hedging helps reduce gold-mining firms' exposure to gold price changes. Petersen and Thiagarajan (2000) examine the operational-hedging behaviors of two gold-mining firms: one uses only financial hedging strategies while the other employs only operating and financial hedging activities. They find that an operationally managed firm has lower costs during a period of declining gold prices, while this is not the case for the financially hedged firm. Since research on operational hedging and commodity-price exposure is still nascent, our paper examines the oil production sector by exploring a novel type of operational hedging, i.e., the natural operational hedging positions between upstream crude oil producers and downstream oil consumers, to shed light on the role of operational hedging in managing oil-price risk.

Within the oil-production industry, some firms engage only in upstream business activities and others include both upstream and midstream/downstream businesses, some of which are not related to crude oil prices. On the other hand, while other businesses such as refining, storage, and transportation are still associated with spot crude oil prices, these physical assets can be used to regulate the earning variation of oil producers. For instance, when owning refinery facilities, producers can process some crude oil to a refined product, which reduces these firms' exposure to spot crude oil price uncertainty. Storage assets can also be used for smoothing out producers' earnings. For example, a storage operator injects oil when the spot price is low and sells it when it is high. The transportation asset is yet another way of regulating earning uncertainty, e.g., under demand uncertainty, a producer can transport crude oil to the location of a potential buyer. All in all, midstream/downstream activities are either unrelated to spot oil price or even decrease exposure to crude oil price risk.[10] Because stock price represents discounted future earnings of a public firm, we present the following hypothesis:

H1. : *Operational hedging reduces the sensitivity of oil producers' stock prices to changes in oil prices.*

Managing commodity risk exposure involves a range of financial and operational hedging tools. The former including futures, swaps, options, etc, comes with direct financial cost and most of the contracts are short-term. In addition, the implementation of financial hedging strategies is contingent on the liquidity and efficacy of the related financial derivatives. As suggested by Hoberg and Moon (2017), operational hedging strategies increase when the liquidity of financial contracts deteriorates or the financial hedging efficacy decreases.

Operational hedging, which involves altering the firm's real operations to reduce overall risk exposure, is a critical element in managing risk exposures and involves costs in a different way, such as capital investment in building plants. Compared with financial hedging strategies, operational hedging has the advantage of flexibility which enables firms to anticipate and respond to demand uncertainties flexibly by means of the firm's operations. Chowdhry and Howe's (1999) model suggests that operational hedging is particularly useful for firms that find it difficult to predict future cash flows. Therefore, Hoberg and Moon (2017) conclude that decreased derivative liquidity and efficacy likely cause substitutions away from financial hedging and toward operational hedging, and these hedges are substitutes. Moreover, if operational hedging is sufficiently effective, financial hedging is not necessarily required (Hutson and Laing, 2014). In this case, the two hedging strategies should be substitutes for each other. Hence, we hypothesize that:

H2. : *There is a negative relationship between financial and operational hedging.*

3. Sample and variable construction

3.1. Sample construction

Our analysis is based on a sample of U.S. oil-producing firms from 2000 to 2021. We rely on various data sources to construct the sample. We select all firms with Standard Industrial Classification (SIC) codes of 1311 and gather data on firm-level characteristics from COMPUSTAT. SIC 1311 firms engage primarily in producing Crude Petroleum and Natural Gas. To quantify firms' operational hedging behaviors, we collect firms' segment information from Compustat Segment files. To quantify firms' financial hedging behaviors, we hand-collect firm hedging data from their 10-K reports.[11] We also collect these oil spot-price data from the Energy Information Administration (EIA). Firms' monthly stock prices are derived from CRSP.[12] All the firm-level characteristic data are gathered from Compustat.

As an alternative to studying multinational firms, we choose to analyze the effects of operational hedging on oil producers for several reasons. First, it is easy for firms to implement hedging strategies because oil is an important energy source and derivative securities are liquid. This advantage makes it easy for us to better investigate both operational and financial hedging activities. Second, the oil-production industry is homogeneous in production output, and firms are similarly exposed to oil-price risk and utilize similar hedging strategies (see Jin and Jorion, 2006). Oil producers are exposed to common market risks, i.e., the movement of oil prices, which has a significant impact on firm cash flows and income. This homogeneity helps minimize endogeneity problems such as omitted variables and spurious correlations. Because of the availability of financial hedging data for oil-producing firms, corporate risk-management theories have been empirically tested by Haushalter (2000), Rajgopal and Shevlin (2002), Jin and Jorion (2006), Kumar and Rabinovitch (2013), Adam et al. (2017), and Laing et al. (2020).

3.2. Hedging measures

3.2.1. Operational hedging

In this paper, we employ the natural operational hedging positions between upstream and downstream oil segments. So why and how can owning upstream and downstream segments simultaneously be natural hedging for a firm and affect hedging with financial derivatives, and why could this natural hedging position lead to less financial hedging? In the oil-producing industry (often called an upstream business), crude oil is the output product, while in the downstream segment, crude oil is the input element. As long as the oil price volatility is costly for firms, higher oil price exposure leads to more financial hedging. However, when a firm owns both upstream and downstream segments at the same time, its net oil price-denominated position (and thus the actual oil price exposure) becomes lower, providing for fewer incentives to hedge

[9] They use the number of subsidiaries, number of countries, and the ABHK multinationality classification system (Aggarwal et al., 2011) as proxies for operational hedging.

[10] See Appendix B for the mathematic proof.

[11] The information we collect from the company's 10-K files includes oil production volume, the hedging volume for next year, hedging instruments, and their strike prices if they are nonlinear derivatives.

[12] We obtain the Fama-French factors online. https://mba.tuck.dartmouth.edu/pages/faculty/ken.french/data_library.html

Table 1 Summary statistics.

Variables	Mean	p5	p50	p95	SD	N
FHedgeRatio	0.1720	0.0000	0.0000	0.7423	0.2558	1822
OPHedgeRatio	0.0933	0.0000	0.0000	0.5465	0.2089	1822
Cash Holding	0.0716	0.0003	0.0234	0.3287	0.1236	1822
Bond Rating	0.1044	0.0000	0.0000	1.0000	0.3059	1822
GEO	0.1044	0.0000	0.0000	1.0000	0.3059	1822
Z-Score	1.0404	-2.3773	1.1149	3.8466	1.8643	1822
Leverage	0.3123	0.0000	0.2972	0.7158	0.2093	1822
Dividend Dummy	0.4538	0.0000	0.0000	1.0000	0.4980	1822
ROA	0.0025	-0.3463	0.0430	0.1678	0.1756	1822
Asset	6.7440	2.9070	6.9306	10.3536	2.2745	1822
Investment Growth	0.2067	0.0217	0.1806	0.4829	0.1442	1822

This table presents the descriptive statistics of SIC 1311 firms' hedging activities and characteristics from 2000 to 2021. The whole sample contains 293 unique firms with 1822 firm-year observations. See Appendix C for variable definitions and sources.

Table 2
Statistical properties of oil price change betas.

Panel A: The Market Model	**Beta_Oil**	**Beta_MKT**	**Beta_SMB**	**Beta_HML**
Mean	0.2434	1.4100		
Median	0.2022	1.1551		
SD	0.4541	1.1960		
p5	-0.4809	0.1597		
p95	0.9677	3.4283		
Percent > 0	88.16 %			
Percent < 0 and significant at p < 0.05	3.07 %			
Panel B: Fama-French 3-factor model	**Beta_Oil**	**Beta_MKT**	**Beta_SMB**	**Beta_HML**
Mean	0.2306	1.3093	0.7384	0.7661
Median	0.1862	1.1353	0.6042	0.7408
SD	0.4652	1.0547	1.1896	0.9172
p5	-0.5061	0.0760	-1.0156	-0.6847
p95	0.9732	3.1546	2.7614	2.3477
Percent > 0	88.60 %			
Percent < 0 and significant at p < 0.05	3.51 %			

This table presents the statistical properties of oil-price change betas estimated based on the market model and the Fama-French three-factor model. Panel A presents the factor coefficients from the market model (model 2). Panel B presents the factor coefficients from the Fama-French three-factor model (model 3).

against it. Upstream and downstream segments are, therefore, natural hedges for each other. If a firm owns both segments, the firm is operationally hedged. In this spirit, we use the ratio of sales from downstream segments to total sales as a proxy for operational hedging (*OPHRatio*). The higher the ratio, the more the firm is operationally hedged. Miller and Reuer (1998) suggest using the ratio of foreign assets to total assets as a proxy for operational hedging. However, this measurement does not consider the distribution of multi-subsidiaries' business activities. As argued by Hutson and Laing (2014), a firm with 60 % of its assets in one subsidiary, for example, might only concentrate on 30 % of the entire firm's profits.[13] Therefore, we use the ratio of assets from downstream segments to total assets as an alternative measurement of operational hedging for robustness tests.

3.2.2. Financial hedging

We hand-collect financial hedging information, such as notional volume, strike prices, and derivative contracts (i.e., futures, forwards, swaps, and options), for each oil-production firm from their 10-K reports.[14] Following Jin and Jorion (2006), for a short position of the linear instrument, we also assume the delta is −1.[15] For a non-linear option position, we calculate the delta position based on the Black-Scholes option-pricing model. Since expiration dates and volatility information are not presented in 10-K reports, we use the average expiration time, which is six months (t = 0.5), and OVX (a proxy for oil-price volatility) as inputs for the Black-Scholes model. The risk-free rate is the 6-month T-bill rate from the U.S. Department of the Treasury. The oil spot price for each benchmark is the average price of each year's monthly prices. Following Jin and Jorion (2006), we define the financial hedging intensity (financial hedge ratio) for each firm *i* in time *t* as follows:

$$FHRatio_{it} = -Portfolio \quad Delta_{it}/Oil \quad Production_{it} \tag{1}$$

To construct the portfolio delta, we multiply the notional amounts (hedging volumes) of each contract by their delta and sum them. We then divide the total delta position by the oil production amount to obtain the financial hedge ratio. The delta hedge position should be greater than or equal to zero for all firms in the entire sample for each year.

We exclude firms without 10-K reports and production information. We also drop observations with missing values in certain firm-level characteristic variables, such as asset and cash-holding levels. Small firms with total assets below $20 million are also dropped, since these firms have fewer disclosure requirements, making it difficult to determine their hedging activities. We winsorize all variables at the 1 % and 99 % levels to mitigate the influence of extreme values, and this results in a final sample consisting of 293 unique firms with 1822 firm-year observations. Appendix C summarizes the definitions and data sources of all variables.

Table 1 describes the summary statistics for all the variables: 45 % of total firm-year observations have financial hedging activities, and less than 30 % of observations have operational hedging activities. The average operational hedging ratio is 9 %. As presented in Table 1, firms' financial hedging intensity is, on average, about 17 %, which is in line with Haushalter (2000), and Jin and Jorion (2006).

4. Empirical testing strategies and results

4.1. Does operational hedging reducing firm exposure to oil-price risks?

We begin with the estimations to test *H1*, i.e., whether operational hedging is effective in reducing firm exposure to oil-price risk (beta risk). Following Jin and Jorion (2006), we first estimate the oil betas for each firm using the market model:

$$R_{i,t} = \alpha_i + \beta_{oil,i} * R_{oil,t} + \beta_{m,i} * R_{mkt,t} + \varepsilon_{i,t} \tag{2}$$

where $R_{i,t}$ is the monthly stock return for each firm *i* in month *t*, $R_{mkt,t}$ is the monthly return for the S&P index, $R_{oil,t}$ is the monthly rate of change in oil spot prices. To mitigate the concern that the stock return is not fully explained by the market model, we also estimate the oil betas based on the Fama-French 3-factor model:

[13] Segment information (i.e., sales from each department every year and each department's name) is also taken from Compustat. Please see Appendix A for the list of segment information.

[14] In January 1997, the SEC required companies to disclose their market-risk information quantitatively. Linsmeier and Pearson (1997) discuss the rules in detail, and Philippe (2001) describes in detail the quantitative risk-measurement methods.

[15] Linear contracts include swaps, futures, and fixed contracts. Nonlinear contracts include put, call, and collar options.

Table 3
The effects of hedging on oil betas.

	Monthly Stock Return					
	The Market Model			The Fama-French 3-factor Model		
	(1)	(2)	(3)	(4)	(5)	(6)
FHRatio × Oil Return	0.0257		-0.0208	0.0235		-0.0281
	(0.0540)		(0.0545)	(0.0531)		(0.0536)
OPHRatio × Oil Return		-0.3422 * **	-0.3588 * **		-0.3653 * **	-0.3982 * **
		(0.0588)	(0.0612)		(0.0579)	(0.0602)
Oil Retrun	0.1738 * **	0.2333 * **	0.2356 * **	0.1564 * **	0.2079 * **	0.2252 * **
	(0.0183)	(0.0168)	(0.0211)	(0.0181)	(0.0166)	(0.0208)
MKT	1.4839 * **	1.4306 * **	1.4817 * **	1.2650 * **	1.2994 * **	1.2606 * **
	(0.0348)	(0.0331)	(0.0347)	(0.0352)	(0.0326)	(0.0352)
SMB				0.9033 * **	0.5587 * **	0.9194 * **
				(0.0612)	(0.0463)	(0.0612)
HML				0.6530 * **	0.8734 * **	0.6497 * **
				(0.0517)	(0.0441)	(0.0516)
Constant	-0.0009	0.0023	-0.0010	-0.0027 *	0.0003	-0.0028 *
	(0.0015)	(0.0014)	(0.0015)	(0.0015)	(0.0014)	(0.0015)
Observations	14,907	14,907	14,907	14,907	14,907	14,907
R-squared	0.1333	0.1249	0.1353	0.1629	0.1528	0.1654

This table presents the results of the sensitivities of stock returns to oil-price changes with coefficients adjusted for the effect of hedging. The dependent variables are firms' monthly stock returns. Columns 1–3 are estimation results based on the market model (Model 4). Columns 4–6 are the results based on the Fama-French three-factor model (Model 5). OPHRatio and FHRatio are the operational and financial hedging variables, respectively. The data are presented as marginal effects with standard error in parentheses. * ** $p < 0.01$, * * $p < 0.05$, * $p < 0.1$.

Table 4
The effect of operational hedging on firm value.

	Tobin's Q	
	(1)	(2)
OPHRatio	0.1891 * **	0.2096 * *
	(0.0651)	(0.0969)
OPHRatio × Crisis		0.1472 * *
		(0.0678)
Crisis		-0.4605 * **
		(0.0646)
FHRatio	-0.0262	-0.0282
	(0.0458)	(0.0457)
GEO	-1.6789 * **	-1.6685 * **
	(0.4316)	(0.4310)
Asset	-0.1122 * **	-0.1120 * **
	(0.0170)	(0.0170)
Leverage	0.1988 * **	0.1970 * **
	(0.0644)	(0.0643)
Dividend Dummy	0.0298	0.0286
	(0.0317)	(0.0316)
ROA	0.1500 * *	0.1459 * *
	(0.0732)	(0.0731)
Investment Growth	0.6305 * **	0.6331 * **
	(0.0884)	(0.0883)
Production Cost	0.0912 * *	0.0866 *
	(0.0463)	(0.0463)
Constant	1.6522 * **	1.6505 * **
	(0.3067)	(0.3063)
Observations	1822	1822
R-squared	0.7219	0.7230
Firm FE	YES	YES
Year FE	YES	YES

This table presents the results of the effects of operational hedging on firm value. The dependent variable is Tobin's Q, measured as the natural logarithm of the ratio of the market value of assets to the book value of assets. OPHRatio and FHRatio are the operational and financial hedging variables, respectively. Crisis equals 1 for the fiscal year ending in calendar year 2008, 2014, 2015, or 2020 and 0 otherwise. See Appendix C for definition and sources of control variables. Column 1 examines the effect of operational hedging on firm value. Column 2 adds the interaction variable between OPHRatio and Crisis and tests if operational hedging is effective during oil crisis periods. The data are presented as marginal effects with clustered standard error in parentheses. * ** $p < 0.01$, * * $p < 0.05$, * $p < 0.1$.

Table 5
Financial hedging difference.

Variables	OP Unhedged	Mean1	OP Hedged	Mean2	MeanDiff
FHRatio	1360	0.1897	462	0.1197	0.0700 * **
FHDummy	1360	0.5018	462	0.3517	0.1447 * **
Asset	1360	6.4049	462	7.7473	-1.3424 * **

This table presents the t-tests for the operational hedged and unhedged groups. The FHRatio is the production-weighted delta hedge ratio based on model (1). The FHDummy is coded 1 if FHRatio is greater than zero, and 0 otherwise. Asset is the natural logarithm of a firm's total assets. * ** $p < 0.01$, * * $p < 0.05$, * $p < 0.1$.

$$R_{i,t} = \alpha_i + \beta_{oil,i} * R_{oil,t} + \beta_{m,i} * R_{mkt,t} + \beta_{SMB,i} * R_{SMB,t} + \beta_{HML,i} * R_{HML,t} + \varepsilon_{i,t} \tag{3}$$

where $R_{SMB,t}$ and $R_{HML,t}$ are the monthly Fama-French size and value factors.

Table 2 presents the statistical properties of oil betas estimated based on models (2) and (3) with monthly data from 2000 to 2021. Since our sample comprises oil production firms, an increase in oil prices is considered a favorable movement for them. Hence, the beta of oil return is expected to be positive. We find that 88.16 % of all oil betas are positive for the market model, and 88.60 % are positive for the Fama-French 3-factor model. For the median firms, a 1 % increase in oil prices leads to a 0.20 % (market model) and 0.18 % (Fama-French model) increase in stock prices. These numbers are very close to those in Jin and Jorion (2006) over the 1998–2001 period and Rajgopal (1999) over the 1993–1996 period.

Next, we examine whether hedging affects oil betas. The estimated model is set as follows:

$$R_{i,t} = \alpha_i + (\gamma_1 + \gamma_2 * OPHRatio_{i,t} + \gamma_3 * FHRatio_{i,t}) * R_{oil,t} + \beta_{m,i} * R_{mkt,t} + \varepsilon_{i,t} \tag{4}$$

$$R_{i,t} = \alpha_i + (\gamma_1 + \gamma_2 * OPHRatio_{i,t} + \gamma_3 * FHRatio_{i,t}) * R_{oil,t} + \beta_{m,i} * R_{mkt,t} + \beta_{SMB,i} * R_{SMB,t} + \beta_{HML,i} * R_{HML,t} + \varepsilon_{i,t} \tag{5}$$

where $OPHRatio_{i,t}$ and $FHRatio_{i,t}$ are the operational and financial

Table 6
Operational hedging v.s. financial hedging.

	(1)	(2)
	FHDummy	FHRatio
OPDummy	-0.3030 * **	
	(0.0750)	
OPHRatio		-0.1625 * **
		(0.0381)
Cash Holding	-3.4993 * **	-0.1833 * **
	(0.4055)	(0.0606)
Bond Rating	0.1450	-0.1297 * **
	(0.1110)	(0.0494)
GEO	-0.2833 * **	-0.0356
	(0.1049)	(0.0417)
Z-Score	-0.0448	-0.0054
	(0.0274)	(0.0041)
Leverage	0.3096	0.1016 * *
	(0.1947)	(0.0459)
ROA	0.3420	0.0738 * *
	(0.2256)	(0.0368)
Asset	0.2816 * **	0.0248 * **
	(0.0203)	(0.0063)
Investment Growth	1.0569 * **	0.1661 * **
	(0.2211)	(0.0573)
Dividend Dummy	0.1559 * *	0.0403
	(0.0680)	(0.0260)
Constant	-0.1352	0.2546 * *
	(0.1070)	(0.1251)
Observations	1822	1822
R-squared		0.1682
Firm FE		YES
Year FE		YES

This table reports the estimation results of the relationship between operational and financial hedging policies. OPHRatio and FHRatio are the operational and financial hedging variables, respectively. See Appendix C for definition and sources of control variables. Column 1 presents the result of the Probit regression (model 7). The dependent variable, FHDummy, equals 1 if FHRatio is greater than zero, and 0 otherwise. The OPDummy is the operational hedging indicator, which equals 1 if OPHRatio is greater than zero, and 0 otherwise. Column 2 presents the results of the OLS regression (model 8). The dependent variable is the financial hedge ratio (FHRatio). The data are presented as marginal effects with standard error in parentheses. * ** $p < 0.01$, * * $p < 0.05$, * $p < 0.1$.

Table 7
Propensity score matching (PSM) analysis.

Variables	Treated	Control	Difference	P-value
FHRatio	0.1384	0.1463	-0.0079	0.6423
Z-Score	0.0729	0.0866	-0.0137	0.1705
Bond Rating	0.2178	0.1995	0.0184	0.5332
Cash Holding	0.1444	0.1181	0.0262	0.2839
Leverage	1.256	1.4074	-0.1513	0.2338
Asset	0.3133	0.2918	0.0215	0.1215
GEO	7.8671	7.6444	0.2227	0.1531
Investment Growth	0.1521	0.1518	0.0003	0.9651
Dividend Policy	0.0136	0.0142	-0.0005	0.8297

This table presents 381 observations (treatment group) that are operationally hedged. The control group consists of operationally unhedged firms but are similar to the treatment group in firm characteristics. We also require the controlled firms to cover the same years as the treatment firms. The 1-to-1 propensity-score-matching method is used to form the control group, and p-values are reported for the mean differences of all matching variables. See Appendix C for definition and sources of the matching variables.

hedging variables, respectively. Since our first hypothesis is that hedging activities can contribute to reducing a firm's exposure to oil-price risk, this should be reflected in the sensitivity of the firm's stock return to the change in oil prices. We predict a negative sign for both γ_2 and γ_3.

Table 3 presents the results of the sensitivities of stock returns to oil-price changes from 2000 to 2021 with coefficients adjusted for the effect of hedging. The first three columns present the estimation results based on model (4), and the last three columns present the results based on model (5). In column 1, the regression tests only for the effect of financial hedging (γ_3) on oil-price changes. The coefficient of *FHRatio* × *OIL* is insignificant, suggesting that the financial hedging strategy is not effective in reducing the sensitivity of stock returns to oil-price changes. In column 2, we test whether operational hedging is effective in reducing the beta of oil-price changes. γ_2 is -0.3422, which is statistically significant at the $p < 1$ % level suggesting, as expected, that operational hedging sufficiently reduces the sensitivity of stock returns to oil-price changes. Choi and Jiang (2009) also report the effects of operational hedging on reducing risk exposure. In column 3, we investigate both financial and operational hedging effects on the oil beta. We see that the effect of financial hedging (γ_3) is insignificant, but that of operational hedging (γ_2) is negative and significant at the $p < 1$ % level. Consistent with the market model, the results from columns 4–6 also show that operational hedging activities are more effective in reducing a firm's exposure to oil-price risk than a financial hedging strategy. In summary, our evidence indicates that the market recognizes the effect of operational hedging activities on firms' stock exposure to oil-price risks, which supports our *H1* that operational hedging reduces exposure to oil price risks.

To better understand the motivation of the practice of operational hedging, besides commodity price risks, we further examine the effects of operational hedging on firm value, as measured by Tobin's Q. Following Jin and Jorion (2006), we use an OLS regression to directly test whether hedging increases firm value. The linear regression model is set up as follows:

$$Q_{i,t} = \alpha + \beta_1 * OPHRatio_{i,t} + \beta_2 * X_{i,t} + \varepsilon. \quad (6)$$

where $Q_{i,t}$ is firm i's value measured by the natural logarithm of Tobin's Q in year t; $X_{i,t}$ are the control variables, including financial hedging policy, firm size, profitability, leverage, dividend policy, investment growth, geographic diversification, and production cost.[16]

The findings regarding the impact of operational hedging on firm value are presented in Table 4. Column 1 follows a similar setup to Jin and Jorion's (2006) study and shows that the *OPHRatio* coefficient is both positive and statistically significant, indicating that operational hedging contributes to overall firm value. As our dataset covers three distinct oil price shocks, namely the 2008 financial crisis, the 2014 oil glut, and the 2020 oil price shock, we further examine whether operational hedging is particularly effective during such crisis periods. To test this, we introduce an interaction variable between the *OPHRatio* and *Crisis*[17] in column 2. Our results demonstrate a positive and significant coefficient for this interaction term, suggesting that operational hedging strategies are indeed effective in managing risk during oil price shocks. This implies that operational hedging may provide firms with greater flexibility and adaptability compared to financial hedging methods, such as oil derivatives, when it comes to mitigating the negative impact of crises on both their operations and financial performance.

4.2. The relation between operational and financial hedging

Our evidence thus far indicates that operational hedging can effectively reduce firm exposure to oil-price risk and also adds to firm value. As suggested by Hutson and Laing (2014), if operational hedging is sufficiently effective, financial hedging activities are not necessarily required. To investigate *H2*, i.e., the relation between operational and financial hedging, we first t-test the financial hedging difference between operationally hedged and unhedged firms. Table 5 reports the t-test results. We see that the average financial hedge ratio for operationally unhedged firms is 18.97 %, which is 11.97 % higher than that

[16] See Appendix C for variable descriptions.

[17] Crisis is an indicator variable that equals to 1 for fiscal year end in calendar year 2008, 2014, 2015 or 2020, and 0 otherwise.

Table 8
Robustness tests of the effects of hedging on oil betas.

	Monthly Stock Return					
	The Market Model			The Fama-French 3-factor Model		
	(1)	(2)	(3)	(4)	(5)	(6)
OPDummy × Oil Return	-0.1966 * **			-0.2095 * **		
	(0.0302)			(0.0297)		
FHDummy × Oil Return	-0.0886 * **			-0.0873 * **		
	(0.0292)			(0.0287)		
OPHRatio2 × Oil Return		-0.3106 * **			-0.3434 * **	
		(0.0395)			(0.0388)	
OPHRatio × Oil Return			-0.1504 * **			-0.1743 * **
			(0.0426)			(0.0416)
FHRatio × Oil Return		0.0037	-0.0755		-0.0009	-0.0889
		(0.0540)	(0.0697)		(0.0530)	(0.0681)
Oil Return	0.3042 * **	0.2393 * **	0.0888 * **	0.2793 * **	0.2291 * **	0.0675 * **
	(0.0259)	(0.0201)	(0.0251)	(0.0255)	(0.0198)	(0.0246)
MKT	1.4302 * **	1.4807 * **	1.6869 * **	1.2985 * **	1.2582 * **	1.4433 * **
	(0.0331)	(0.0347)	(0.0470)	(0.0326)	(0.0351)	(0.0470)
SMB				0.5631 * **	0.9308 * **	0.9326 * **
				(0.0463)	(0.0611)	(0.0818)
HML				0.8708 * **	0.6470 * **	0.8042 * **
				(0.0441)	(0.0516)	(0.0680)
Constant	0.0022	-0.0010	-0.0017	0.0002	-0.0029 * *	-0.0016
	(0.0014)	(0.0015)	(0.0020)	(0.0014)	(0.0015)	(0.0020)
Observations	16,683	14,907	7497	16,683	14,907	7497
R-squared	0.1255	0.1369	0.1574	0.1535	0.1673	0.1983

This table presents the robustness tests of the sensitivities of stock returns to oil-price changes with coefficients adjusted for the effect of hedging policies. The dependent variables are firms' monthly stock returns. Columns 1–3 are estimation results based on the market model (model 4). Columns 4–6 are the results based on the Fama-French three-factor model (model 5). Column 1 replaces the OPHRatio and FHRatio in the market model with OPDummy and FHDummy, respectively. OPDummy equals 1 if OPHRatio is greater than zero, and 0 otherwise. FHDummy, equals 1 if FHRatio is greater than zero, and 0 otherwise. Column 2 replaces the OPHRatio in the market model with OPHRatio2. OPHRatio2 is defined as the ratio of assets from downstream segments to a firm's total assets. Column 3 is the estimation of the market model but based on the 1-to-1 matched sample. Columns 4–6 present the same settings as the first three columns but are based on the Fama-French three-factor model (model 5). The data are presented as marginal effects with standard error in parentheses. * ** $p < 0.01$, * * $p < 0.05$, * $p < 0.1$.

for operationally hedged firms. The probability of being financially hedged is also higher for operationally unhedged firms. In addition, operationally hedged firms are, on average, larger than unhedged firms, which supports our argument that the operational hedging strategy requires high levels of capital investment.

To further investigate whether the operational hedge is a substitute for or a complement to financial hedging, we employ both Probit and OLS models and control for firm characteristic-related variables. Following Haushalter (2000) and Jin and Jorion (2006), the Probit regression model and the OLS regression model are set as follows respectively:

$$FHDummy_{i,t} = \alpha + \beta_1 * OPDummy_{i,t} + \beta_2 * X_{i,t} + \varepsilon \tag{7}$$

where $FHDummy_{i,t}$ is the financial hedging indicator variable[18]; $OPDummy_{i,t}$ is the operational hedging indicator[19]; X_t are the control variables.

$$FHRatio_{i,t} = \alpha + \beta_1 * OPHRatio_{i,t} + \beta_2 * X_{i,t} + \varepsilon \tag{8}$$

where $FHRatio_{i,t}$ is the financial hedge ratio; $OPHRatio_{i,t}$ is the operational hedge ratio; $X_{i,t}$ includes the following control variables.

Financing cost: The previous literature has suggested that a firm's financing cost will affect its financial hedging decision. We use bond rating and cash holdings as proxies for a firm's financing cost. A firm with a higher debt rating will have lower financing costs (Barclay and Smith Jr, 1995). If firms have more cash on hand, the need for financing will be reduced and, thus, financing costs will also be lower, which will consequently impact firms' financial hedging decisions.

Financial-distress cost: Corporate hedging activities can reduce expected financial-distress costs (Stulz, 1984; Smith and Stulz, 1985). It is, therefore, important to control for expected financial-distress costs. We use firm leverage and Z-score as proxies for a firm's expected financial-distress cost.[20] Whited (1992) and other studies argue that firms with higher leverage are more likely to have financial constraints. Z-score measures a firm's bankruptcy probability (Altman, 1968) and the higher the Z-score, the less likely is the firm to go bankrupt. Thus, expected financial-distress costs will also be lower.

Profitability: Profitable firms are more likely to hedge, and it is, thus, important to control for it. We use ROA as a proxy for a firm's profitability.

Size: Döhring (2008) suggests that large firms are more likely to hedge due to the high fixed cost of hedging, and we use the log of firm total assets to proxy for size.

Payout policy: A firm's payout policy may reflect its financial situation and, as a result, may also affect its hedging decision (Haushalter, 2000).

Investment growth: We control for investment growth because expected bankruptcy costs are an increasing function of a firm's investment opportunities (Myers, 1984), which may affect its hedging decision. We use capital expenditures over total assets as a proxy.

GEO: Some existing studies have documented that geographic operational hedging has an impact on financial hedging positions, therefore we also control for a firm's geographic diversification.[21]

Table 6 presents the empirical results of the relationship between operational and financial hedging. Specifically, column 1 reports the result of Model (7), the Probit regression. The coefficient of *OPDummy* is negative and significant, which indicates that the implementation of operational hedging strategy reduces the likelihood of financial hedging.

[18] $FHDummy_{i,t}$ equals to 1 if the firm is financially hedged and 0 otherwise.
[19] $OPDummy_{i,t}$ equals to 1 if the firm is operationally hedged and 0 otherwise.
[20] See Appendix C for the definition of Z-score.
[21] See Laing et al. (2020) for the review.

Table 9
Robustness tests of operational hedging v.s. financial hedging.

	(1) FHDummy	(2) FHRatio	(3) FHRatio	(4) FHDummy	(5) FHRatio
OPDummy				-0.2837 * **	
				(0.1043)	
OPHRatio					-0.0640 *
					(0.0384)
OPDummy2	-0.4886 * **				
	(0.0752)				
OPHRatio2		-0.0830 * **			
		(0.0274)			
DID			-0.0752 *		
			(0.039)		
Cash Holding	-2.4190 * **	-0.2017 * **	-0.1780 * **	-2.7726 * **	-0.2199
	(0.4558)	(0.0390)	(0.041)	(0.7187)	(0.1349)
Bond Rating	-0.5547 * **	-0.1396 * **	-0.1358 * **	-0.0311	-0.0457
	(0.1171)	(0.0179)	(0.015)	(0.1683)	(0.0357)
GEO	-0.4730 * **	-0.0319 *	-0.0312	-0.7638 * **	-0.3916
	(0.0919)	(0.0168)	(0.021)	(0.1570)	(0.2875)
Z-Score	-0.0931 * **	-0.0057 * *	-0.0053 * *	-0.2273 * **	-0.0131
	(0.0268)	(0.0025)	(0.002)	(0.0592)	(0.0104)
Leverage	-0.1202	0.0958 * **	0.1033 * **	-0.5931	-0.1633 *
	(0.1612)	(0.0324)	(0.034)	(0.3835)	(0.0847)
ROA	0.6602 *	0.0751 *	0.1041 *	0.9417 *	-0.0840
	(0.3962)	(0.0415)	(0.052)	(0.4818)	(0.0732)
Asset	0.2465 * **	0.0238 * **	0.0250 * **	0.1806 * **	0.0460 * *
	(0.0234)	(0.0030)	(0.003)	(0.0390)	(0.0202)
Investment Growth	1.7294 * **	0.1816 * **	0.1728 * **	3.5052 * **	0.0493
	(0.1985)	(0.0405)	(0.049)	(0.5739)	(0.1223)
Dividend Dummy	0.0357	0.0393 * **	0.0315 * **	0.0149	0.0153
	(0.0610)	(0.0106)	(0.010)	(0.1258)	(0.0342)
Constant	-0.3033 *	0.2220 * **	-0.0580 *	-0.0483	0.1927
	(0.1594)	(0.0235)	(0.031)	(1.1419)	(0.2401)
Observations	1822	1822	1822	762	762
R-squared		0.1581	0.168		0.6162
Firm FE	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES

This table reports the robustness tests of estimation results of the relationship between operational and financial hedging policies. The dependent variables are FHDummy and FHRatio respectively. FHDummy, equals 1 if FHRatio is greater than zero, and 0 otherwise. OPHRatio and FHRatio are the operational and financial hedging variables, respectively. See Appendix C for definition and sources of control variables. Column 1 replaces the OPDummy variable in the Probit regression (model 7) with OPDummy2. OPDummy2 equals 1 if OPHRatio2 is greater than zero, and 0 otherwise. OPHRatio2 is defined as the ratio of assets from downstream segments to a firm's total assets. Column 2 presents the results of the OLS regression (model 8) with OPHRatio replaced by OPHRatio2. In column 3, the result of the Difference-in-Difference (DID) approach (model 9) is reported. The variable DID represents treated firms that changed from operationally unhedged to operationally hedged firms. Columns 4 and 5 are the estimation results of models 7 and 8 but are based on the 1-to-1 matched sample. The data are presented as marginal effects with standard error in parentheses. * ** $p < 0.01$, * * $p < 0.05$, * $p < 0.1$.

In column 2, we test Model (8), the OLS regression. The negative and significant coefficient of *OPHRatio* indicates the negative relation between financial hedging and operational hedging. The results in Table 6 show that operational hedging is a substitute for financial hedging.

In summary, we identify an inverse relationship between operational hedging and financial hedging, supporting the notion that the two hedging strategies are substitutes. Our empirical evidence suggests that, on average, oil firms hedge less than 20 % of their production by means of financial derivatives. Since operational hedging is a substitute for financial hedging, and if the former is effective, the demand for the latter will be lower.

5. Robustness tests

Despite the benefits derived from operational hedging activities, less than 30 % of our observations implement the operational hedging strategy since implementing such a strategy requires high levels of capital investment (opening a production facility), which can be financially challenging since it involves extra investment, asset purchases, or completing a merger and acquisition (M&A) process. As a result of the unbalanced sample distribution, our results may be endogenous, and some omitted factors may also contribute to reducing a firm's exposure to oil-price risk. To mitigate the endogeneity concerns, and make our results more robust, we perform the following tests. First, we replace the *OPHRatio* with *OPDummy* (i.e., the indicator variable) and we also use the ratio of assets from downstream segments to total assets as an alternative measurement of operational hedging for robustness tests. Second, we use the one-to-one propensity-score-matching (PSM) method to form an operationally hedged (treatment) group and an operational unhedged (control) group, and then test the effects of operational hedging.

Table 7 reports the variables for the one-to-one PSM groups and the mean comparison (t-tests) across the two groups. Specifically, we identify 381 observations in the treatment group that are operationally hedged. The control group consists of 381 matching firms that are not operationally hedged but share similar firm characteristics with firms in the treatment group. The results suggest that the treated and control groups are comparable and that the parallel-trend assumption is satisfied (Roberts and Whited, 2013). Moreover, to tease out any potential effects of economic shocks, we require observations for firms in the control group to be of the same years as those in the treatment group.
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Table 7 presents robustness tests of the effects of operational hedging on oil betas. Column 1–3 examines the market model (i.e., model 4). In column 1, we replace the *OPHRatio* with *OPDummy* (i.e., the indicator variable). In column 2, we replace *OPHRatio* with *OPHRatio2* (i.e., the ratio of assets from downstream segments to total asset as an alternative measurement of operational hedging). In column 3, we test the effects of operational hedging on oil betas based on the matched sample. The results are consistent with previous findings that the coefficients of operational hedging(γ_2) are all negative and significant. Columns 4–6 examine the Fama-French 3-factor model (i.e., model 5) with the same settings as the first three columns, and the results are also consistent with Table 3's. The results from Table 7 indicate that our *H1* that operational hedging reduces exposure to oil price risks is robust.

Table 9 tests if the relation between operational hedging and financial hedging is robust. In particular, we replace the *OPHRatio* with *OPDummy* variables from Model (7) and (8) with *OPHRatio2* and *OPDummy2* in columns 1 and 2.[22] We also perform the Difference-in-Difference (DID) approach to examine the relationship between financial and operational hedging in column 5. We estimate the DID regression of the following form:

$$FHRatio_{i,t} = \alpha + \beta_1 * DID_{i,t} + \beta_2 * X_{i,t} + \alpha_t + \gamma_i + \varepsilon \quad (9)$$

where $FHRatio_{i,t}$ is the financial hedge ratio; $DID_{i,t}$ represents treated firms that changed from operationally unhedged to operationally hedged firms; $X_{i,t}$ includes the control variables as in Model (8); α_t and γ_i are year and firm dummies to control for time and firm fixed effects. Column 3 shows that the coefficient of DID is negative and significant at $p < 10$ % confidence level, which suggests that the inverse relationship between financial hedging and operational hedging strategies is robust.

The results from the first two columns show a negative and significant relation between operational hedging and financial hedging. Columns 4 and 5 have the same setting as the first two columns but are based on the matched sample, and the results are consistent with the first two columns. The results from Table 9 indicate that our *H2* that operational hedging leads to less financial hedging is robust.

6. Conclusion

Crude oil market shocks have created sluggish demand for crude oil. With the demand uncertainty and thus oil price volatility, how can oil-producing firms whose revenues and cash flow are extremely sensitive to oil-price changes manage their exposure to unfavorable oil-price movement is a very important question. In this paper, we investigate the effectiveness of operational hedging in managing firm exposure to oil-price risk by addressing two research questions using the oil-production industry from 2000 to 2021. First, does operational hedging reduce a firm's risk exposure? Second, what is the relationship between financial and operational hedging and are they substitutes for or complementary to each other? By constructing a novel type of operational hedging, i.e., the natural operational hedge position between upstream crude oil production and downstream activities in the supply chain, we show that operational hedging is more effective in reducing the firm's exposure to oil prices than financial hedging. To better understand the motivation for the practice of operational hedging, we also provide further evidence that operational hedging also adds to firm value. Our evidence also suggests a negative relationship between operational and financial hedging, which indicates that operational and financial hedging are substitutes for each other.

Acknowledgements

We would like to express our sincere appreciation to the reviewer(s) and editor(s) for their valuable comments and suggestions, which have significantly improved the quality of this manuscript.

Appendix A. The list of business segments

Business Segment	Segment Name	Segment Identifier (sid)
Upstream	Oil & Gas Exploration, Development & Production	1, 4, 5, 7, 9, 10, 11, 14, 15, 16, 17, 18, 19, 20, 24, 25, 27, 29, 30, 31, 32
	Upstream Conventional	
Midstream	Pipelines & Gas Processing	12, 13, 33, 99
	Transportation	
	Gas Storage & Hub Services	
Downstream	Convenience Store Operation	2, 3, 6, 8, 21, 22, 23, 26, 28
	Refined Product Distribution	
	Retail Marketing & Other	

Appendix B. Mathematical Proof

Let C be the spot crude oil price; and R be the corresponding spot refined product price. Without loss of generality, let $\mathrm{var}(C) = \mathrm{var}(R) \equiv \sigma^2$ *and* $corr(C, R) = \rho$ where $0 < \rho < 1$. Consider a pure upstream firm p who will produce $V > 0$ units of crude oil. Selling the crude oil to the spot market, her revenue will be $\pi_p = VC$. On the other hand, consider a producer d who produces the same amount V, but converts k percent of production into the refined product where $0 < k < 1$. Then, her revenue will be $\pi_d = V(1-k)C + VkR$.

Proposition 1. The absolute value of the minimum-variance optimal hedge position of producer d is less than that of producer p. That is, producer d's exposure to spot oil price uncertainty is less than the producer p's.

Proof:

$$\left| -\frac{\mathrm{cov}[\pi_d, C]}{\mathrm{var}[C]} \right| = \frac{\mathrm{cov}[V(1-k)C, C] + \mathrm{cov}[+VkR, C]}{\mathrm{var}[C]} = \frac{V(1-k)\sigma^2 + Vk\rho\sigma^2}{\sigma^2}$$

[22] *OPHRatio2* is the ratio of asset from downstream segments to total asset as an alternative measurement of operational hedging. *OPDummy2* equals to 1 if *OPHRatio2* is greater than zero, and 0 otherwise.

$$= (1-k)V + kV\rho < (1-k)V + kV = V = \left| -\frac{\mathrm{cov}[\pi_p, C]}{\mathrm{var}[C]} \right|, \text{Q.E.D.}$$

Appendix C. Variable definitions

Variables	Definition	Data Source
FHRatio	The production-weighted total delta position.	10-K
OPHRatio	The percentage of sales from downstream segments.	Compustat Segments
Asset	The natural log of total assets.	Compustat Annual
Leverage	Computed as the sum of current debt, plus long-term debt, all divided by total assets.	Compustat Annual
Cash Holding	Total cash divided by total assets.	Compustat Annual
Dividend	A dummy that equals 1 if a firm pays dividend and 0 otherwise.	Compustat Annual
ROA	Net income divided by total assets.	Compustat Annual
Investment Growth	Capital expenditure divided by total assets.	Compustat Annual
Bond Rating	A dummy that equals 1 if a firm is rated BBB or above and 0 otherwise.	Compustat Annual
Z-score	Computed as the sum of 3.3 times earnings before interest and taxes, plus sales, 1.4 times retained earnings, plus 1.2 times working capital, all divided by total assets, plus 0.6 times market value of equity divided by liabilities.	Compustat Annual
GEO	A dummy that equals 1 if a firm is geographically diversified and 0 otherwise.	Compustat Segments
Tobin's Q	Following Fracassi and Tate (2012), Tobin's Q is computed as the ratio of the market value of assets to book value of assets. The book value of assets is total assets. The market value of assets is total assets plus the market value of equity minus the book value of equity.	Compustat Annual

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