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Dynamic link between liquidity and return in the crude oil market

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ABSTRACT

In this study, we investigate the dynamic relationship between return and liquidity in the Brent and the West Texas Intermediate (WTI) oil markets. The research utilises daily oil price and volume data and monthly macroeconomic data from January 1, 1996 to April 28, 2023 obtained from the Energy Information Association (EIA), the Organisation for Economic Co-operation and Development (OECD), the Federal Reserve Economic Data (FRED), investing.com, and the International Monetary Fund (IMF). We employ the ARMAX(1,1)-aDCC-GARCH-t(1,1) model to capture time-varying associations between return and liquidity. Our findings reveal a significant impact of speculation on the return-liquidity relationship, which is more persistent in the WTI market. Furthermore, we observe a pattern between the Brent and WTI markets during the study period, which the heterogeneous trader hypothesis can explain. These insights hold implications for policymakers aiming to enhance the crude oil market's stability, as well as for market traders in developing trading and risk management strategies.

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1. Introduction

In this article, we investigate the dynamic relationship between price fluctuations and liquidity in the Brent and WTI oil markets. We aim to understand the factors that drive this relationship and their interactions over time. Our research offers valuable insights into energy market dynamics, particularly the role of speculation and trader heterogeneity in shaping the return-liquidity relationship. This understanding contributes to developing more efficient energy planning, management, and integrated energy systems by informing decision-makers about the factors affecting oil market stability.

Numerous studies have focused on liquidity and its association with price and other aspects of the stock market (e.g. Amihud & Mendelson, 1986; Chordia et al., 2000, 2008; Hameed et al., 2010; Lo & Hall, 2015; Leirvik, 2022). Research on liquidity in the crude oil market remains limited, with only a few studies examining this microstructure feature in the commodity market (e.g. Haugom & Ray, 2017; Marshall et al., 2012; Marshall et al., 2013; Smales, 2019; Zhang et al., 2019). Furthermore, there is a lack of research exploring the dynamic relationship between liquidity and returns in the crude oil market. Consequently, the factors contributing to the relationship between price and liquidity in the oil market remain uncertain. In this paper, we compute the liquidity of Brent and WTI oil prices and analyze their relationship with returns in the oil market.

The importance of examining the interaction between market liquidity and return in the commodity market stems from the vital roles these microstructure features play in both the financial market and the global economy. As identified by Hamilton (2003), commodity price movements serve as indicators of

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shifts in the macroeconomy and are significant factors in preemptive monetary policy formulation. Market liquidity is crucial when evaluating the quality of a financial market, and the timing of illiquidity is a concern for various stakeholders due to its impact on trading costs and the profitability of trading strategies. Investors diversifying their equity portfolios with oil commodity assets must consider the negative effects of trading costs when re-balancing their portfolios. For oil companies and other traders with physical stakes in the crude oil market, trading costs are essential when assessing the benefits of hedging a physical position in the commodity market. The price-liquidity relationship is vital for determining risk management and trading strategies, timing trade order execution, and evaluating the effectiveness of technical indicators (see Amihud & Mendelson, 1986; Chordia et al., 2000; Huberman & Stanzl, 2005; Kyle, 1985). Consequently, this study explores the dynamic relationship between price and liquidity in the crude oil market while controlling for changes in market fundamentals. We investigate not only the existence of a relationship between liquidity and oil price but also how this relationship has evolved over the study period. We pay close attention to periods of significant fluctuation in this relationship to gain insights into the potential drivers of these changes.

This empirical paper fills the current gap in the study of commodity market liquidity. In addition, the design of this study highlights the evolution of the relationship between return and liquidity, which has not been previously studied in any market. This study's findings not only enhance our knowledge of the crude oil market's microstructure but also provide critical insights for policymakers, market traders, and researchers, fostering informed decision-making in the energy sector and promoting a more resilient and efficient global energy landscape.

The rest of this paper is structured as follows: Section two (2) continues the discussion on the extant literature on this topic, Section three (3) describes the research data and methodology, section four (4) presents and discusses the empirical results, and section five (5) concludes.

2. Literature review

Even though the relationship between market liquidity and price movements in financial markets has been thoroughly investigated, there is no consensus on how liquidity affects the returns of different types of assets. For example, the seminal research of Amihud and Mendelson (1986) find that between two otherwise equal assets in terms of cash flows, the less liquid asset has a higher expected return of two assets. This suggests that liquidity is priced in equity stocks. Chen et al. (2007), Lin et al. (2011), and Fontaine and Garcia (2012) find that liquidity risk is priced in corporate bonds and yield spreads. In the equity options market, Christoffersen et al. (2018) find evidence that traders are compensated for the risks associated with holding risky illiquid equity options.

While Cakici and Zarembo (2021) and French and Taborda (2018) find a negative relationship between return and illiquidity, suggesting the absence of an illiquidity premium, Ben-Rephael et al. (2015) discover that stock liquidity has significantly improved in recent decades, leading to a decreased liquidity premium that is no longer significantly different from zero. In contrast, Leirvik (2022) finds no relationship between liquidity variation and returns in the cryptocurrency market. Szymanowska et al. (2014) and Batten et al. (2019) report that oil liquidity is priced, but Leirvik et al. (2017) argues that this liquidity premium does not extend to the aggregate stock market. Even in a small market dominated by energy, there is no relationship between market liquidity and stock returns, implying that time-varying liquidity in oil prices does not translate into returns for companies reliant on oil as their main source of profitability. In light of these contradictory findings, this paper aims to investigate the dynamic relationship between liquidity and returns in the crude oil market.

Numerous models and hypotheses attempt to explain the relationship between price and liquidity, as well as the reasons for variations in this relationship across financial markets over time. In these models, liquidity is a proxy for other unobserved market traits, such as trader heterogeneity, information asymmetry, and market sentiment, which influence price and liquidity beyond the market's fundamentals. Wang (1994) proposes trader heterogeneity as a trait represented by market liquidity, explaining price-liquidity dynamics in the equity market. As market traders differ in their information sets, capital constraints, risk appetites, and the resulting trading strategies they adopt, market dynamics change depending on the predominant type of trader at any given time.

Behavioural asset pricing theory and the impact of heterogeneous traders on a market's microstructure have gained popularity in the literature. For example, Baker and Stein (2004) demonstrates how market members' sentiment about expected returns affects liquidity and, consequently, the price-liquidity relationship in the equity market. Liu et al. (2023) reveals the existence of a significant liquidity premium in the Chinese stock market, attributable to firm-specific news sentiment. In addition to return predictability, Beschwitz et al. (2020) shows that market sentiment impacts liquidity and trading behaviors. Several other studies highlight how the behavior of heterogeneous investors may sustain incorrect prices and influence demand for financial instruments at different points (see, for example, Chau et al., 2016; Lee et al., 2020; Schneider, 2022; Zheng et al., 2018).

Concerning heterogeneity in trading strategies, empirical findings suggest that the relationship between price and liquidity is influenced by the trading strategies adopted by different market traders. For instance, DE Long et al. (1990) posits that when noise traders use a positive feedback strategy—buying when the market price rises and selling when it falls—they create positive causality from price to market liquidity. When employing a speculative trading strategy, other traders act as contrarians in the market, trading against recent price movements. This results in different dynamics between actual price movements and liquidity changes, with an increase in market liquidity being associated with adverse price movements (Bloomfield et al., 2009; Lee et al., 2020). Pereira and Zhang (2010) and Batten and Vo (2014) suggest that the activities of traders who adapt their trades to market liquidity conditions or prioritize diversification influence the dynamics of price and liquidity in the equity market.

Extending the findings from these studies to the oil market suggests that heterogeneity and market sentiment, which cannot be directly observed, may be inferred by the price-volume relationship and how it changes over time. Empirical studies on price and liquidity in the oil commodity market support some of the aforementioned hypotheses to varying degrees. For instance, Moosa and Silvapulle (2000) find evidence supporting the noise trading model in the relationship between price movements and volume in the WTI market. Manera et al. (2016) find that speculation of non-financial traders affects price volatility in the energy markets, although its impact on the price-liquidity relationship is not analysed. Haugom and Ray (2017) finds evidence of the heterogeneous trader hypothesis and its impact on the relationship between the number of trades and return distribution in the commodity market. Alfano et al. (2020) find that speculative noise traders contribute to the volatility in oil prices by overreacting to language sentiment in the news about oil market fundamentals. During periods of high volatility, Liu et al. (2021) find that irrational trading behaviour contributes more to illiquidity in the Chinese commodity futures market than the activities of fundamental/rational traders. Kang et al. (2020) finds evidence of liquidity premia in the commodity market, which differs based on the trading strategies adopted by the different types of traders within the market. In general, few studies have examined the relationship between price and liquidity in the commodity market compared to other financial markets. The few that exist have focused on trading volume as a measure of liquidity, and the method of analysis applied does not capture the time-variant nature of this relationship. Although volume is an integral aspect of market liquidity, Jones et al. (1994); Chordia et al. (2000) suggest that it becomes less informative when separated from trading frequency and does not account for transaction costs and price impacts of trading. In this study, we examine the price-liquidity dynamics in the crude oil market, focusing on the price impact of illiquidity. Furthermore, we capture any short and long-run effects of significant shocks to the crude oil market. Controlling for oil market fundamentals, we examine the changes in this relationship over time and test to what extent the aforementioned hypotheses explain the variations in the price-liquidity relationship.

Due to the strong link between inflation, the macro economy and the commodity market identified in seminal studies, macroeconomic factors are vital considerations when attempting to understand the nature of the commodity markets in general, and the price-liquidity dynamics of the commodity market in particular. Macroeconomic factors such as exchange rate fluctuations, interest rates, GDP growth, foreign direct investment, and other monetary policy announcements have also been identified as significant influences on demand and supply conditions within the economies and the oil market, see, for example, Browne and Cronin (2010), and Durguti et al. (2021). Furthermore, Akram (2009) find that commodity prices increase in response to the dollar's depreciation. Ratti and Vespignani (2013) show that increases in the M2 money supply of BRIC countries accounted for an increase in real oil prices owing to its positive impact on liquidity from the demand side. Moreover, Kilian (2009) provides a structural

decomposition of oil price shocks into the aggregate oil demand and oil supply, with the residuals being accounted for by precautionary demand shocks. In this study, we model the impact of speculative non-market fundamentals on the price-liquidity relationship by controlling for the macroeconomic variables which affect the fundamentals of the crude oil market. We hypothesise that there is a significant residual impact on price and liquidity after controlling for these macroeconomic fundamentals, which is accounted for by the impact of speculative/non-fundamental factors.

3. Data and methodology

3.1. Data

3.1.1. Crude oil return

In this study, we utilise daily price and volume data from Brent and West Texas Intermediate (WTI) near-month futures contracts as proxies for the crude spot market, from January 1, 1996, to April 28, 2023. The data set range is sufficiently large enough to capture recent and relevant events in the crude market, such as the global financial crisis of 2008–09, the 2014 oil glut, the aftermath of the global shut-down due to the Covid-19 pandemic, and the global turmoil due to the Russian war in Ukraine during 2022–23. Missing values or seemingly erroneous observations are checked manually. For example, some days are registered with Open, High, Low, and Close prices equivalent to the previous day's closing value combined with zero volume. We assume this is an erroneous observation, and we have deleted 12 observations where this was the case. For days with changes in prices, as well as prices being different than the day before, but no volume registered, we used the previous two day's average volume. This was the case for 115 observations. We end up with 6975 observations for WTI. Using the same methodology for Brent, we end up with 7001 daily observations.

We obtained data for the WTI and Brent Crude Oil Financial futures contract, primarily traded at the New York Mercantile Exchange (NYMEX) from investing.com, and quality checked the data against observations retrieved from the Federal Reserve Economic Data (FRED). However, the FRED data only have prices for WTI and Brent, and not volume traded. Nevertheless, the prices obtained from investing.com were identical to the FRED observations. The observations for the volume variable had a few missing values for WTI. The WTI price is for a contract of 1000 US barrels, or 42000 US gallons, of WTI crude oil. The minimum tick size of the contract is \$0.01 per barrel (\$10 for contract), and the contract price is quoted in US dollars. The Brent contract is cash-settled based on the ICE Brent crude oil Index price. In contrast, WTI contracts are physically settled, linking their future prices closely to spot prices. Both contracts are sold at 1000 barrels per unit and have their contract prices quoted in USD. Prices from both crude oil markets serve as benchmarks for pricing other crude products globally, making them suitable proxies for the crude oil market. Daily crude oil price data is aggregated to monthly frequency to match the frequency of the macroeconomic variables used as control variables in this study. The relative monthly change in the oil price is computed using log-returns, scaled by 100 to represent percentages:

$$R_{it} = \ln\left(\frac{P_{it}}{P_{it-1}}\right) \times 100 \quad (1)$$

$i = \text{brent, wti}$

3.1.2. Crude oil liquidity

The level of illiquidity within the commodity market is measured by the price-impact measure (*ILLIQ*) of Amihud (2002). Amihud's *ILLIQ* is preferred over trading volume in this study as Jones et al. (1994) suggest that trade volume may become less informative about liquidity variation once separated from trading frequency. Further, Marshall et al. (2012) identify that Amihud's measure provides the most accurate representation of transaction costs when examining liquidity in commodity markets. However, this price-based liquidity proxy is limited by its tendency to underestimate the actual price impact within the commodity market, as identified in Marshall et al. (2012). The monthly *ILLIQ* estimate is given as:

$$ILLIQ_{it} = \frac{1}{T} \sum_{t=1}^T \frac{|R_t|}{DVol_t} \quad (2)$$

where R_t is the daily absolute percentage oil price change, $DVol_t$ is the daily dollar trading volume, and T is the number of trading days in the month. Despite being widely used in research, Amihud's measure of illiquidity, ILLIQ, primarily focuses on the price impact component of liquidity and may not fully capture other aspects of liquidity, for example, the bid-ask spread. Consequently, it provides a partial picture of overall liquidity conditions. Specific market microstructure characteristics, such as trading rules, market depth, or order book dynamics may also influence ILLIQ. Despite these drawbacks, this measure of liquidity has several positive sides, as it can easily be compared across assets, is easily understood, and takes only positive values. The ILLIQ measure has also been widely adopted and extensively used in numerous empirical studies, which makes it easier to compare results to one another. In this study we utilize the ILLIQ measure because it provides a straightforward and intuitive way to capture the price impact component of liquidity, allowing us to examine the relationship between liquidity and asset prices and assess potential liquidity risks, as well as comparing our results with recent findings in the literature.

3.1.3. Fundamentals of the crude oil market

In studying the relationship between price and liquidity in the crude oil market, we recognise the influence the market's fundamentals may individually and jointly have on these variables. Based on the decomposition of oil price shocks by Kilian (2009) and other notable studies which have identified the macro-economic factors which influence oil market fundamentals such as Hamilton (2003); Ratti and Vespignani (2013); Kang et al. (2016), we include aggregate demand, aggregate oil supply, exchange rate, and money supply as external regressors in the conditional mean equation of the GARCH model to account for their impact on the relationship between oil price changes and liquidity.

The weekly US Field Production of crude oil (*oilprod*) is used as a proxy for aggregate supply in the oil market and was obtained from the Energy Information Association (EIA). The weekly *oilprod* dataset spanning February 16th 1996–March 26th 2021, was transformed to monthly frequency to match the frequency of other variables used in this study. Due to the unavailability of global oil production data at the desired frequency, we have utilised data from the US market which is readily available.

We apply the monthly Index of Global Economic Activity (*igrea*) derived by Kilian as a proxy for aggregate demand in the oil market. The *igrea* is computed as the weighted and inflation-adjusted percentage change in the single-voyage ocean shipping freight rates for several bulk dry cargoes. This business cycle index is superior to the proxies of aggregate demand used in other studies for several reasons. Unlike global GDP, the *igrea* is available at a higher (monthly) frequency and is immune to the increasing influence of the service sector on the real GDP of most countries. Unlike industrial production, the *igrea* is a leading indicator of the demand for commodities, as shipping rates for commodities may be seen as an indicator of a firm's future production.

The US Nominal Effective Exchange Rate (*neer*) index, which measures the dollar value (USD) against a weighted average of several other foreign currencies, is the proxy for the exchange rate in this study. An increase in the *neer* of the dollar indicates that the dollar has appreciated relative to several other currencies. As the majority of trades in the global economy are denominated in the dollar, a change in the dollar *neer* index has a strong influence on the demand and supply of commodities. The monthly *neer* data was obtained from the International Financial Statistics of the International Monetary Fund.

The importance of money supply on the fundamentals of the oil market was identified in Ratti and Vespignani (2013) where an increase in the money supply of China and India was associated with an increase in global oil production and real aggregate oil demand. We broaden the scope within this study and control for the impact of global money supply on the commodity market. As a proxy for the global money supply, we utilise the Money Supply (*m1*) for the OECD countries, which consists of currency (banknotes and coins) and overnight deposits. The monthly *m1* data was obtained from the OECD database.

Aside from the *igrea*, all control variables have been transformed by taking their logarithmic difference to ensure stationarity before their inclusion in the regression model. This is based on the recommendation by Kilian and Zhou (2018) that the *igrea* is a business cycle index which must not be differenced or transformed in any way.

Table 1. This table presents the descriptive statistics for the variables studied. All variables have been transformed by taking the logarithmic price difference except for the Index for Global Real Economic Activity (igrea). The mean and standard deviation values for Brent and WTI returns have been annualised. The values of the returns for Brent and WTI, Nominal Effective Exchange Rate (neer), Money Supply (m1), Oil Production (oilprod), and Global Real Economic Activity (igrea) are given in percentages, while the illiquidity (ILLIQ) series have been multiplied by 100. The ADF is the Augmented Dickey-Fuller test for stationarity, Q(5) is the Ljung-Box test for autocorrelation and ARCH (5) tests for the presence of ARCH effect up to 5 lags. (***, **) denote significance at the 1% and 5% levels.

Descriptive statistics	Mean	Std.Dev	Max	Min	Skew	Kurtosis	ADF	Q (5)	ARCH (5)
<i>Brent_{ret}</i>	5.7005	31.1395	22.9488	-49.7617	-1.0199	3.1634	-11.445***	31.509***	39.643***
<i>Brent_{ILLIQ}</i>	0.1141	0.1673	1.0227	0.0026	2.2019	5.9246	-4.4973***	1149.1***	234.98***
<i>WTI_{ret}</i>	5.1496	34.9048	54.4478	-60.0585	-0.8705	7.6797	-12.127***	24.482***	188.73***
<i>WTI_{ILLIQ}</i>	0.0553	0.0760	0.4586	0.0026	2.0944	4.8808	-5.0114***	1073***	192.5***
neer	0.0790	1.2701	6.4856	-3.7891	0.3932	1.6391	-11.676***	45.695***	16.657***
m1	0.9650	4.7767	85.9818	-1.2480	17.3053	304.8411	-11.499***	4.7302	0.0210
oilprod	0.1950	2.9329	15.2878	-24.8563	-2.9088	31.3087	-14.334***	4.4736	18.822***
igrea	3.6076	66.6258	189.0402	-161.8379	0.6242	0.0570	-3.6012**	1131.6***	274.59***

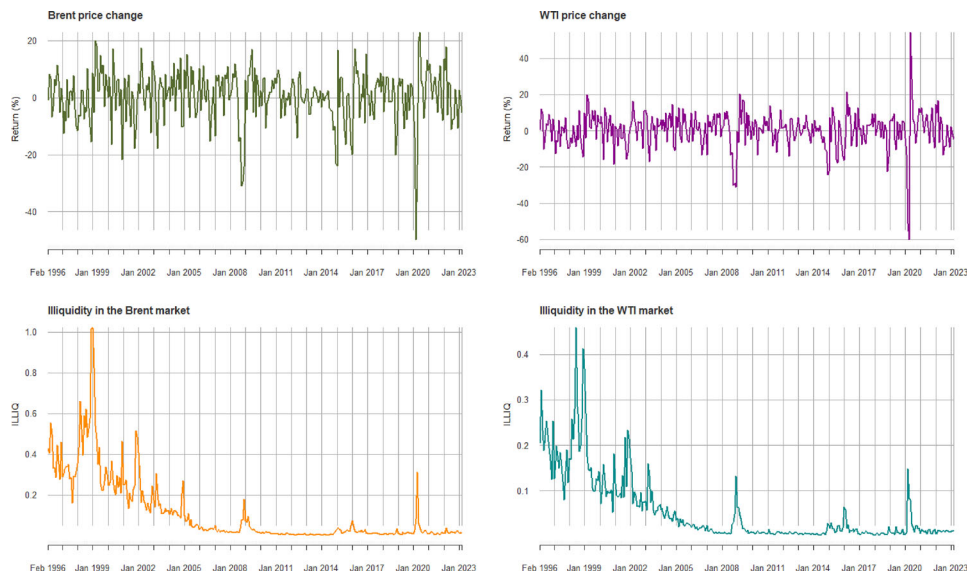


Figure 1. Return and illiquidity in the Brent and West Texas Intermediate (WTI) crude-oil market.

The descriptive statistics for the variables under study are presented in Table 1. On average, the Brent market exhibits higher returns than the WTI market, though the WTI market experiences greater fluctuations and price changes during the sample period. The maximum and minimum values reveal that the WTI market has higher peaks and lower troughs than the Brent market, which is also evident in Figure 1. Figure 2 contains the time series plot for the control variables.

The *ILLIQ* estimates for each market suggest that illiquidity has a more significant price impact in the WTI market compared to the Brent market. The distribution of price impacts due to illiquidity in the WTI market exhibits higher peaks and lower troughs than those in the Brent market. Furthermore, the fluctuations in the *ILLIQ* values for both markets reflect the events in the crude oil market such as the Global Financial Crisis and the initiation of lockdown restrictions in early 2020.

The skew, kurtosis, and Augmented Dickey-Fuller (ADF) test statistics indicate that the return and *ILLIQ* series are not normally distributed, but they are trend stationary. Furthermore, the Ljung-Box and ARCH-LM tests reveal the presence of autocorrelation and heteroskedasticity in the return and illiquidity time series, suggesting that GARCH models are appropriate for this dataset.

The degree of unconditional correlation between the variables has been estimated using the Pearson correlation test, and the results are presented in Table 2. The Pearson coefficient for the correlation between oil price changes and illiquidity is negative for the Brent and WTI markets, which suggests that a reduction in the level of illiquidity within the market accompanies positive oil price movements. There is a negative (positive) relationship between the exchange rate and return (illiquidity) in both the Brent

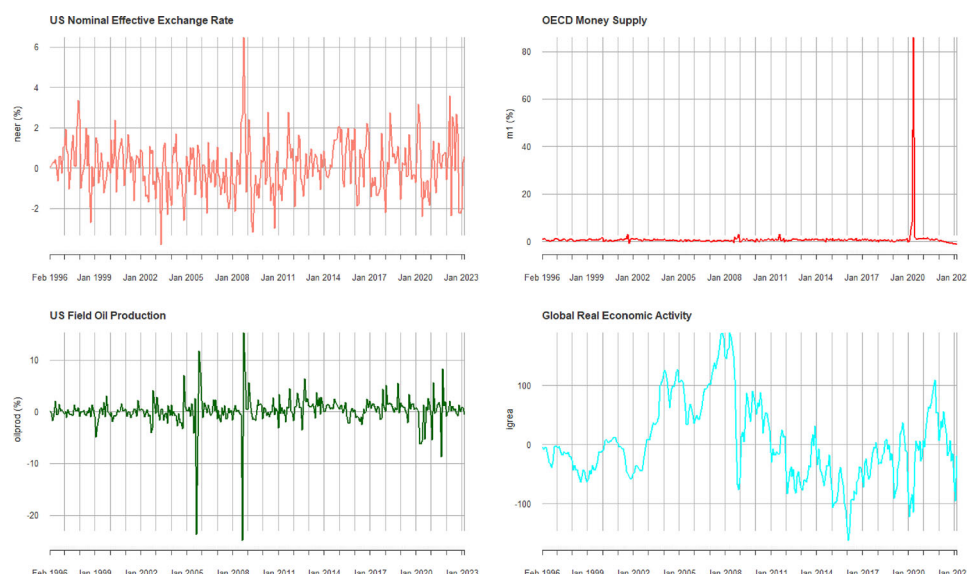


Figure 2. Time series plot of the Nominal Effective Exchange Rate (neer), Money supply (m1), oil production (oilprod) and the Index for Global Real Economic Activity (igrea).

Table 2. This table presents the Pearson correlation between the variables. ILLIQ refers to the Amihud illiquidity measure. The neer, m1, oilprod and igrea refer to the nominal effective exchange rate, money supply, US Oil production, and Kilian's index of Global Real Economic Activity. (***, **, *) denotes significance at the 1%, 5% and 10% levels.

Unconditional correlation coefficients	<i>Brent_{ret}</i>	<i>Brent_{ILLIQ}</i>	<i>WTI_{ret}</i>	<i>WTI_{ILLIQ}</i>	neer	m1	us.oilprod	igrea
<i>Brent_{ret}</i>	1.0000	−0.0763	0.9285***	−0.1166**	−0.3958***	0.0913*	−0.1209**	0.1463***
<i>Brent_{ILLIQ}</i>		1.0000	−0.0771	0.9429***	0.0712	−0.0035	−0.0852	−0.1873***
<i>WTI_{ret}</i>			1.0000	−0.1033*	−0.3851***	0.2533***	−0.1157**	0.1329**
<i>WTI_{ILLIQ}</i>				1.0000	0.0919*	0.03710	−0.0859	−0.2218***

and WTI markets. This supports the conclusion of Sadorsky (2000); Akram (2009), which shows that an increase in the exchange rate is associated with an adverse change in oil price and increased illiquidity in these markets. As indicated in Ratti and Vespignani (2013) and Kang et al. (2016), the correlation between money supply and price movements in the crude oil market is positive. Interestingly, the correlation between money supply and illiquidity is also positive, which indicates that increases in money supply are associated with an increase in the price impact of illiquidity in the Brent and WTI markets.

The correlation coefficient between *oilprod* and the variables indicates that an increase in aggregate oil supply is associated with a reduction in oil price and illiquidity in the crude oil market. The reasons for this includes: *Supply and demand dynamics*: When oil supply increases, the availability of the commodity in the market is greater, leading to a better balance between supply and demand. This increased availability eases the pressure on prices and improves market liquidity by facilitating more trading opportunities. *Lower transaction costs*: With greater oil supply, the cost of trading (i.e. bid-ask spreads) may decrease as market participants can find counterparties more easily. *Market efficiency*: As oil supply increases, the market becomes more efficient in reflecting new information, resulting in a more stable and liquid environment. This stability reduces the price impact of illiquidity as the market can better absorb fluctuations in supply and demand. *Reduced price volatility*: An increase in oil supply can lead to reduced price volatility, as there is more certainty about the availability of the commodity. With less price volatility, the market is less likely to experience abrupt changes in liquidity, which would otherwise exacerbate the price impact of illiquidity.

In the case of the *igrea*, which represents aggregate demand, the Pearson correlation coefficient indicates that an increase in aggregate demand is associated with positive price movements and reduced illiquidity in the crude oil market.

In summary, an increase in oil supply contributes to a reduction in the illiquidity level or price impact of illiquidity in the crude oil market by improving the supply-demand balance, lowering transaction costs, enhancing market efficiency, and reducing price volatility.

In the following section, we analyze how these relationships vary dynamically over time.

3.1.4. Notable events and price movements

Over the period from the mid-1990's to 2021, the history of Brent and the West Texas Intermediate (WTI) prices reveals significant volatility, characterized by notable price swings driven by factors such as geopolitical events, supply-demand dynamics, and macroeconomic conditions. Price shocks, including those caused by the Asian financial crisis in the late 1990s, the global financial crisis in 2008, the oil-price glut of 2014–15, have led to substantial fluctuations. These events provide a snapshot of the key trends and events that have shaped the history of oil prices over the past three decades, highlighting the dynamic nature of the oil market and the multiple factors that influence its price movements and time-varying volatility.

The significance of the 2014–15 oil-price glut and the 2020–2021 COVID-19 pandemic lies in their considerable impact on oil prices. The collapse in oil prices from 2014–16 resulted from a growing supply glut, which failed to provide the expected global growth boost. The benefits of lower oil prices were tempered by the limited responsiveness of economic activity in key oil-importing emerging markets, the contraction in energy investment impacting US activity, and the slowdown in major oil-exporting nations. From its peak at \$107.95 a barrel on June 20, 2014, WTI petroleum prices dropped by 59.2 percent to \$44.08 a barrel by January 28, 2015, within a span of just over seven months. In 2020, the COVID-19 pandemic led to a rapid decline in global oil demand due to government-imposed business closures and travel restrictions. A price war between Russia and Saudi Arabia erupted in March when they failed to agree on oil production levels. Subsequently, an oversupply of oil in April caused an unprecedented collapse in prices, with the contract futures price for West Texas Intermediate (WTI) plunging from \$18 a barrel to around -\$37 a barrel. These events had substantial repercussions on market dynamics and the computation of various financial market information metrics, including the assessment of liquidity.

3.2. ARMAX (1,1)-aDCC-GARCH-t(1,1)

In this paper, the ARMAX(1,1) method, a combination of autoregressive moving average and exogenous variables, is employed to capture the dynamic relationship between return and liquidity in the crude oil market. The aDCC-GARCH-t(1,1) method is utilized to model time-varying associations and analyze the volatility dynamics in the data.

The ARMAX(1,1) method is advantageous for capturing the dynamic relationship between return and liquidity by incorporating exogenous variables. It allows for the inclusion of external factors that may influence the relationship, providing a more comprehensive analysis.

The aDCC-GARCH-t(1,1) method, a variant of the DCC-GARCH(1,1) method, offers the additional benefit of modeling time-varying associations and capturing volatility dynamics in the data. This allows for a more nuanced understanding of how the relationship between return and liquidity evolves over time.

Compared to the standard DCC-GARCH(1,1) method, both the ARMAX(1,1) and aDCC-GARCH-t(1,1) methods provide a more sophisticated and detailed analysis, enabling us to uncover time-varying patterns, incorporate relevant external variables, and gain deeper insights into the dynamics of the return-liquidity relationship in the crude oil market.

The GARCH model is specified using the *student* – *t* distribution as the skew and kurtosis statistics indicate that the variables are not normally distributed. The standard specification of the symmetric DCC-GARCH model as given in Engle (2002) is as follows:

$$\begin{aligned} H_t &= D_t R_t D_t \\ D_t &= \text{diag}[\sqrt{h_{1t}}, \dots, \sqrt{h_{Nt}}] \\ R_t &= \text{diag}[Q_t]^{-1/2} Q_t \text{diag}[Q_t]^{-1/2} \end{aligned} \quad (3)$$

In Equation (3), D_t is the diagonal matrix containing the univariate conditional variance (h_{it}); R_t is the correlation matrix containing the conditional correlations and Q_t is the conditional covariance matrix.

The parameters in Equation (3) are obtained from the mean equation modelled as an autoregressive moving average (ARMAX) model with the aforementioned macro-variable as exogenous inputs.

$$\begin{aligned} Y_t &= \theta + \sum_{i=1}^p \vartheta_i Y_{t-i} + \sum_{i=0}^q \Theta_i \epsilon_{t-i} + \phi X_{t-1} \\ \epsilon_t &= D_t^{1/2} \nu_t \end{aligned} \quad (4)$$

where $Y_t = (Ret_t^i, Amihud_t^i)$ contains the variables being studied; $X = (neer, m1, indprod, igrea)$ contains the exogenous inputs; ϵ_t contains the residual term; ν_t contains the standardised residuals derived as $\epsilon_t/\sqrt{h_t}$; and D_t is defined as in Equation (3). Next, the conditional variance is obtained from the univariate GARCH(1,1) model using the residuals from Equation (4):

$$h_{i,t} = \omega_{i,0} + \alpha \epsilon_{i,t-1}^2 + \beta h_{i,t-1} \quad (5)$$

Finally, the covariance matrix Q_t is obtained using the asymmetrical DCC equation of Cappiello et al. (2006). The choice of the asymmetrical GARCH models is influenced by studies such as Moosa and Silvapulle (2000), which identify non-linearity in the relationship between price and volume in the crude oil market.

$$Q_t = S(1 - \alpha - \beta) - \gamma \hat{Z} + \alpha(\epsilon_{t-1} \epsilon'_{t-1}) + \beta Q_{t-1} + \gamma \zeta_{t-1} \zeta'_{t-1} \quad (6)$$

where S is the unconditional correlation matrix of ϵ ; ϵ is the consistent estimator of the unconditional correlation matrix, and α and β are parameters indicating that the model is mean-reverting as long as $\alpha + \beta < 1$. The asymmetrical dynamic conditional correlation between the variables is captured by γ coefficient

Applying the asymmetrical GARCH specification overcomes the major limitation associated with GARCH models, i.e. the assumption of symmetry in the conditional relationship of the studied variables. Although a popular model for capturing time-varying conditional covariance between two variables, GARCH models are restricted by their reliance on historical information.

4. Empirical results and discussion

In this section, we provide a comprehensive explanation to reinforce the suitability and robustness of the employed econometric model. We emphasize its ability to effectively capture and analyze the dynamics between return and liquidity in the crude oil market. By addressing potential concerns and

Table 3. This table presents the results from the conditional mean and variance equations of the ARMAX(1,1)-GARCH(1,1)-t model. ILLIQ refers to the Amihud Illiquidity measure. p-values are reported in parentheses. “neer”, “m1”, “oilprod” and “igrea” denote nominal effective exchange rate, money supply, US oil production and the Index for Global Real Economic Activity.

Empirical results from the ARMAX-GARCH-t model	<i>Brent_{ret}</i>	<i>Brent_{ILLIQ}</i>	<i>WTI_{ret}</i>	<i>WTI_{ILLIQ}</i>
Panel A: Mean equation parameters – ARMAX (1,1)				
Constant	0.8777 (0.1290)	0.0045 (0.1793)	0.8986 (0.7969)	0.0049 (0.0149)
AR (1)	−0.1662 (0.8108)	0.9473 (0.0000)	0.0975 (0.9766)	0.9418 (0.0000)
MA (1)	0.3144 (0.6341)	−0.4885 (0.0000)	0.0017 (0.9996)	−0.5803 (0.0000)
neer	−0.6472 (0.1181)	0.0006 (0.0366)	−0.4969 (0.7955)	0.0004 (0.0178)
m1	0.2458 (0.0000)	0.0000 (0.9811)	0.2749 (0.7794)	−0.0002 (0.5582)
oilprod	0.1875 (0.2722)	0.0002 (0.0690)	0.2299 (0.5043)	0.0001 (0.5283)
igrea	0.0136 (0.0549)	−0.0000 (0.7913)	0.0137 (0.4418)	−0.0000 (0.0198)
Panel B: Variance equation parameters – GARCH-t (1,1)				
omega	40.9295 (0.0061)	0.0000 (0.0878)	52.5818 (0.7628)	0.0000 (0.3305)
alpha ₁	0.3101 (0.0111)	0.4080 (0.0000)	0.3201 (0.3880)	0.3016 (0.0000)
beta ₁	0.1136 (0.6518)	0.5910 (0.0000)	0.0000 (0.9999)	0.6974 (0.0000)
Panel C: Model diagnostics				
Q (5)	3.0984 (0.6848)	2.1569 (0.827)	5.8499 (0.3211)	1.3645 (0.9282)
ARCH (5)	0.7075 (0.9826)	0.2551 (0.9984)	2.7359 (0.7406)	0.0415 (0.9999)
Li-Mak (5)	0.6737 (0.9545)	0.4065 (0.9819)	1.9229 (0.7499)	0.0477 (0.9997)

Table 4. This table presents the dynamic conditional correlation (DCC) parameters and descriptive statistics of the DCC coefficients. ILLIQ refers to the Amihud illiquidity measure. (***, **, *) denotes significance at the 1%, 5% and 10% significance levels.

Time-varying conditional correlation between return and illiquidity in the Brent and WTI market	DCC α	DCC β	DCC γ	Mean	Std.Dev	Max	Min
$Brent_{ret, ILLIQ}$	0.2493**	0.0000	0.8570***	-0.38133	0.17711	0.6620	-0.5193
$WTI_{ret, ILLIQ}$	0.0196	0.8824***	0.0548	-0.4065	0.0344	-0.2479	-0.4611

discussing the model's strengths, we ensure the reliability and soundness of our findings. Subsequently, we present the results in the table, providing a clear understanding of the empirical outcomes derived from our sustainable econometric analysis.

The results from fitting the data to the ARMAX-aDCC-GARCH-t model are presented in Table 3. In Panel B, where the parameters of the variance equation are presented, the significance of the α in the GARCH equation indicates that return and liquidity volatility in the Brent and WTI markets is affected by speculative shocks in the short term. However, the β parameter is only significant in the GARCH equation for illiquidity, which suggests that speculative shock in the oil market only has a long-term impact on liquidity in the oil market.

In Panel A, the index for global real economic activity (*igrea*) and money supply (*m1*) have a significant positive impact on the Brent return. The AR_1 and MA_1 terms are significant for the illiquidity in both markets. The nominal effective exchange rate (*neer*) has a significant positive impact on the illiquidity of the oil markets.

Finally, Panel C shows the model has been successfully fitted, as the residuals exhibit no residual heteroskedasticity or autocorrelation. This indicates that the ARMAX-aDCC-GARCH-t model is appropriate for analyzing the relationship between return and liquidity in the Brent and WTI markets.

In Table 4, we present the parameters obtained from the asymmetrical Dynamic Conditional Correlation (DCC) model, which examines the time-varying correlation between return and illiquidity in the Brent and WTI markets. The table also summarises the distribution of the conditional correlation in the crude oil market.

The DCC_α parameter, which measures the short-term impact of shocks on the correlation between return and illiquidity, is only statistically significant for the Brent market. This suggests that the short-term effect of speculative shocks on the return-illiquidity relationship is observable in the Brent market but not in the WTI market. In contrast, the DCC_β parameter is significant for the WTI market, indicating that speculation has a significant long-term impact on the return-illiquidity relationship in this market. The significance of the DCC_γ parameter for the Brent market suggests that negative and positive shocks have statistically different effects on the relationship between return and illiquidity. This means that the impact of speculation on the return-illiquidity relationship varies based on the market's perception of new information.

On average, the conditional correlation between return and illiquidity in both markets is negative, implying that an increase in market return corresponds to a decrease in illiquidity. The relationship between illiquidity and return is stronger in the WTI market compared to the Brent market, although this relationship is more volatile in the Brent market during the sample period. The maximum and minimum values show that the time-varying conditional correlation between return and illiquidity fluctuates between negative and positive values during the period studied.

To identify significant changes in the relationship, we compute the 3-month and 12-month moving averages of the time-varying conditional correlation, as illustrated in Figures 3 and 4. The plot reveals that the relationship between return and illiquidity is predominantly negative throughout the study sample, supporting findings from previous studies such as Chordia et al. (2002) and Zhang et al. (2019). The dynamic nature of the price-liquidity relationship indicates that forecasts of future price movements based on trading activity or liquidity will yield varying levels of accuracy for technical analysts and traders.

The plots demonstrate that speculation has a stronger influence on the price-liquidity relationship in the WTI market compared to the Brent market. During significant shocks to the oil market, such as the 2020 pandemic and the Russian-Ukraine war in 2022, the impact of speculation on the price-liquidity

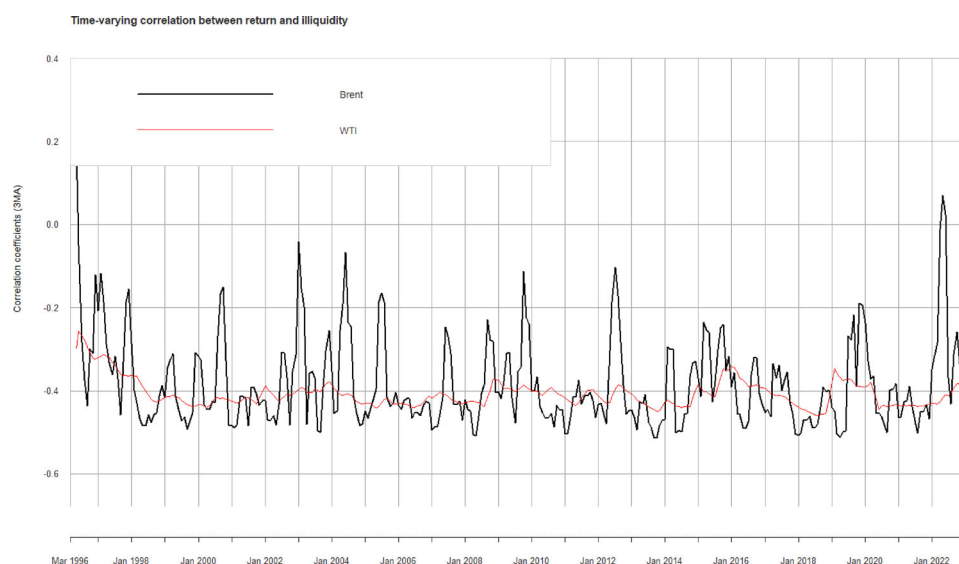


Figure 3. Time-varying correlation between return and illiquidity in the Brent and WTI crude-oil market based on the 3-month moving average of the dynamic conditional correlation coefficient.

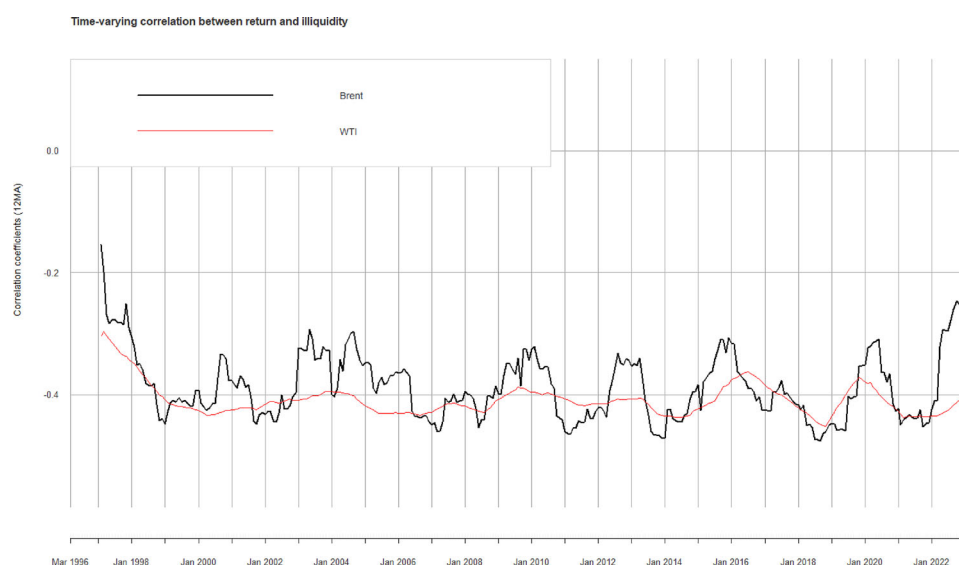


Figure 4. Time-varying correlation between return and illiquidity in the Brent and WTI crude-oil market based on the 12-month moving average of the dynamic conditional correlation coefficient.

relationship in the Brent market is relatively weak. Moreover, the Brent market exhibits increased variation in this relationship, indicating that the influence of speculative activities on the price-liquidity relationship is generally less persistent. It is noteworthy that speculation in the Brent market leads to a positive relationship between return and illiquidity during the onset of the Russian-Ukraine war, as shown in Figure 3.

To gain further insights into the differing impact of speculation in these markets, we examine the monthly price differential between the Brent and WTI markets presented in Figure 5. The plot illustrates a growing spread between both oil markets over time, suggesting the absence of arbitrage/informed traders and an increasing inefficiency in one or both crude oil markets during these periods. This observation aligns with findings from Okoroafor and Leirvik (2022), which reported the WTI market as less efficient. Hence, the persistent effect of speculation on the price-liquidity relationship may be attributable to the dominance of contrarian noise traders.

If we assume that there are at least two groups of traders in the crude oil market—Group A, traders with a sensitivity to the oil market based on their physical stakes in the market, and Group B, neutral or

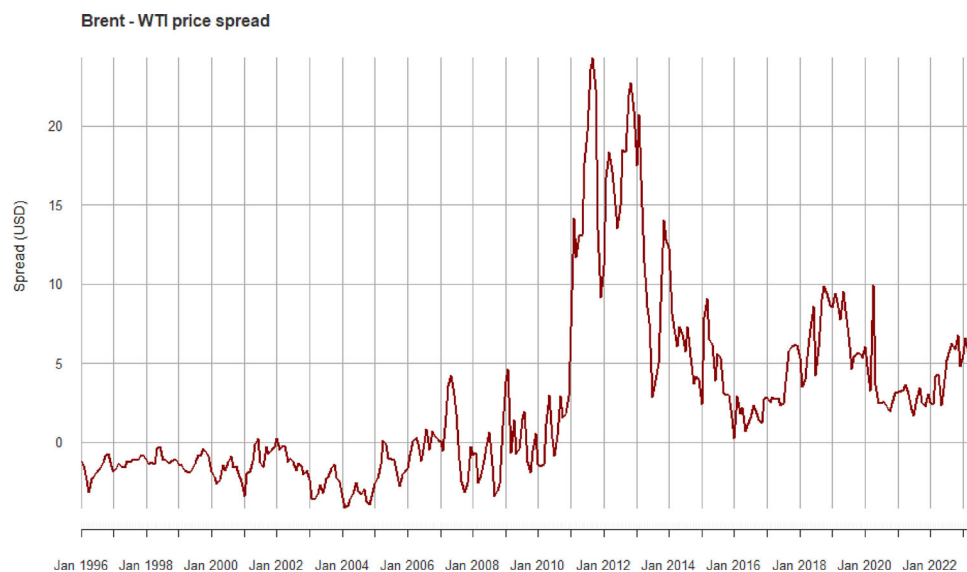


Figure 5. Price differential between the Brent and WTI crude-oil market.

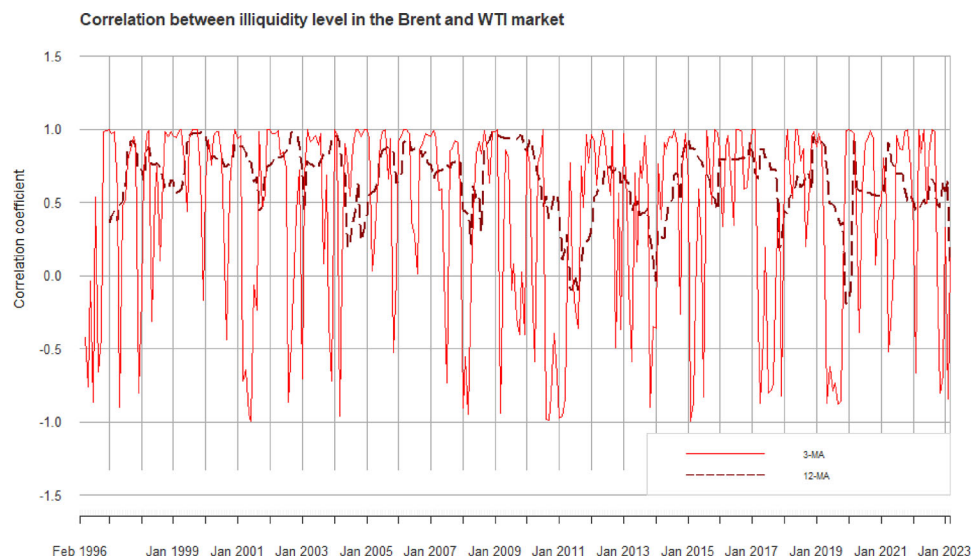


Figure 6. Moving correlation between the illiquidity level in the Brent and WTI crude market based on 3-month and 12-month window widths.

risk-seeking traders with no physical stake in the oil market. Another explanation suggested by the results is the dominance of heterogeneous traders within each market. To illustrate this point, current literature highlights that hedgers, such as oil companies with physical stakes in the oil market, primarily act as liquidity consumers since they require liquidity to hedge their existing risks. On the other hand, speculators and other non-commercial traders are considered providers of liquidity and show less sensitivity to illiquidity (see Haugom & Ray, 2017). Within this context, the findings indicate that risk-seeking or speculative traders without a physical stake in the oil market generally dominate the WTI market. The plot presented in Figure 6 provides further support for heterogeneous traders with differing liquidity needs and risk exposures within these markets, as it shows periods of negative correlation between the illiquidity levels in both markets.

4.1. Insights for policymakers, traders, and researchers

In this study, our findings hold important implications for policymakers, market traders, and researchers in the crude oil market. The significant impact of speculation on the return-liquidity relationship, which

has grown stronger over time, calls for policymakers to address speculative behavior and take measures to enhance market stability. The observed converging pattern between the Brent and WTI markets suggests that considering the heterogeneous trader hypothesis is crucial in policymaking decisions.

For policymakers, our insights provide guidance on mitigating risks, making informed decisions, and developing effective strategies to manage trading and risk in the crude oil market. By incorporating our research into their policymaking frameworks, policymakers can work towards fostering a more stable and efficient crude oil market.

Market traders can utilize our findings to develop trading strategies based on the pattern of illiquidity-price movements in the Brent and WTI markets, taking into account their risk appetite. Understanding the dynamic relationship between liquidity and price changes can inform traders in making informed decisions and managing their trading positions more effectively.

From a research perspective, our study contributes to filling the existing literature gap by analyzing the dynamic relationship between liquidity and price changes in the crude oil market. Future research can build upon our findings to further explore the implications of liquidity on pricing efficiency and the quality of the crude oil market. Additionally, studying the influence of different market participants, such as financial actors, can deepen our understanding of the market dynamics and inform future research directions.

Overall, our study's implications provide practical applications for policymakers, market traders, and researchers in navigating the complex landscape of the crude oil market, fostering stability, and enhancing market efficiency.

5. Conclusion

The relationship between price and liquidity contains information about the market, and variation in this relationship is important to all stakeholders in the commodity market. This article fills the existing literature gap by analysing the dynamic relationship between liquidity and price changes in the crude oil market. The empirical results indicate an inverse relationship exists between illiquidity and return in the crude oil market on average. Furthermore, the strength of this relationship is not constant but varies over time. Similar to Haugom and Ray (2017), the results indicate that the dynamics of oil price movements and illiquidity are affected by the nature of traders that dominate the market when new information arrives in the crude oil market. The over-reactionary trading of positive feedback traders and the activities of arbitrage traders taking advantage of the Brent-WTI price spread may account for the variations in the relationship between price and illiquidity in the crude oil market.

There are several implications which may be inferred from the results of this study. The first consequence relates to the financialisation phenomenon in commodity markets. The observed structural change in the relationship between liquidity and price in the crude oil markets after 2008 supports the proponents of a financialised crude oil market. In addition to having a more active derivatives market, the results of this study also suggest that the WTI market has more financial actors than the Brent oil market.

The second consequence relates to developing profitable trading strategies based on the pattern of illiquidity-price movements in the Brent and WTI markets and with consideration to the risk appetite of the trader.

The third consequence relates to pricing efficiency and the quality of the crude oil market. Chordia et al. (2008) show that market liquidity is essential to improving and maintaining the efficiency level within a market. Liquidity in the Brent market has a stronger connection to price movements, which indicates that market regulators will have to take measures to maintain the liquidity level in the market during a market decline. In contrast, we observe a weaker connection between price movements and illiquidity in the WTI, which suggests that liquidity will have minimal effect on the level of pricing efficiency within the market.

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Disclosure statement

The authors report there are no competing interests to declare.

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