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# **Extreme Dependence Between Crude Oil and Stock Markets in Asia-Pacific Regions: Evidence from Quantile Regression**

*Huiming Zhu, Hui Huang, Cheng Peng, and Yan Yang*

**Abstract**

This paper investigates the extreme dependence between the Asia-Pacific stock markets and the international crude oil market by applying the quantile regression theory and using daily data from January 4th, 2000 to July 4th, 2016. The authors obtain a more detailed result on the degree and structure of the dependence, and furthermore, the results present an asymmetric and heterogeneous dependence. Moreover, the dependence increases dramatically after a structural break point, meaning a crisis. Additionally, the authors observe a more significant dependence at the lower tails than the upper tails. They demonstrate the positive relationship at low quantiles, which is evidence of positive dependence in recessions or bearish markets.

**JEL** E44 Q43

**Keywords** Extreme dependence, Crude oil, Asia-Pacific stock market, Quantile regression, Structural breaks

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## 1. Introduction

As a nonrenewable natural resource, crude oil occupies a prominent position in the development of the economy and stock market. In addition, the stock market is usually viewed as an economic barometer. Hence, the link between oil prices and stock returns has attracted substantial attention from many scholars in the last few years. Hamilton (1983) conducted pioneering research on the relationship between oil prices and the economy, and subsequently, researchers have continued to explore this relationship. Le (2015) investigates the impacts of oil price and macroeconomic shocks on the housing market in Malaysia. This topic is also relevant to investors and policymakers because it has implications for asset allocation, portfolio selection and risk management.

Lee and Zeng (2011) show that the dependence degree between oil prices and stock returns rises in bearish and bullish periods. Therefore, in our study, we explore the extreme dependence between crude oil prices and stock returns in Asia-Pacific regions. There are several reasons why we fix the research scope on the Asia-Pacific region. First of all, as the British Petroleum Energy Review reported in 2016, crude oil consumption in many Asia-Pacific countries has increased. Specifically, oil consumption in the Asia-Pacific region was 4.1% higher in 2015 than in 2014 and now accounts for 34.7% of total world oil consumption. Furthermore, the volatility of crude oil prices has a greater impact on Asian economies than on the economies of developed countries, such as the US, because Asia-Pacific countries rely more heavily on the natural and non-renewable resource. In addition, most existing papers investigating the connection between crude oil prices and the stock market have mainly focused on the US and other developed countries, while few researchers have explored the extreme dependence between oil prices and stock returns in the Asia-Pacific region.

Although an abundance of literature has researched the relationship between crude oil prices and the stock market, the results have been inconsistent on this topic. Chen et al. (1986) study the relationship between oil prices and stock returns from 1958 to 1984 in the US and first propose that oil prices cannot influence the stock market significantly. Some other researchers have obtained the same results (Huang et al., 1996; Apergis and Miller, 2009;) indicating independence between oil shocks and stock returns. However, some papers discover a negative relationship between the crude oil market and the stock market (Jones & Kaul, 1996; Sadorsky, 1999; Hammoudeh & Li, 2005; Basher & Sadorsky, 2006; Hammoudeh & Choi, 2007; Nandha & Faff, 2008; Miller & Ratti, 2009; Kilian & Park, 2009;). Finally, other papers demonstrate a positive connection between crude oil prices and stock returns (Faff & Brailsford, 1999; Papapetrou, 2001; Sadorsky, 2001; El-Sharif, Brown, Nixon, & Russel, 2005; Kilian & Park, 2009; Narayan & Narayan, 2010; Zhang & Chen, 2011; Arouri & Rault, 2012;).

We apply the quantile regression method to determine the effects of crude oil prices on stock returns in the Asia-Pacific region. Quantile regression was first introduced by Koenker and Bassett (1978) and it depicts the estimation of the structure and degree of dependence conditional on the quantile  $\tau$  for all quantiles (Baur, 2012). In contrast to OLS regression, which estimates the average impacts of the regressors on response variables, quantile regression model is an extension of ordinary regression and can precisely describe the information about the dependence between crude oil prices and stock market returns in the Asia-Pacific. Further, stock markets all have characteristics of sharp peaks and heavy tails, and since quantile regression is robust to heteroskedasticity, skewness and

leptokurtosis, quantile regression is used broadly to study the dependence between financial variables (Basset and Chen, 2001; Koenker, 2004; Baur and Schulze, 2005; Chuang et al., 2009; Baur et al., 2011; Lin, 2013; Mensi et al., 2014).

Bai and Perron (1998) proposed a method for detecting structural breaks. Nevertheless, a great deal of research has ignored the structural changes resulting from market turmoil or a past financial crisis. If we do not consider the effects of structural breaks, the results we obtain may be inaccurate. Recently, scholars have investigated the link between oil prices and stock markets by applying the quantile regression model with structural breaks (Lee and Zeng, 2011; Li et al., 2012; Ajmi et al., 2014). Li et al. (2012) argue that structural breaks indicate rare parameter variations arising from changes in policy regime or infrequent but vital geopolitical events (e.g., subprime crisis). According to Ajmi (2014), changes in the oil price impact the stock market differently before and after a crisis.

Our research contributes to the current literature in the following ways: First, few studies have investigated the extreme dependence between crude oil prices and Asia-Pacific stock markets. Second, whereas previous literature has used VAR or copula methods to analyse the dependence between crude oil prices and stock markets, we use quantile regression, which is a more flexible method and can provide a more perfect picture of the distribution. Finally, previous research on Asia-Pacific stock markets has not considered multiple structural breaks. We explore the extreme dependence between the two financial variables across different countries considering the distinctive break points in each.

The paper is organized as follows: Section 2 briefly reviews literature. Section 3 explains the data and methodology used in this paper. Section 4 presents empirical results and a discussion of the findings. Finally, some conclusions are provided in section 5.

## **2. Literature Review**

A large number of existing studies have found a link between crude oil prices and stock returns. Kling (1985) apply the vector autoregressive (VAR) to examine the impacts of oil price movements on the S&P500 and five US industries. Jones et al. (1996) demonstrate the impact of oil price shocks on the unexpected stock return. Some papers state that oil price variances are vital in accounting for the changes in aggregate stock returns (Sadorsky, 1999; Papapetrou, 2001; Miller and Ratti, 2009). On the one hand, Sadorsky (1999) show that the impact of oil prices on the US stock market is negative. On the other hand, El-Shrif et al. (2005) find a positive connection between the energy market and the stock market. Furthermore, Nandha and Faff (2008) indicate that oil price and stock market return are positively correlated in oil-exporting countries. Zhang and Wei (2011) study the relationship between the international crude oil market and stock market risk in the US, UK, and Japan and find asymmetric effects. Using sector stock prices and oil prices from January 1991 to May 2009 in the G7 countries, Lee et al. (2012) find that fluctuations of stock markets in Germany, the US and the UK cause significant changes to the oil price, although oil price shocks have nearly no effect on the stock returns of the G7 countries. Wen et al. (2012) use time-varying copulas to explore whether there were contagion effects between the energy and stock markets during the recent financial crisis. Lee and Ryu (2013) re-examine the relationship between stock returns and implied volatility by applying a new VAR approach. Silva et al. (2014) use copula methods to explore tail dependence of financial stocks and CDS markets. Kang et al. (2016) investigate the effects of oil supply shocks on the US stock market

and find a positive impact.

In exploring the relationship between crude oil prices and stock markets, prior research has focused on developed countries. However, there are still some researchers who have studied this topic in developing countries, especially those experiencing rapid progress. Papapetrou (2001) suggest that oil prices impact the Greece stock market significantly. Maghyreh (2004) investigates the dynamic linkages between crude oil price shocks and stock market returns in 22 emerging economies by applying the VAR analysis. Hammoudeh and Choi (2007) report that a negative relationship between crude oil prices and stock markets exists in emerging countries. Cong et al. (2008) first use a VAR model to research the relationship between the oil price and the stock composite index in China. Changes in oil prices are found to result in the volatility of stock markets in Brazil, Russia, India and China (BRIC) (Bhar and Nikolova, 2009). There is evidence that oil prices have a positive impact on stock returns in Vietnam (Narayan and Narayan, 2010). Li et al. (2012) employ panel cointegration to investigate the relationship between oil shocks and the Chinese stock market and find a minor positive effect. Sukcharoen et al. (2014) apply the copula approach to investigate the interdependence of oil prices and stock market indices in both developed countries and developing countries for the period spanning January 7, 1982 to December 31, 2007. Jain and Biswal (2016) report the dynamic relation between global oil prices and the stock market in India.

Few scholars have conducted research on the dependence between crude oil prices and stock markets in the Asia-Pacific. Nandha and Hammoudeh (2007) determine the sensitivities of stock markets in 15 Asia-Pacific countries to systematic risk, oil price and the exchange rate by applying an international factor model. Raheman et al. (2012) examine the effects of oil price fluctuations on stock returns in Asia-Pacific regions using the VAR method. Zhu et al. (2014) analyse the link between the crude oil price and Asia-Pacific stock returns using the copula model and find the dynamic dependence between them. Koh (2016) employ structural vector autoregression (VAR) to explore how oil price shocks influence Asian stock returns. They infer that an increase in the oil price may be viewed as bad news only if the source is an oil-market-specific change in demand.

Some empirical research has considered structural breaks resulting from financial crisis or market chaos. Bai and Perron (2003) propose a method to discover structural breaks in research. Li et al. (2012) examine the links between oil prices and stock markets in China at the sector level by employing a panel cointegration test with multiple breaks. Zhu et al. (2015) describes the presence of multiple structural breaks in the relationship between oil prices and stock returns in various industries.

We use quantile regression aimed at demonstrating the extreme dependence between crude oil prices and stock markets in Asia-Pacific regions, because very few previous studies have applied quantile regression to research this relationship. In addition, quantile regression can precisely describe the relationship between the two variables whether in the upper tail, lower tail or centre of the conditional distribution of dependent variables. Further, we consider the effects of financial crisis and test break points in different Asia-Pacific regions.

### 3. Data and Methodology

#### 3.1 Data and descriptive statistics

We use ten daily stock indexes in the Asia-Pacific and crude oil price changes from January 4th, 2000 to July 4th, 2016 due to the availability of data. The period is long enough that we can explore the dependence between crude oil prices and stock returns by dividing the period into multiple shorter periods along structural breaks. The ten Asia-Pacific indexes covered are the following: Australia S&P/ASX 200, Hong Kong Hang Seng Index, India S&P BSE SENSEX, Indonesia Jakarta Composite Index, Japan Nikkei 225, Korea KOSPI Composite Index, Philippine PSEI, Malaysia FTSE Bursa Malaysia KLCI, Shanghai SSE Composite Index, and Taiwan TWSE TAIWAN 50. These data are collected from the website <http://finance.yahoo.com>. The Cushing, OK WTI Spot Price, which is the major indicator of international crude oil prices, was obtained from the EIA. Some papers use exchange rates to convert WTI oil prices into local oil prices. However, the return that we use reduces the impact of the exchange rate. Therefore, we calculate crude oil price changes as follows:

$$Oil = 100 \times (\ln P_t - \ln P_{t-1}), \quad (1)$$

where  $P_t$  denotes the oil price at time  $t$ . The stock returns are defined in a similar manner. Table 1 presents the descriptive statistics of crude oil price changes and of stock market returns in the different regions.

**Table 1**

Descriptive statistics.

	Mean	Median	Maximum	Minimum	Std.Dev.	Skewness	Kurtosis	ADF	PP
Oil	0.0157	0.0747	16.4137	-17.0918	2.5095	-0.1504	7.2905	-66.3791***	-66.4412***
Australia	0.0108	0.0352	5.6282	-8.7043	1.0235	-0.4671	8.4660	-66.6972***	-66.8279***
Hong Kong	0.0027	0.0070	13.4068	-13.5820	1.5350	-0.0652	10.8204	-65.0886***	-65.1315***
India	0.0307	0.0822	15.9900	-11.8092	1.5451	-0.16225	9.96094	-58.9124***	-58.801***
Indonesia	0.0452	0.1115	7.6231	-10.954	1.4129	-0.6633	9.3287	-56.0622***	-55.9025***
Japan	-0.0091	0.0160	13.2346	-12.1110	1.5683	-0.4107	8.9919	-65.1511***	-65.3706***
Korea	0.0088	0.0556	11.2844	-12.8047	1.5919	-0.5591	9.1877	-62.3002***	-62.4999***
Malaysia	0.0157	0.0335	16.0204	-15.5682	0.9546	-0.4893	62.6580	-62.7928***	-62.8635***
Philippines	0.0317	0.0000	16.1776	-13.0887	1.3064	0.2821	18.8656	-56.9095***	-56.5858***
Shanghai	0.0190	0.0074	9.4008	-9.2562	1.6196	-0.2846	7.7664	-62.6457***	-62.6457***
Taiwan	-0.0086	0.0262	6.5246	-9.9360	1.4214	-0.26886	6.155935	-59.9783***	-59.9833***

**Notes:** This table provides the descriptive statistics of crude oil price changes and of stock market returns of ten Asia-Pacific stock markets. The statistics consist of Mean, Median, Maximum, Minimum, Std.Dev, Skewness, Kurtosis, Augmented Dickey-Fuller test (ADF), and Phillips-Perron test (PP).

\*\*\* denotes statistical significance at the 1% level.

We focus on the last four statistics. The results show that the Philippine stock market returns are left skewed, whereas the rest are right skewed. Furthermore, all variables have excessive kurtosis, indicating that all distributions are non-normal and asymmetric, which is consistent with the characteristics of sharp peaks and fat tails in stock markets. This observation sufficiently proves the necessity of studying the impacts of crude oil price on stock market returns at different quantiles. Thus, we apply the quantile regression approach to investigate the dependence between the crude oil price and the Asia-Pacific stock markets, an approach that can characterise the degree and structure of dependence more flexibly and precisely. In contrast, ordinary linear regression is not suitable for our study of oil prices and the stock market because of its hypothesis that the error term is normally distributed. Furthermore, through the unit root test, including the Augmented Dickey-Fuller (ADF) test and Phillips-Perron (PP) test, we can reject the null hypothesis at the 1% significance level. Hence, all variables proved to be stationary at the 1% significance level through the ADF test and PP test.

### 3.2 Methodology

Quantile regression is first introduced by Koenker and Bassett (1978) and is widely used to research the dependence between financial variables. Ordinary least squares (OLS) regression is a linear model represented as  $y = \beta'x + \varepsilon$ . It provides the estimation of the conditional mean of the dependent variable  $y$  given the explanatory variables  $x$ . However, Binder and Coad (2011) suggest that OLS regression may result in inexact estimation of relevant parameters or the loss of significant relationships. Compared with OLS regression, quantile regression presents a more precise picture of a conditional distribution, which is an expansion of ordinary linear regression. Quantile regression has a hypothesis that the value of  $\varepsilon_i$  conditional on the regressors at  $\tau$ -th quantile is equal to 0. The basic quantile regression model is specified as follows:

$$Q_{y|x}(\tau) = \inf\{b \mid F_{y|x}(b) \geq \tau\} = x' \beta(\tau), \quad (2)$$

where  $0 < \tau < 1$ ,  $Q_{y|x}(\tau)$  is the  $\tau$ -th conditional quantile of  $y$ , which is assumed to be linearly dependent on  $x$ .  $\beta(\tau)$  denotes the dependence degree. That is to say, the estimation of  $\beta(\tau)$  can show the influence of  $x$  on the  $\tau$ -th quantile of  $y$ . The coefficients of the  $\tau$ -th quantile of the conditional distribution are estimated as:

$$\hat{\beta}(\tau) = \arg \min_{\beta(\tau)} \sum_{i=1}^n \rho_{\tau}(y_i - x_i' \beta(\tau)) \quad (3)$$

If  $u_i = y_i - x_i' \beta(\tau)$ , then the loss function of the segmented quantile is:

$$\rho_{\tau}(u_i) = u_i[\tau - I(u_i < 0)], \quad (4)$$

where  $I(\cdot)$  is an indicator function. In addition, considering fixed effects that are unknown, we extend the basic model specification in Eq.(1). The expression for quantile regression with fixed effects is as follows:



$$Q_{y_i|x}(\tau) = \alpha(\tau) + x_i' \beta(\tau), \quad (5)$$

where  $\alpha(\tau)$  denotes the unobserved effect. Specifically, the coefficients of the  $\tau$ -th quantile of the conditional distribution are estimated as follows:

$$(\hat{\alpha}(\tau), \hat{\beta}(\tau)) = \arg \min_{\alpha(\tau), \beta(\tau)} \sum_{i=1}^n \rho_{\tau}(y_i - \alpha(\tau) - x_i' \beta(\tau)) \quad (6)$$

This method divides the residuals into positives and negatives, and also gives the weights of  $\tau$  and  $1 - \tau$ , so the estimator is robust.

We use the quantile regression model to investigate the extreme dependence between crude oil prices and the Asia-Pacific stock markets. As is common knowledge, financial data have characteristics of sharp peaks and fat tails that accord with the results shown in Table 1. As a result, quantile regression matches the needs of our research and it is robust to heteroskedasticity, skewness and leptokurtosis (Baur et al., 2011). Some prior papers such as those of Broadstock and Cao (2012) and Moya et al. (2014) note that the dependence degree will be changed by a crisis. Thus, we test for break points and the results indicate that four regions, Hong Kong, India, Indonesia and Taiwan, have breakpoints. Because of the existence of multiple structural breaks in the relationship between crude oil prices and stock returns in the Asia-Pacific, we add dummy variables into our model as follows:

$$Q_r(\tau | x) = \alpha(\tau) + \beta(\tau) \cdot oil + \sum_{j=1}^n \gamma_j(\tau) \cdot oil \cdot D_j, \quad (7)$$

where  $r$  represents the stock return of different regions in the Asia-Pacific and  $oil$  represents the oil price changes. We utilise daily data for both the crude oil and stock markets. When the return is from the period after the eruption of  $j$ -th break, the dummy variable  $D_j$  equals one. In the remaining cases, the dummy variable is equal to zero. Our model aims to explore the extreme effects that crude oil prices have on stock returns in ten Asia-Pacific regions. In our model,  $\beta(\tau)$  measures the dependence degree between oil prices and Asia-Pacific stock returns. In other words, the estimation of  $\beta(\tau)$  describes the impacts of the crude oil price on the  $\tau$ -th quantile of the stock return. We select three series of quantiles for our study. The first series, which is defined as the lower tail, consists of three quantiles (0.01, 0.05, 0.1). Quantile (0.5) represents the middle of the distribution. Lastly, the upper tail refers to the quantiles (0.9, 0.95, 0.99). In total, seven quantiles are included in our research. If the parameter  $\beta(\tau)$  is significantly positive, we infer that the stock return would increase when the crude oil price increases and would decrease when the oil price decreases. Further, if the estimated  $\beta(\tau)$  is negative, then oil prices and stock market returns will be inversely related; when the oil price rises, the stock return would decline, and vice versa. Estimated values of  $\gamma_j(\tau)$  denotes the variation of dependence arising from the  $j$ -th break. Our results confirm that the extreme dependence between oil prices and stock returns across quantiles differs between normal and crisis periods. The variable  $j$  in our final expression is a segment index, denoting the breakpoints which are definitely viewed as undiscovered. Bai and Perron (1998) proposed a method for detection of structural breaks. With the

breakpoint  $j$ , a comparison of the OLS residuals  $\hat{e}_j$  from one regression for each sub-sample and the residuals  $\hat{e}$  from the whole model is via:

$$F_j = \frac{\hat{e}'\hat{e} - \hat{e}'_j\hat{e}_j}{\hat{e}'_j\hat{e}_j/(n-2k)}, j = n_h, \dots, n - n_h (n_h \geq k), \quad (8)$$

where the  $F$ -statistic (Andrews, 1993; Andrews and Ploberger, 1994; Andrews et al., 1996) is specified to test the alternative hypothesis of one break with unknown timing against the null hypothesis. The null hypothesis is that there is no break point. Subsequently, Bai and Perron (1998, 2003) extend this method to test for 0 vs.  $L$  breaks and  $L$  vs.  $L+1$  breaks. In order to identify the number of break points, first it is necessary for us to examine whether there is at least one break on the basis of  $UD$ max and  $WD$ max tests (Bai and Perron, 1998; Bai and Perron, 2003). Next, we calculate the precise number of break points by sequential procedure of the  $\sup F_T[(L+1)/L]$  statistics.

#### 4. Empirical Analysis

##### 4.1 Multiple structural breaks

Our results reveal notable heterogeneity in structural breaks among the different regions studied. From Table 2, we know that there are four regions that have breakpoints, Hong Kong, India, Indonesia and Taiwan, while others have no breakpoints. Hong Kong and India both have two breaks, and just one break exists in Indonesia and Taiwan.

**Table 2**

Estimation of multiple structural breaks in the relationship between crude oil price and stock returns.

Regions	Number of breaks	Break dates
Australia	0	
Hong Kong	2	2007-7-31, 2012-7-30
India	2	2006-3-24, 2013-8-26
Indonesia	1	2003-4-3
Japan	0	
Korea	0	
Malaysia	0	
Philippines	0	
Shanghai	0	
Taiwan	1	2003-4-22

**Notes:** 1.Specification: Method: BREAKLS-Least Squares with Breakpoints; 2.Options: Coefficient covariance matrix: HAC (Newey-West); (Lag specification: Auto-AIC; Maximum lags:\*; Kernel: Bartlett; Bandwidth method: Newey-West Automatic; Lag selection parameter:\*; Offset: 0;) d.f. Adjustment; Allow error distribution to differ across breaks; Method: Sequential  $L+1$  breaks vs.  $L$ ; Trimming:15; Maximum breaks: 5; Significance:0.05.

In Hong Kong, the first break, which occurred on July 31st, 2007, may have been caused by the U.S. sub-prime mortgage crisis that triggered the global financial turmoil in the last half of 2007. The second breakpoint in Hong Kong appeared on July 30th, 2012. This break may be related to the Hong Kong Stock Exchange's acquisition of the London Metal Exchange (LME) in June 2012. In India, the break on March 24th, 2006 may have resulted from the galloping Sensex and the expose of the IPO or demat scam from 2005 to 2006. The second break in India on August 26th, 2013 resulted from the lack of formal banking in many rural areas, which gave rise to many Ponzi schemes. Indonesia and Taiwan had only one break point in April, 2003, which may be related to a sharp increase in crude oil prices in 2003.

#### **4.2 Extreme dependence**

The estimation results in Table 3 reveal that the dependence between the stock market and crude oil prices is dissimilar across different regions. As shown in Table 2, Hong Kong, India, Indonesia and Taiwan all have breakpoints. In these four regions, we find that almost all the stock markets are not significantly affected by oil price before the break, while they are sensitive to oil price shocks after the break. Thus, the dependence degree between stock return and oil price increased significantly after the recent financial crisis, which is consistent with previous research on the stock market (Wen et al., 2012 and Zhu et al., 2014). The research of Wen indicates that there was a statistically significant rise in conditional dependence between crude oil and US/Chinese stock markets during the post-crisis period. According to Zhu et al. (2014), this enhanced dependence between oil prices and stock returns may be caused by expectations of economic recovery in the Asia Pacific stock markets due to the increased oil price. Strong economic growth may increase the confidence of investors and the steady appreciation of currencies in the Asia-Pacific region may have significantly driven demand for crude oil, causing the dependence between oil prices and stocks returns to strengthen in the post-crisis. Chen (2010), Hamilton (2009) and Guo et al. (2010) find that increasing oil prices caused a dampening of US stock returns, and conclude that the dependence of oil prices and stock prices returns is markedly decreased before a crisis. Chen and Lv (2015) investigate the contagion effect and their results indicate the increasing dependence between the Chinese stock market and the world crude oil market during the crisis period. The International Energy Agency reports that a rapid recovery of the world economy results in a sharp increase in energy demand, especially in the Asia Pacific countries. Additionally, investors are usually more susceptible to bad news and pay less attention to good news from other markets. Accordingly, the dependence between oil prices and stock returns will strengthen after a break. Moreover, the rapid development of financial markets means that changes in oil prices are not only affected by the supply and demand of crude oil but also by the aggregate risk-based preferences for assets and investment behavior, causing the dependence degree to increase dramatically. Through our findings above, investors should regard oil prices as an investment signal, especially during a crisis period, due to the extreme dependence between the stock indices and oil prices.

**Table 3** Estimation results for the quantile regression and OLS regression.

Regions	parameter	Q <sub>0.01</sub>	Q <sub>0.05</sub>	Q <sub>0.1</sub>	Q <sub>0.5</sub>	Q <sub>0.9</sub>	Q <sub>0.95</sub>	Q <sub>0.99</sub>	OLS
Australia	$\alpha$	-2.8483***	-1.5833***	-1.1385***	0.0373***	1.0975***	1.5095***	2.5475***	0.0102
	$\beta$	0.1492**	0.0616***	0.0685***	0.0258***	0.0287***	0.0249	0.0322	0.0431***
Hong Kong	$\alpha$	-4.1567***	-2.3477***	-1.6293***	0.0102	1.6253***	2.2695***	3.9422***	0.0025
	$\beta$	-0.0261	0.0125	0.0062	0.0089	-0.0263	-0.0385	-0.1196	-0.0051
	$\gamma_1$	0.2624*	0.1846***	0.1913***	0.1480***	0.1810***	0.1508**	0.3301	0.2033***
	$\gamma_2$	0.2529**	0.0868	0.0877*	0.0017	0.0748*	0.1109	0.0998	0.0484*
India	$\alpha$	-4.3827***	-2.3429***	-1.6276***	0.0614***	1.6318***	2.2359***	3.9983***	0.0299
	$\beta$	-0.0786	0.0023	-0.0155	-0.0048	-0.0196	-0.0445	-0.1473	-0.0174
	$\gamma_1$	0.3250*	0.1805**	0.2183***	0.1929***	0.2030***	0.2317***	0.1979	0.2103***
	$\gamma_2$	0.3849**	-0.0045	0.0588	0.0303	0.0560	0.0517	0.2968	0.0524*
Indonesia	$\alpha$	-4.1282***	-2.1962***	-1.5077***	0.1157***	1.5034***	2.0655***	3.5532***	0.0449**
	$\beta$	-0.1556	0.0526	0.0397	-0.0012	0.0262	0.0457	-0.0281	0.0112
	$\gamma_1$	0.4065	0.0993**	0.0764*	0.0445**	0.0586**	0.0819*	0.2074*	0.0731***
Japan	$\alpha$	-4.4258***	-2.4640***	-1.7969***	0.0115	1.7356***	2.2779***	3.6328***	-0.0105
	$\beta$	0.1924**	0.0823***	0.0689***	0.0486***	0.0392**	0.0602**	0.0825	0.0643***
Korea	$\alpha$	-4.7447***	-2.6034***	-1.7540***	0.0699***	1.6509***	2.3391***	4.3866***	0.0079
	$\beta$	0.2347**	0.0841***	0.0687***	0.0462***	0.0685***	0.0709***	0.0287	0.0708***
Malaysia	$\alpha$	-2.4876***	-1.2916***	-0.8811***	0.0354***	0.8814***	1.3006***	2.3157***	0.0151
	$\beta$	0.0631	0.0315**	0.0257**	0.0223***	0.0381***	0.0387**	0.0357	0.0241***
Philippines	$\alpha$	-3.8421***	-1.9076***	-1.3111***	0.0075	1.4208***	1.9273***	3.0593***	0.0311
	$\beta$	0.1604**	0.0626***	0.0264**	0.0032	0.0169	0.0251	0.0030	0.0300***
Shanghai	$\alpha$	-5.1357***	-2.5428***	-1.7297***	0.0283**	1.7819***	2.5088***	4.3054***	0.0180
	$\beta$	0.1624*	0.0816**	0.0459**	0.0142***	0.0198	0.0488***	0.1853***	0.0453***
Taiwan	$\alpha$	-3.8649***	-2.4137***	-1.6182***	0.0350*	1.5254***	2.1210***	3.8775***	-0.0098
	$\beta$	0.0084	-0.0054	0.0182	-0.0264*	-0.0679***	-0.0453	-0.0503	-0.0200
	$\gamma_1$	0.1979	0.1970***	0.1180***	0.0611***	0.1164***	0.1086	0.1443	0.0971***

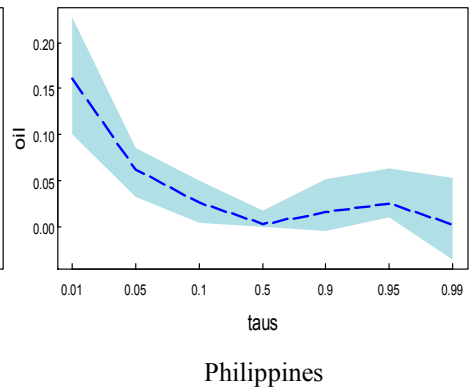
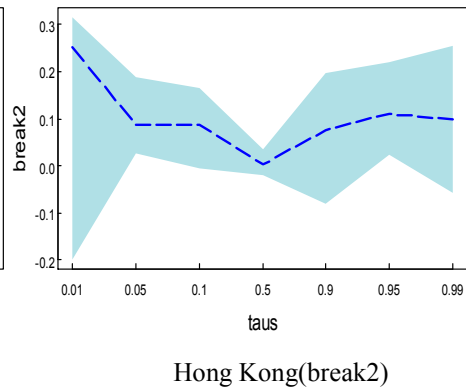
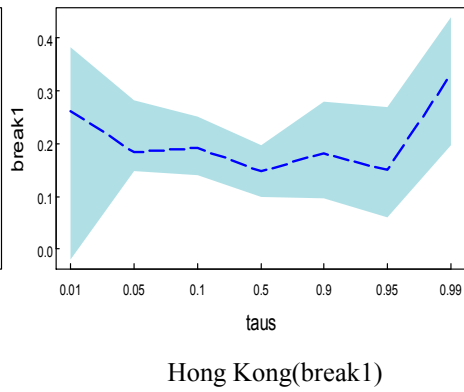
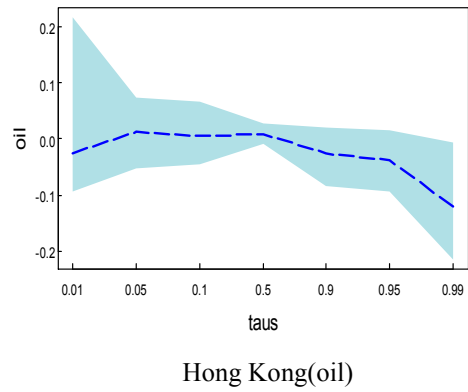
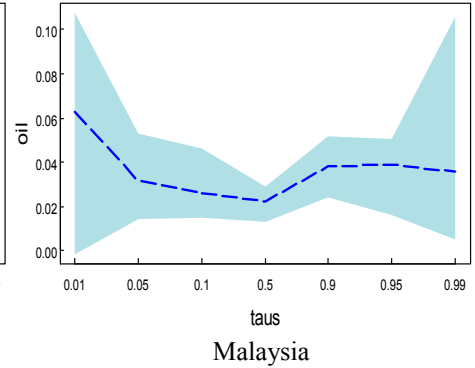
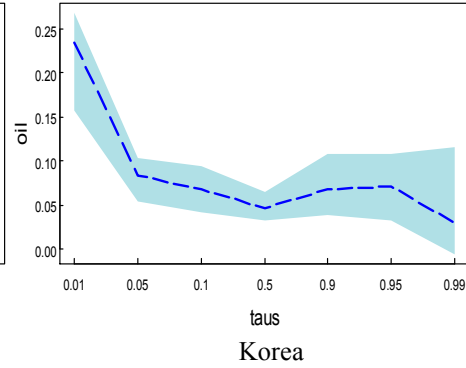
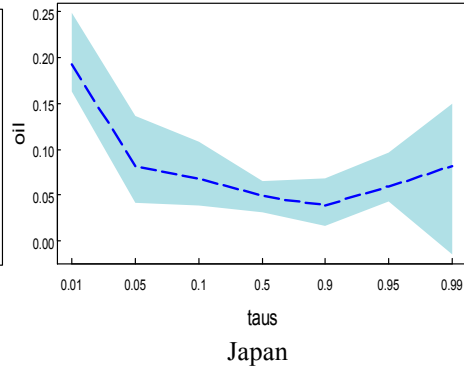
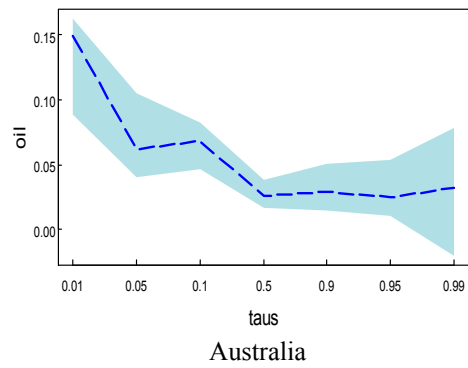
Notes: \*\*\*, \*\*, \* denote statistical significance at the 1%, 5%, 10% levels, respectively.

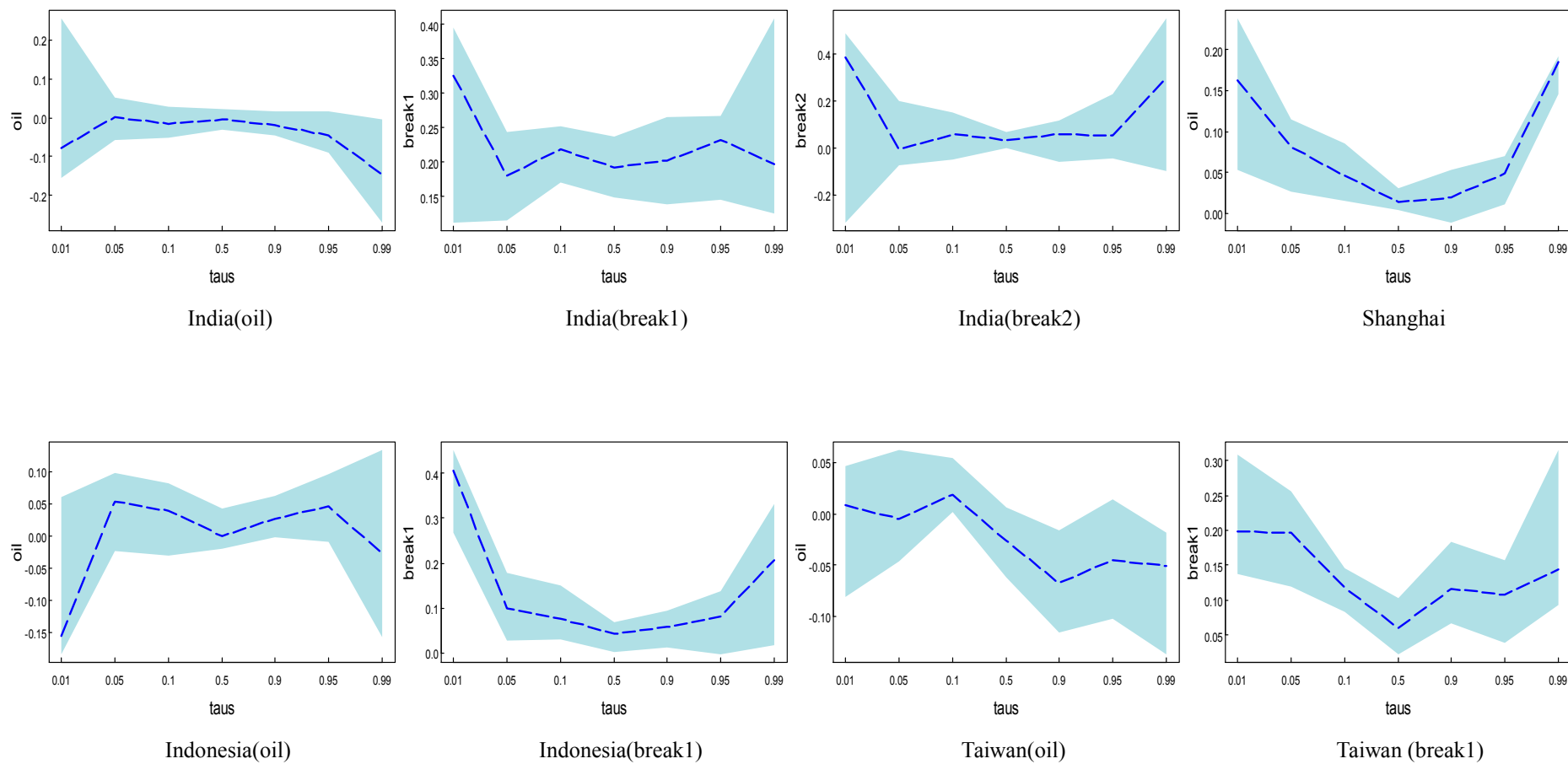
Baur (2013) proposes that quantile regression can present asymmetric and non-linear dependence. Moreover, the relationship between oil prices and US equities is asymmetric (Sim et al., 2015). Table 3 presents the calculations of extreme dependence levels between crude oil prices and the Asia-Pacific stock markets. We find an asymmetric property in the upper and lower tails. For instance, in Australia, the dependence between crude oil prices and stock returns in the lower tails is highly different from that in the upper tails. Specifically, the extremal dependence is more significant in the lower tails than in the upper tails. This finding is consistent with the research of Hu (2006), whose result indicates that the dependence between financial markets is asymmetric and left-tailed. In the energy realm, Lee and Zeng (2011) explore the asymmetric effect of oil price shocks on the real stock returns of G7 countries, and this effect is similar to that found in the former study of Chang et al. (2010). The asymmetry of the dependence indicates that policymakers and investors should take different measures in response to different changes in oil prices under variational economic conditions.

Quantile regression in Table 3 comprehensively describes information about the dependence between oil prices and stock market returns. We observe that the values of the parameter estimates at the 0.5 quantile are close to those of the ordinary least squares regression. In addition, stock market breaks have different impacts on the dependence between oil prices and stock returns across the four regions with one or two breaks. The oil prices also affect the dependence to different degrees across the regions without a break point. We are amazed to find that the extreme dependence parameter estimates are more significant at low quantiles, which is consistent with the research of Zhu et al. (2016) and Hu (2006). Hu argues that people paying more attention to negative news than positive news from other markets results in the asymmetric and left-tailed dependence in financial markets. When crisis approaches, investors all lose confidence in the future economy following a crisis and realise that bad news will impact markets more widely (Wen et al., 2012; Basistha and Kurov, 2008). Another possible reason for the asymmetry is that the herd effect is exacerbated during economic recession (Lao and Singh, 2011). This explanation is consistent with the conclusion of Wen et al. (2012) that in a tranquil period, passive market sentiment may cause dispersed market behavior to converge and be more accordant. Consequently, the extreme dependence of crude oil prices and stock returns is greatly increased in the lower tails. Policymakers and investors can consider crude oil prices as a vital economic signal. It is necessary for policymakers and investors to give special attention to crude oil prices and the Asia-Pacific stock markets during times of economic depression.

The extreme dependence between crude oil prices and stock returns is positive in the lower tail. In other words, the stock index rises as the crude oil price increases during a recession. A small amount of literature has affirmed this positive dependence. Kilian and Park (2009) explain the positive dependence by making use of the business cycle theory. An unexpected global economic expansion, contributing directly to the unanticipated rise in oil prices, stimulates the stock market. That is to say, the expansionary shock brings the persistent positive effects of oil prices on stock markets. The research of Narayan and Narayan (2010) indicates that oil price has a positive and statistically significant effect on Vietnamese stock returns. Investors' estimates of future stock market returns depend on the expectation of oil price fluctuations. Therefore, crude oil prices have a positive effect on China's stock returns (Zhang and Chen, 2011). Li (2012) describes several factors causing the positive

dependence, including international and domestic events, alternative energy and a leverage effect existing in stock markets. Hence, in bearish periods, a decrease in the WTI oil price will bring about a fall in stock market returns. Zhu et al. (2014) show that the dependence between crude oil prices and Asia-Pacific stock market returns is positive both before the global financial crisis and in the aftermath of the crisis. The rapid economic growth in Asia-Pacific countries can immensely weaken the negative effects of oil prices. Chen and Lv (2015) investigate the asymptotic dependence between the crude oil market and the Chinese stock market and find a significantly positive extremal dependence. In particular, the state-regulated oil pricing mechanism in countries such as China may lead to the positive dependence. The aforementioned authors attribute the positive correlation to the co-movements of the Chinese stock market, the world oil market and the global economic cycle. According to Zhu et al. (2016), the benefits of diversification are reduced in a recession. In times of economic downturn, risk diversification becomes less effective due to the increased dependence between oil spot prices and stock returns. Our findings have significant implications. As an indicator of world economic development, crude oil prices can be viewed as a vital index for investors and policymakers. Risk managers can use it to measure risk more accurately. Portfolio managers should focus on the energy markets when the world economy is deeply depressed. Specifically, when the oil price is rising during tranquil periods, investors should augment the ratio of their investments in Asia-Pacific stock markets. On the opposite side, investors should allocate less assets in stocks when the oil price is declining.





**Fig. 1.** Dynamic trace of quantile regression coefficients; vertical axes depict coefficient estimates of variables over the stock return distributions; horizontal axes show the quantiles of the dependent variables; quantile regression error bars correspond to bootstrapped 95% confidence intervals.



In Fig. 1, we vividly describe bootstrapped coefficient estimates for the stock market return distribution of each country with 95% confidence intervals (in shaded area). Fig. 1 presents dynamic estimates of quantile regression coefficients. Because of the estimation results for different quantiles from the quantile regression model, a richer picture of the dependence between crude oil prices and stock markets can be observed. Specifically, estimated coefficients for each stock market vary as  $\tau$  varies. Dynamic traces present heterogeneity and asymmetric effects in the conditional distribution of different stock market returns. The dependence degree between oil prices and stock returns and changes to it caused by breaks are not consistent across different percentiles.

## 5. Conclusions

The degree and structure of dependence between crude oil prices and stock markets is an attractive topic. Much research on this issue has been conducted in relation to the US and some developed European countries. However, few studies have explored developing countries, especially in the Asia-Pacific region. Crude oil consumption in the Asia Pacific region accounted for 34.7% of total world consumption in 2015 and has been increasing yearly. Hence, we examine the extreme dependence between crude oil prices and stock returns in the Asia-Pacific.

In this paper, we employ the quantile regression model with multiple structural breaks to study the dependence between oil prices and stock returns in Asia-Pacific regions from January 4th, 2000 to July 4th, 2016. Our findings show the asymmetric and heterogeneous dependence between the two financial variables, which suggests that investors and decision makers should take different measures in response to different economic conditions. The dependence degree between stock returns and oil prices is significantly increased after a break, and therefore we argue that investors should regard oil prices as an investment signal, especially during a crisis period, because of the strong dependence between the stock indices and oil prices. Our results indicate that the extreme dependence between crude oil prices and stock returns is positive in the lower tail. That is to say, an increase in crude oil prices would cause stock returns to increase during a recession. This positive relationship can help investors to adjust the structure of their investment portfolios when the market changes. Specifically, if the oil price is rising, investors should increase the ratio of their investments in Asia-Pacific stock markets during a down economy. On the opposite side, it is suggested that investors hold a smaller ratio of assets in stocks when the oil price is declining. Because of the strong dependence that exists on the downside, measuring the dependence has significant implications for policymakers, risk managers and investors.

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