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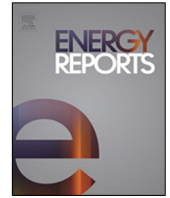
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Research paper

Crude oil maritime transportation: Market fluctuation characteristics and the impact of critical events

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ABSTRACT

The international crude oil maritime transportation system has always been disturbed by the external environment and its own mechanism of supply and demand, which can sometimes last for a long time. BDTI (Baltic Exchange Dirty Tanker Index) is one of the most typical indexes in the crude oil maritime transportation market, which is affected by many uncertain events and often lasts for a long time. So it is very significant to study fluctuation characteristics of the crude oil maritime transportation system and assess the impact of critical events, which have been referred to in this paper by improving the R/S model and selecting three international transportation lines in marine shipping ranging from 2008 to 2019. Through model applications, numerical results validate the effectiveness of this method, showing all of the three transportation lines possess long-term memory. The impact of the four critical events has also been evaluated. The study will help crude oil enterprises make investment decision on potential transportation lines and give policymakers advice to maintain stability of the crude oil industry.

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1. Introduction

The crude oil transportation system is an important support for every country in providing industrial production materials, promoting economic development and guaranteeing military security. The international transportation of crude oil is dominated by marine shipping, which, as a foundation for the large-volume and long-distance transportation, has greatly enriched international economic cooperation in crude oil resources (Wan and Chen, 2018). The United Nations has issued an estimation of 1.8749 billion tons of seaborne trade of crude oil worldwide in 2017 (UNCTAD, 2018). BDTI (Baltic Exchange Dirty Tanker Index) is one of the most important indexes, reflecting the existing circumstance and tendency of the crude oil marine shipping system. Affected longtime by a combination of external environment and

internal supply–demand relationship, BDTI fluctuates frequently and sharply, from which, however, laws of fluctuation could be discovered. For example, after the financial crisis in 2008, BDTI of the ship route from Middle East to US Gulf dropped from 174.23 in January to 47.29 at the end of that year and BDTI of the other two lines also plummeted at the same time. The oil spill accidents occurred in the Gulf of Mexico in 2010 and Bohai Gulf of China in 2011 attracted great social attention, which also increased demand for the import crude oil in the US and China, indirectly spurring BDTI. Another two landmark events, relevant to the development of crude oil market, included the signing of Paris Agreement in 2016 and the withdrawal of Qatar from OPEC in 2019. These events above can be classified into four categories, which simultaneously influence BDTI at present and possibly in the long run.

The selected three crude oil transportation lines in marine shipping are very representative whose departure point is countries in Middle East or West Africa, which boast great potential for exploitation of crude oil and nearly half of the world's oil producers (UNCTAD, 2018). Ending point is located in the US or Singapore or China, among which the US and China rank the top two in the world economy and in the consumption of crude oil (Chen et al., 2018). Singapore, located in the Strait of Malacca, plays an important role in world shipping and it is also in need of

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a great deal of crude oil to produce diesel oil for the ships passing by.

The paper will adopt R/S model to study the market fluctuation characteristics and the impact of critical events. “R/S model” is the abbreviation of “Rescaled Range Analysis”, which was proposed by British hydrologist Hurst. The calculation result of the model is named “Hurst Value”, which is used to measure whether a time series has a fractal structure and a correlation persistence. The Hurst Value ranges from 0 to 1. There are four kinds of meaning in accordance with the results of Hurst Value. When Hurst Value ranges from 0 to 0.5, it represents future trend of the research sequence runs in the opposite direction against previous development, namely, if the sequence of the previous period demonstrates an upward (downward) trend, it is very likely to run downward (upward) in the next period. When Hurst Value equals 0.5, it features random walk for the sequence. When Hurst Value is between 0.5 and 1, it represents a positive correlation between future trend of the research sequence and previous development. When Hurst Value equals 1, it means future trend can be totally reflected by the past. However, traditional R/S model has some limitations, such as the sensitivity in the short-term (Gomes et al., 2018) and the overall and fuzzy impact of events. So the paper will creatively establish an improved R/S model based on the traditional model to overcome these shortcomings. The feature of the improved model is based on the subsection analysis, which can help to assess the impact of critical events in a quantitative way. The study will help the crude oil enterprises make the investment decision on potential transportation lines and give policymakers advice to maintain the stable development of the crude oil industry.

The rest of the paper is organized as follows. After a relevant literature review, knowledge gaps are identified in Section 2, with the research objectives and contributions declared. In Section 3, the paper will elaborate the concept of long-term memory and the establishment of the improved R/S model. In Section 4, the research launches empirical research on the fluctuation characteristics of BDTI and its quantified events based on the traditional and improved R/S model to explore whether the long-term memory is existent or not and to compare the impact degrees from the critical events. The conclusions of this paper are summarized and future research directions are elaborated in Section 5, the final section of this paper.

2. Literature review

The factors on the crude oil market and the quantitative calculation methods on the crude oil market have long been a focus in the global marine shipping research. A summary of these academic works is presented below. Main existing academic research focuses on the factor analysis of the market fluctuations and the quantitative calculation methods on the crude oil market.

The researches on the qualitative factors on the BDTI are one of the main literature. In recent years, the international crude oil transportation system is disturbed by many factors, including the financial crisis, the environmental crisis, the crude oil agreement and the competition in the market. The relevant researches are divided as follows. (1) Financial crisis: Tsouknidis (2016) revealed the existence of volatility spillover effects on shipping freight markets during and after the global financial crisis. Chen et al. (2017) pointed out that the strength of multifractality of BDTI after the financial crisis was larger than that before, indicating the frequent fluctuation caused by the factor. (2) Environmental crisis: Wang et al. (2018) presented the maritime transportation costs associated with the oil spilling crisis were significant. Van Fan et al. (2018) highlighted the role of air pollution crisis in freight mode selection. (3) Crude oil agreement: After the Paris

Agreement, shipping lines were faced with a lot of challenges, such as the increasing operation costs and the compulsive carbon emission reduction target (Lam and Wong, 2018), which would affect the shipping freight to some extent. Psaraftis (2018) pointed out that after some pieces of regulations were adopted by the International Maritime Organization (IMO), such as the Energy Efficiency Design Index (EEDI) and the Ship Energy Efficiency Management Plan (SEEMP), freight rate became one of the most significant factors on the choice of the appropriate speed. (4) Market competition: In recent years, the competition in crude oil industry has become more and more frequent and fierce, which greatly affects the freight rate. Sahoo (2018) held the view that the tanker freight markets were less reactive to new market information as compared to the dry-bulk freight markets based on the characteristic of monopolization. The above studies on the factor analysis of the freight rate were unexceptionally dependent on the qualitative explanation, which could not show a quantitative comparison of the impact degrees from different factors.

The quantitative calculation methods on the crude oil market acts as the other major direction of research. Main models are the Regime-Switching model, the Empirical Mode Decomposition method, the GARCH model, the Artificial Neural Network and the Stochastic Differential Equations. The relevant researches are divided into five parts as follows. (1) Regime-Switching model: Alizadeh et al. (2015) used a data set for six major tanker routes from 2005 to 2013 and adopted the Regime-Switching GARCH models to capture the dynamics of volatility. Lauenstein and Walther (2016) attested that Regime-Switching GARCH models exhibited an excellent out-of-sample forecasting performance of tanker freight volatility. (2) Empirical Mode Decomposition method: He et al. (2016) proposed a new multivariate Empirical Mode Decomposition (EMD) model to reveal the diverse heterogeneous data characteristics in the crude oil market. (3) GARCH model: Zhang and Zeng (2017) combined the GARCH model with the EMD method to analyze the volatility of the tanker freight market, pointing out that the volatility spillover effects happened in the reconstructed components, not in the original time series. Liao et al. (2018) used DCC-GARCH model and found that the relationship between crude oil prices and the US dollar index was time-varying since 1990. (4) Artificial Neural Network: Eslami et al. (2017) developed a hybrid prediction model based on an Artificial Neural Network to predict the tanker freight rates, which had a small root mean squared error. The Artificial Neural Network was also used to forecast BDTI and BPI, which also had a nice performance (ŞAHİN et al., 2018; Yang and Mehmed, 2019). (5) Stochastic Differential Equations: Jafari and Rahimi (2018) used the Stochastic Differential Equations to forecast BDTI, getting a more accurate result than that of the ARIMA model. However, the above models have not taken the Non-periodic Cycle and the self-correlation character of freight rate into account.

Besides the above factors and models about the relevant researches, Monge et al. 2017 analyzed the real oil prices of West Texas Intermediate (WTI) before and after the different military conflicts and political events. What is more, they used the wavelet methodology to relate the shale oil revolution in the United States with WTI oil price behavior Monge et al. 2017. Although BDTI is different from WTI, the above researches provided a very insightful impact on the long-term correlation analysis on the oil market, which have great contribution to the current research.

In summary, relevant literature focuses on the factor analysis of the market fluctuations and predictions about the freight rate. However, the research on the internal fluctuation mechanism and fluctuation characteristics of the crude oil market is insufficient and has not taken the Non-periodic Cycle into account, lacking

quantitative research on the assessment of the impact degrees from various factors. This paper is dedicated to addressing the following four issues: (1) explaining whether the long-term memory is existent in BDTI or not; (2) calculating the Hurst Value and the Non-periodic Cycle of BDTI for judging its tendency and duration in the future ; (3) assessing the impact degrees from different factors to quantitatively compare the effect of each factor; (4) and providing scientific decision-making schemes for government departments and investors in crude oil marine shipping to avert market risks.

3. The concept of long-term memory and the establishment of improved R/S model

3.1. The concept of long-term memory

As early as 1950, British hydrologist (Hurst, 1951) assessed the long-term dependence about the hydrological phenomena. Mandelbrot and Wallis (1968) defined a feature of time series as the “Joseph Effect”, which means that the movements in the series tend to be part of larger trends and cycles more often they are completely random. McLeod and Hipel (1978) elaborated the feature in an equation, pointing out if the limit of the sum of the self-correlation coefficients was nonfinite, the series had long-term memory. Time series may exhibit long-range dependence, displaying cycles of many periods even as long as the span of the sample (Lo, 1989). The latest relevant researches also hold the similar definitions (Jiang et al., 2018; Gomes et al., 2018). According to this kind of research, the paper summarizes the definition of “long-term memory” as follows: The long-term memory is a study on dependency of time series, indicating part is the epitome of the whole and the later sequence is affected by the former, which is not completely random and may have the cycle as long as the sample size.

The benchmark for identifying the existence of long-term memory is the Hurst Value of the time series. The mathematical meaning of the Hurst Value can be explained by its relationship with the self-correlation coefficient of the time series' first difference, presenting as $C = 2^{2H-1} - 1$. The above H represents the Hurst Value; C is the self-correlation coefficient. The self-correlation coefficient must be in the range between -1 and 1 , so the range of the Hurst Value should also be from -1 to 1 .

The different intervals in which a Hurst Value is located shows the different statistical characteristics of the time series. The intervals can be divided into four kinds (Peters et al., 1994; Cao et al., 2018; Guo et al., 2018):

(i) When $0 \leq H < 0.5$, the time series is anti-persistent. If the series in the initial phase is rising (or declining), its future trend will decline (or rise) on the contrary. When a H value is closer to 0 , the time series is more anti-persistent.

(ii) When $H = 0.5$, the time series completely follows a random walk, meaning the historical data will not affect the current values and it is impossible to predict the future values based on that.

(iii) When $0.5 < H < 1$, the time series is persistent. If the series in the initial phase is rising (or declining), its future trend will still rise (or decline). When a H value is closer to 0 , the time series is more persistent.

(iv) When $H = 1$, the current and future trends can be fully predicted using the historical data.

In summary, the criterion of a time series for judging the existence of long-term memory is that its Hurst Value is not equal to 0.5 . If the value is bigger than 0.5 , the time series is persistent (positively correlated); if the value is smaller than 0.5 , the time series is anti-persistent (negatively correlated).

3.2. Model establishment

The traditional R/S model is a useful tool to test whether a nonlinear time series follows a random walk or some other rules. After 1980s, the model has been extensively used in stock and futures markets. However, the previous studies only studied whether a series had the long-term memory or not and how long the cycle would last. The paper will improve R/S model to assess the impact degrees from various qualitative events in a quantitative way, being helpful for the quantitative analysis on some events which are hard to quantify.

The research framework of this paper is showed in Fig. 1. The light color part in Fig. 1 is from the traditional R/S model (Mandelbrot and Wallis, 1969), while the gray part is creatively extended from the paper. The traditional steps will be divided into 5 steps to solve out the Hurst Value and the Non-periodic Cycle. While the step 6 is innovative to evaluate the impact degrees from the related events. The main steps for model constructing will be introduced in detail as follows.

Step 1: The prerequisite of the existence of the long-term memory is that the time series is based on the non-normal distribution, so the test of normality is a must.

Step 2: Segment the time series and work out the mean of each segment.

If the sample size is N and it is divided into m segments, so the length of each segment is $n = \frac{N}{m}$. X_i ($i = 1, 2, \dots, n$) represents the series in a segment, so the mean of each segment is:

$$\bar{X} = \frac{1}{n} \sum_{i=1}^n X_i \quad (1)$$

Then calculate the first difference of the series in each segment.

Step 3: Calculate the accumulated difference in each segment as Eq. (2):

$$\gamma_i = \sum_{j=1}^i (X_j - \bar{X}) \quad (2)$$

Work out the range and the standard deviation using the following equations:

$$R = \max(\gamma_i) - \min(\gamma_i) \quad (3)$$

$$S = \sqrt{\frac{1}{n} \sum_{j=1}^n (X_j - \bar{X})^2} \quad (4)$$

Step 4: The range in Eq. (3) is divided by the standard deviation in Eq. (4):

$$(R/S)_n = \frac{1}{m} \sum_{k=1}^m \frac{R_k}{S_k} \quad (5)$$

Based on $\frac{R(\tau)}{S(\tau)} \propto (\frac{\tau}{2})^H$ (Hurst, 1951), establish the traditional R/S model as Eq. (6):

$$\ln\left(\frac{R(\tau)}{S(\tau)}\right) = \ln(\alpha) + H * \ln\left(\frac{\tau}{2}\right) \quad (6)$$

In Eq. (6), τ represents the time sequence.

Then set the $\ln(\frac{\tau}{2})$ as the independent variable and $\ln(\frac{R(\tau)}{S(\tau)})$ as the dependent variable. According to the linear fitting for the variables, the paper can work out the slope of the regression line as the Hurst Value.

Step 5: Calculate the V statistics based on Eq. (7) for working out the Non-periodic Cycle.

$$V_N = \frac{(R/S)_N}{\sqrt{N}} \quad (7)$$

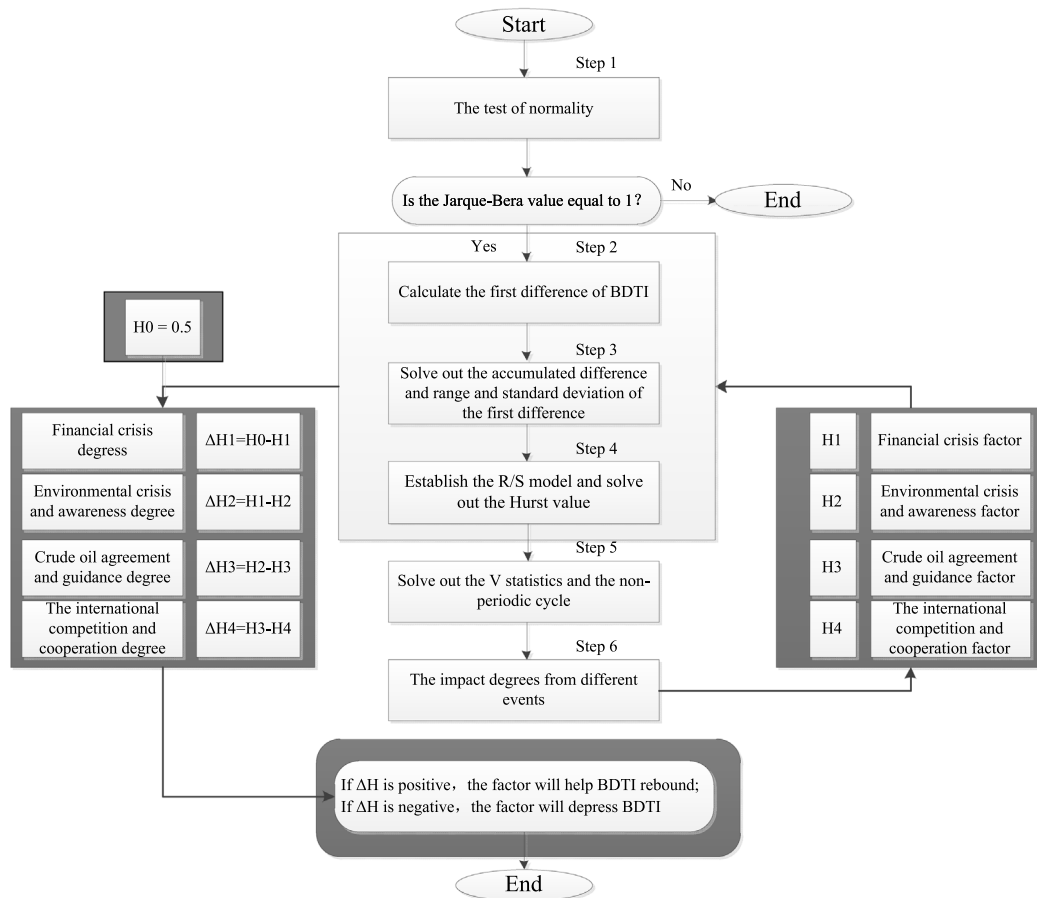


Fig. 1. Research framework for fluctuation characteristics and the impact of critical events.

When the V statistics is stable in an approximate horizontal line, the long-term memory has lost.

Step 6: For overcoming the shortcomings of the overall and fuzzy impact of events, the paper supplements a new step in the traditional model as follow, which can assess the impact degrees from critical events:

$$\Delta H_{i,j} = H_{i-1,j} - H_{i,j} \quad (8)$$

In Eq. (8), j represents the sequence of the crude oil shipping lines; i represents the sequence of the events, and the paper sets $H_{0,j} = 0$ as the benchmark. For example, the impact degree of the 3rd event in the 2nd shipping line should be: $\Delta H_{3,2} = H_{2,2} - H_{3,2}$.

3.3. Chapter summary

This chapter introduces the concept of long-term memory and R/S model. In the introduction of long-term memory, the origin, definition, formula and meaning of Hurst Value are stated respectively, while for the presentation of R/S model, original modeling idea has been added to the traditional model (see the gray part of Fig. 1), compensating the flaw of the previous literature with mere self-correlation study on the sequence and applying an innovative method to quantitatively deal with qualitative external factors.

4. Model application and result analysis

4.1. Data collection

This paper studied the fluctuation characteristics of BDTI, including three main lines of crude oil transportation in the world:

Middle East–US Gulf, Middle East–Singapore, West Africa–China. The data was from June 2008 to April 2019, totaling 2689 sample size from each line, which was contributed by [CRSL](#). The raw data of BDTI was shown in Fig. 2.

Seen from Fig. 2, the span of BDTI from 2008 to 2019 had been divided into 4 stages: the first stage from 2008 to 2009 dominated by the financial crisis (typical event: the 2008 Global Financial Crisis), the second stage from 2010 to 2015 dominated by environmental crisis and awareness (typical events: the crude oil accidents in the Gulf of Mexico and in Bohai Gulf), the third stage from 2016 to 2018 led by crude oil agreement and guidance (type event: the Paris Agreement) and the fourth stage from January 2019 till now guided by the international competition and cooperation (typical event: the withdrawal of Qatar from OPEC). The paper tried to study the quantitative effect of the above 4 events on the current BDTI and explained how the long-term memory would influence the tendency of BDTI in the future.

The three BDTI from different lines of crude oil transportation had met extremely similar fluctuation rules, which indicated the existence of the long-term memory of BDTI influenced by some typical events such as: External economic environment, the environmental awareness sourced from oil spilling crisis, the agreement and guidance relating to crude oil and the international competition and cooperation. After the global financial crisis happened in 2008, BDTI from different lines were all falling continually and sharply from June that year. Two large-scale crude oil accidents respectively occurred in the Gulf of Mexico in 2010 and in Bohai Gulf in China in 2011, which arouse public's environmental awareness and to some extent affected the movement of BDTI. In 2016, the Paris Agreement was signed in

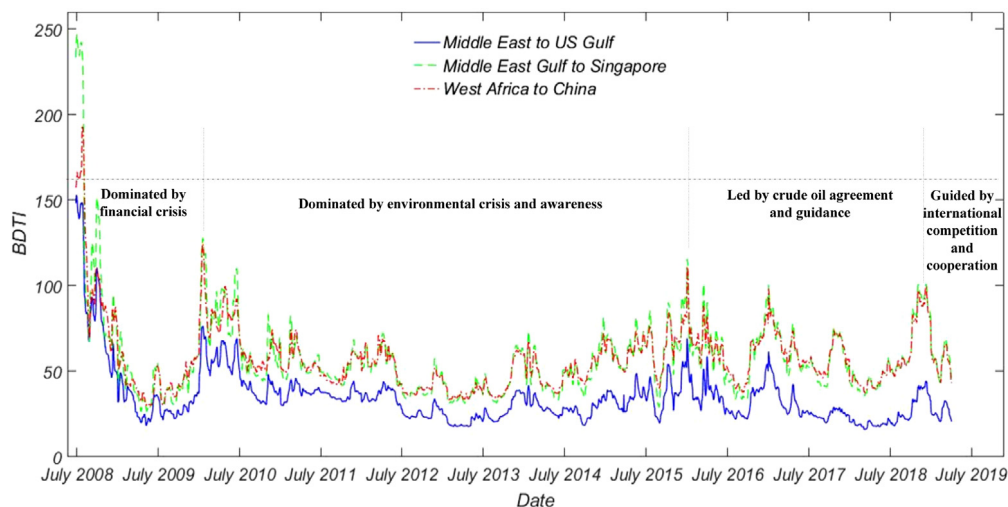


Fig. 2. Raw data of BDTI. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

New York, demanding each member to hold the increase in the global average temperature to well below 2 degrees Celsius (UN, 2015), which restricted the extraction of crude oil in the world to a certain extent and the People's Republic of China sped up its SPR (Strategic Petroleum Reserve) system in April of the same year (NEA, 2016). The withdrawal of Qatar from OPEC marked a renewed international competition and cooperation on the trade of crude oil in 2019.

4.2. Model application

The verification of the long-term memory in BDTI of three lines of crude oil transportation was divided into three parts, including the test of normality, the comprehensive memory effect on BDTI and the degrees of impact from critical events on the memory of BDTI. The prerequisite of the existence of the long-term memory was that the time series was non-normality. Then the comprehensive memory effect on BDTI was quantitatively evaluated by R/S model, whose index would exactly point out the direction of BDTI in the future, and V statistic would be used to estimate the Non-periodic Cycle of BDTI. At last, the times series would be divided into 4 stages and calculated the degrees of impact from critical events including financial crisis, environmental crisis and awareness, crude oil agreement and guidance and the international competition and cooperation on the memory of BDTI, which could explain a qualitative event in a quantitative way.

4.2.1. The test of normality

The application premise of using R/S model is that the time series is non-normal. This paper used both qualitative and quantitative methods to test the time series.

From the perspective of qualitative analysis, Fig. 3 displayed that all the three BDTI from different lines had obvious distinction with the normal curve. Then from the perspective of quantitative analysis, Table 1 showed that although the three skewness values were close to zero (the skewness of the normal curve is zero), but the kurtosis values were all obviously different from three (the kurtosis of the normal curve is three), what is more the Jarque-Bera value was one indicating the time series was non-normal. So based on the non-normal characteristics, the next steps could continue further.

Table 1

Non-normality test on BDTI by statistical results.

Statistics	BDTI difference in Middle East to US Gulf	BDTI difference in Middle East to Singapore	BDTI difference in West Africa to China
Sample size	2689	2689	2689
Mean	−0.0466	−0.0689	−0.0423
Max	17.2300	26.7700	29.0000
Min	−21.7300	−29.6800	−23.8400
Skewness	0.1211	−0.3381	1.3567
Kurtosis	40.46178	23.4825	38.1594
Jarque-Bera value	1	1	1

4.2.2. The comprehensive memory effect on BDTI

The comprehensive memory effect on BDTI from July 2008 to April 2019 was studied in two parts. Firstly, the paper used the traditional R/S model, the testing tool of the long-term memory, to obtain Hurst Values of the BDTI from three lines of crude oil transportation. The Hurst Values were the benchmarks for judging whether BDTI had the long-term memory of something happened in the past or not and which direction would BDTI go in. Secondly, the paper would utilize V statistics of BDTI to research the Non-periodic Cycle of the three lines, which statistics had the ability to depict the length of time that BDTI would move in a certain direction.

According to Step 2, the first difference of BDTI from three lines had been drawn in Fig. 4, intuitively displaying that the difference of BDTI in Middle East Gulf to US Gulf line in blue color was mostly close to zero with the minimum standard deviation. While the difference of BDTI in green, representing the time series from Middle East Gulf to Singapore, possessed the largest standard deviation among the three lines.

Following Step 3, the paper calculated the accumulated difference γ_i and solved the range and standard deviation of the first difference of BDTI according to Eqs. (3) and (4).

Based on the above range and standard deviation, the value of traditional R/S could be calculated following Step 4. Then the paper utilized Eq. (6) to establish the traditional R/S model, which had been depicted in Fig. 5.

Fig. 5 shown the Hurst Value. According to the R/S model: $\frac{R(\tau)}{S(\tau)} \propto (\frac{\tau}{2})^H$, the Hurst Values are the superscripts of $(T/2)$. The coefficients of the R/S model and the R-square had been collected in Table 2.

Seen from Table 2, all the Hurst Values from three lines were not 0.5, which demonstrated BDTI from the three lines of crude

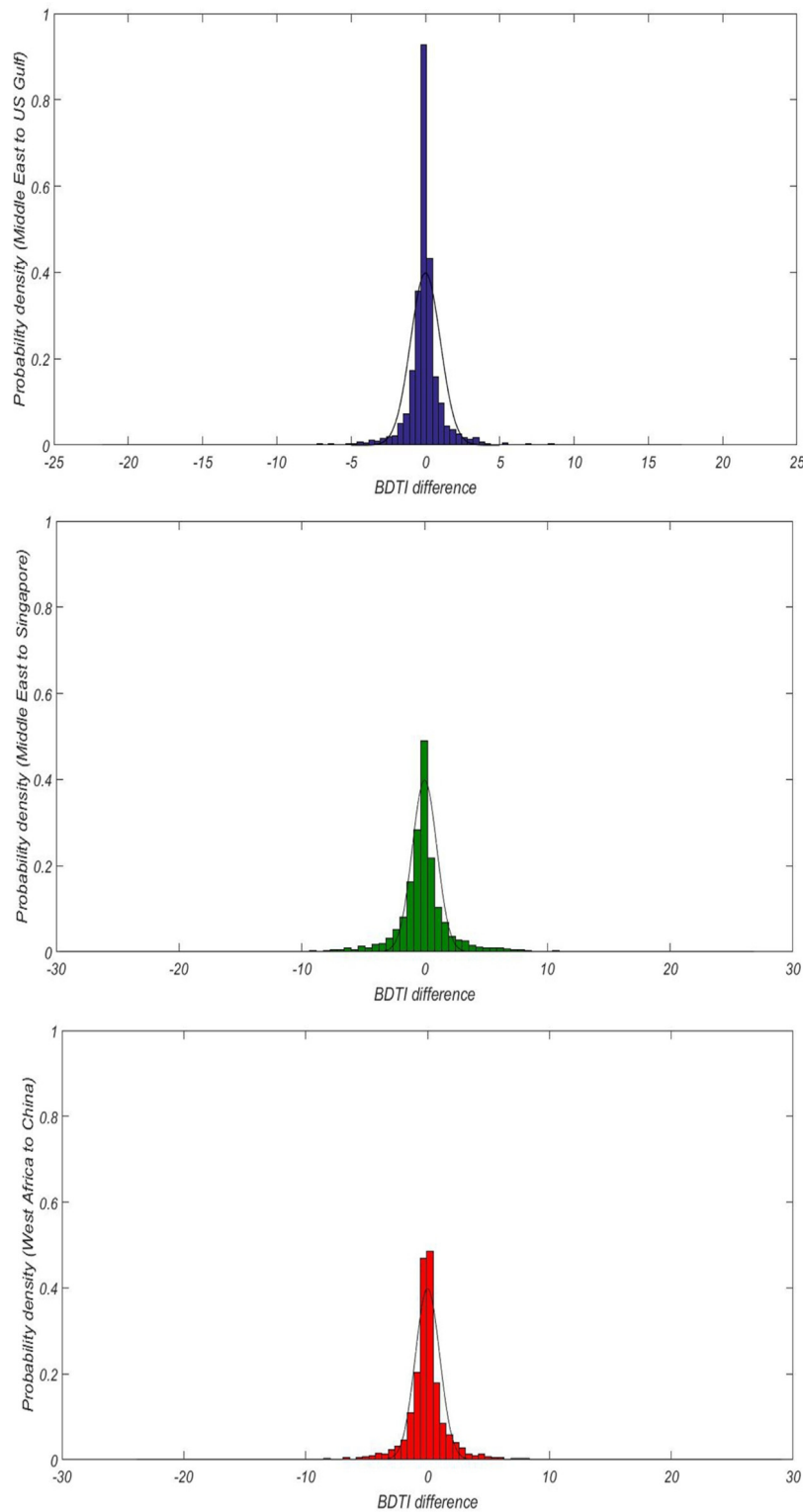


Fig. 3. Non-normality test on BDTI by observation.

oil transportation had the obvious fluctuation characteristics. The BDTI of Middle East to US Gulf possessed the positively correlated tendency as in the past, because the Hurst Value in this line was higher than 0.5. While the BDTI of Middle East to Singapore and West Africa to China had the negatively correlated tendency in the future. R/S model was very effective and reliable to explain the existence of the long-term memory based on the remarkable R-square, which was close to 100.

Since the paper made it clear that the BDTI of Middle East to US Gulf would continue to fall as usual, while the other two BDTI were going to rebound with the anti-persistent tendency, then another question needed to be elaborated that how long would BDTI follow their own direction.

According to Step 5, the paper solved the V statistics value, which showed the fluctuation duration. Seen from Fig. 6, the Non-periodic Cycle of Middle East to US Gulf was 587 the same as

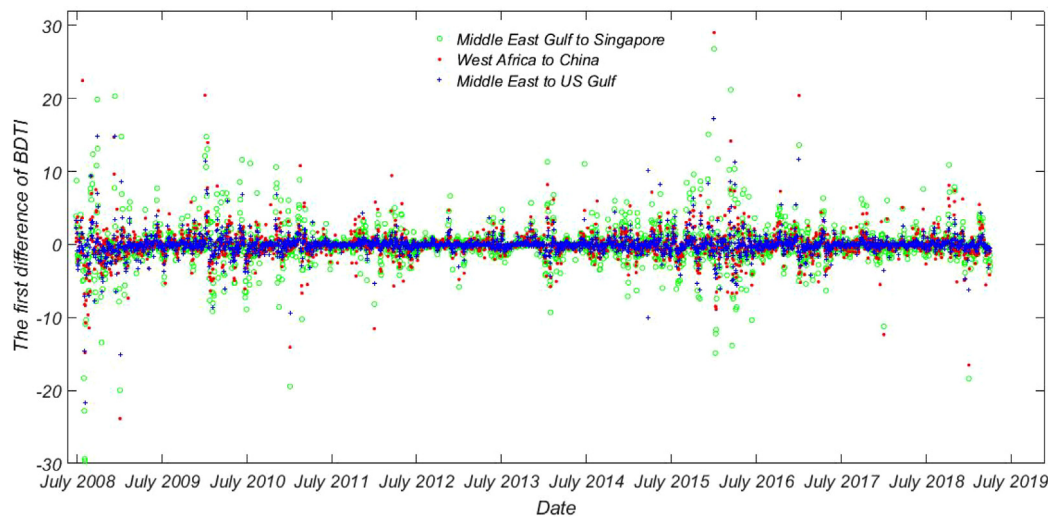


Fig. 4. The first difference of BDTI.

Table 2

The coefficients of the R/S model and the R-square.

Time periods	Three lines	Hurst value	a	R-square	C
From 2008 till now	Middle East to US Gulf	0.5537 ^a	1.8002	0.9831	0.0773
Financial crisis	Middle East to Singapore	0.4562 ^b	3.2082	0.9666	−0.0589
dominated	West Africa to China	0.4357 ^b	3.7145	0.9424	−0.0853

^aH > 0.5 and C > 0. It represents a positive correlation between future trend of the research sequence and previous development.

^bH < 0.5 and C < 0. It represents future trend of the research sequence runs in the opposite direction against previous development.

that of Middle East to Singapore, and the Non-periodic Cycle of West Africa to China was 678. Because the size of the sample was 2689, however the period of study from 25th June 2008 to 1st April 2019, totaling up to 3932 days, so the conversion ratio was 0.6839. Subsequently, the above Non-periodic Cycle could be converted to the number of days, the result showed that both Middle East to US Gulf line and Middle East to Singapore line had about 858 days in their cycle, while West Africa to China line possessed about 991 days in its cycle.

4.2.3. The degrees of impact from critical events based on the improved model

In 4.2.2, the paper had explained the direction of the three BDI of different lines in the future. However, the direction was only the overall effect of various historical events. So, how to evaluate the degrees of impact from critical events in a quantitative way was also very important.

The time series was divided into four stages, including the financial crisis from 2008 to 2009, the environmental crisis and awareness from 2010 to 2015, the crude oil agreement and guidance from 2016 to 2018 and the international competition and cooperation from 2019 till now.

The results of the first stage (2008 to 2009) had been established in Fig. 5, and the rest of the results belonging to the second stage (2010 to 2015), the third stage (2016 to 2018) and the fourth stage (2019 till now) were showed in Fig. 7 and Table 3. In addition, the Hurst Values and R-square based on different time periods in the three crude oil lines had been collected in Table 3. The Hurst Values were obviously different from 0.5, meaning that the main events in their corresponding stages all played important roles in the performance of BDTI at present and might continuously influence on it in the future. What is more, the R-square statistics were all higher than 80, which meant an excellent fitting effect.

Then according to Step 6, the paper evaluated the degrees of impact from the international competition and cooperation at first based on the Hurst Values of the third and fourth stage. For example, the degree of the international competition and cooperation in Middle East to US Gulf line was $0.7445 - 0.5123 = 0.2320$, then the degrees of the event in the other two lines could be easily calculated in the same way. Subsequently, the degrees of impact from the crude oil agreement and guidance were evaluated by the Hurst Values of the second and third stage. In accordance with the sequence of calculation, the assessment results of the impact degrees from the different critical events had been calculated in Fig. 8. The figure indicated that both the financial crisis and the international competition, which were lower than the line 0, depressed BDTI in the three crude oil transportation lines. While the environmental awareness and the crude oil agreement had the ability to stimulate BDTI, which were higher than the line 0.

4.3. Result analysis

In this paper, the fluctuation characteristics of BDTI had been studied in a quantitative manner with the help of traditional and improved R/S model. The structure of the model had been divided into three parts, including the testing of non-normality, the comprehensive memory effect on BDTI and the degrees of impact from critical events.

The results are summarized as follows: Firstly, BDTI meets the demand on non-normality, which means the index is interfered by the external factors. Secondly, all of the Hurst Values of the three crude oil transportation lines are not equal to 0.5, which indicates the existence of the long-term memory in BDTI. The empirical finding is in accordance with some prior studies (Liu et al., 2016; Zheng and Lan, 2016). The historical event which happened long before also has an imperceptible influence on

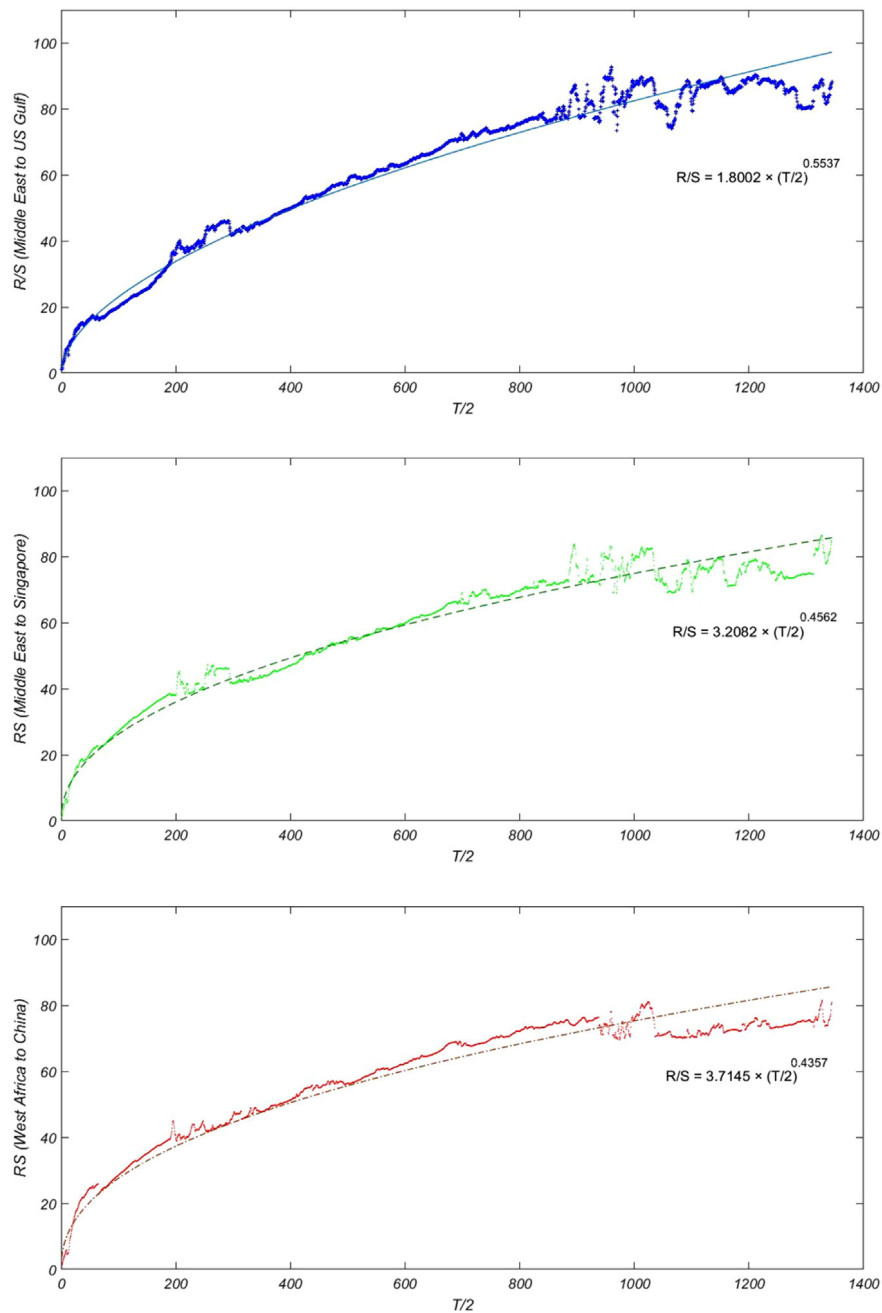


Fig. 5. Traditional R/S model of BDI.

Table 3

The Hurst values and R-square from different origins.

Time periods	Three lines	Hurst value	a	R-square	C
From January 2010 till now Environmental crisis and awareness dominated	Middle East to US Gulf	0.3640 ^a	3.9888	0.8347	−0.1718
	Middle East to Singapore	0.3404 ^a	4.2086	0.8367	−0.1985
	West Africa to China	0.3611 ^a	4.4558	0.8427	−0.1752
From January 2016 till now Crude oil agreement and guidance dominated	Middle East to US Gulf	0.5125 ^b	1.5771	0.9695	0.0174
	Middle East to Singapore	0.5223 ^b	1.3829	0.9659	0.0313
	West Africa to China	0.5402 ^b	1.3713	0.9722	0.0573
From January 2019 till now International competition and cooperation dominated	Middle East to US Gulf	0.7445 ^b	0.9042	0.9708	0.4035
	Middle East to Singapore	0.7303 ^b	0.8804	0.9522	0.3762
	West Africa to China	0.7205 ^b	0.9288	0.9740	0.3575

^aH < 0.5 and C < 0. It represents future trend of the research sequence runs in the opposite direction against previous development.

^bH > 0.5 and C > 0. It represents a positive correlation between future trend of the research sequence and previous development.

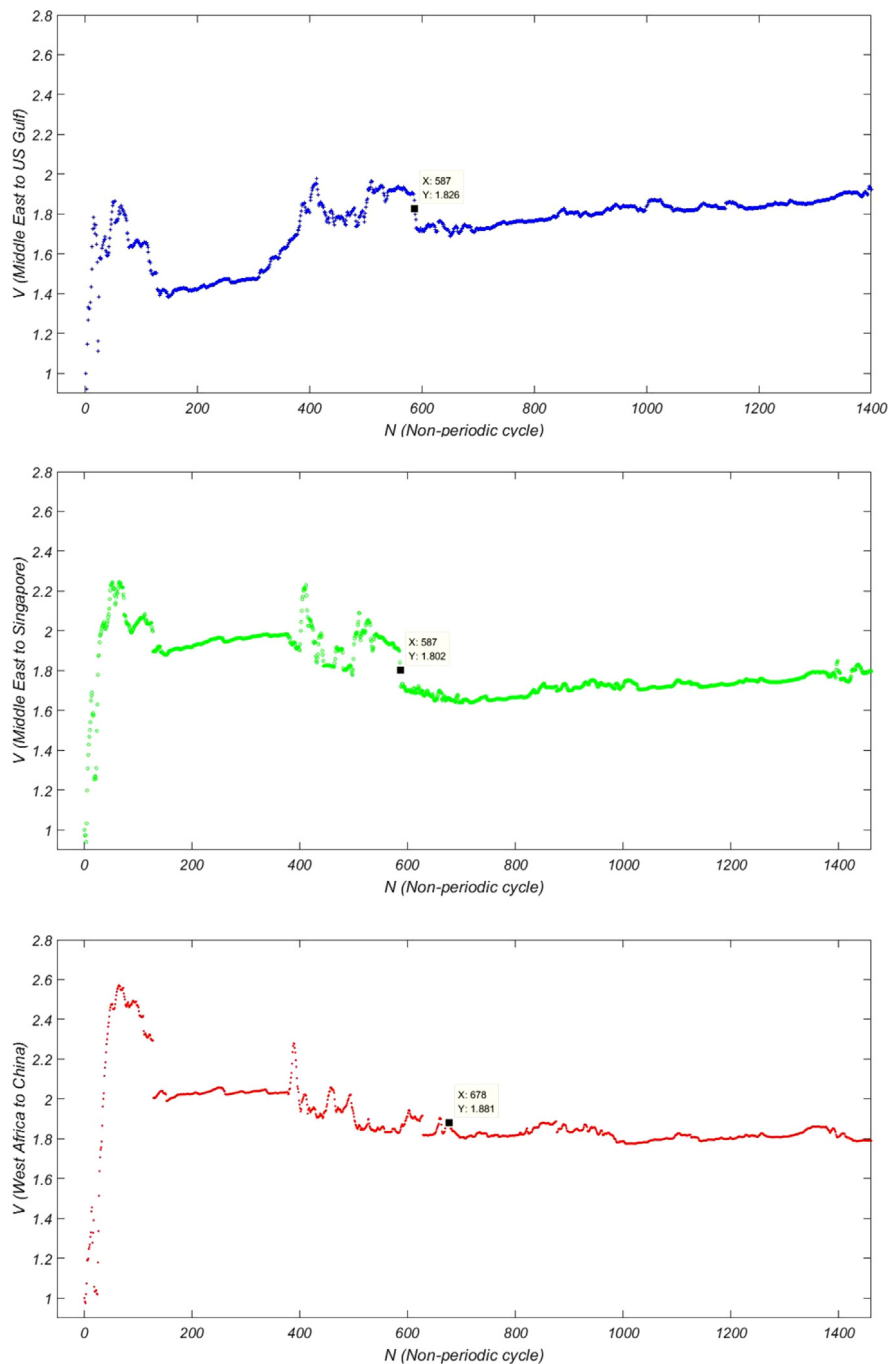


Fig. 6. The result of the non-periodic cycle.

BDTI. According to the paper, the BDTI in Middle East to US Gulf line will continue to fall in the next 858 days on account of its Hurst Value higher than 0.5, while the BDTI in Middle East to Singapore line and West Africa to China line are going to rebound in the next 858 and 991 days owing to their Hurst Values lower than 0.5, so it will be an investment opportunity for crude oil shipping companies to enhance the investment in the lines of Middle East to Singapore and West Africa to China. Thirdly, the impact degrees from critical events have been evaluated in Fig. 8. The financial crisis still has a significantly negative impact on the tendency of BDTI now, although the crisis has passed nearly 11 years. The finding can also demonstrate the influence on BDTI from the 2008 Financial Crisis (Chen et al., 2017). What is more, the impact on the US is larger than Singapore and China validated

by the impact degrees -0.1897 , -0.1159 and -0.0746 . Then both the environmental awareness and the crude oil agreement have the ability to stimulate BDTI at present, and the impact of agreement is a little larger than environmental awareness because the stage dominated by the agreement and guidance is closer to the present, so the paper suggests relevant energy sectors of China, Singapore and the US to play a more important role in the publicity of environmental protection to both the public and the crude oil production enterprises. Furthermore, the agreement or guidance on crude oil industry need to be drafted more frequently and strictly to reduce the supply of crude oil and meanwhile increase the demand on that, and the issuing time is also critical. According to the moving rule of BDTI, it often increases to a relatively high level from December to January in

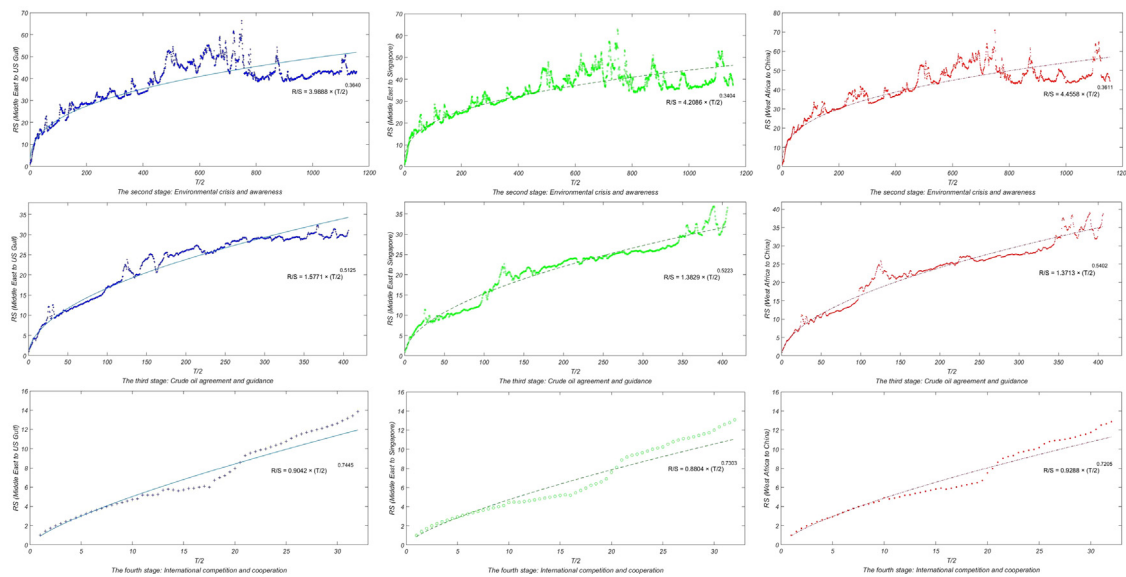


Fig. 7. Improved R/S model belonging to the second stage to the fourth stage.

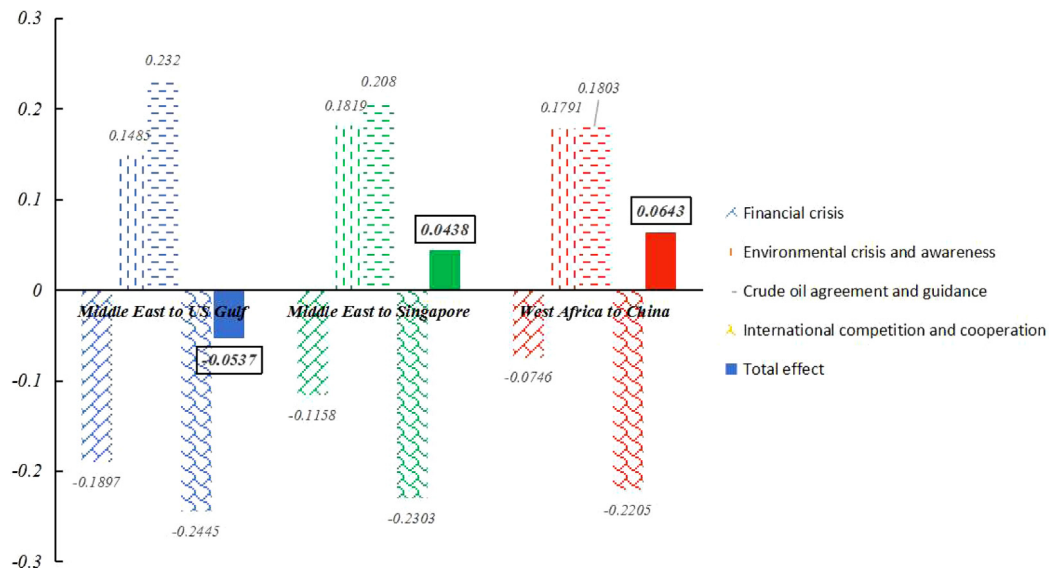


Fig. 8. The impact degrees from critical events.

the next year (see Fig. 2), so the combination of the moving rule and the benefit of an issued agreement towards December will greatly spur the BDTI to a higher level. The intense international competition on crude oil is bad for the BDTI, which can be reflected on the events such as: the withdrawal of Qatar from OPEC and the growing exploitation intensity of a Singaporean energy enterprise in Cambodia are both harmful to the BDTI in the lines from Middle East countries. And the West Africa countries also have to reduce the BDTI to compete with the other crude oil supply countries to China, such as Russia and Kazakhstan. So Middle East countries and West Africa countries urgently need to cooperate with the above crude oil importers.

Besides the above results, the paper also provides a good way to stimulate BDTI. If policymakers of shipping matters could let the positive factor which enhances BDTI growth into full play and learn from the practice of International Maritime Organization (IMO) which regularly holds conferences on marine environment protection, thereby influencing BDTI for a better development. What is more, some guidance document on crude oil industry

need to be drafted more frequently to coordinate the supply and demand of crude oil.

5. Conclusions and future research

It has been widely studied in terms of whether fluctuation characteristics could be applied to the time series of financial markets, however, the research on it in transportation has just begun, let alone in the field of marine shipping. In addition, the previous studies lacked assessment of the Non-periodic Cycle and they hardly explained the impact of qualitative events in a quantitative way. Therefore, the paper tries to make up for the research gaps above and studies fluctuation characteristics of BDTI based on the traditional R/S model and its improved version. The conclusions are summed up as follows.

Firstly, three crude oil transportation lines in marine shipping have been considered in the paper, whose BDTI are abnormally distributed, indicating that they are impacted by some uncertain events. Secondly, among the three lines, the first difference of

BDTI in the line of Middle East to Singapore witnesses the largest standard deviation, implying a larger volatility. Thirdly, all the three BDTI have remarkable long-term memory, and only BDTI in the line of Middle East to US Gulf is consistent while the other two BDTI possess the potential to rebound. Fourth, BDTI in the line of West Africa to China shows the largest Non-periodic Cycle of 991 days, and in spite of the opposite tendency of BDTI in the line of Middle East to US Gulf and Middle East to Singapore, they demonstrate the same Non-periodic Cycles of 858 days. Fifth, the various qualitative events exert different impact on the development tendency of BDTI, showing that both the financial crisis and the international competition depress BDTI, while the environmental awareness and the crude oil agreement are able to stimulate BDTI. So, more and more publicity of marine environmental protection is required not only to decrease marine pollution but also to boost the BDTI. In addition, a more compulsive and strict international agreement on crude oil should be drafted to maintain the stability of crude oil transportation system in marine shipping.

The research findings of this paper will provide constructive suggestions and research achievements for investors of crude oil ship routes and relevant scholars. First of all, investors of crude oil ship routes could choose lines from Middle East to Singapore and from West Africa to China in that the Hurst Value calculated based on Table 2 shows the two ship routes boost long-term memory and the future BDTI trend of the two lines is negatively correlated with that of financial crisis in 2008. In addition, on the basis of measurement of Non-periodic Cycle in Fig. 6, regarding the proportion of sample to actual cycle in the research scope, it indicates that Non-periodic Cycle for the ship route from West Africa to China outlasts that from Middle East to Singapore by approximately 4 months. Therefore, it is recommended to make short-term investment for the ship route from Middle East to Singapore while making a bit longer investment for the other line. Second, scholars can quantify originally touch qualitative factors by referring to the modeling idea in this paper, and in this way helps them better understand how relevant factors impact this matter, which is beneficial to scientific decision-making.

Applying R/S model to analyze the fluctuation characteristics of BDTI in the crude oil transportation system is an innovative attempt. However, there are still some limitations in the paper. Further studies can be conducted in the following two aspects in the future. Firstly, the R/S model can be further improved for making a quick response to the latest events and adjusting the weight of various stages. Secondly, more and more qualitative events need to be considered in a quantitative way in such studies, including natural disasters, protectionist policies, local conflicts and so on, which may indirectly influence the memory of BDTI for the fluctuation of the supply and demand on the crude oil market.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

CRediT authorship contribution statement

Yijie Fei: Data curation, Form analysis, Investigation, Methodology, Software, Writing-original draft, Validation. **Jihong Chen:** Writing-review, Funding acquisition, Methodology, Supervision, Validation. **Zheng Wan:** Supervision. **Yaqing Shu:** Supervision. **Lang Xu:** Data curation. **Haoqiang Li:** Data curation. **Yun Bai:** Resources. **Tianxiao Zheng:** Resources.

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