## RESEARCH

# Uncertainty about interest rates and crude oil prices

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## Abstract

The yield on the 10-year U.S. Treasury Note is among the most cited interest rates by investors, policymakers, and financial institutions. We show that the 10-year Treasury yield's forward-looking volatility, a VIX-style measure that is a proxy for uncertainty about future interest rates, is a useful state variable capable of predicting the returns and volatility of crude oil prices over the near term. Using monthly data from 2003 to 2020, we document that higher implied volatility in the 10-year U.S. Treasury derivatives market predicts declining oil prices and higher forward-looking volatility in those prices. Our results are robust to different subsamples and various empirical designs.

**Keywords:** Bond VIX, Forecasting, Treasury futures, Options, Implied volatility, Oil price

**JEL Classification:** G12, Q43, Q47

## Introduction

The U.S. Treasury market is one of the largest and most influential markets in the world. Due to the special status of the U.S. dollar as an international exchange currency and the fact that the U.S. government is highly unlikely to default on its debts, U.S. Treasury securities serve as a global safe haven and a benchmark for banking systems and market participants in the U.S. and around the world (e.g., Habib and Stracca 2015; Hager 2017; Liu 2020; Zhou and Meng 2021).

 Central bankers and economists regard both short-term and long-term (in particular 10-year maturity) yields of U.S. Treasuries as indicators of where the economy is heading (e.g., Ang et al. 2006). Empirical studies also find that U.S. Treasury yields have substantial explanatory power for future oil prices (e.g., Arora and Tanner 2013; Dai and Kang 2021). However, the literature is largely silent regarding the links between uncertainty about interest rates and crude oil prices. Thus, the aim of this study is to fill this gap and explore the interplay between uncertainty about interest rates and the future evolution of oil prices. We contribute to the literature by showing that greater uncertainty about interest rates, captured via a VIX-style measure constructed using put and call options on 10-year U.S. Treasury futures, predicts declining oil prices and increased volatility in those prices.

Our research hypothesis is consistent with the theoretical and empirical models in Ang and Bekaert (2002), Bansal and Zhou (2002), Dai et al. (2007) and Cremers et al. (2021). These studies establish that uncertainty about interest rates co-varies strongly with business cycles and is a major macroeconomic state variable that captures both the growth and variability of real macroeconomic activity. Under the New Keynesian macroeconomic framework, interest rates are assumed to impact the real macro economy through the cost of capital and discount rates (Bekaert et al. 2010). In this spirit, David and Veronesi (2014) construct an equilibrium model that includes a direct link between the implied volatility of interest rates and real economic activity. They show that a spike in implied volatility in the Treasury market (i.e., increased uncertainty about interest rates) may hint that a recession is likely to occur. Building on the "option value to wait" that Bernanke (1983) suggests, when shocks hit the economy and uncertainty about economic conditions escalates, payoffs from irreversible investments become more uncertain. Such uncertainty causes a delay in quantity adjustments and a sharper price response. Extensive theoretical and empirical evidence shows how uncertainty affects the decisions made by economic agents regarding whether to invest or consume products and services (see, among others, Pindyck 1991; Dixit and Pindyck 1994; Bloom 2009; Baker et al. 2016).

These theoretical predictions, in turn, overlap with research showing that oil prices react to shocks in real economic activity (e.g., Kilian 2008; Duarte et al. 2021). Empirical studies report a strong connection between commodity prices and economic cycles (e.g., Chevallier et al. 2014). In addition, it is well documented in the literature that greater volatility in industrial production (a proxy for macroeconomic uncertainty) reduces oil price elasticity and reinforces oil price reactions to shocks in supply and demand, creating greater oil price volatility (e.g., Van Robays 2016). Thus, our results suggest that uncertainty about interest rates may indicate the future evolution of oil price movements because such uncertainty can affect the cost of hedging interest rate risk in the options and futures markets. We interpret our results as lending direct support for this theory. To the best of our knowledge, this study is the first to empirically show that the forward-looking volatility of 10-year U.S. Treasury securities provides valuable information regarding the current and future evolution of crude oil prices.

We first show that uncertainty in interest rates provides substantial forward-looking information about the future evolution of crude oil price movements and volatility. The results of a Granger-causality test demonstrate that uncertainty originating in the 10-year Treasury market drives oil price returns. In parallel, the results also indicate that such uncertainty is a strong driver of the oil volatility index (OVX). We extend our analysis by forecasting oil price returns using a battery of real economic and financial explanatory variables. By doing so, we demonstrate that adding any or all of these potential alternative explanatory variables only marginally affects the coefficients or their statistical significance. Finally, the results of the various regression models show that uncertainty about interest rates is significant in explaining current and future changes in oil price returns. The slope coefficients are all negative and statistically significant at the 10% level at least. The regressions' R-squared values range from 2.2 to 29.9%, which substantially exceeds the corresponding values of a random walk model.

Our results are of interest to policymakers, asset managers, scholars, and corporations whose profitability is linked to oil prices for several reasons. First, this study reinforces the view that not only do current interest rate levels affect future oil prices, the expected volatility of interest rates affects them as well. In particular, our findings indicate that interest rate uncertainty contains additional information beyond what is implied by other real economic and financial factors regarding the evolution of future oil prices. Thus, our study adds to the literature on how interest rates impact crude oil prices. Important contributions to the literature on this topic include Wang and Chueh (2013), Arora and Tanner (2013), Gruber and Vigfusson (2018), Dai and Kang (2021), and Kilian and Zhou (2022). While these studies deal mainly with the ability of short- and long-term bond yields to predict oil prices, our study focuses on the uncertainty surrounding the level of interest rates as a predictor.

Second, despite extensive research on the potential drivers of oil price volatility, we show the importance of a factor that has not yet been considered in this literature, namely uncertainty in the U.S. Treasury market. Volatility in oil prices by itself is a major concern for economists, corporations, and policymakers because it has an adverse impact on economic activity (e.g., Mork 1989; Jo 2014). Thus, we contribute to the literature by suggesting the use of the VIX-equivalent for interest rates as reflected in the Chicago Board Options Exchange's (Cboe's) 10-Year U.S. Treasury Note futures as a potential predictor of the forward-looking volatility in oil prices.

Third, recent evidence indicates that crude oil has become an asset class held not only by entities that use the futures market to hedge economic exposure to oil prices (e.g., refineries, airlines, and oil importers), but also in the portfolios of institutional investors and households in the form of futures, exchange traded notes and exchange traded funds (ETFs) (e.g., Adams et al. 2020). In addition, recent evidence indicates rapid evolving innovations in the Fintech investment industry that is facilitating trading activities across a wide range of financial products (Kou et al. 2021). Hence, changes in uncertainty about future interest rates may be useful for both professionals and retail investors who can exploit this study's insights to time their investment decisions, improve asset selection, and rebalance their portfolios by reacting immediately to signals about the future of the economy.

The remainder of this study is organized as follows. In "Literature review" section reviews the relevant literature. In "Data" section provides the data used in our analysis. In "Method" section describes the methodology, "Empirical findings" section discusses our empirical findings, and "Conclusions" section is concludes.

## Literature review

Understanding the interplay between interest rates and oil prices is very important, particularly because oil prices help determine a wide range of consumer and producer prices and play a role in predicting returns for major U.S. stock indices and in overall economic uncertainty (e.g., Kang et al. 2017; Gurrib 2018, 2019; Qadan and Nama 2018). The literature on the relationship between interest rates and oil prices focuses mainly on the level of interest rates. For example, Akram (2009) finds that oil prices increase after real U.S. interest rates decline. Arora and Tanner (2013) confirm the inverse relationship between oil prices and interest rates, documenting that oil prices decline after an

unexpected rise in the ex-ante real interest rate. Wang and Chueh (2013) report that when the Fed lowers nominal interest rates to boost the economy, market participants interpret this as an indication that an economic recession in the U.S. is likely, and oil prices fluctuate. Scrimgeour (2015) reports that a 10 basis-point surprise increase in interest rates prompts commodity prices to fall by about 0.6%. Dai and Kang (2021) find that long-term government bond yields Granger-cause oil returns but not vice versa. In addition, Idilbi-Bayaa and Qadan (2021, 2022) indicate that the slope of the U.S. yield curve is useful in predicting future energy prices.

While the relationship between oil prices and monetary policy has been scrutinized over the years, few studies, if any, have investigated the effect of interest rate uncertainty on oil prices. There are several reasons why uncertainty about interest rates is a major concern from a macroeconomic viewpoint. First, this uncertainty may imply concerns about the central bank's monetary policy (e.g., Baker et al. 2016). Second, the literature has established that Treasury yields contain valuable information about the current and future states of the economy and inflation (e.g., Evgenidis et al. 2020; McMillan 2021). Accordingly, uncertainty about interest rates is linked to real economic and financial uncertainty (e.g., David and Veronesi 2014; Istrefi and Mouabbi 2018; Qadan et al. 2023). Third, such uncertainty might reflect uncertainty about the systematic components of monetary policy (Orphanides et al. 2000; Sims and Zha 2006).

Studies suggest various methods for capturing uncertainty about interest rates. For example, Mumtaz and Zanetti (2013) refer to this uncertainty as the volatility of monetary policy and calculate it as the standard deviation of the innovation to the Taylor rule. Creal and Wu (2017) use the stochastic volatility of macroeconomic series such as short-term rates and the term premium. Istrefi and Mouabbi (2018) use information from economics surveys that poll both public and private economic institutions. These surveys ask participants to forecast the yields on 3-month and 10-year government debt. Finally, Cremers et al. (2021) use Black and Scholes' (1973) implied volatility for put and call options on U.S. Treasury futures contracts traded on the Chicago Mercantile Exchange.

We add to this literature by suggesting the use of a VIX-style measure to mirror the forward-looking volatility of interest rates as reflected in the Cboe's 10-Year Treasury Note futures contract. Given that Treasury securities play an important role in policy-makers' decisions and in many investors' portfolios, understanding the uncertainty surrounding this market and the potential implications for the energy market, including clean energy such as solar energy projects (e.g., Kou, Yüksel, Dinçer, 2022), are of major economic importance.

## Data
We utilize the Cboe's 10-Year Treasury Note Volatility Futures Index (VXTYN) to capture the implied volatility of options on 10-year Treasury futures or the uncertainty in the U.S. bond market. This index is a VIX-style estimate of the expected 30-day volatility using the CBOT's 10-year Treasury Note options prices. Data about the VXTYN are available from the St. Louis Fed's Federal Reserve Economic Data (FRED) database for the period from January 31, 2003 to May 15, 2020. We use the spot prices of West Texas Intermediate (WTI) crude oil as a proxy for crude oil prices.
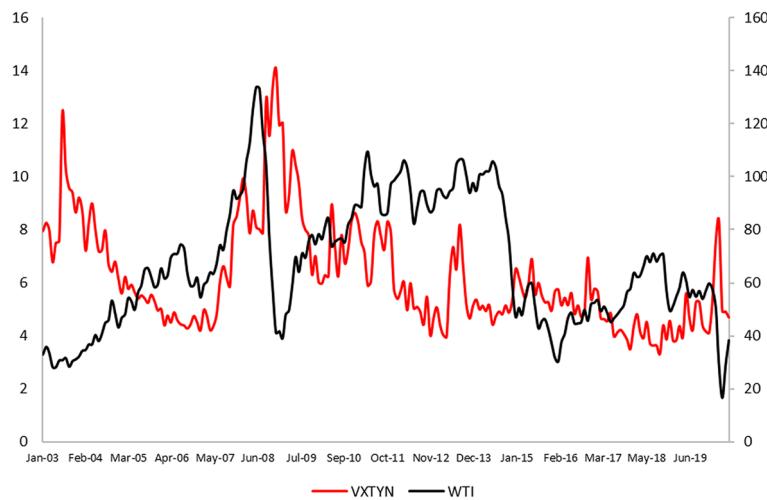
**Fig. 1** The evolution of interest rate uncertainty (VXTYN; left vertical axis) and crude oil prices (WTI; right vertical axis) over time. Sample: January 2003 to May 2020. Data from the FRED database
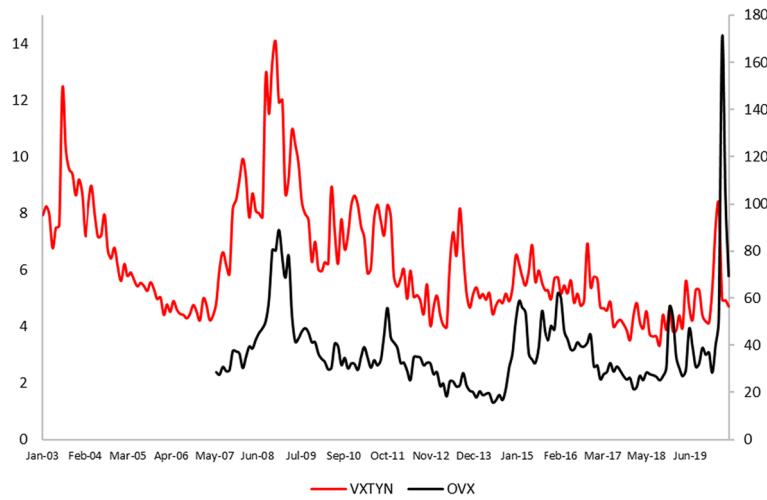


**Fig. 2** The evolution of interest rate uncertainty (VXTYN; left vertical axis) and the oil price volatility index (OVX; right vertical axis)

Data on WTI as well as other macro-financial variables including industrial production, a weighted basket of USD exchange rates, gold prices, and spreads between 10-year and 3-month Treasuries were obtained from the FRED database. Data about the OVX is from the Cboe website, starting in May 2007. Figure 1 depicts the evolution of WTI prices and uncertainty about interest rates across the study period. Figure 2 depicts the behavior of the OVX and VXTYN.

Our interest rate uncertainty measure differs from what has been used in other recent studies. For example, Istrefi and Mouabbi (2018) as well as Beckmann and Czudaj (2023) use data from Consensus Economics surveys to construct a measure of interest rate uncertainty. This measure is based on forecasts for 3-month (short-term) and 10-year (long-term) yields at a 3-month-ahead horizon. In line with Lahiri

and Sheng (2010), these uncertainty measures are the sum of two components: (1) disagreement among forecasters, and (2) the perceived variability of future aggregate shocks. The second component is allowed to be time varying and stochastic. This type of survey-based uncertainty measure builds on the premise that disagreement among forecasters and the perceived variability of future aggregate shocks are positively correlated with uncertainty.

Our proxy for interest rate uncertainty (the 10-year U.S. Treasury Note VIX; VXTYN) is based on put and call options data on 10-year U.S. Treasury futures. The VXTYN is derived from the prices of options from the Cboe following the procedure used by its better-known stock market counterpart, the Cboe's VIX index. Accordingly, the VXTYN is considered a gauge of expected uncertainty in the U.S. Treasury market. Thus, a major difference between the two types of measures discussed here is that, as a proxy for uncertainty, the VXTYN uses market data rather than periodic surveys. Given that the VXTYN is computed from prices of financial instruments traded on an exchange, this suggested proxy has a significant advantage in that it instantaneously reflects all new information regarding uncertainty about future interest rates.

## Method

We use the Cboe's 10-Year Treasury Futures Volatility index as a proxy for uncertainty about interest rates. Also known as the 10-year U.S. Treasury Note VIX (VXTYN), this measure is computed using the following formula from the Cboe, which is rooted in Neuberger (1990) and Carr and Madan (2001):

$$VXTYN = 100 \times \sqrt{\frac{365}{30} \cdot \frac{1}{\tau} \left[ 2e^{rt} \left\{ \sum_{k_i} \frac{\Delta K_i}{K_i^2} Price_{K_i} + \sum_{k_j} \frac{\Delta K_j}{K_j^2} Price_{K_j} \right\} - \left( \frac{F}{K_{ATM}} - 1 \right)^2 \right]}.$$
(1)

Multiplying the radicand by $\frac{365}{30}$ translates a one-month variance into an annualized variance; $\tau$ denotes the time to the option contract's expiration; $r$ is the risk-free interest rate to expiration; $\Delta K$ is the strike interval associated with $K$; $Price_{K_i}$ is the mid-quote of out-of-the-money puts and calls with strike values $K_i$ and $K_j$, respectively. Similarly, $K_{ATM}$ denotes the average of the mid-quotes of at-the-money puts and calls. F is the forward index level.

We first use the Granger (1980) causality test to examine whether changes in uncertainty about interest rates ($\sigma_t$) Granger-cause crude oil returns $\left( R_t^{oil} \right)$. If this association holds true, then lagged values of $\sigma_t$ should contain information that helps predict $R_t^{oil}$. This relationship can be expressed as follows.

$$\begin{pmatrix} R_t^{Oil} \\ \sigma_t \end{pmatrix} = \begin{pmatrix} \beta_{10} \\ \beta_{20} \end{pmatrix} + \begin{pmatrix} \beta_{11} & \alpha_{11} \\ \alpha_{21} & \beta_{21} \end{pmatrix} \begin{pmatrix} R_{t-1}^{Oil} \\ \sigma_{t-1} \end{pmatrix} + \begin{pmatrix} \beta_{12} & \alpha_{12} \\ \alpha_{22} & \beta_{22} \end{pmatrix} \begin{pmatrix} R_{t-2}^{Oil} \\ \sigma_{t-2} \end{pmatrix} + \cdots + \begin{pmatrix} \beta_{1L} & \alpha_{1L} \\ \alpha_{2L} & \beta_{2L} \end{pmatrix} \begin{pmatrix} R_{t-L}^{Oil} \\ \sigma_{t-L} \end{pmatrix} + \begin{pmatrix} v_{1t} \\ v_{2t} \end{pmatrix}.$$
(2)

The oil price return is calculated as the first difference of the log prices at $t$ and $t-1$, i.e., $R_t^{Oil} = 100 \times \left( Log[P_t] - Log(P_{t-1}) \right)$, where $P_t$ is the closing price. "L" denotes the length of the lag and $v_{it}$ ($i=1, 2$) is the error term. Formally, if the hypothesis that $\alpha_{11} = \alpha_{12} = \cdots = \alpha_{1L} = 0$ is rejected, then lagged values of uncertainty help to explain the current values of oil returns. On the other hand, if we cannot reject this hypothesis,

then the interest rate uncertainty variable does not Granger-cause the other variable – oil price returns. We use this to model the causal relationships between $\sigma$ and $R^{Oil}$, and between $\sigma$ and the forward-looking volatility of oil prices, captured by the oil volatility index (OVX). We also formulate the following model to trace the effect of current uncertainty about interest rates on the cumulative rate of change in oil prices in the next period:

$$R_{t+1}^{Oil} = C_0 + \beta_1 \sigma_t + Controls_t + \psi_{t+1}. \tag{3}$$

$C_0$ is the intercept and $\sigma_t$ is the VIX-style estimate of the expected 30-day volatility of 10-year Treasury notes. Given that the distributions of financial data are always complex due to changing human behavior and market environments (Li et al. 2021), we use a matrix of additional explanatory variables (*Controls*) that includes real economic and financial metrics typically viewed as predictors of crude oil prices. $\psi_{t+1}$ is the forecast error. Given that the forecast errors could be autocorrelated, we use Newey and West's (1987) corrected covariance estimator. The estimated coefficients guarantee consistency in the presence of both heteroscedasticity and autocorrelation (HAC) of unknown form.

## Empirical findings

Table 1 reports the mean, median, standard deviation, minimum, maximum, skewness and kurtosis for key variables over the entire sample period—January 31, 2003 to May 31, 2020. The VXTYN has a monthly average value of 6.24% and a standard deviation (i.e., volatility of implied volatility) of 2.03%. Its maximum value is 14.1, which is more than twice its mean value.

Table 2 reports the pairwise correlations between the key variables. A quick glance at the table shows that uncertainty about interest rates and crude oil price returns are negatively correlated. However, uncertainty about interest rates is positively correlated with the forward-looking volatility of oil as reflected by the OVX. In line with Istrefi and Mouabbi (2018), who show that uncertainty about interest rates has a significant negative and persistent effect on the economy, uncertainty about interest rates is negatively correlated with the equity market as captured by the S&P 500, which is viewed in the

**Table 1** Descriptive statistics

|       | VXTYN  | ΔOIL    | ΔIP     | ΔGOLD    | OVX    | ΔS&P     | SPREAD  |
|-------|--------|---------|---------|----------|--------|----------|---------|
| Mean  | 6.238  | 0.076   | − 0.001 | 0.752    | 37.682 | 0.616    | 1.735   |
| Med   | 5.610  | 1.351   | 0.111   | 0.972    | 33.640 | 1.201    | 1.890   |
| Max   | 14.070 | 61.50   | 6.012   | 13.026   | 170.55 | 11.942   | 3.790   |
| Min   | 3.340  | − 78.19 | − 14.610| − 19.095 | 15.610 | − 18.564 | − 0.600 |
| Stdev | 2.026  | 11.59   | 1.322   | 4.975    | 17.916 | 4.114    | 1.131   |
| Skew  | 1.282  | − 1.061 | − 6.407 | − 0.390  | 3.424  | − 0.978  | − 0.236 |
| Kurt  | 4.701  | 15.59   | 75.35   | 4.105    | 22.35  | 5.759    | 2.081   |
| N     | 209    | 209     | 209     | 209      | 157    | 209      | 209     |

The table reports the summary statistics for the key variables in the study. The table includes the mean, median, maximum, minimum, standard deviation, skewness and kurtosis. All values are expressed in percentage terms. VXTYN is the expected volatility of the interest rate; $R^{Oil}$ is the rate of change in oil prices, ΔIP is the rate of change in industrial production, OVX is the monthly oil volatility, ΔS&P is the value-weighted returns of the S&P500 and spread captures the difference between the yields of 10-year and 3-month bonds. Data about OVX are available since June 2007

**Table 2** Correlations between the key variables

|  | ΔVXTYN | $R^{Oil}$ | ΔIP | ΔGOLD | ΔOVX | ΔS&P |
|---|---|---|---|---|---|---|
| $R^{Oil}$ | − 0.237*** <br> (− 3.041) | 1.000 |  |  |  |  |
| ΔIP | − 0.112 <br> (− 1.409) | 0.210*** <br> (2.678) | 1.000 |  |  |  |
| ΔGOLD | − 0.077 <br> (− 0.966) | 0.153** <br> (1.928) | − 0.100 <br> (− 1.257) | 1.000 |  |  |
| ΔOVX | 0.136* <br> (1.704) | − 0.334*** <br> (− 4.404) | − 0.125 <br> (− 1.567) | 0.104 <br> (1.302) | 1.000 |  |
| ΔS&P | − 0.148* <br> (− 1.859) | 0.500*** <br> (7.194) | − 0.059 <br> (− 0.734) | 0.052 <br> (0.654) | 0.024 <br> (0.297) | 1.000 |
| ΔSPREAD | 0.085 <br> (1.057) | 0.056 <br> (0.703) | − 0.100 <br> (− 1.246) | − 0.208*** <br> (− 2.642) | − 0.001 <br> (− 0.014) | 0.055 <br> (0.685) |

The table reports the pairwise Pearson correlation between the monthly key variables. The values in parentheses are the t-stat. values

***, ** and *Statistical significance at the 1%, 5% and 10% levels, respectively

**Table 3** Causality tests

|  | L = 1 | L = 2 | L = 3 | L = 4 | L = 5 | L = 6 |
|---|---|---|---|---|---|---|
| *Panel A: oil returns versus VXTYN for January 2003 to May 2020* |  |  |  |  |  |  |
| ΔVXTYN ↛ $R^{Oil}$ | 4.129** | 3.112** | 2.513* | 2.044* | 1.774 | 1.623 |
| $R^{Oil}$ ↛ ΔVXTYN | 6.984*** | 6.717*** | 4.563*** | 3.097** | 2.503** | 2.147** |
| *Panel B: OVX versus VXTYN for May 2007 to May 2020* |  |  |  |  |  |  |
| ΔVXTYN ↛ ΔOVX | 8.159*** | 7.102*** | 6.084*** | 5.622*** | 4.517*** | 3.891*** |
| ΔOVX ↛ ΔVXTYN | 1.904 | 1.735 | 0.911 | 0.872 | 0.43 | 0.375 |

ΔVXTYN denotes changes in the expected 30-day volatility of the CBOT's 10-Year Treasury futures, a proxy for uncertainty about interest rates. $R^{Oil}$ is the WTI returns. By Y ↛ Z we mean Y does not Granger-cause Z. "L" denotes the lag underlying the test estimation. ΔOVX denotes the rate of change in the oil volatility index. The values in the table are the F-statistics related to the Granger-causality test

***, ** and *Statistical significance at the levels 1%, 5% and 10%, respectively

literature as a leading indicator of economic activity (Berge 2015). This finding supports the claim that uncertainty about interest rates is a successful forward-looking state variable that is capable of indicating risk at the macroeconomic level (Cremers et al. 2021).

To obtain an initial view of the nature of the relationship between the variables of interest, we conduct a Granger (1980) causality test and report the results in Table 3. We present six lags (L = 1,..., 6) according to the AIC criterion that guarantees significance at least at the 10% level. Panel A in Table 3 shows the results of the Granger-causality test between oil price returns and uncertainty about future interest rates proxied by the VXTYN. The results indicate that the VXTYN Granger-causes crude oil price returns for at least four months. Consistent with the finding, the alternative hypothesis also holds, implying that oil price returns drive changes in the implied volatility of the U.S. Treasury market.

Panel B of Table 3 reports the results of the Granger-causality test between the VXTYN and the volatility of crude oil prices as captured by the OVX index. The latter estimates the expected 30-day volatility derived from the implied volatility of options on the U.S. Oil ETF. The results indicate unidirectional and significant causality. They also show that changes in the uncertainty about future interest rates Granger-cause the

expected volatility of oil prices. Regardless of the lags considered, uncertainty about interest rates drives oil price volatility, but not vice versa. These results lend support to the premise that investors react to changes in uncertainty about future interest rates. Indeed, David and Veronesi's (2014) model assumes that investors constantly adjust their portfolios based on what they learn about economic and policy variables. Their model indicates that implied volatility in the Treasury markets is positively linked to the probability of a recession. The stylized fact that financial variables, including the implied volatility of interest rates, move more quickly than the real economy (e.g., Billio et al. 2016) may explain the causal relationship between this predictor of uncertainty and forward-looking returns and volatility.

Table 4 presents the estimation results for our prediction model. The model is regressed gradually to validate the robustness of the outcomes in terms of statistical significance and sign direction. In constructing the matrix of control variables we rely on earlier studies that point to the industrial production index (e.g., Duarte et al. 2021), equity market returns proxied by the S&P 500 (e.g., Olson et al. 2014), the U.S. dollar exchange rate (e.g., Jawadi et al. 2016; Malik and Umar 2019), speculative assets such as gold (e.g., Zhang and Wei 2010) and yield spreads (e.g., Dai and Kang 2021) as possible predictors of oil prices. The results of the regression, in terms of both the coefficient's sign and statistical significance, still hold even after controlling for these predictors.

Panel A of Table 4 reports estimation results for the entire sample period (February 2003–May 2020). Across all six model specifications (M1–M6), we find that the VXTYN coefficients are consistently negative and statistically significant. This indicates that oil prices react negatively to an increase in uncertainty about future interest rates. One possible explanation for this negative relationship may be the perception that a spike in uncertainty about interest rates may suggest that a recession is more likely (e.g., David and Veronesi 2014). These findings are consistent with empirical evidence confirming that changes in the implied volatility of options on Treasury securities affect future economic growth and increase economic growth volatility (Cremers et al. 2021). Similarly, previous studies find a strong relationship between real economic activity and oil prices (e.g., Dees et al. 2007; He et al. 2010). Thus, signals about the future evolution of economic growth prompt traders, institutional investors, and hedge funds to rebalance their oil-related holdings and portfolios. Our results are also in line with Ding et al. (2022) who document the significant multi-dimensional impact of uncertainty about economic policy, geopolitical risk, and uncertainty about climate policy on oil prices.

For robustness, we separate the sample period into two relatively equal parts: the first starts in February 2003 and ends in September 2011, and the second starts in October 2011 and ends in May 2020. The results for both sub-periods are shown in Panels B and C of Table 4, respectively. Regardless of the period selected, in the vast majority of the model specifications the coefficient of VXTYN is negative and statistically significant, indicating that greater uncertainty about future interest rates predicts that oil prices will be lower in the future.

Finally, we assess the stability of the parameters in the models and test for possible structural breaks between the variables of interest over time. We use Brown et al. (1975) cumulative sum test (CUSUM), which is based on the cumulative sum of the recursive residuals. Figure 3 plots the cumulative sum together with the 5% critical lines. Generally, the test

**Table 4** Estimation results of the multivariate regression

| | RW | M1 | M2 | M3 | M4 | M5 | M6 |
|---|---|---|---|---|---|---|---|
| *Panel A: full sample* | | | | | | | |
| C | 0.031 [0.039] | 0.08 [0.10] | 0.004 [0.00] | − 0.395 [− 0.42] | − 0.437 [− 0.45] | − 0.273 [− 0.29] | − 0.274 [− 0.29] |
| ΔVXTYN | | − 0.141** [− 2.56] | − 0.163** [− 2.31] | − 0.136** [− 2.33] | − 0.137** [− 2.33] | − 0.143** [− 2.44] | − 0.142** [− 2.36] |
| ΔIP | | | − 2.301 [− 1.49] | − 2.119 [− 1.56] | − 2.095 [− 1.57] | − 2.199 [− 1.64] | − 2.209* [− 1.66] |
| ΔS&P | | | | 0.661** [2.11] | 0.732** [2.02] | 0.677* [1.92] | 0.679* [1.88] |
| ΔEX | | | | | 0.275 [0.64] | 0.025 [0.05] | 0.025 [0.05] |
| ΔGOLD | | | | | | − 0.175 [− 1.22] | − 0.18 [− 1.2] |
| ΔSPREAD | | | | | | | − 0.384 [− 0.1] |
| R$^2$ | 0.00 | 0.031 | 0.093 | 0.147 | 0.149 | 0.153 | 0.153 |
| n | 207 | 207 | 207 | 207 | 207 | 207 | 207 |
| *Panel B: Feb 2003–Sep. 2011* | | | | | | | |
| C | 0.956 [1.01] | 1.111 [0.98] | 0.99 [0.89] | 0.839 [0.78] | 0.933 [0.81] | 1.016 [0.81] | 0.986 [0.81] |
| ΔVXTYN | | − 0.163** [− 2.43] | − 0.165** [− 2.31] | − 0.130** [− 2.08] | − 0.130** [− 2.07] | − 0.131** [− 2.04] | − 0.138** [− 2.03] |
| ΔIP | | | 2.787 [1.29] | 2.504 [1.31] | 2.418 [1.23] | 2.38 [1.19] | 2.497 [1.28] |
| ΔSP | | | | 0.433* [1.69] | 0.579** [2.24] | 0.552** [2.02] | 0.524* [1.72] |
| ΔEX | | | | | 0.468 [1.02] | 0.361 [0.71] | 0.312 [0.58] |
| ΔGOLD | | | | | | − 0.068 [− 0.31] | − 0.051 [− 0.24] |
| ΔSPRD | | | | | | | 1.933 [0.51] |
| R$^2$ | 0.00 | 0.050 | 0.11 | 0.148 | 0.156 | 0.157 | 0.161 |
| n | 104 | 104 | 104 | 104 | 104 | 104 | 104 |
| *Panel C: Oct. 2011–May 2020* | | | | | | | |
| C | − 0.91 [− 0.69] | − 0.958 [− 0.8] | − 1.393 [− 1.2] | − 2.025* [− 1.75] | − 1.99 [− 1.65] | − 1.833 [− 1.11] | − 1.919 [− 1.22] |
| ΔVXTYN | | − 0.127* [− 1.84] | − 0.193** [− 2.56] | − 0.181** [− 2.47] | − 0.181** [− 2.45] | − 0.195** [− 2.09] | − 0.188** [− 2.06] |
| ΔIP | | | − 3.896*** [− 5.22] | − 3.515*** [− 4.73] | − 3.524*** [− 4.69] | − 3.722*** [− 10.58] | − 3.852*** [− 12.07] |
| ΔSP | | | | 0.785** [2.51] | 0.77** [2.22] | 0.70 [1.19] | 0.721 [1.34] |
| ΔEX | | | | | − 0.076 [− 0.11] | − 0.484 [− 0.6] | − 0.63 [− 0.79] |
| ΔGOLD | | | | | | − 0.353 [− 1.52] | − 0.447** [− 2.07] |
| ΔSPRD | | | | | | | − 6.264 [− 1.2] |
| R$^2$ | 0.00 | 0.022 | 0.231 | 0.277 | 0.277 | 0.289 | 0.298 |
| n | 103 | 103 | 103 | 103 | 103 | 103 | 103 |

**Table 4** (continued)

The table reports the estimation results for $R_{t+1}^{Oil} = \alpha_1 + \beta_1 \sigma_t + Controls_t + \psi_{t+1}$. The estimation is conducted gradually and concludes with six different model (M) specifications. The values in brackets are the t-statistics and are Newey-West (HAC) corrected. RW is defined as the random walk model $R_{t+1}^{Oil} = \alpha_0 + \varepsilon_t$. The rest notations are defined as in Table 1

\*\*\*, \*\* and \* denote statistical significance at the levels 1%, 5% and 10%, respectively
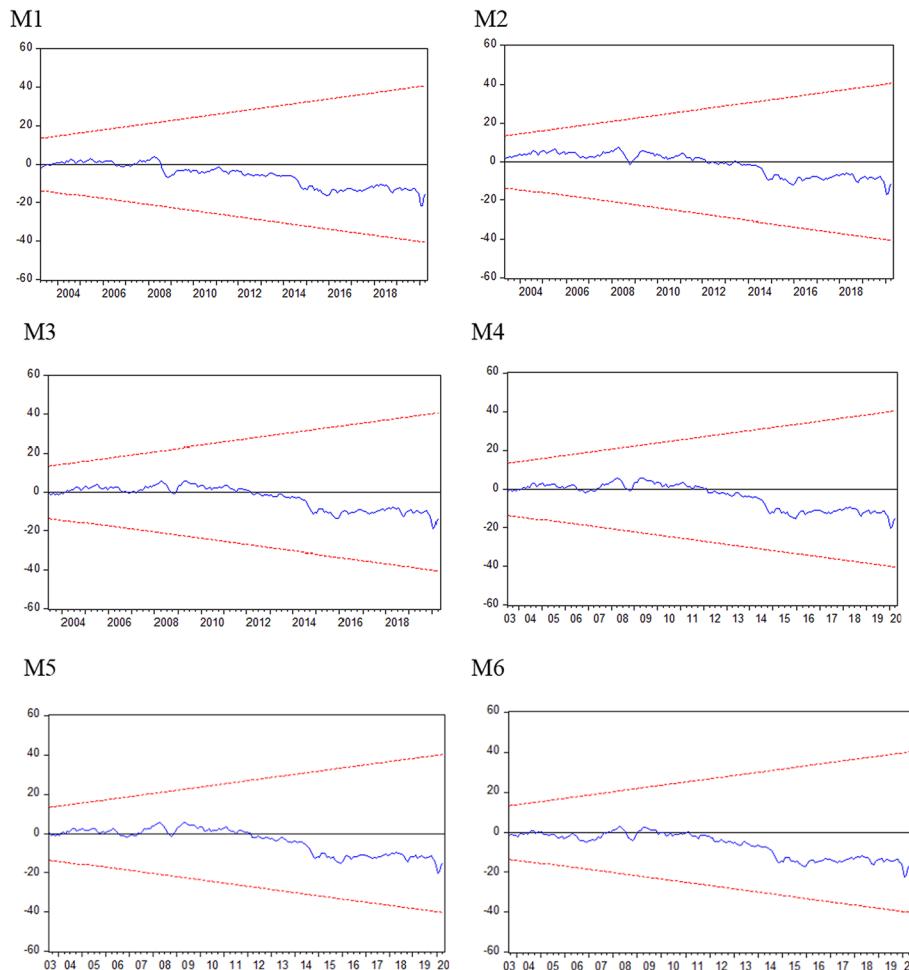


**Fig. 3** Parameter instability test. The figure plots the cumulative sum of the recursive residuals stemming from the cumulative sum test (CUSUM) suggested by Brown et al. (1975). The continuous line plots the cumulative sum together with the 5% critical lines denoted by the dotted red lines. If the cumulative sum goes outside the area between the two critical lines, it indicates parameter instability. The cumulative sum of the six models (M1–M6) regressed in Table 4 fails to cross the critical (dotted) lines

finds a parameter to be unstable if the cumulative sum goes outside the area between the two critical (dotted red) lines. The results of the CUSUM stability test reject the hypothesis of structural breaks and confirm that the parameters are stable over time in the different six model specifications we used. Additional support comes from Bai and Perron's (2003) structural break test. Results from this test (not reported here but available upon request)

show no evidence of structural breaks between uncertainty about future interest rates and oil price returns.

## Conclusions

Numerous studies have explored the relationship between various financial variables and crude oil prices. Yet, little, if anything, is known about the impact of interest rate uncertainty on this market. We show that uncertainty about interest rates, captured using a VIX-style estimate of the expected 30-day volatility of 10-year U.S. Treasury futures contracts, provides forward-looking information about the crude oil market. Our findings indicate that oil prices react negatively to an increase in uncertainty about future interest rates. Such uncertainty is also shown to increase the volatility of oil prices. One possible explanation for this negative relationship may be the perception that a spike in uncertainty about interest rates may hint that the probability of a recession is increasing.

The findings that uncertainty about future interest rates impacts the evolution of future oil prices and oil price volatility can be useful to policymakers seeking to design monetary policies that target inflation by accounting for such uncertainty and developing operational frameworks and strategies to mitigate it. Corporations and investors may find our results useful in making decisions about hedging exposures to rising interest rates and greater volatility in the fixed-income market, improving asset selection, and managing downside and/or upside risk. Companies in the energy industry may want keep a close eye on the evolution of interest rate uncertainty to better time their investments. In this study, we focused on the U.S. as a major oil-dependent economy. Future research may examine other types of economies.

**Abbreviations**
U.S.       United States of America
VIX        Volatility Index
Cboe       Chicago Board Options Exchange
ETFs       Exchange Traded Funds
OVX        Oil Volatility Index
VXTYN      CBOE's 10-Year Treasury Note Volatility Futures Index
WTI        West Texas Intermediate crude oil
ATM        At-the-money
HAC        Heteroscedasticity and autocorrelation
CUSUM      Cumulative sum test
M1-M6      Model 1 to Model 6

## Declarations

**Competing interests**
The authors declare that they have no competing interests.

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