The Influence of Oil Price Fluctuations on Indonesian Stock Prices Through Wavelet Coherence

Qoniti Amalia$^1$ and Acep Purqon$^2$

Department of Physics, Institut Teknologi Bandung, Indonesia

E-mail: $^1$qonitiamalia38@gmail.com; $^2$acep@fi.itb.ac.id

Abstract. Oil is the most important source of energy in the world. In 2014 price of world oil (WTI / West Texas Intermediate) showed a decline. The decline in oil price was followed by stock prices including the price of Indonesian stocks. A phenomenon where asset price move together, known as comovement be an important indicator for investors to make investment decisions. This study aimed to know the influence of oil price fluctuations on Indonesian stock prices during the oil prices downturn from 2014 (March 2014-March 2017). Shares study consist of five Indonesian stocks: Adaro Energy Tbk (ADRO), Aneka Tambang Tbk (ANTM), Vale Indonesia Tbk (INCO), Perusahaan Gas Negara (Persero) Tbk and Tambang Batubara Bukit Asam (Persero) Tbk. The method used the method of wavelet coherence. Based on this method, the time series can be investigated in time domain and frequency domain. Plot of wavelet coherence gave information about comovement of two time series. The result of this study indicate that Adaro Energy Tbk has the most significant comovement while Perusahaan Gas Negara (Persero) Tbk shows the least. Perusahaan Gas Negara (Persero) Tbk showed a lower risk and more stable and are not affected by oil price fluctuations.

1. Introduction

Oil become the most important source of energy and driving the global industry. Oil prices fell rapidly in 2014 since the global financial crisis in 2008. When the stock closed at the end of 2014, the price of Brent crude from the North Sea and West Texas Intermediate of America which is the International benchmark has dropped more than 45 percent. The decline in world oil prices caused by several factors including the supply glut in the world market. The fracking technology that allows drilling reach oil deposits are not reached before, increasing the production of oil the United States and Canada. High production of oil in the United States and Canada beat Saudi Arabia. OPEC actions continue to boost oil output to balance the market not create excess supply of oil so that the oil price fell.

The decline in world oil prices was also caused by the economic slowdown experienced by the Chinese. China is an economic driver a few years earlier, but due to the economic slowdown makes world commodity prices decline, including crude oil. China's economic slowdown led to a decrease in the stock price of the world. The decline in China's stock price impact on Indonesia because Indonesia is a trade partner of China.

Integration or movement together between one asset with another asset which is referred to as comovement be an important indicator for investors to invest their capital. If comovement predictable and patterns can be studied, investors will avoid errors in the transaction. The method used to measure this comovement is wavelet analysis. Through the wavelet transform, financial data can be analyzed in the time domain and frequency domain. This is what distinguishes the wavelet transform with a
Fourier transform. Stock which has a low comovement indicates the sector more stable and not affected by the economic turmoil (oil price fluctuations).

The data used is the price of crude oil, West Texas Intermediate (WTI) and the closing price of Indonesian stocks. Indonesia stock prices studied consisted of five shares, namely Adaro Energy Tbk (ADRO), Aneka Tambang Tbk (ANTM), Vale Indonesia Tbk (INCO), Perusahaan Gas Negara (Persero) Tbk (PGAS) and Aneka Tambang Bukit Asam (PTBA). Period of data from March 2014-March 2017.

2. Method
Wavelet is a small wave packet that grows and decays in limited time period [1]. Wavelet can transform time series into a time-frequency representation. It is convenient for the decomposition in the situation when the time series under study is non stationary, or only locally stationary [2]. Wavelet function in general is defined as:

$$\psi_{u,s}(t) = \frac{1}{\sqrt{s}} \psi\left(\frac{t-u}{s}\right)$$  \hspace{1cm} (1)

$\frac{1}{\sqrt{s}}$ is a normalization factor that makes it possible to compare the wavelet at different scales, $u$ represents the time domain parameters (translational) and $s$ is frequency domain (scale). Scale has an inverse relation to frequency. A low wavelet scale means the high frequency part of the time series.

There are three conditions that a wavelet needs to satisfy, namely [3]:

- The average should be equal to zero
  $$\int_{-\infty}^{\infty} \psi(t)dt = 0$$  \hspace{1cm} (2)

- The results of the integral of the mother wavelet squared is equal to 1
  $$\int_{-\infty}^{\infty} \psi^2(t)dt = 1$$  \hspace{1cm} (3)

- Admissibility condition, which is defined as
  $$0 < c_\psi = \int_{0}^{\infty} \left|\hat{\psi}(\omega)\right|^2 d\omega < +\infty$$  \hspace{1cm} (4)

The first condition ensures that the wavelet function, the area above and below the time axis (horizontal) cancel each other out. The second condition indicates that the wavelet function has a value (not zero) and oscillating around the time axis (horizontal) and wavelet has a unit of energy. Condition of admissibility is needed in order to afford the inverse wavelet function back to the time domain and obtain the original time series data.

There are various type of mother wavelet, such as Morlet, Haar, Mexican hat, etc. One of the most used is the Morlet wavelet introduced by Goupillaud et al (1984) [4]. Complex wavelets are such wavelets that have both real and imaginary part and their Fourier transform are zero for negative frequencies (Adisson (2002)). Morlet wavelet is orthogonal, complex, and offers a good analysis for detecting oscillation, peak, and discontinuities.

$$\psi_{\omega_0}(t) = \pi^{-\frac{1}{4}}e^{-i\omega_0 t}e^{-\frac{t^2}{2}}$$  \hspace{1cm} (5)

Where $\omega_0$ is the central frequency of the wavelet. $\omega_0 = 6$ [5], here taken to be 6 to satisfy the admissibility condition (Farge 1992).

There are four characters owned morlet wavelet, namely, [6]
1. Wavelet can be treated as an analytic wavelet.
2. Frequency of peak, energy frequency, and the center frequency of Morlet has the same value.
\[ \omega_{\psi_{\omega_0}}^P = \omega_{\psi_{\omega_0}}^E = \omega_{\psi_{\omega_0}}^I = \omega_0 \] (6)

3. Box Heisenberg reaches the lower limit when Morlet used, so the uncertainty is at the minimum value.

\[ \sigma_{\psi_{\omega_0}} \sigma_{\psi_{\omega_0}} = \frac{1}{2} \] (7)

4. A time and a frequency radius are equal, namely

\[ \sigma_{\psi_{\omega_0}} = \sigma_{\psi_{\omega_0}} = \frac{1}{\sqrt{2}} \] (8)

Before determining the Wavelet Power Spectrum (WPS) in advance to determine the Continuous Wavelet Transform (CWT). CWT uses to calculate the inner product similarity between time series signal with wavelet function is used. Continuous Wavelet Transform equation is as follows:

\[
W_x(u, s) = \frac{1}{\sqrt{s}} \int_{-\infty}^{\infty} x(t) \psi^* \left( \frac{t-u}{s} \right) dt
\] (9)

\[
W_x(u, s) = \frac{1}{\sqrt{s}} \sum_{l=1}^{N} x(t \psi^* \left( \frac{(t-u)\delta t}{s} \right)
\] (10)

**Figure 1.** Scaled and shifted real parts of Morlet (solid) wavelet alongside a sine wave (dashed) [7]

As figure above, the parameters \(s\) and \(u\) determine, how stretched or compresses (dilation) the wavelet is and where it is localized in time (translation) [7].

The equation of Wavelet Power Spectrum (WPS) that is:

\[ |W_x(u, s)|^2 \] (11)

WPS measure the local variance of the time series at various scales. Hence we get variance decomposition with a good time localization of the time series under investigation (Torrence and Compo, 1998). In the visualization of the power spectrum, the result of multiplying large are shown in red and the amounts that are indicated in blue.

Torrence and Compo (1998) defines Cross Wavelet Transform (XWT) of two time series as:

\[ W_{xy}(u, s) = W_x(u, s)W_y^*(u, s) \] (12)
In this case, $W_x$ and $W_y$ is the wavelet transform of the time series $x_t$ and $y_t$ and (*) indicates the conjugate of complex numbers. Here is the equation of Cross Wavelet Power (XWT), which shows both time series $x_t$ and $y_t$ that have high energy.

\[ (XWP)_{xy} = |W_{xy}| \]  

(13)

According to Torrence and Webster (1998) [8], the squared wavelet coherence can be defined as the squared absolute value of the smoothed cross wavelet power spectrum, normalized by the product of the smoothed individual wavelet power spectra of each time series,

\[ R^2(u,s) = \frac{|S(s^{-1}w_{xy}(u,s))|^2}{s(s^{-1}|w_x(u,s)|^2) s(s^{-1}|w_y(u,s)|^2)} \]  

(14)

Where $S$ is smoothing operator both in time and scale, which ensures that the coherence does not take value one at all scales and times, Torrence and Compo (1998).

\[ S(W) = S_{\text{scale}} \left( S_{\text{time}}(W_n(s)) \right) \]  

(15)

For Morlet wavelet, smoothing operator is given by:

\[ S_{\text{time}}(W) = \left( W_n(s) \ast c_1 \frac{\xi^2}{2\pi^2} \right) \]  

(16)

\[ S_{\text{scale}}(W) = \left( W_n(s) \ast c_2 \Pi(0.6s) \right) \]  

(17)

$c_1$ and $c_2$ is a normalization constant, $\Pi$ is box-function and 0.6 is the factor that determined the length of decorrelation scale for Morlet wavelet.

Wavelet coherence ranges between 0 and 1, if the value close to zero indicates weak correlation between two time series and the value close to one means strong correlation.

We use phase differences to give details about delays of oscillation between two time series. According to Torrence and Webster (1999) the phase difference can be calculated using the imaginary and the real part of the cross wavelet transform, by following equation,

\[ \phi_n(s) = \tan^{-1} \left[ \frac{\Re(s^{-1}w_{xy}(u,s))}{\Im(s^{-1}w_{xy}(u,s))} \right] \]  

(18)

\[ \phi_n(s) = \begin{cases} 
\left( -\frac{\pi}{2}, 0 \right), & \text{in phase, y leading} \\
\left( 0, \frac{\pi}{2} \right), & \text{in phase, x leading} \\
\left( -\pi, \frac{\pi}{2} \right), & \text{out of phase, x leading} \\
\left( -\frac{\pi}{2}, -\pi \right), & \text{out of phase, y leading} 
\end{cases} \]  

(19)

Phase difference are indicated by arrows pointing in the areas with significant coherence. Time series are in phase (positively correlated) represented by arrows pointing to the right, while arrows pointing to the left when time series are out of phase (negatively correlated). A phase difference zero means that two time series move together at a specific scale. Arrows pointing up (down) indicate that the first (second) time series leads the second (first) one in positive correlated (negative correlated).
3. Result and Discussion
Analysis of comovement useful in making investment decisions. If the price of a stock has a high comovement on oil prices mean the stock is very risky to invest. Comovement analysis done through methods Wavelet Coherence. In the wavelet coherence plot, a strong correlation with the value of approximately 1 marked in red while the correlation is low or does not correlate with values close to 0 is indicated by a blue color in the image. Plot of wavelet coherence is completed by phase difference analysis.

The phase difference indicated by arrows on significant area in the plot of wavelet coherence. The arrows to the right in time series illustrate the positive correlation in which both move in the same phase, while the arrows to the left show the time series moves in the opposite phase (negative correlation). Arrow pointing up means the first series lead in the second in positive correlation and the second lead the first time series in a negative correlation. Conversely, arrow pointing down shows the time series of the second lead in the first time series in positive correlations and the first to lead the second time series in a negative correlation. The first time series is a return of WTI and the second is a stock return of Indonesia.

By observing the wavelet coherence plot, all of the shares have shock long-term in low-frequency range is 128-256 days in November 2014-July 2016 with a different degree of correlation. This suggests that the decline in oil prices affect the price of shares of Indonesia.

Stock of Adaro Energy Tbk (ADRO) and WTI have significant comovement at some time, namely in November 2014-July 2016 with a low frequency is 128-256 days when stocks moves in the same phase with the first series lead the second time series is indicated by arrows pointing up and right. This means that the price of WTI is followed by ADRO shares. In March 2015- July 2015, stocks move in the same phase with the first series lead the second time series with frequency about 64 days, then the two series move together marked with arrows to the right in the December 2015-March 2016 with a high frequency that is 32 days. Both time series experienced a phase difference in the range of September 2014-December 2014 in which the movement of WTI precede ADRO shares that occurred in the frequency of 16-32 days. ADRO stock and WTI in general have the same phase, with WTI lead price movements. This shows that the world crude oil price fluctuations affect the movement of stock prices of ADRO.

Comovement between stock of Aneka Tambang Tbk and crude oil prices (WTI) has only two significant regions in the plot of wavelet coherence, less than ADRO shares. Areas that have a high comovement occurred in October 2014- January 2015 with the second row ahead of the first series in the same phase and occurs at low scale (high frequency) that is 32-64 days. Furthermore, with movement in the same phase as well but the second row lead the first series took place in March 2015-June 2016 with low frequency of around 256 days. Based on the observation that has a high comovement, WTI movements that affect stock prices only occur at low frequencies.

Furthermore, stock of Vale Indonesia Tbk (INCO) to WTI experienced comovement in the same phase in December 2015-March 2016 with frequency about 16-32 days. Same frequency occurred in November 2016 in which the movement of stock of INCO preceded by WTI. Furthermore, these stocks have movement in the same phase marked by the arrows to the right in November 2014-July 2016 with low frequency in the range of 128-256 days. The movement of the two stocks also occur in the opposite phase where the shares of INCO lead the WTI movement with frequency about 64 days in July 2015- November 2015. Furthermore, the movement of the INCO stock to WTI in two observation areas, namely in December 2016- February 2016 and around November 2016, with the frequency of each is 32 days and 64 days. Generally, INCO and WTI stocks move in the same phase that is marked with the direction of the arrow to the right. So investors should watch the world crude oil price fluctuations when investing in these stocks.

Comovement happens to the stock of Perusahaan Gas Negara (Persero) Tbk (PGAS) against WTI occurred in three significant areas where the two regions moving in the same phase and an observation area which moves in the opposite phase. The high frequency is 32-64 days in November 2014-February 2015 in which two time series of moves in the same phase marked by the arrows to the right.
Furthermore, the first series lead the second series in positive correlation in May 2014-June 2014 with 16-32 days. Both time series of moves in the opposite phase where the arrow is generally toward the up and left, which means PGAS move ahead of WTI with lower scale is 16-64 days in November 2016-February 2017. Based on plot of wavelet coherence on this stock, shows that the price of crude oil and stock of PGAS have the least comovement area. Although the stock is experiencing low frequency phase difference with yellowish tint, but the area is not surrounded by a thick black line which means that the significance is not equal to 5%. So the second comovement this stock is very low compared to other Indonesia’s stocks.

For observations in the area of comovement, significant area of stock of Tambang Batubara Bukit Asam (Persero) Tbk (PTBA) against WTI generally moving in the same phase. In January 2015- April 2015 frequency that occurs is 64 days, followed in February 2016- March 2016 with a frequency of 32-64 days. Furthermore, these stocks also suffered long-term shock in November 2014-July 2016 with frequency about 128-256 days. In this time span, the dominant direction of the arrows to the right and up that show the WTI price lead the PTBA stock. High frequency (about 32 days) also occurred in November 2016-February 2017.

Based on analysis of comovement seen that all stocks examined have correlation to WTI, where a significant decrease in crude oil prices provide a long-term impact on the stock of Indonesia. The most significant comovement of Indonesia’s stock indicated by ADRO shares where comovement most occur at a high frequency so the stock is very risky to invest compared to other stocks. While the lowest comovement indicated by PGAS stock, where these shares are not too affected by the turmoil in world crude oil prices.

![WTI-ADRO](image1.png)

![WTI-ANTM](image2.png)
4. Conclusion

Wavelet coherence profiles provide information for investor to make investment decisions. Indonesian stocks that have significant comovement on oil prices mean higher risk in investment. Otherwise low comovement means low acceptable risk. Based on red areas and move in phase of wavelet coherence visualizations can be concluded that oil prices and stock of Adaro Energy Tbk (ADRO) had greatest risk and Perusahaan Gas Negara (Persero) Tbk (PGAS) stock have the lowest risk. Stock of Tambang Batubara Bukit Asam (Persero) Tbk (PTBA), Vale Indonesia Tbk (INCO), and Aneka Tambang Tbk (ANTM) are between the two indices above.

Figure 2. Wavelet coherence between oil prices and Indonesia’s stock prices
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