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King Abdullah Petroleum Studies and Research Center

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Benchmark pricing and storage valuation: investigating the link between pricing dynamics and market fluctuations

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Questions to Address

We find that the index performs well as a leading indicator for the major crude oil benchmarks, outperforming a naive auto regressive forecast for heavy crudes such as Basrah, and the majors WTI and Brent.

- What is a global benchmark?
- How to model the problem?
- Empirical results
- Policy implications and benefits to be derived from the index

Benchmark pricing and storage valuation

- We examine the links between global benchmark pricing and local and regional economic and geopolitical fluctuations and introduce an index that captures the price movements of heavy crude oil
- We derive a high frequency oil storage index as a benchmark for heavy oil prices and examine the potential for the index to capture the transmission of geopolitical risk to energy markets from a spot and futures market perspective, as well as the risk management and policy applications with forecasting potential.

W hat is a global benchmark?

The link between benchmark pricing and economic and geopolitical fluctuations

What is a global benchmark?

Three primary benchmark or marker crudes serve as a reference price for buyers and sellers, West Texas Intermediate, Brent Blend and Dubai crude .

- A true benchmark should have the capacity to reflect all similar crude oil prices under its jurisdiction.
- There is no single reference or benchmark crude that captures the heavy oil market.
- A global benchmark index should provide price leadership and have the ability to forecast crude oil prices.

We investigate the dynamics between the prices of heavy crudes, the primary benchmarks, WTI Brent and Dubai, and economic fluctuations.

What is a global benchmark?

Isolated physical, regional, and institutional factors can affect the spread of reaction to geopolitical shocks. Under these circumstances, market analysts and policy makers are forced to track numerous local and regional prices and all three of the major benchmarks.

There are clear benefits to be derived from the existence of a single representative global crude oil benchmark.

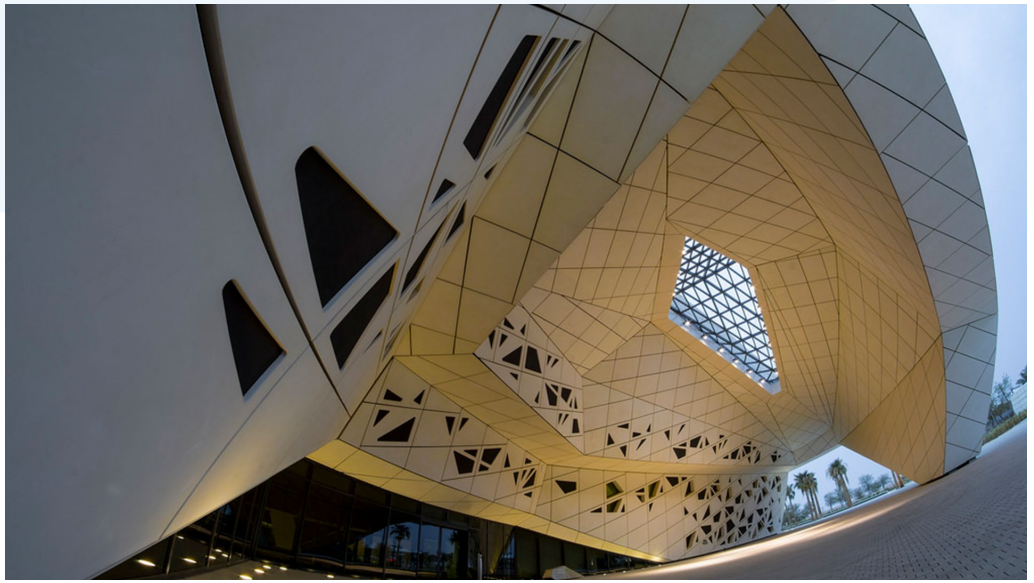
We derive a high frequency oil storage index as a benchmark for heavy oil prices and examine the potential for the index to capture the transmission of geopolitical risk to energy markets from a spot and futures market perspective, as well as the risk management and policy applications with forecasting potential.

The link between benchmark pricing and economic and geopolitical fluctuations

The relationship between storage costs and the spot and futures prices reflects both competitive market dynamics and regional geopolitics.

The price of storage, or convenience yield, has been modeled as a forward-looking spread option variable based on the prices of crude oil at different locations, storage and transportation costs, and the time required to transport oil between them.

The adoption of an asset pricing based crude oil index facilitates the ability of the index to reflect future economic fluctuations and geopolitical risk in energy markets.



02

Towards a global benchmark

How to model the problem?

How to model the problem?

We assume that the storage firm has with a constant relative risk coefficient, γ, and maximizes its utility from storage revenue (R) as follows:

$$max_{X_0^A}\ E[U(R)] = max_{X_0^A}\left[\ E\left(\frac{1}{\gamma}\right)(1 - e^{-\gamma R})\right]\ 1)$$

Where:

$$R\ \ = \boldsymbol{s^A} * Q_0^A - ((\ Q_0^A - X_0^A)\boldsymbol{s^A} + X_0^A(\boldsymbol{s^E}) + \boldsymbol{rK} + \boldsymbol{wL})$$

Q_0^A = The total capacity by the storage operator at the beginning of the period,

R = The revenue to be gained from storing the oil.

$(\ Q_0^A - X_0^A)$ = The quantity of oil taken from storage at location A at the beginning of the period

X_0^A = The quantity of oil purchased from a competitor at the beginning of the period,

$\boldsymbol{s^A}$ = The spot price of oil location A

$\boldsymbol{s^E}$ = The minimum spot price of oil purchased from competitors' location A

r = The short-term risk-free interest rate.
K = The capital investment in the storage facility
w = Wages
L = Labor

How to model the problem?

Assuming fixed capital and labor costs over the period, the firms' revenues are distributed normally, $R \sim N(\mu_R, \sigma_R^2)$ the firms problem becomes:

$$max_{X_0^A}\ E[U(R)] = max_{X_0^A}\ [\emptyset(X)] = max_{X_0^A}\left[\mu_R - \left(\frac{\gamma}{2}\right)\sigma_R^2\right]$$

Where:

$$\mu_R = E\left(\boldsymbol{s^A} Q_0^A - \left(\left(Q_0^A - X_0^A\right)\boldsymbol{s^A} + X_0^A\left(\boldsymbol{s^E}\right) + \boldsymbol{rK} + \boldsymbol{wL}\right)\right) \quad \text{and} \quad \sigma_R^2 = {X_0^A}^2\sigma_{\boldsymbol{s^E}}^2 + {X_0^A}^2\sigma_{\boldsymbol{s^A}}^2 - 2{X_0^A}^2\sigma_{\boldsymbol{s^E s^A}}^2$$

The revenue maximizing value of the quantity of oil purchased from the competitor is given by:

$$X_0^{A^*} = \frac{\left(\boldsymbol{s^A} - \boldsymbol{s^E}\right)}{\gamma\left(\sigma_{\boldsymbol{s^E}}^2 + \sigma_{\boldsymbol{s^A}}^2 - 2\sigma_{\boldsymbol{s^E s^A}}^2\right)}$$

The optimal allocation of crude oil purchases is related to the risk premium, the variance in the spot prices minus transportation costs, and the covariance with domestic oil prices.

How to model the problem?

There are a variety of methods that can be used to aggregate the components of a nominal quantity, or in the case of this study index of international crude oil storage costs, which is made up of diverse components such as regional prices and quantities.

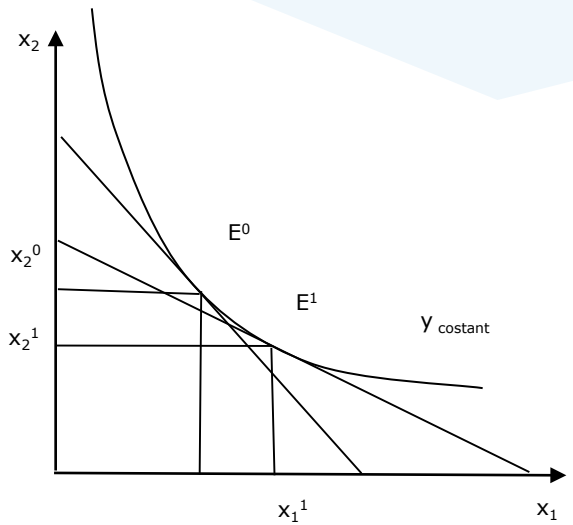
The three main formulae used to calculate price indices are Laspeyres, Paasche, and Konus or true cost. The first two, Laspeyres and Paasche have an inherent bias due to the fact that the optimal bundle of goods desired by a consumer will change as soon as the relevant prices change.

The Konus index was designed specifically to correct for this bias and provide the “true” cost of living at any given time period.

Figure 1 shows the implied bias of most PPI indexes. The constant level of the isoquant yields a different optimal cost minimization solution, from equilibrium point E^0 to E^1, i.e., from the optimal input quantities (x_1^0, x_2^0) to the new optimal quantities (x_1^1, x_2^1).

How to model the problem?

Figure 1 . **The implied bias of the Laspeyres and Paasche price indices**



How to model the problem?

We employ the first principles of micro economic theory to derive a true cost index TCI for heavy crude oil that includes the possibility of substitution between similar grades of crude oil purchased from international sources.

For the purpose of this analysis, the commodities underlying the index make up a shopping basket of heavy crude oil at different locations.

To begin, we postulate the firm's optimization problem. We assume that the firm (a refiner) at location A

has the choice over n types of oil crude available in different locations (j) X_j^{Ak} where j = 1,2 ,…n over two time periods k=1,2. We further assume that there are n types of heavy crude oil available on world oil markets that can be substituted in a refiner's portfolio

How to model the problem?

The refiner maximizes the following decision (profit) function:

$$Max\ \Pi_{X_j^{Ak}}\left(P_k Y_k - \boldsymbol{rK} - \boldsymbol{wL} - \sum_{k=1}^{2}\sum_{j=1}^{n}\left(E\left(s_j^{Ak}\middle|I^1\right) * X_j^{Ak}\right)\right) \qquad 6)$$

Where:

$Y_k = F\left(A, K, L, X_j^{Ak}\right)$ is the firm's production function

X_j^{Ak} = The quantity of oil purchased from a competitor located at location j and delivered to location A at period k,

$S_j^{Ak} = E\left(s_j^{Ak}\middle|I^1\right)$ = The expected value of the spread option value purchased from competitors j location A at period k, given information known in period 1,

A = Technical progress assumed to be fixed over the period.

r = The short-term risk-free interest rate.

K = The capital investment in the storage facility assumed to be fixed over the period.

w = Wages

L = Labor, assumed to be fixed over the period.

If the output is held constant at $\bar{Y}$ the profit maximization problem, with the expenditure function for a

How to model the problem?

If the output is held constant at $\bar{Y}$ the profit maximization problem, with the expenditure function for a heavy crude oil consumer known for certain, then it is certainly possible to determine the exact index for changes in purchasing power between two different time periods that will take commodity substitution into account.

Assume there are n types of heavy crude oil available on world oil markets that can be easily substituted in a refiner's portfolio. Using duality, we can represent the refiners cost for the heavy crude by a parametric function, such as the Cobb-Douglas cost function: $C\left(A, S_j^{Ak}, \bar{Y}\right) = A\prod_{j=1}^{n}\left(E\left(S_j^{Ak}\middle|I^1\right)\right)^{\alpha_j} * \bar{Y}$, where k=1,2, and $\sum_{j=1 i=1}^{n} \alpha_j = 1$.

The refiner minimizes cost subject to a given level of production, and applying Shephard's Lemma the optimal quantities of heavy crude oil from different locations are:

$$X_j^{Ak} =, \frac{\mathrm{d}C\left(A, S_j^{Ak}\right)}{dS_j^{Ak}} \qquad 7)$$

How to model the problem?

The solution yields an expenditure function: $C\left(A, S_j^{Ak}, \bar{Y}\right)$. Holding the refiner's production constant $\bar{Y}$ between two distinct time periods, 1 and 2, can provide the incremental cost of heavy crude storage costs between time periods, or the exact TCI.

$$TCI_{1'2} = \quad I_{1'2} = \frac{C\left(A, S_j^{A2}, \bar{Y}\right)}{C\left(A, S_j^{A1}, \bar{Y}\right)}$$

Since the refiner's expenditure function is assumed to be Cobb-Douglas , the TCI between time 1 and 2 can be shown to be:

$$TCI_{1'2} = \frac{A\prod_{j=1}^{n}\left(S_j^{A2}\right)^{\alpha_j} * \bar{Y}}{A\prod_{j=1}^{n}\left(S_j^{A1}\right)^{\alpha_j} * \bar{Y}} = \frac{\prod_{j=1}^{n}\left(S_j^{A2}\right)^{\alpha_j}}{\prod_{j=1}^{n}\left(S_j^{A1}\right)^{\alpha_j}}$$

03

Towards a global benchmark

Data and Empirical results

Empirical results

Our criteria for the suitability of the Heavy Oil Index as a benchmark is its potential to reflect future economic fluctuations and geopolitical risk in energy markets, and its potential to forecast crude oil prices with applications to risk management and policy. We test the theory for all three indexes, the Paasche, Laspeyres and Konus or exact price index, chained and unchained using a simple autoregressive distributed lag (ARDL) structure.

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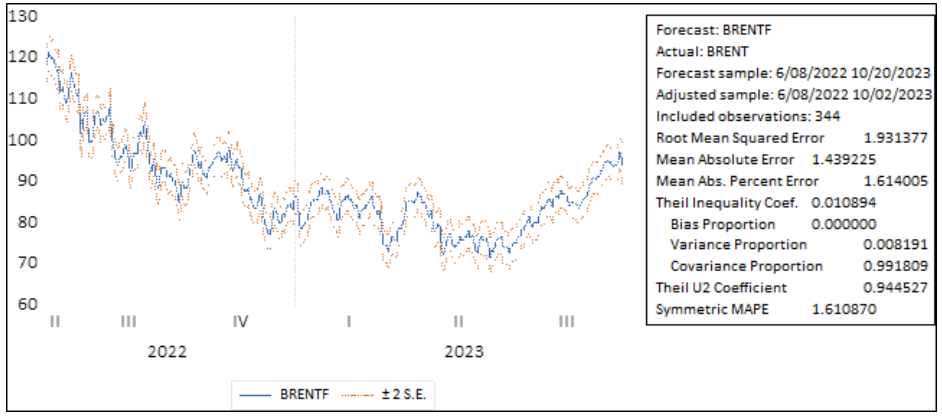
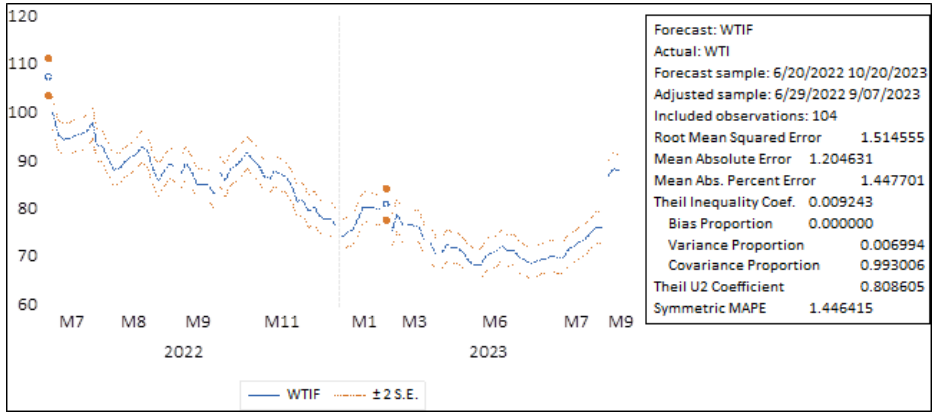
Brent forecast



WTI forecast



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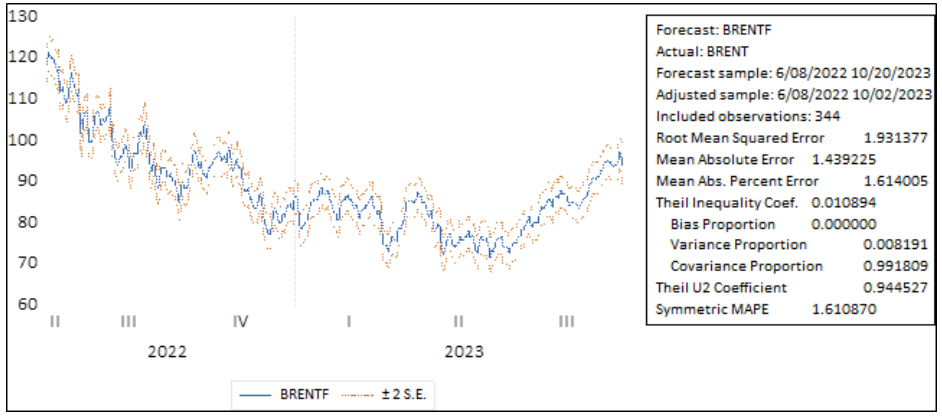
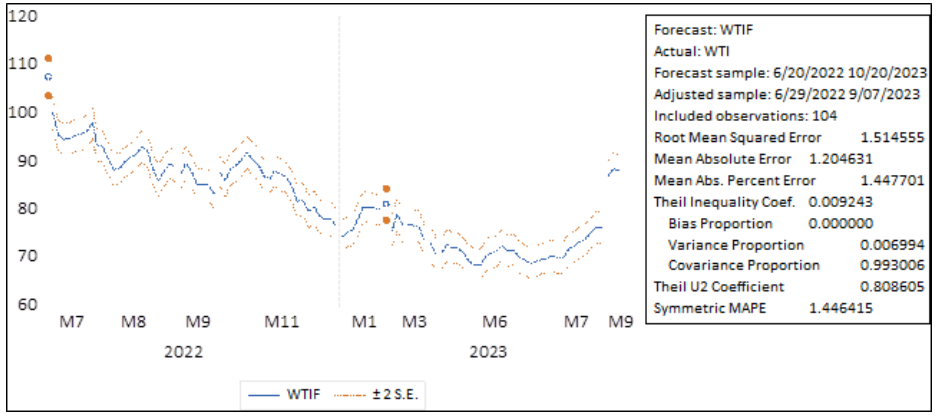


WTI forecast

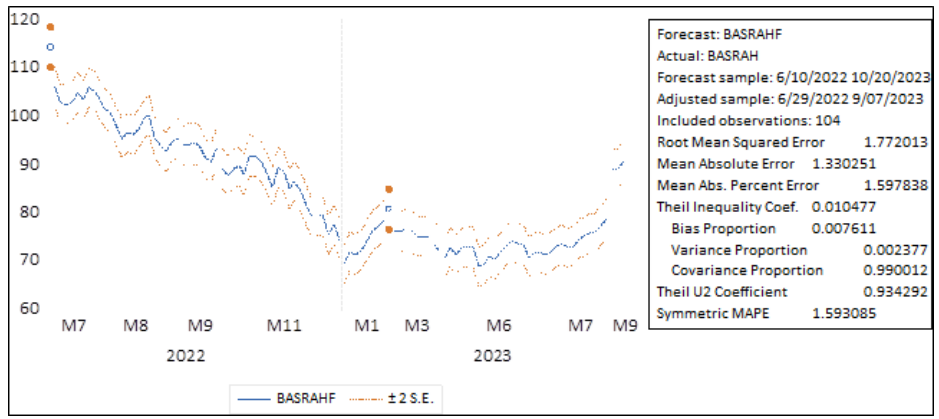


Empirical results

- We tested 52 candidate relationships using GH analysis, fully modified OLS (FOMS) CCR and ranked the candidate relationships on the basis of their ability to forecast a variety of heavy oil and benchmark oil prices.

- The IAC, HQC and SC criterion were used to evaluate the models and revealed that the Paasche TCI chained index outperforms the others as candidate benchmark index for the heavy crudes, Basrah, Dalia and Castilla.

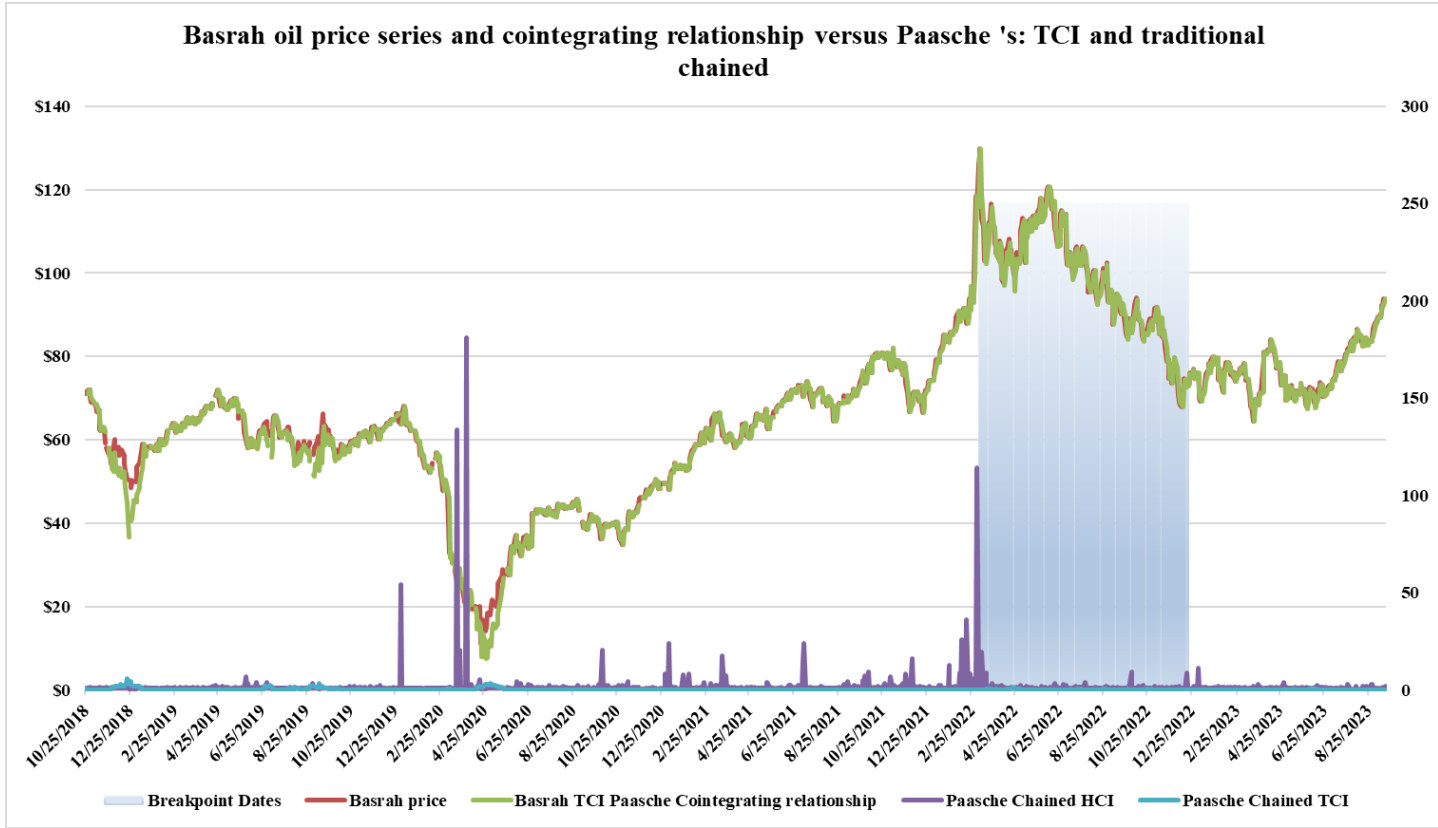
Basrah forecast



Empirical results

The traditional Paasche index, on the other hand, receives a high level in the ranking and is distinguished by its ability to forecast a regime change in the data well ahead of the break point dates selected by the G-H cointegration models.

For example, the Paasche traditional index spiked on January 2, 2020, predating the sudden downward trend in world oil prices following the outbreak of Covid, on February 9th, 2022, well ahead of the official recognition of COVID-19, on March 19, 2020.



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04

Towards a global benchmark

Policy implications and benefits to be derived from the index

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The TCI performs well as a leading indicator for the major crude oil benchmarks, outperforming a naive auto regressive forecast for heavy crudes such as Basrah, and the majors WTI and Brent.

As a benchmark it can help to facilitate regional price consistency and transparency, thereby improving the performance of market participants in heavy crude oil trading, hedging and investments.

The TCI provides a unique standard that reflects contemporary and expected future economic fluctuations, simplifying transactions between countries and nations, and helping to standardize international investment decisions in heavy crude oil.

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