Market efficiency of the crude palm oil: Evidence from quantum harmonic oscillator

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Abstract. This study examines the weak-form efficient market hypothesis of the crude palm oil market by adopting the quantum harmonic oscillator. This approach allows us to analyze market efficiency by estimating one parameter: the probability of finding the market in a ground state. Our results confirm that the crude palm oil market is more efficient than the West Texas Intermediate crude oil market. We explain the greater market efficiency comes from a small proportion of speculative transactions, resulting from tight market operation policies.

1. Introduction

Crude palm oil (CPO), the leading commodity in the edible oil markets, is a vegetable oil that is important and has many uses in peoples’ lives. Economic growth in China and India, who are the major CPO importers, and increase in the use of CPO as a biofuel are the background for the rapid growth of the CPO market [1]. Consequently, CPO production nearly quintupled from 1990 to 2013 [2]. Therefore, interest in the CPO market on the part of various stakeholders, including academics, industrial entities, and regulatory authorities, has risen in recent years.

However, the CPO market is comparatively under-researched compared to markets for other commodities such as West Texas Intermediate (WTI) and Brent crude oil, which in turn results in the ambiguity of the CPO market. This study aims to uncover a key property of the CPO market, in particular whether the weak-form efficient market hypothesis (EMH) holds [3]. We also examine the EMH for WTI, a heavily traded commodity as a well-known benchmark in the crude oil markets, for a comparison.

Extensive studies have taken numerous approaches to test the market efficiency of financial assets. Some have investigated market efficiency using statistical methods such as the variance ratio test [4] and the adjusted market inefficiency magnitude [5]. Others have explored market efficiency through the Hurst exponent [6,7,8]. This study attempts to use the quantum harmonic oscillator (QHO) which nests geometric Brownian motion (GBM) as a ground state solution and captures the probability assigned to each state, including the ground state [9].

2. Methodology and data

2.1. Methodology

We mostly follow Ahn et al. [9] to model the evolution of the return distribution. First, we consider

the following stochastic differential equation:

\[ dX_t = \mu X_t dt + \sigma X_t dW_t \]

\[ X_0 = x_0 \]

where \( X_t \) is the price process, \( \mu \) is the drift coefficient, \( \sigma \) is the diffusion coefficient, and \( dW_t \) is the Wiener process. The solution to this equation is

\[ X_t = X_0 e^{(\mu - \sigma^2/2)t + \sigma W_t} \]

which is the log-normal distribution.

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\[ dx = v(x, t)dt + \sigma(x, t)dW_t, \]

where \( x \) represents an asset return, \( v(x, t) \) denotes a drift, \( \sigma(x, t) \) represents volatility, and \( W_t \) is a standard Wiener process.

Introducing the probability density function (PDF) \( \rho(x, t) \) of the random variable \( x \) at time \( t \), we obtain the Fokker Planck (FP) equation from equation (1):

\[
\frac{\delta}{\delta t} \rho(x, t) = \frac{\delta^2}{\delta x^2} \left( D(x, t) \rho(x, t) \right) + \frac{\delta}{\delta x} \left( \rho(x, t) \frac{\delta V(x, t)}{\delta x} \right),
\]

where \( D(x, t) \equiv \sigma^2(x, t)/2 \) is the diffusion coefficient and \( V(x, t) \) is the external potential that determines the drift term according to \( \nu(x, t) \equiv -\delta V(x, t)/\delta x \).

In the case of constant \( D \) with time-independent potential \( V(x) \), equation (2) can be expressed in terms of the FP operator:

\[
\frac{\delta}{\delta t} \rho(x, t) = \left( \frac{\delta^2 V}{\delta x^2} \right) + \frac{\delta V}{\delta x} + D \frac{\delta^2}{\delta x^2} \rho(x, t) \equiv \hat{L} \rho(x, t).
\]

We finally obtain the solution of the FP equation whose time-independent solution takes the form of a mixed \( \chi \) distribution [9]:

\[
\rho(x, t) = \sum_{n=0}^{\infty} C_n(t)\rho_n(x)
\]

with \( C_n(t) = (A_n/\sqrt{2^{n+1}n!})\sqrt{m\omega/\pi h}e^{-E_n t} \) and \( \rho_n(x) = H_n(\sqrt{m\omega/2h})e^{-(m\omega/h)x^2} \). \( H_n \) is the \( n \)-th Hermite polynomial.

In particular, the random variable \( x \) follows the Gaussian, Rayleigh, and Maxwell–Boltzmann distributions for \( n = 0, 1, \) and \( 2 \). They all describe the displacement of asset prices per unit time (namely, return) in \( n \)-dimensional Euclidean space, respectively.

2.2. Data
Since Malaysian palm oil serves as a global benchmark for the palm oil industry [10], we retrieve daily prices for palm oil from the Malaysian palm oil board. Daily prices of WTI are obtained from the Federal Reserve Economic Data. Both CPO and WTI data span the period from January 2008 to October 2019. However, the number of observations differs due to the difference in holidays and operating policies of the two markets. The data is converted to log returns and annualized as shown below:

\[ x_t = 252.5 \ln \left( \frac{p_t}{p_{t-1}} \right), \]

where \( x_t \) and \( p_t \) are the log return and price at time \( t \).

Table 1 lists descriptive statistics for our samples. The standard deviation for CPO is close to a half of WTI’s. Hence, CPO prices are less volatile than WTI prices. In addition, CPO shows negative skewness, which is typical for emerging markets, suggesting that investors are risk-averse in their decisions [11] compared to symmetric distributions [12]. Lastly, while both datasets are leptokurtic, excess kurtosis for CPO is greater than for WTI, indicating that a higher proportion of CPO returns are at the extreme ends of the distribution.

| Table 1. Descriptive statistics. |
|-----------------------------------|
| No. of obs. | Mean    | Std.    | Skewness | Excess Kurtosis |
|-------------|---------|---------|----------|-----------------|
| CPO         | 2859    | -0.0359 | 3.5388   | -0.4174         | 6.2292          |
| WTI         | 2964    | -0.0529 | 6.1746   | 0.1537          | 4.7396          |

3. Results and discussion
Figure 1 displays a histogram of the actual return distributions and the distributions derived from the QHO and GBM. It can be seen that the distribution obtained from the QHO fits the data quite well
while the lognormal distribution derived from GBM significantly underestimates the weight of both datasets, i.e., CPO and WTI, around the center. This is mainly due to the fact that QHO incorporates market uncertainty through the properties of wave functions and further assumes market forces will pull short-run fluctuations back to the long-run equilibrium. In particular, it is shown analytically that a closed-form solution for stock return distributions, derived in equation (3), captures not only Gaussian (for \( n = 0 \)) and also non-Gaussian (for \( n \geq 1 \)) features.

![Figure 1. PDF of log returns in QHO (red) and GBM (black): (a) CPO and (b) WTI.](image)

In Table 2, we show the probabilities of the five low-lying eigenstates and the parameter \( m\omega \). The amplitudes of the 6th and higher eigenstates are rather small and negligible. We can think of \( m \) as market capitalization while \( \omega \) is the angular frequency measuring the rate of oscillations around the equilibrium level [9]. Considering that the market capitalization of WTI is much larger than that of CPO [13], we can claim that \( \omega \) for CPO is significantly greater than for WTI, suggesting that information discovery is much faster in the CPO market [14,15]. Accordingly, we conclude that the CPO market is more efficient than the WTI market [3]. Our findings are also supported by the probability assigned to the ground state: \( P_0 \) is larger for CPO than for WTI by approximately 1.4\%, which means that a larger proportion of its log returns is explained by Gaussian distribution.

|       | \( m\omega \) | \( P_0 \) | \( P_1 \) | \( P_2 \) | \( P_3 \) | \( P_4 \) |
|-------|--------------|-----------|-----------|-----------|-----------|-----------|
| CPO   | 7.0669       | 0.9948    | 0.0000    | 0.0047    | 0.0001    | 0.0003    |
| WTI   | 2.8175       | 0.9814    | 0.0002    | 0.0176    | 0.0002    | 0.0006    |

The greater efficiency of the CPO market can be understood from distinct market operation policies such as price quotation, trading hours, price limits, etc. Comparing the two markets, the CPO market has less friendly trading policies than the WTI market. Thus, CPO market is less attractive to non-commercial investors, namely, speculators. Accordingly, the price of CPO is more likely determined by fundamental economic motives such as supply and demand and less likely to be influenced by speculation, resulting in a more efficient market compared to the WTI market [16].

4. Conclusion
This study investigates the weak-form market efficiency for the CPO and WTI markets through the use of the QHO. By comparing the two markets in terms of (1) the probability assigned to the ground state and (2) the rate of oscillations around the equilibrium level, we conclude that the CPO market is more efficient than the WTI market. We attribute this to a smaller proportion of speculators in the CPO market, resulting from relatively strict trading policies. However, this study analyzes the
relatively long time horizon and it provides overall market condition in regard to market efficiency; we did not take into account exogenous shocks and policy changes. Accordingly, future research could consider changes in market efficiency in terms of various exogenous shocks.

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