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Time varying market efficiency in the Brent and WTI crude market

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ABSTRACT

This paper examines time-varying market efficiency in the crude oil spot market using a recently derived measure of market efficiency: the Adjusted Market Inefficiency Model (AMIM). Analysing efficiency in the crude oil market, and its response to significant events within the global financial and commodity market, we identify that the Brent market is on average more efficient than the West Texas Intermediate (WTI). We also find that the WTI market is persistently inefficient during financial crises, with high volatility of the efficiency in such periods. In addition to confirming the adaptive market hypothesis, this study offers a new perspective by highlighting the non-uniform response of efficiency in similar markets to global events.

1. Introduction

In this paper, we examine the evolution of market efficiency in the Brent and WTI market in response to global events using the Adaptive Market Hypothesis (AMH) of Lo (2004) and the Adjusted Market Inefficiency Magnitude (AMIM) measure derived in Tran and Leirvik (2019). We find that these markets exhibit time varying market efficiency and respond adversely to any announcements which affect supply or demand conditions in the global oil market. In addition, we find that there is some non-linearity in the efficiency response of both markets to market events.

Although frequently discussed in relation to the equity market, market efficiency is equally relevant in the study of commodity markets. This is because commodity traders need to be aware of profitable opportunities within this market even as market regulators need to be assured that the informational role of the price is preserved. The Efficient Market Hypothesis (EMH), derived by Fama (1970), faced major criticism for its focus on equilibrium pricing models and the presumed rationality of investors as central to market efficiency and its study, see Malkiel (2003) and Barber and Odean (2001). Furthermore, Alizadeh and Muradoglu (2014) find that international shipping rates can be used to predict stock returns and is one out of many studies which suggest a myriad of variables capable of predicting returns. The findings on predictable returns are contrary to the assertion of the EMH, which implies that stock prices cannot be predicted from past information. Equating the financial market to a natural system in which market participants compete for profit opportunities, the Adaptive Market Hypothesis (AMH), introduced by Lo (2004), asserts that market efficiency is determined by the response of market participants to changing market conditions. The rationality assertion of the EMH is not completely discounted by the AMH. Rather, it is the attempt by market members to process changes in the “market ecosystem” and ensure that they remain competitive that results in behaviour which is interpreted as irrational. Lo further suggests that these behaviours are not isolated, independent or constant, but rather change as conditions within the market change.

The AMH has influenced the study of market efficiency, receiving confirmation from several studies and across different asset classes. For example, Lim et al. (2008), Ito et al. (2014) and Noda (2016) have all documented time-varying efficiency in several international stock markets. In the markets for foreign exchange, Charles et al. (2012) utilise the Automatic Variance ratio test in

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documenting time-varying return predictability in five major foreign exchange rates. Furthermore, (Tran and Leirvik, 2020), use the Adjusted Market Inefficiency Magnitude (AMIM), derived by Tran and Leirvik (2019), and find significant inefficiency in the cryptocurrency market but with improving efficiency levels towards the end of the sample period indicating that the market exhibits time-varying properties. In a study of 79 commodity futures, Kuruppuarachchi et al. (2019) find improving market efficiency over time, which is further evidence of the evolving nature of market efficiency. These are just a few of several studies which have focused on efficiency in the financial market. Our study contributes to literature by examining time-varying efficiency in the oil commodity market.

Various methods have been applied by numerous studies in studying the nature of efficiency in the oil market albeit with differing results. Charles and Darné (2009) apply the Variance Ratio test and show that, the Brent spot market is weak-form efficient while the WTI was mostly inefficient for major parts of the sample period (1982–2008). Zhang et al. (2014) studies the Brent, WTI, Dubai and Daqing crude spot markets, and finds intermittent and inconsistent efficiency in all markets when using daily data and the Threshold GARCH model. Using the Generalised Spectral test with rolling sample analysis, Zhang (2013) suggest that the WTI market has been more efficient than the Brent since 2005. Applying the Automatic Portmanteau and the Generalised Spectral test, Ghazani and Ebrahimi (2019) found the Organisation of Petroleum Exporting Countries (OPEC) basket to be the most inefficient of the major oil markets.

Our paper is distinguished by the use of a long sample period which offers a broad view of the evolving nature of market efficiency throughout the history of the crude spot market. We also utilise a time-varying efficiency model instead of the statistical test with moving windows method applied by most of the other studies. In addition to overcoming the problem of choosing the optimal window length, the AMIM is chosen for its ability to give a direct measure of the level of efficiency in a market and therefore aids comparison across different markets and even asset classes. This is achieved by its ability to quantify efficiency levels. Taking as its foundation Lo's proposition of evolving market efficiency, this paper analyses efficiency in the oil market taking into consideration the role played by significant events within the market. Using daily return from the Brent and WTI market, we find that (a) efficiency in both markets display time-varying properties (b) on average, the WTI market displays higher inefficiency levels although both markets have substantial periods of inefficiency, (c) both markets have volatile efficiency levels and (d) there is a non-linearity in how inefficiency in both markets respond to financial crises.

2. Data and methodology

2.1. Data description

This study makes use of Brent and WTI daily price data obtained from International Energy Agency (IEA). Data set ranges from May 20, 1987–September 21, 2020 which consists of 8464 observations. The sample period was chosen with consideration to the earliest available public data for the Brent spot market. As the aim of this study is to analyse the evolution of market efficiency, it is important that our data begin as close to the inception of the market as possible. This will allow the comparison of efficiency levels in the market during different events in the market. To enable comparison between results obtained for both markets, the same start date is also chosen for the WTI market, although earlier data is available. Fig. 1 shows a time-series plot of price and return in the Brent and WTI crude market for the chosen sample period. Daily logarithmic returns are computed from price data which forms the input for obtaining daily efficiency values over a 240-day overlapping window. The choice of daily data enables analysis without the aggregating effect of low frequency data.

2.2. Adjusted Market Inefficiency Magnitude (AMIM)

The Adjusted Inefficiency Magnitude (AMIM) is a market efficiency test derived by Tran and Leirvik (2019) which captures the time-varying properties of efficiency across different asset classes and regions. In addition, the AMIM offers a direct measurement of the significance of efficiency in a market over a period of time.

Beginning with an auto-regressive $AR(q)$ return equation as in Eq. (1), the EMH requires that the beta coefficients from this equation not be significantly different from zero indicating that past returns do not predict future returns.

$$r_t = \alpha + \beta_1 r_{t-1} + \cdots + \beta_q r_{t-q} + \varepsilon_t \tag{1}$$

The degree of inefficiency within the market, measured by the Market Inefficiency Magnitude (MIM), is derived from the standardised beta coefficients from Eq. (1). See the appendix for a derivation of MIM. However, the MIM will need to be adjusted as there is a tendency for it to give high values due to the positive correlation with the number of lags in the base $AR(q)$ equation. This is carried out with the *adjusted* MIM (AMIM) at time t, and is given as:

$$AMIM_t = \frac{MIM_t - R_{CI}}{1 - R_{CI}} \tag{2}$$

where MIM_t is the Market Inefficiency Magnitude at time t and R_{CI} is the range of confidence intervals for the MIM. A thorough derivation and the range of confidence intervals used in Eq. (2) is provided in Tran and Leirvik (2019).

The denominator in Eq. (2) is a common ground which enables comparison across periods, assets, and regions. In interpreting the model, $AMIM_t \leq 0$ indicates that a market is efficient while $AMIM_t > 0$ values represent inefficiency within the asset or market.

Table 1
Summary statistics for daily logarithmic price differences and efficiency (AMIM) for the Brent and West Texas Intermediate (WTI) crude oil market. Mean,Median, and Standard deviation of return in the Brent and WTI are annualised figures. AMIM values are computed from 240-day overlapping data using logarithmic price differences. The sample period is 27 May 1987–25 September 2020.

	Mean	Median	Standard deviation	Max	Min	Skewness	Kurtosis
Panel A: Descriptive statistics, Return							
Brent	4.840%	7.301%	3.896%	41.20%	−36.12%	0.05	26.75
WTI	4.407%	15.512%	4.247%	42.58%	−40.64%	0.05	29.14
Panel B: Descriptive statistics, Market efficiency							
Brent	0.013	0	0.010	0.365	−0.521	−0.174	4.039
WTI	0.014	0	0.088	0.670	−0.382	1.108	5.014

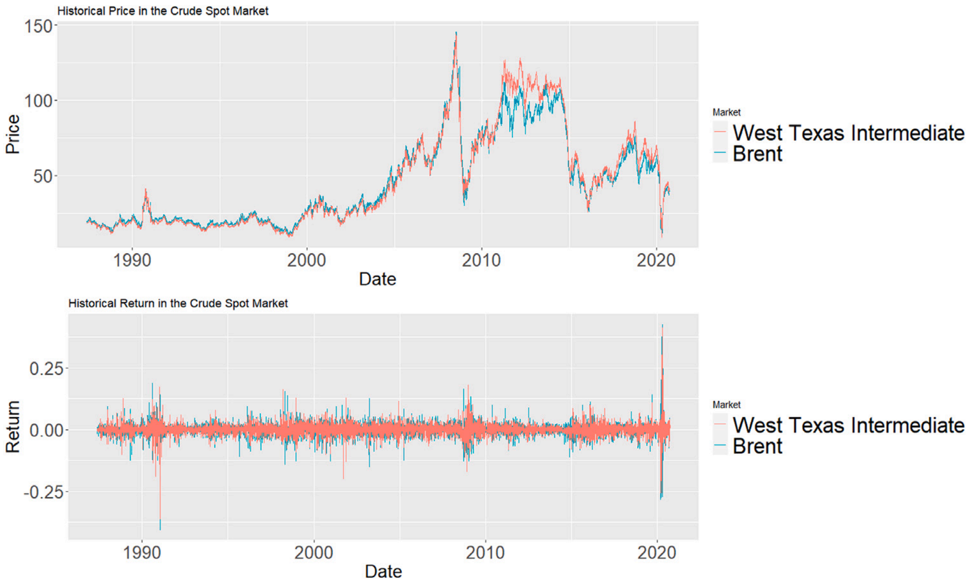

Fig. 1. Historical price and return in the brent and WTI spot market from May 20 1987–September 21 2020.

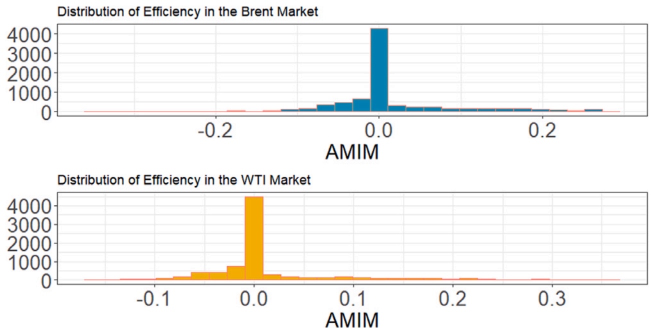

Fig. 2. Distribution of efficiency in the Brent and West Texas Intermediate (WTI) spot market. Data sample is from May 20 1987–25 September 2020.

3. Empirical results and discussion

AMIM values for the Brent and WTI market have been computed using a 240-day overlapping window of logarithmic price differences from the crude oil spot market. The summary statistics of AMIM values for both markets are contained in Table 1. The Brent and WTI spot market are on average inefficient as they both have AMIM values greater than 0. The median values suggest that a substantial amount of the AMIM observations are zero. This indicates that in over half of the study period, oil prices are efficient. The skewness and kurtosis results suggest that efficiency in the Brent and WTI crude market do not follow a normal distribution. This is confirmed by the examination of the histogram in Fig. 2.

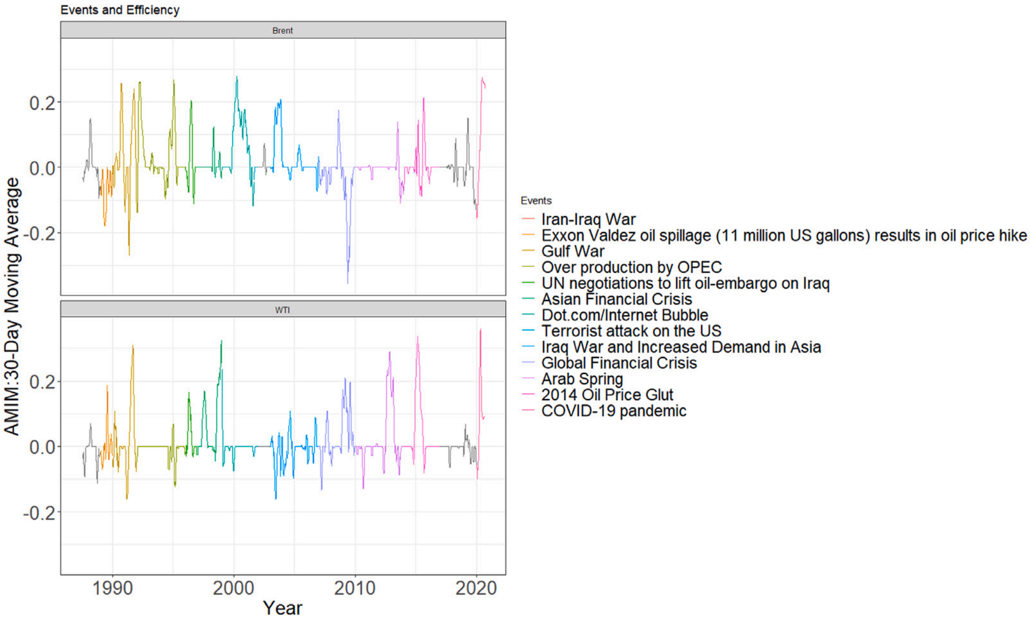

Fig. 3. 30-day Moving-Average AMIM values for the Brent and West Texas Intermediate (WTI) spot market from May 20 1987–September 25 2020. Line-plot has been colour coded to reflect events in the global oil market.

Efficiency in the Brent and WTI crude market over the sample period is illustrated in Fig. 3. Daily AMIM values have been smoothened using a 30-day moving-average and the line plot has been colour-coded to reflect some events within the global oil market during the sample period.

In interpreting the results, the area of the graph above zero represents inefficient periods within the market. Changes in the level of market efficiency can be observed in both markets, which confirms that efficiency in the crude spot market is time-varying and further lends support to the AMH. We perform a statistical test of the mean efficiency level in both markets at the beginning (first ten years) and end (last ten years) of the sample. We find that, efficiency in the Brent has significantly improved while that of the WTI market has worsened. However, we note that in the beginning of the sample period, the WTI market is more efficient than the Brent. This reconciles findings from earlier studies which suggest that the WTI market is more efficient than the Brent market. In addition, we find that the recovery of efficiency in the Brent spot market was faster following the Asian financial crisis and the Global Financial Crisis (GFC). This is contrary to the results obtained from the WTI market, where inefficiency was more persistent. Because of the proximity of the WTI market to the US where the GFC originated, we suggest this as an explanation for the results obtained during the GFC. However, this explanation cannot be extended to the findings obtained from the earlier Asian financial crisis. Below, we discuss other factors which may explain the results obtained.

The concept of commodity market financialization has been blamed for increased price volatility among other anomalies within the market for commodities. Financialisation refers to the high involvement of financial traders in commodity markets, such that the spot price is influenced by the activities of these traders in addition to demand and supply within the market. Several studies have documented evidence of strong correlations between the WTI and other US and non-US stock markets (see Creti et al. (2013)) suggesting a continuous financialization of the market. However, the financialization of commodity markets in general, and the crude oil market in particular, is a highly contested idea. For example, Fattouh et al. (2013) argues that although there has been an increase in the number of financial actors in the crude market, speculative trading has not had any significant impact on price in the crude oil market as its price development is similar to those of other commodities which do not have active futures market.

Some studies have traced the pricing issues within the WTI crude market to storage problems specific to this market (see Charles and Darné (2009) and the references within). The WTI crude market is known to suffer from limited storage capacity and this may influence price efficiency within this market through crude oil demand shocks. Unlike the Brent, which has a more flexible sea-based storage system, the WTI is more vulnerable to demand shocks due to its land-based storage infrastructure.[1] During financial crises, the demand for oil reduces as global economic activity reduces. However,oil producers continue to produce and supply oil as it is more expensive to shut down production due to fixed overheads. This soon results in excess supply and places further strain on the storage system. The impact of the storage crisis become more apparent during the Covid-19 pandemic in 2020. During this period,

[1] Brent crude is stored on ship tankers which makes it easier to scale storage capacity. In contrast, a landlocked main hub at Cushing Oklahoma and pipeline storage make scaling difficult for the WTI crude market

Table 2
Correlation between efficiency and liquidity. CSS is liquidity measured by the Corwin–Schutz high-low spread estimator. ILLIQ is liquidity measured by Ahmihud's ratio. The table contains the Pearson correlation coefficient.

	AMIM-CSS	AMIM-ILLIQ
Panel A: Correlation between liquidity and efficiency, Brent market		
Full sample	0.0512*	0.1400*
Asian financial crisis	−0.0789	0.0760
Global financial crisis	−0.0242	−0.1888*
Panel B: Correlation between liquidity and efficiency, WTI market		
Full sample	0.2912*	0.2322*
Asian financial crisis	0.3282*	0.2021*
Global Financial crisis	0.3839*	0.4796*

*denotes statistical significance at the 1% level.

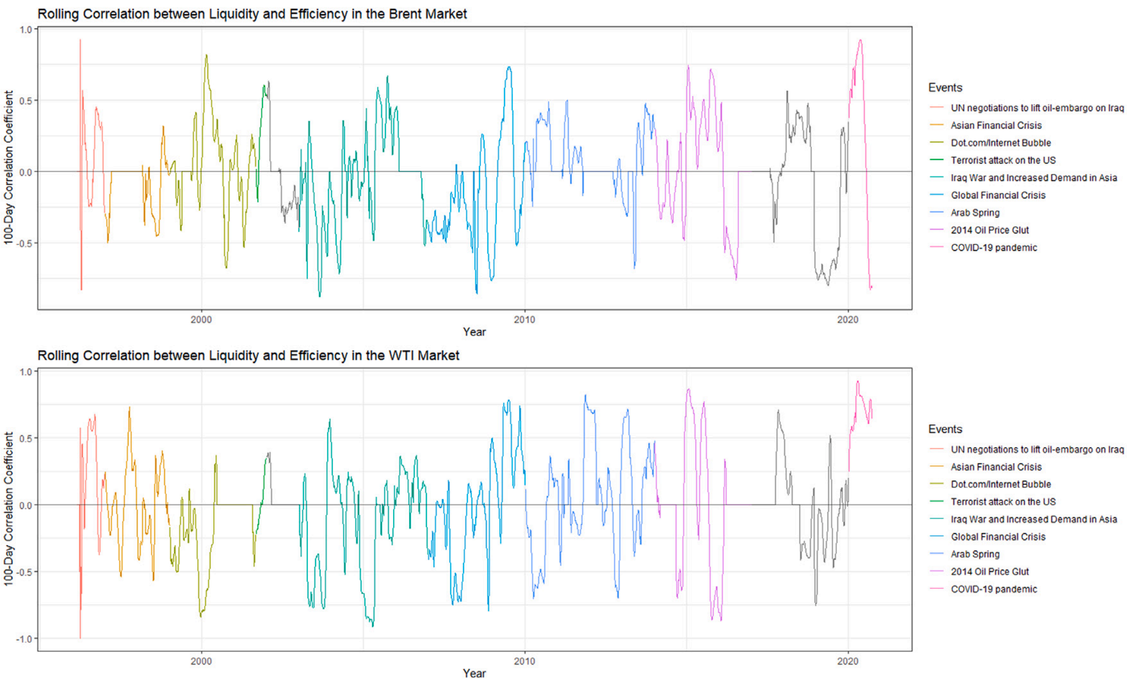

Fig. 4. 100-Day rolling correlation between efficiency and liquidity in the Brent and West Texas Intermediate (WTI) crude market.

WTI crude oil price reached unprecedented negative values as the supply glut resulted in entities paying to have excess supply taken off their hands (Fawthrop, 2020).

Another factor which may explain changes in efficiency level within a market is market liquidity. Liquidity in commodity markets are provided through the trading activities of speculators and hedgers. Empirical support for a positive relationship between liquidity and market efficiency has been documented by studies of the stock market (Chordia et al., 2008), cryptocurrency market (Wei, 2018), and even the carbon exchange market (Ibikunle et al., 2016). Frequent trading provides an opportunity for new information to be absorbed during the price discovery process. In addition, a liquid market enables market members act on any available arbitrage opportunities thereby making prices more efficient, whereas in an illiquid market investors will not be able to take advantage of mispricings, thus making the market less efficient. Testing the null hypothesis that there is a positive relationship between market efficiency and liquidity in the crude market, we apply two popular measures of liquidity.

The first measure of liquidity applied is the ILLIQ by Amihud (2002), which measures the ratio of daily absolute price change to trading volume. The higher the ratio, the more illiquid the market is. The second measure is the High-Low spread estimator by Corwin and Schultz (2012). Spread estimators are popular measures of liquidity within a market as smaller spreads are indicative of a more liquid market. See the appendix for a derivation of both measures.

The results indicate that liquidity in both markets is mostly stable, with large spikes registered only in the periods corresponding to the GFC and Covid-19 pandemic, being similar to findings for the cryptocurrency market, see Leirvik (2021) (see Table 3).

The Pearson correlation test shows that there is significant positive correlation between the spread estimator and inefficiency in the Brent and WTI crude market (see Table 2 and Fig. 4). This is also confirmed by the significant positive correlation between illiquidity and inefficiency within these markets. We find that the correlation relationship is stronger in the WTI crude market than

Table 3
Descriptive statistics for liquidity in the Brent and WTI crude market. CSS is liquidity measured by Corwin–Schutz high-low spread estimator. ILLIQ is liquidity measured by Ahmihud's ratio.

	Mean	Median	Standard deviation	Skew	Kurtosis
Panel A: Liquidity in the Brent crude market					
CSS	0.0070	0.0100	0.0034	3.0249	19.952
ILLIQ	7.0e−07	1.8e−06	2.6e−07	8.9807	112.259
Panel B: Liquidity in the WTI crude market					
CSS	0.0081	0.0113	0.0044	3.5090	32.352
ILLIQ	6.0e−07	1.1e−05	1.4e−07	72.0223	5401.74

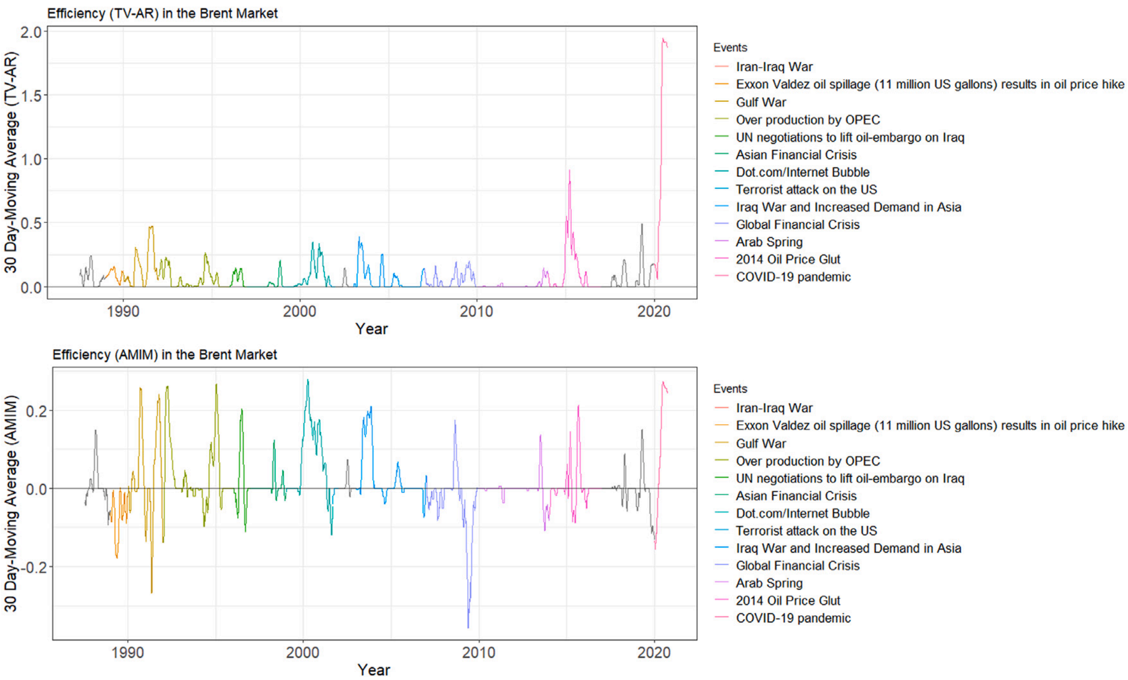

Fig. 5. Degree of market efficiency based on the model by Noda(2016) (top panel) and the Adjusted Market Inefficiency Magnitude model (bottom panel).

in the Brent market. We also test for correlation between these variables in sub-sample periods corresponding to the Asian and Global financial crises. We find that there is significant positive correlation between illiquidity and inefficiency in the WTI crude market during both financial crises. In contrast, we find significant negative correlation in the Brent market during the GFC. This suggests that despite reduced liquidity during this period, the market remained mainly efficient. In addition, the strength of the correlation between liquidity and the degree of market efficiency in the WTI crude market increases during the financial crisis. The results obtained in the WTI market confirm the findings by studies such as Chordia et al. (2008). These results suggest that liquidity is a more significant influence on efficiency in the WTI market than in the Brent market. It may also suggest that more arbitrage is available in the WTI market and sufficient liquidity is required to correct such price predictability.

Other measures of market efficiency

We also apply the Time Varying Autoregressive (TV-AR) measure of market efficiency by Noda (2016) to check the robustness of the results obtained in our study. Similar to the AMIM, the TV-AR model measures time-varying market efficiency. The results obtained from the TV-AR model supports the results obtained from the AMIM model (see Figs. 5–6). The WTI crude market shows significantly higher deviations from zero, indicating that it is less efficient than the Brent crude market. In addition, the results also highlight the different responses of both markets to the financial crises. This indicates that the results obtained from our study are robust to other time-varying measures of market efficiency.

4. Conclusions

We examined the evolution of oil market efficiency over the history of the crude oil spot market in relation to the response of the market to changing market conditions. The results show a significant improvement in efficiency in the Brent market which confirms

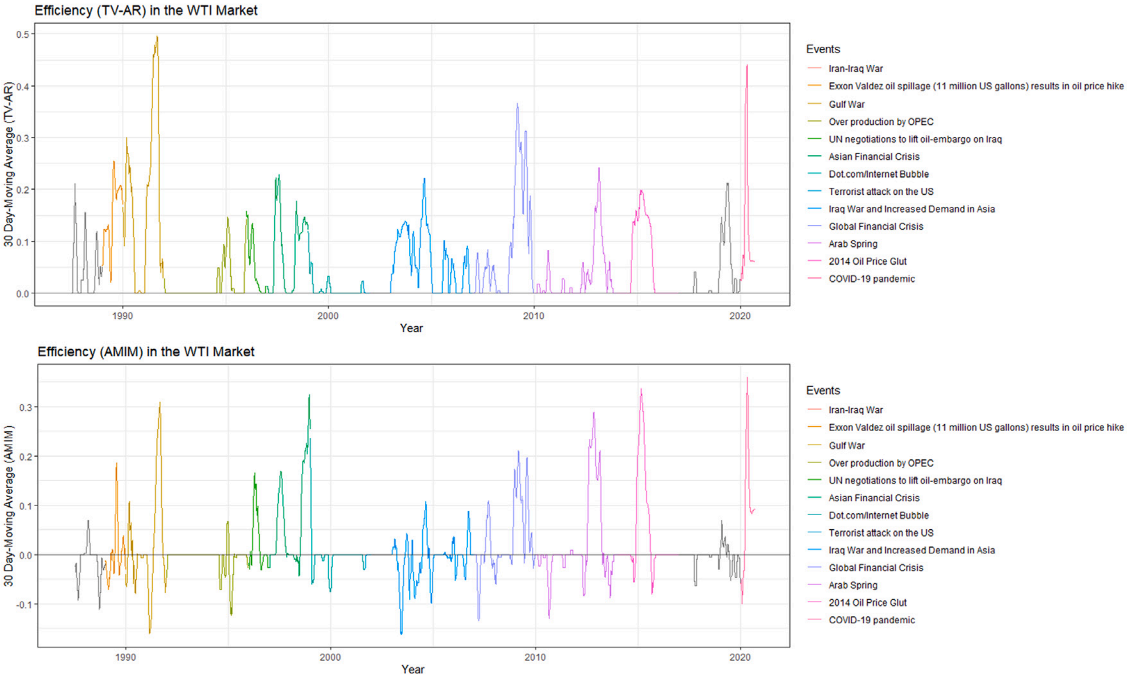

Fig. 6. Degree of market efficiency based on the model by Noda(2016) (top panel) and the Adjusted Market Inefficiency Magnitude model (bottom panel).

the position of the AMH. Persistent inefficiency was found in the WTI market during the Asian and the Global financial crises which may suggest that the WTI is more integrated with the financial market than the Brent market. We also find that efficiency levels in both markets are volatile and respond acutely to macroeconomic events. The findings of this study are useful for all market participants. For speculative traders, understanding the response of the market to significant announcements and events may assist with predicting periods of inefficiency which could be useful for identifying trading opportunities as well as managing their portfolio risk. The significance of news may depend on the perception of market members as to the impact of the news on supply and demand conditions within the market. By identifying periods when the market is prone to inefficiency, this study also equips policy makers and regulators with the necessary information which can lead to the formulation of proactive and effective market policies.

CRediT authorship contribution statement

Ugochi Chibuzor Okoroafor: Conceptualization, Formal Analysis, Writing – original draft, Visualisation. **Thomas Leirvik:** Conceptualization, Resources, Writing - review & editing, Validation, Supervision.

Appendix A

In Eq. (2), the Market Inefficiency Magnitude (MIM) is included. The MIM is given by:

$$MIM_t = \frac{\sum_{j=1}^{q} \mid \hat{\beta}_{j,t}^{standard} \mid}{1 + \sum_{j=1}^{q} \mid \hat{\beta}_{j,t}^{standard} \mid}. \tag{3}$$

where MIM_t is the Market inefficiency Magnitude at time t, a and $\hat{\beta}_{j,t}^{standard}$ is the standardised beta coefficient from an auto-regressive model with q number of lags AR(q) as in Eq. (1).

Appendix B

Amihud's ratio for measuring market illiquidity is given as:

$$ILLIQ = \frac{1}{D_{it}} \sum_{d=1}^{D_{it}} \frac{\mid r_{i,d} \mid}{Vol_{id}} \tag{4}$$

where $r_{i,d}$ is daily percentage returns, $dVol$ is the dollar trading volume for each crude market on day d and D_{it} is the total trading days in a month.

Appendix C

The High-Low spread estimator derived by Corwin and Schultz (2012) is given as:

$$S_t = \frac{\sqrt{2\beta} - \sqrt{\beta}}{3 - 2\sqrt{2}} - \frac{\sqrt{\gamma}}{\sqrt{3 - 2\sqrt{2}}} \tag{5}$$

Beta is the two-day sum of the squared natural logarithm of the high-low price ratio at time t:

$$\beta_t = \mathbf{E}\left[\sum_{j=t-1}^{t} \left(ln\left(\frac{H_j}{L_j}\right)\right)^2\right] \tag{6}$$

Gamma is the squared natural logarithm of the ratio of the two-day maximum and minimum prices at time t:

$$\gamma_t = ln\left(\frac{H_{t,t-1}}{L_{t,t-1}}\right)^2 \tag{7}$$

where S_t is the bid–ask spread estimator at time t, and $H_{t,t-1}$ ($L_{t,t-1}$) is the maximum (minimum) price of the days t and $t-1$.

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