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# The crude oil market and the gold market: Evidence from cointegration, causality and price discovery

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## Abstract:

Given that the gold market and the crude oil market are the main representatives of the large commodity markets, it is of crucial practical significance to analyze their cointegration relationship and causality, and investigate their respective contribution, from the perspective of price discovery, to the common price trend so as to interpret the dynamics of the whole large commodity market and forecast the fluctuation of crude oil and gold prices.

Empirical analysis indicates that, firstly, there are consistent trends between the crude oil price and the gold price with significant positive correlation coefficient 0.9295 during the sampling period, from January of 2000 to March of 2008. Secondly, there can be seen a long-term equilibrium between the two markets, and the crude oil price change linearly Granger causes the volatility of gold price, but not vice versa; moreover, the two market prices do not face a significant nonlinear Granger causality, which overall suggests their fairly direct interactive mechanism. Finally, with regard to the common effective price between the two markets, the contribution of the crude oil price seems larger than that of the gold price, whether with the Permanent Transitory (PT) model (86.50% versus 13.50%) or the Information Share (IS) model (50.28% versus 49.72%), which implies that the influence of crude oil on global economic development proves more far-reaching and extensive, and its role in the large commodity markets has attracted more attention in recent years.

**Keywords:** Crude oil market; Gold market; Granger causality; Permanent Transitory model; Information Share model; Price discovery

## Introduction

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In recent years, the prices of crude oil and gold, as the two main representatives of the large commodity markets, were not completely driven by the basic market supply-demand considerations any more. In fact, a great amount of evidence has suggested the financial features of the international crude oil and gold markets, and a close interaction between the two markets. Consequently, from the evolving path of the two markets these years, we might see that they basically maintained a neighboring trend.

For instance, in 2002, caused by US dollar depreciation, global inflation, oil supply manipulation by the OPEC and some sensational geopolitical events, both the crude oil and gold prices entered into a boom time, and started to soar approximately at the same time, and kept a almost consistent surging momentum till the first half of 2008.

In the second half of 2008, due to the serious global financial and economic crisis, the large commodity markets basically faced an austere test. As a result, the crude oil price continually declined from 147 \$ per barrel to nearly 30 at the end of 2008; at the same time, the gold also saw a sharp price collapse from over 1000 \$ per ounce to 700 or so. However, ever since 2009, with the emergence of global economic recovery expectation, the large commodity market demand began to rise again and both the crude oil and gold prices changed their staggering tumble trends and started a new surging stage.

This paper aims to shed light upon the reasons for the consistent changes of the two prices, as well as the interactive mechanism of them. It should be noted that discussion on these topics is of crucial importance for risk managers so as to resist the large commodity market risk and forecast market dynamics in the future.

Additionally, as we know, price is a concentrated carrier of market information and price fluctuations can often reflect the comprehensive change of market information. According to Stock and Watson (1988), market information is comprised of two parts, effective information and noisy information. Therefore, the real market price can be divided into two parts, effective price and noisy price. In this paper, the common effective price of the crude oil and gold markets embodies the common effective information between the two markets, which can be viewed as an important reference of the overall trend of the large commodity markets, due to the dominant positions of crude oil and gold in the large commodity markets. However, the contribution of the two markets to the common effective price may be different, and the goal of price discovery research is to examine their respective contribution. In terms of not only the outstanding trading volume and value, but also evident market influence and attraction among investors, the crude oil and the gold play the main roles in the large commodity markets, hence it is fairly important for related market consultants and investors to conduct an investigation of price cointegration relationship, lead-and-lag

relationship between the two markets and the contribution of them to price discovery.

The rest of the paper is organized as follows. The next section briefly summarizes the existing literature related with the topics in this paper. Section “Methodology” presents the empirical methodologies and data definition section follows. Then, section “Empirical results and discussions” provides the empirical study and policy implications of this paper, which mainly includes three parts, i.e. the long-term equilibrium and short-term adjustment between the crude oil and gold markets, the analysis of price information spillover across the two markets, and the analysis of contribution to price discovery between the two markets. Finally, some concluding remarks are put forward in the last section.

## **Literature review**

Gold has been an important precious metal for many centuries, and plays a special role as a store of value especially in times with political and economic uncertainties (Aggarwal et al., 2007). Hence, compared with other metals in the large commodity market, gold registers an evident advantage and outstanding position. In recent years, because of the nice profit-making situation and remarkable risk-avoidance feature, gold market has seen a very active picture. As a result, the role of gold market in the large commodity market even in the whole social economy has received increasing attention by both academia and industrial cycles, and research concerned also can be found emerging. For instance, Xu et al. (2005) used a bivariate asymmetric GARCH model to examine the information flow across the US and Japan markets for gold, platinum and silver futures contracts, and found that the volatility spillover across the two markets was strong but US market played the leading role. Sjaastad et al. (1996) and Sjaastad (2008) studied the relationship between gold price and euro and US \$ exchange rate respectively, and argued that in terms of exchange rate, in the 1980s, gold price was dominated by euros but as of the 1990s, US \$ gradually replaced the position of euros before. Tully et al. (2007) developed an APGARCH model to investigate the shocks of macroeconomy to gold spot and futures markets and also found that US \$ was a major macroeconomic variable to influence the gold price volatility. And Nakamura et al. (2007) pointed out that both daily gold price and crude oil price data were essentially random walk, and their first differences were independently distributed random variables or time-varying random variables. It should also be noted that research on crude oil price is a hot topic and a great many of publications concerned have been found up to now (Zhang et al., 2008).

Overall, an array of research on the price dynamics in crude oil market and gold market respectively has

been identified and historical data indicated that their price movement proved highly related, but research on the interaction of the two markets appears still scarce now (Yang, 2007; Zhang, 2007), and even some key topics have not been discussed by existing literature. For example, whether there is strong influence between the crude oil and gold markets, what the influential extent may be and what their relative positions may stay in the large commodity market etc. However, these topics are of crucial practical significance for further recognizing the features of commodity markets and forecasting their price volatility. Therefore, more careful investigation should be carried out. For this purpose, this paper aims to explore the interaction between the two markets from three perspectives, price cointegration, price causality and price discovery.

As for the price cointegration discussion, the cointegration theory and error correction model provided by Engle and Granger (1987) are applied here. And then this paper attempts to quantitatively study the lead-and-lag relationship between the crude oil price and the gold price. For this topic, it has been universally acknowledged that one of the main methods should be Granger causality test approach, especially the linear Granger causality test (Yang, 2000; Jiao et al., 2004; Jiao et al., 2005; Tang, 2008; Erdal et al., 2008; Bekiros et al., 2008; Henriques et al., 2008; Zhang et al., 2008;).

Nevertheless, the interaction among economic variables tends to show some complexity, and nonlinear characteristics can be found pervasive. Since Baek and Brock (1992), Hiemstra and Jones (1994) put forward the nonlinear Granger causality test approach, many authors have found it favorable and used it in many fields. For instance, Wang and Wu (2005) used this approach to empirically study the nonlinear causality between stock price and volume in Chinese Shanghai stock exchange and Shenzhen stock exchange. Fang et al. (2006) made an empirical study on the relationship between Chinese stock markets and warrant markets with the help of this approach. Ma and Kanas (2000) discussed the interaction between exchange rate and macroeconomic variables. Rashid (2007) evaluated the linear and nonlinear Granger causality between stock price and volume in Pakistan. Chiou-Wei et al. (2008) empirically researched the causality between economic growth and energy consumption. Despite so much literature about the nonlinear Granger causality approach application, there are few publications in an attempt to investigate the nonlinear lead-and-lag relationship between the crude oil and gold markets. However, the previous applications of nonlinear causality test indeed provide favorable references for the study here.

Besides, as far as the price discovery issue, there has been a large amount of literature up to now, and most of them were focused on two aspects. One was based on the securities of the same asset which is listed in different exchanges, and the other concentrated on the price discovery between derivative products and their corresponding subject matters in the same market. As for the empirical research methodologies of

price discovery, the permanent transitory (PT) model (Gonzalo, Granger, 1995) and information share (IS) model (Hasbrouck, 1995) were often used, whose difference told the PT model emphasizes the decomposition of the common factor (i.e. permanent impact), while the IS model distributed error terms into different markets. For example, Harris et al. (1995) studied the price discovery of the IBM corporation stock in three exchanges which located in New York, Pacific region and Middle East, and results showed that there could be found close relationship among different markets, which commonly determined the price of IBM stock. Wang and Zhang (2005) investigated the price discovery function of crude oil futures market and found that, compared with crude oil spot market, the futures took the main contribution with the rate 54%. Ates and Wang (2005) analyzed the contribution of traditional index futures trading and electronic trading to futures price discovery, and found that the contribution of electronic trading outweighed that of traditional trading. Su and Chong (2007) discussed the price discovery of some Chinese stocks which were listed in the New York NYSE and Hong Kong SEHK simultaneously, and results indicated that some cointegration relationship could be identified and Hong Kong stock price might explain more information than New York price. Li (2007) analyzed the price discovery mechanism among Shanghai stock index, H stock index and H stock index futures. Jiao and Liao (2008) investigated the price discovery relationship between the Chinese Huangpu fuel spot price and Shanghai fuel futures price. It also should be noted that, besides the PT and IS models, Moosa (2002) still used the G-S model to examine the price discovery topic in the crude oil market, and argued that the contribution of crude oil futures price appeared larger than that of spot price. However, no literature has been found to study the price discovery mechanism between the crude oil and gold markets. Anyway, these previous applications presented helpful references for our research here.

To sum up, it should be noted that existing research related with the crude oil and gold prices has some shortcomings in at least three folds. Firstly, given two typical large commodity markets with similar price trends, whether there is statistical evidence showing long equilibrium relationship between the two markets. Secondly, how about the price lead-and-lag relationship between the two markets? Put it another way, whether there exists a situation that one market leads or lags another market, and whether their relationship takes on linear or nonlinear feature. Finally, although an array of studies on the two markets respectively can be identified, study on the interaction between the two markets especially their price discovery mechanism appears scarce. Overall, it is of great practical significance for market dynamics forecasting to overcome these shortcomings above. Therefore, three folds of corresponding contribution can be found in this paper.

## Methodology

It is of great importance for not only the crude oil market and gold market dynamic analysis but also for the whole large commodity market forecast to test whether there exists a lead-and-lag price mechanism between the crude oil price and gold price. For this purpose, a cointegration test is investigated at first, and then both linear and nonlinear Granger causality test approaches are used here so as to fully examine the price information transfer mechanism. Additionally, the PT and IS models are applied in order to find out the respective contribution of the two markets for their common price.

### *Cointegration test approach between the crude oil market and the gold market*

In theory, the cointegration relationship indicates that neither market prices is stationary, but there does exist some long equilibrium interaction relationship between the two markets. As for the crude oil and gold price, we may see that neither of them follows a stationary dynamic, but whether there is long equilibrium relationship between them should be further studied.

To this end, we introduce the two-step procedure provided by Engle and Granger (1987) to check the cointegration between oil price and gold price. And the cointegration equation is established as (1).

$$\begin{aligned} P_t^O &= \omega_1 + \delta_1 * P_t^G + \varphi_{1t}, \\ P_t^G &= \omega_2 + \delta_2 * P_t^O + \varphi_{2t}. \end{aligned} \quad (1)$$

where  $P_t^O$  and  $P_t^G$  denote the logarithmic crude oil price and gold price respectively, and both  $\varphi_1$  and  $\varphi_2$  are residuals. If ADF test for  $\varphi_1$  or  $\varphi_2$  indicates that they are stationary, then we may say there is cointegration relationship between the crude oil price and gold price.

### *Linear Granger causality test procedure between the crude oil market and the gold market*

Firstly, linear Granger causality relationship between the two markets is tested. Based on the stationary market returns, a VAR model is developed as Equation (2).



$$R\_OIL_t = \pi_{10} + \sum_{i=1}^p \pi_{11i} R\_OIL_{t-i} + \sum_{j=1}^p \pi_{12j} R\_GOLD_{t-j} + \varepsilon_{1t},$$

$$R\_GOLD_t = \pi_{20} + \sum_{i=1}^p \pi_{21i} R\_GOLD_{t-i} + \sum_{j=1}^p \pi_{22j} R\_OIL_{t-j} + \varepsilon_{2t}, \quad (2)$$

where  $R\_OIL$  stands for the oil price return, and  $R\_GOLD$  denotes the gold price return. Then a hypothesis test can be done for the first equation in Equation (2), in which the null hypothesis is  $\pi_{12j} = 0$  ( $j = 1, 2, \dots, p$ ). When the null hypothesis is rejected, then it can be argued that the change of gold price return linearly Granger causes the volatility of international crude oil price return; similarly, we also can test whether the change of crude oil price return linearly Granger causes the change of gold price return. In Equation (2),  $p$  represents the largest lag order, which is obtained according to the principle of minimum AIC value.

### ***Nonlinear Granger causality test procedure between the crude oil market and the gold market***

The complexity of energy economic system determines that the relationship among economic variables usually does not take simple linear causality but nonlinear causality can be seen extensively. In this way, based on the residual series removed linear predictive power with a linear VAR model like Equation (2), the nonlinear Granger causality approach provided by Baek and Brock (1992) and Hiemstra and Jones (1994) is employed here to investigate the interaction between the crude oil market and the gold market. The specific idea of the approach can be briefly summarized as follows.

Suppose  $X$  and  $Y$  denote the residual series from Equation (2) respectively, where  $X$  stands for the residual series when the crude oil price return acts as the dependent variable (i.e.  $\varepsilon_1$ ), and  $Y$  implies the residual series when the gold price return is the dependent variable (i.e.  $\varepsilon_2$ ). And suppose

$$X_t^m = (X_t, X_{t+1}, \dots, X_{t+m-1}), \quad m = 1, 2, \dots, \quad t = 1, 2, \dots$$

$$X_{t-L_x}^{L_x} = (X_{t-L_x}, X_{t-L_x+1}, \dots, X_{t-1}), \quad L_x = 1, 2, \dots, \quad t = L_x + 1, L_x + 2, \dots$$

$$Y_{t-L_y}^{L_y} = (Y_{t-L_y}, Y_{t-L_y+1}, \dots, Y_{t-1}), \quad L_y = 1, 2, \dots, \quad t = L_y + 1, L_y + 2, \dots \quad (3)$$

If  $\Pr(\|X_t^m - X_s^m\| < e \mid \|X_{t-L_x}^{L_x} - X_{s-L_x}^{L_x}\| < e, \|Y_{t-L_y}^{L_y} - Y_{s-L_y}^{L_y}\| < e)$

$$= \Pr(\|X_t^m - X_s^m\| < e \mid \|X_{t-L_x}^{L_x} - X_{s-L_x}^{L_x}\| < e) \text{ holds,} \quad (4)$$

then we may say  $Y$  does not nonlinearly Granger cause  $X$ . Moreover, if suppose

$$\begin{aligned} C_1(m+L_x, L_y, e) &= \Pr(\|X_{t-L_x}^{m+L_x} - X_{s-L_x}^{m+L_x}\| < e, \|Y_{t-L_y}^{L_y} - Y_{s-L_y}^{L_y}\| < e), \\ C_2(L_x, L_y, e) &= \Pr(\|X_{t-L_x}^{L_x} - X_{s-L_x}^{L_x}\| < e, \|Y_{t-L_y}^{L_y} - Y_{s-L_y}^{L_y}\| < e), \\ C_3(m+L_x, e) &= \Pr(\|X_{t-L_x}^{m+L_x} - X_{s-L_x}^{m+L_x}\| < e), \\ C_4(L_x, e) &= \Pr(\|X_{t-L_x}^{L_x} - X_{s-L_x}^{L_x}\| < e), \end{aligned} \quad (5)$$

then according to the definition of conditional probability, i.e.  $\Pr(E|F) = \Pr(EF)/\Pr(F)$ , Equation (4)

can be rewritten as

$$\frac{C_1(m+L_x, L_y, e)}{C_2(L_x, L_y, e)} = \frac{C_3(m+L_x, e)}{C_4(L_x, e)}. \quad (6)$$

Furthermore, Correlation Integral<sup>1</sup> is introduced to express the joint probability as Equation (7).

$$\begin{aligned} C_1(m+L_x, L_y, e, n) &= \frac{2}{n(n-1)} \sum \sum_{t < s} I(X_{t-L_x}^{m+L_x}, X_{s-L_x}^{m+L_x}, e) \bullet I(Y_{t-L_y}^{L_y}, Y_{s-L_y}^{L_y}, e), \\ C_2(L_x, L_y, e, n) &= \frac{2}{n(n-1)} \sum \sum_{t < s} I(X_{t-L_x}^{L_x}, X_{s-L_x}^{L_x}, e) \bullet I(Y_{t-L_y}^{L_y}, Y_{s-L_y}^{L_y}, e), \\ C_3(m+L_x, e, n) &= \frac{2}{n(n-1)} \sum \sum_{t < s} I(X_{t-L_x}^{m+L_x}, X_{s-L_x}^{m+L_x}, e), \\ C_4(L_x, e, n) &= \frac{2}{n(n-1)} \sum \sum_{t < s} I(X_{t-L_x}^{L_x}, X_{s-L_x}^{L_x}, e), \end{aligned} \quad (7)$$

where  $t, s = \max(L_x, L_y) + 1, \dots, T - m + 1$ ,  $n = T - \max(L_x, L_y) - m + 1$ .  $I(X, Y, e)$  is a kernel-based function, and its value is 1 when the maximum norm of vector  $X$  and  $Y$  proves within the given parameter  $e$ , otherwise 0.

Given  $m, L_x, L_y \geq 1$ ,  $e > 0$ , and stationary and dependent residual series  $X$  and  $Y$ , if Equation (8) holds, which means the statistic  $W$  follows the asymptotical normal distribution, then we may say the change of  $Y$  does not nonlinearly Granger cause the change of  $X$ .

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<sup>1</sup> Briefly, Correlation Integral  $C(e)$  is defined as the rate of the number of pairs of points  $(X_i, X_j)$  whose distance is within  $e$  to the number of all possible pairs of points for the vector, given any  $e$ .

$$W = \sqrt{n} \left[ \frac{C_1(m + L_x, L_y, e)}{C_2(L_x, L_y, e)} - \frac{C_3(m + L_x, e)}{C_4(L_x, e)} \right]^a \sim N(0, \sigma^2(m, L_x, L_y, e)) \quad (8)$$

### ***PT-IS models for price discovery between the crude oil market and the gold market***

In this paper, the PT and IS models are used in order to explore the price discovery issue. Specifically, the IS model is based on the PT model while the PT model is based on the vector error correction model (VECM). Suppose  $P_t^O$  and  $P_t^G$  denote the logarithmic crude oil price and gold price respectively. If there can be ascertained cointegration relationship between them, according to Engle and Granger (1987), a vector error correction model can be specified as:

$$\Delta P_t = \alpha * \beta' P_{t-1} + \sum_{i=1}^q A_i \Delta P_{t-i} + \zeta_t, \quad (9)$$

where  $P_t = (P_t^O, P_t^G)'$  is the price vector,  $\alpha = (\alpha_1, \alpha_2)'$  is the error correction coefficient vector,  $\beta$  is the cointegrating coefficient vector, and  $\zeta_t = (\zeta_{1t}, \zeta_{2t})'$  refers to the random error term with  $\zeta_{1t} \sim N(0, \sigma_1)$  and  $\zeta_{2t} \sim N(0, \sigma_2)$ . It should be pointed out that there is no autocorrelation feature with respect to the two error terms and their covariance matrix is stated as:

$$\Omega = \begin{pmatrix} \sigma_1^2 & \rho \sigma_1 \sigma_2 \\ \rho \sigma_1 \sigma_2 & \sigma_2^2 \end{pmatrix}, \quad (10)$$

where  $\sigma_1^2$  and  $\sigma_2^2$  are the variance of  $\zeta_{1t}$  and  $\zeta_{2t}$  series respectively, and  $\rho$  is their correlation coefficient.

Based on the historical trading data of the two typical commodities, there exist a clear common trend between the crude oil price and the gold price. According to Stock and Watson (1988) and Su and Chong (2007), the price vector  $P_t$  may be divided into two parts, the common effective price (i.e. common factor) of the two markets and noisy price of each market. This means:

$$P_t = f_t + \mu_t, \quad (11)$$

where  $f_t$  is the common effective price, which denotes the common changing trend of crude oil market and gold market, and  $\mu_t = (\mu_{1t}, \mu_{2t})'$  is the noisy price vector, which means the specific change of each

market. Hence,  $P_t^O = f_t + \mu_{1t}$  and  $P_t^G = f_t + \mu_{2t}$  can be specified.

According to Gonzalo and Granger (1995), here the common factor  $f_t$  may be defined as a linear combination of  $P_t^O$  and  $P_t^G$ , i.e.  $f_t = \gamma_1 P_t^O + \gamma_2 P_t^G$ ; put it another way, the common factor can be viewed as a portfolio consisting of the crude oil price and the gold price. And  $\Gamma = (\gamma_1, \gamma_2)$  denotes the coefficient vector of common factor, which can be considered as the weights of crude oil price and gold price in the portfolio, and  $\gamma_1 + \gamma_2 = 1$ . As proved by Gonzalo and Granger (1995), the vector  $\Gamma$  is orthogonal to vector  $\alpha$  of the error correct model, which implies that  $\alpha_1 \gamma_1 + \alpha_2 \gamma_2 = 0$ . Therefore,  $\gamma_1$  and  $\gamma_2$ , which stand for the contribution of the two markets to price discovery, can be worked out using the two equations above. This process is the main idea of the PT model, which stresses the decomposition of common factor (i.e. permanent influence).

Based on the results above, the IS model (Hasbrouck, 1995) can be developed so as to find out the contribution of the crude oil price and the gold price to price discovery. Different from the PT model, the IS model emphasizes the variance decomposition of innovations to the common factor and defines the price discovery in terms of the contribution of each market to the variance.

According to Baillie et al. (2002), when there does not exist significant correlation between the two residual terms arising from the cointegration regression equations for the crude oil price and gold price, the IS model can be specified as:

$$IS_i = \frac{\gamma_i^2 \sigma_i^2}{\gamma_1^2 \sigma_1^2 + \gamma_2^2 \sigma_2^2}, \quad i = 1, 2. \quad (12)$$

But when the two error terms are highly correlated, Equation (12) does not hold. In this way, Cholesky factorization method is used to transform the covariance of error terms of the vector error correction model as  $\Omega = MM'$ , where

$$M = \begin{pmatrix} m_{11} & 0 \\ m_{21} & m_{22} \end{pmatrix} = \begin{pmatrix} \sigma_1 & 0 \\ \rho \sigma_2 & \sigma_2 (1 - \rho^2)^{1/2} \end{pmatrix}. \quad (13)$$

As a result, the IS model can be figured out as Equation (14), and we can see  $IS_1 + IS_2 = 1$ .

$$IS_1 = \frac{(\gamma_1 m_{11} + \gamma_2 m_{21})^2}{(\gamma_1 m_{11} + \gamma_2 m_{21})^2 + (\gamma_2 m_{22})^2},$$

$$IS_2 = \frac{(\gamma_2 m_{22})^2}{(\gamma_1 m_{11} + \gamma_2 m_{21})^2 + (\gamma_2 m_{22})^2} \quad (14)$$

It should be noted that, Cholesky factorization method imposes a greater information share on the first market in the equation; therefore, it needs to change the order of variables in the factorization procedure so as to get the upper and lower limits of their information shares. For example, when the crude oil price works as the first variable, then the calculated information share is its upper limit, whereas it lies as the second variable, then corresponding information share should be its lower limit. As presented by Baillie et al. (2002), the average of upper and lower limits for each variable here can be a reasonable estimate of its contribution to price discovery.

## Data definition

In this paper, we use daily data from January 4<sup>th</sup> 2000 to March 31<sup>st</sup> 2008, with total 2064 price samples and their trends in Figure 1. The crude oil price data are derived using Brent spot price from the US Energy Information Agency (EIA) and quoted in US dollars per barrel, while the gold price data come from the Global Insight and are based on the London PM fix, which are also spot price and quoted in US dollars per ounce. Roughly, it can be seen that the two markets take very consistent price trends even though there exists some inconsistent volatility in some short periods. And our calculation results show that the two prices are highly correlated with the correlation coefficient 0.9295 in the sampling period, which indicates that they do take some common information.

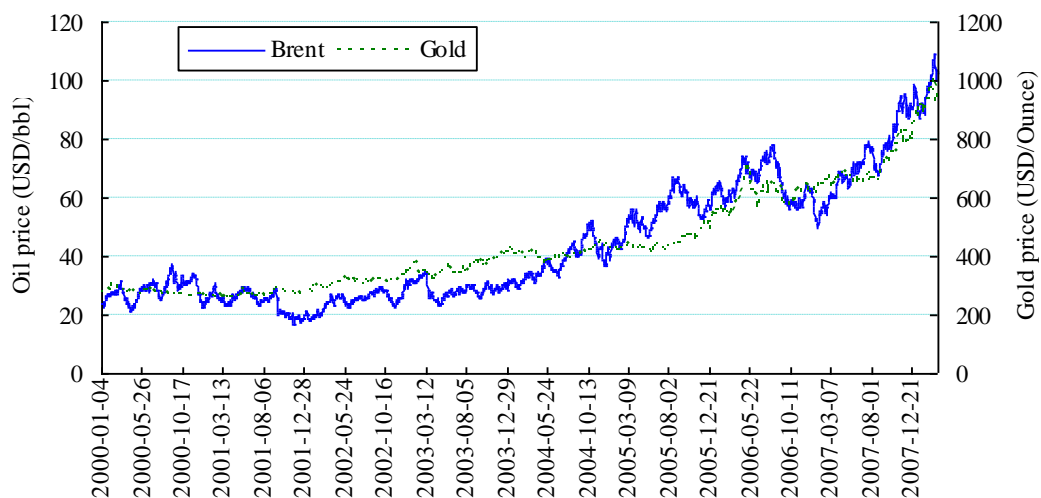

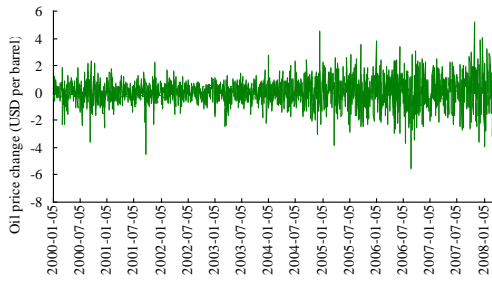


Fig. 1. Crude oil price and gold price.

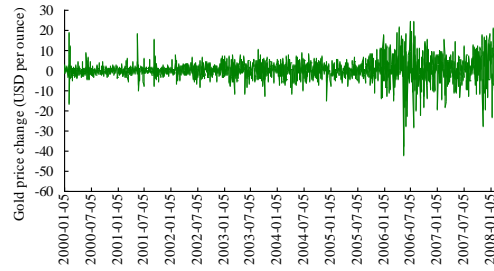
The research in this paper mainly comprises three parts, price cointegration, causality and price discovery. As for the data, the empirical research about linear and nonlinear causality between the crude oil and gold markets is based on price returns (logarithmic difference of original price series) multiplied by 100, in which  $R\_OIL_t$  and  $R\_GOLD_t$  stand for the crude oil and the gold price return at time  $t$  respectively. And the price cointegration and price discovery research use the logarithmic values of original price series; specifically,  $P_t^O$  and  denote logarithmic crude oil price and gold price at time  $t$  respectively.

In order to derive a general image of the crude oil price and gold price, we further calculate the frequency distribution and basic statistics of logarithmic crude oil and gold prices, and find that neither of oil price and gold price follows a normal distribution because of their significant JB statistics at 1% level, right kurtoses and positive skewnesses.

Additionally, the volatility magnitude of the crude oil price appears about 2 times larger than that of the gold price, which is validated from the coefficients of variances (CV in brief, i.e. the sample mean divided by the sample standard deviation) during the sampling period. The CV of crude oil price is 0.1230 while that of gold price is 0.0587, which is less than a half of the former. Moreover, if the whole sampling period is divided into two segments, i.e. 2000.1-2003.12 and 2004.1-2008.3, then we may find that after 2004, both the crude oil market and gold market have more dramatic volatility (see Figure 2 for the first difference of the crude oil price and gold price series); specifically, both the coefficients of variances for the crude oil price and the gold price have increased about 100%. As for the reasons behind, we argue that after 2004, a large sum of international speculating money especially some huge index funds has been fast swarming into the crude oil futures market and the gold market for profit-making and risk-avoidance. And their fast-growing scale and frequent speculating activities caused both the crude oil market and gold market witnessed continual sharp fluctuations and market risk soared rapidly.



(a) Crude oil price



(b) Gold price

Fig. 2. First differences of the crude oil price and gold price.

## Empirical results and discussions



The empirical results are reported from three parts, i.e. the long-term equilibrium and short-term adjustment, the price information spillover and the contribution to price discovery between the crude oil market and the gold market.

### *Long-term equilibrium and short-term adjustment between the crude oil market and the gold market*

Before we test the long equilibrium, according to the cointegration theory, stationary properties of price series should be examined. ADF approach is used and results are shown in Table 1. We may find that from the p values, at 1% level, both of the crude oil price and the gold price are I(1) series, which are up to the preconditions of cointegration relationship test.

Table 1

T statistic values of ADF test for the crude oil price and the gold price

		
Level price series	-2.6567 (0.2551)	-2.3185 (0.4231)
First-order difference price series	-45.0919 (0.0001)	-45.1876 (0.0001)

Note: p-values are reported in parentheses.

Because the crude oil price  $P_t^O$  and the gold price  $P_t^G$  are I(1) series, according to Equation (1), the cointegration test results can be seen from Table 2, which indicate that both the variables and equations are significant at 1% level, and both residual series  $\hat{e}_t^O$  and  $\hat{e}_t^G$  are stationary, hence we may say there exists a significant cointegration relationship between the crude oil price and gold price. Put it another way, they have long-term equilibrium interaction for each other.

Table 2

Cointegration results of the crude oil price and the gold price

Dependent variables	$\omega$	$\delta$	F statistic	T statistic of ADF test for $\rho$
$P_t^O$	-3.4793 (0.0000)	1.1894 (0.0000)	13098.34 (0.0000)	-45.8011 (0.0001)
$P_t^G$	3.3452 (0.0000)	0.7264 (0.0000)	13098.34 (0.0000)	-45.7372 (0.0001)

Note: *p*-values are reported in parentheses.

As for the reasons for the cointegration relationship between the crude oil market and gold market, in our opinions, this arises from the fact that both markets are influenced by several similar even the same contributing factors.

Firstly, both of international crude oil and gold trading are quoted and invoiced in US dollars, as a result, the volatility of US dollars tends to cause the fluctuations of the crude oil price and the gold price to the same direction. For instance, the US \$ continuous depreciation in the sampling period has become an important force to commonly support the volatile boost of the crude oil price and gold price. Based on the Nominal Broad US Dollar Index<sup>2</sup> and simple calculation, we find that the correlation coefficient between the US dollar exchange rate and the crude oil price is -0.9071, while that between the US dollar exchange rate and the gold price appears -0.9070 in the sampling period, which suggests the high correlations between the US dollar exchange rate and the two prices. Furthermore, we find that the US dollar index may

<sup>2</sup> The broad index is a weighted average of the foreign exchange values of the U.S. dollar against the currencies of a large group of major U.S. trading partners. The index weights, which change over time, are derived from U.S. export shares and from U.S. and foreign import shares. For details on the construction of the weights, see the article in the Winter 2005 Federal Reserve Bulletin.



Granger cause the change of both the crude oil price and the gold price. Quantitatively, we find that when the US dollar index depreciates 1%, on average, the crude oil price and gold price may increase 5.6% and 4.4% respectively.

Secondly, generally, the high crude oil price aggravates the inflation, while the gold has an excellent nature to resist inflation and maintain its value so as to become an effective tool to hedge inflation, hence high inflation causes the surge of gold investment demand and thus steps up the gold price.

Thirdly, dominant crude oil exporting countries make use of high oil revenue and increase gold investment so as to cause their volatility to the same direction. After their oil revenue fast expands, they buy a large amount of gold in order to disperse market risk and maintain commodity value, as a result, the gold market investment appears enhanced and gold price sees an ascending.

Last but not the least, the crude oil price and the gold price are influenced by some geopolitical events simultaneously. Actually, both the crude oil market and the gold market are very sensitive to the turmoil of international political situation, and as soon as the geopolitical deterioration occurs, citizens often rush to buy gold like the sheep-flock effect in the financial market; consequently, the gold price sees a skyrocketing. Moreover, some key international political events directly influence the global economy and the US dollar exchange rate thus stimulate the gold price. Meanwhile, in the sampling period, many key events tended to have a bearing with the crude oil, which consequently affected the regular production and supply of crude oil thus raised the crude oil price.

Besides the long-term equilibrium across the crude oil market and the gold market, based on Equation (9), we further introduce the error correction model (Granger, 1988) to study the short-term interaction across the two markets. And estimated results can be seen in Table 3.

Table 3

Estimated results of the error correction model

	Dependent: D_GOLD		Dependent: D_OIL	
	Coefficient	P value	Coefficient	P value
C	0.0005	0.0186	0.0005	0.3111
D_OIL	0.0724	0.0000	—	—
D_OIL(-1)	0.0249	0.0103	0.0064	0.7716
D_OIL(-2)	-0.0043	0.6568	0.0275	0.2137
D_GOLD	—	—	0.3747	0.0000
D_GOLD(-1)	-0.0010	0.9645	-0.0817	0.1031
D_GOLD(-2)	-0.0100	0.6495	0.0073	0.8840
<i>ecm</i> (-1)	-0.0024	0.0856	-0.0094	0.0020
F statistic and p value	10.9694(0.0000)		11.5435(0.0000)	
Adjusted R squared	0.0282		0.0298	

Note: C denotes the constant term. D\_OIL stands for the first difference of the oil price, while D\_OIL(-1) is the 1-order lagged series of D\_OIL, and other related series have similar implication. *Ecm* represents the error correction term.

Results in Table 3 tell that from the short-term perspective, the interaction across the crude oil market and the gold market appears strong in terms of their price change on the same day at 1% level, and the shock magnitude of the gold price to the crude oil price is about 5 times larger than that of the crude oil price to the gold price. Specifically, when the crude oil price changes 1%, the gold price changes 0.07% to the same direction; whereas the gold price changes 1%, the crude oil price changes 0.37%, which seems much stronger than the shock of the crude oil price to the gold price.

Furthermore, we may find some differences as for their interaction with 1-day lagged price series. At 5% level, the influence of 1-day lagged crude oil price change on the gold price proves significant but the 1-day lagged gold price change does not exert significant shock to the crude oil price. And neither of their influence in terms of 2-day lagged price series is significant statistically. Therefore, it should be noted that although the influence of the crude oil price change on the gold price is considered to be relatively smaller, it can last for a longer time; that is, 1 day. And the influence of gold price change on oil price is found much stronger, yet it can just continue for a shorter time, exactly, only on the same day.

Additionally, according to the value of *ecm* term in Table 3, it can be found that although the long-term equilibrium between the crude oil market and the gold market may significantly adjust the short-term

changes of the crude oil and the gold prices and cause that their short-term changes do not deviate from their long-term equilibrium path very far, the adjusting extent appears quite limited. Specifically, the adjusting extent to the crude oil price short-term change is -0.94%, which is about 4 times larger than that to the gold price change (-0.24%).

### ***Analysis of price information spillover across the crude oil market and the gold market***

In order to have a profound interpretation of the price dynamics of the crude oil and gold markets, it is essential to investigate the spillover effect between the crude oil market and gold market. And price or return information is the concentrated reflection of a market, so it should be attached great importance to examine the price or return lead-and-lag relationship between the two markets, to forecast the crude oil and gold prices and analyze the dynamics of the large commodity market. Therefore, linear and nonlinear Granger causality approaches are adopted here to check the price interaction between the two markets.

Because the VAR model, linear and nonlinear Granger causality test all require related time series be stationary, hence logarithmic crude oil and gold returns  $R\_OIL_t$  and  $R\_GOLD_t$  are used, both of which are significantly stationary at 1% level based on the ADF test results<sup>3</sup>.

#### ***(1) Linear causality between the crude oil market and the gold market***

Both the  $R\_OIL_t$  and  $R\_GOLD_t$  series are stationary, which comply with the precondition of the VAR models, so a VAR model like Equation (1) is developed, and according to the principle of minimum AIC value, the optimum lag order proves 1. And then linear Granger causality test is done whose detailed results are shown in Table 4. Meanwhile, we also carry out the linear Granger causality test with other lag orders in order to examine the robustness of the linear Granger causality between the two markets (see Table 4).

Table 4

Linear Granger causality test results

Null Hypothesis	Lag	F statistic	Probability
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<sup>3</sup> Detailed ADF test results can be obtained from the authors upon request.

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$R\_GOLD \not\rightarrow R\_OIL$		2.2828	0.1310
	1		
$R\_OIL \not\rightarrow R\_GOLD$		7.4642	0.0064
$R\_GOLD \not\rightarrow R\_OIL$		1.2456	0.2880
	2		
$R\_OIL \not\rightarrow R\_GOLD$		3.6859	0.0252
$R\_GOLD \not\rightarrow R\_OIL$		1.8693	0.1327
	3		
$R\_OIL \not\rightarrow R\_GOLD$		2.8311	0.0371
$R\_GOLD \not\rightarrow R\_OIL$		1.4920	0.2020
	4		
$R\_OIL \not\rightarrow R\_GOLD$		2.2415	0.0623

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*Note:*  $R\_OIL$  denotes the logarithmic crude oil price returns, and  $R\_GOLD$  denotes the logarithmic gold price returns, while  $\not\rightarrow$  means there does not exist linear Granger causality from the left market to the right market.

According to Table 4, it should be noted that no matter what lag orders are adopted, the test results prove very similar, that is, there exists a significant unilateral linear Granger causality between the crude oil market and the gold market. Specifically, in the sampling period, the crude oil price return change significantly linearly Granger causes the change of the gold price returns; put it another way, the crude oil price soaring causes the gold price moving to the same direction based on the fact that the two prices have very similar trends. However, the gold price return change does not significantly linearly Granger cause the volatility of the crude oil price returns.

To our knowledge, these results are closely related with the natural properties of the crude oil and the gold. Crude oil is an important raw material of industrial production and oil price skyrocketing tends to bring about some inflation. Different from the crude oil, the gold naturally plays a nice role in hedging inflation, which is rooted in gold's abilities to ensure against uncertainty and instability and protect against risk. In the sampling period, the international crude oil price broke through historic records time and time again, which augmented the attraction of gold for hedging inflation and spurred on a great deal of gold trading for resisting market risk; as a result, the gold price saw a fast soaring.

On the other hand, the dramatically surging crude oil price boosts the oil revenue of dominant oil exporting countries, i.e. oil dollars, which can be confirmed from Figure 3. Specifically, since the starting year 2002 of the crude oil price surge, oil export value relative to GDP of Middle East and North Africa has continuously risen, nearly up 59% from 2002 to 2005, which largely reflectes the increase of oil price (IMF,

2008); so in order to reduce the market risk and enrich investment variety, those countries tend to increase the gold investment demand, which leads to the gold price rise. According to a report of the World Gold Council, since 2002, gold investment in Middle East has shown a continuous rise; by the end of 2007, gold investment had increased about 50% compared with that in 2002. Especially in Saudi Arabia, its gold consumption had a year-on-year 15% strong growth in 2007, and its gold investment value reached 2.9 billion US dollars, which surpassed for the first time the previous value peak of 2.7 billion US dollars in 1997 (World Gold Council, 2008). So it can be seen those oil dollars from Middle East must be an important impetus to promote the gold investment demand and trigger the gold price soaring in a large scale these years.

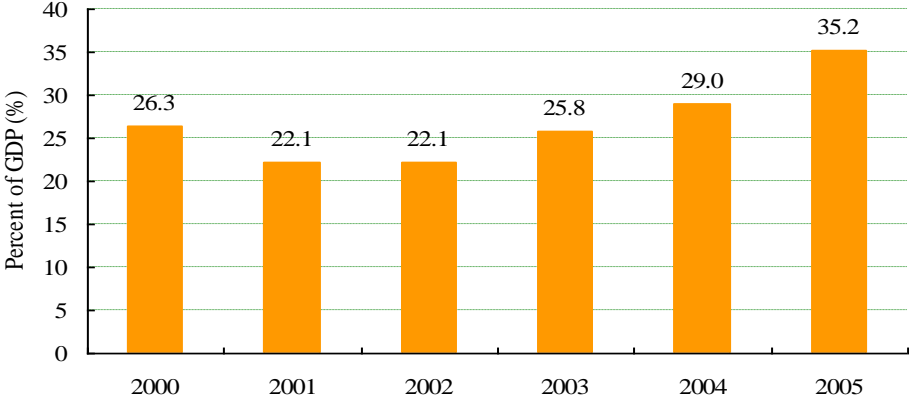


Fig. 3. Percent of the fuel export value to GDP in Middle East and North Africa.

**(2) Nonlinear causality between the crude oil market and the gold market**

Besides linear causality, there can often be identified complex nonlinear relationship among economic variables, which adds difficulties for recognizing and judging the market situation. Anyway, it is crucial for better appreciating the crude oil and the gold market dynamics to study whether there is some nonlinear relationship between the two prices. Therefore, based on the two residual series removed linear influence from a VAR model above, the nonlinear Granger causality approach provided by Baek and Brock (1992) and Hiemstra and Jones (1994) is used to investigate the nonlinear interaction between the two markets.

According to Hiemstra and Jones (1994), Chiou-Wei et al. (2008) and other authors, we specify  $H_0: \beta_1 = \beta_2 = \dots = \beta_p = 0$ ,

and  $H_0: \gamma_1 = \gamma_2 = \dots = \gamma_p = 0$ , and the results of nonlinear Granger causality test for the crude oil and

the gold markets can be seen from Table 5, which demonstrates that at 10% level, all null hypotheses can

not be rejected. Hence there does not exist significant nonlinear Granger causality between the crude oil market and the gold market in the sampling period.

To summarize the linear and nonlinear causality between the two markets, it should be noted that their interaction shows more linear features and appears relatively direct, concise and swift but not very complicated.

Table 5

## Nonlinear Granger causality test results

Null Hypothesis	Lx=Ly	W statistic	Probability
$Y \not\rightarrow X$	1	-0.0446	0.5178
$X \not\rightarrow Y$		-0.1435	0.5570
$Y \not\rightarrow X$	2	-0.1121	0.5446
$X \not\rightarrow Y$		-0.2266	0.5896
$Y \not\rightarrow X$	3	-0.1901	0.5754
$X \not\rightarrow Y$		-0.2894	0.6139
$Y \not\rightarrow X$	4	-0.2610	0.6030
$X \not\rightarrow Y$		-0.4803	0.6845
$Y \not\rightarrow X$	5	-0.4814	0.6849
$X \not\rightarrow Y$		-0.5008	0.6918
$Y \not\rightarrow X$	6	-0.7372	0.7695
$X \not\rightarrow Y$		-0.4548	0.6754
$Y \not\rightarrow X$	7	-1.0542	0.8541
$X \not\rightarrow Y$		-0.7925	0.7860
$Y \not\rightarrow X$	8	-1.9524	0.9746
$X \not\rightarrow Y$		-1.9506	0.9744

Note:  $X$  denotes the residual series when the oil price return acts as the dependent variable in the VAR model, and  $Y$  denotes the residual series when the gold price return acts as the dependent variable in the VAR model, while  $\not\rightarrow$  means there does not exist nonlinear Granger causality from the left market to the right market. And W statistic is the statistic in Equation (8).

### *Analysis of the contribution to price discovery between the crude oil market and the gold market*

As stated above, the crude oil and gold are supposed to be the representatives of the large commodity

markets, and their price movement basically can reflect and guide the price trends of the whole large commodity market. In this way, quantitatively investigating their contribution to price discovery helps to judge the influence extent of the crude oil market and the gold market respectively, which may provide some reference information for forecasting the crude oil price, the gold price and the movement of the whole large commodity market, such as the CRB index.

Due to the cointegration relationship between the crude oil price and the gold price, a vector error correction model can be developed as Equation (15).

$$\Delta P_t^O = \eta_1 + \sum_{i=1}^q \phi_{1i} * \Delta P_{t-i}^O + \sum_{i=1}^q \theta_{1i} * \Delta P_{t-i}^G + \alpha_1 * vecm_{1(t-1)} + \zeta_{1t},$$

$$\Delta P_t^G = \eta_2 + \sum_{i=1}^q \phi_{2i} * \Delta P_{t-i}^G + \sum_{i=1}^q \theta_{2i} * \Delta P_{t-i}^O + \alpha_2 * vecm_{2(t-1)} + \zeta_{2t}. \quad (15)$$

From the regression equations above, the vector error correction coefficient  $\alpha = (\alpha_1, \alpha_2)'$  can be attained (see Table 6). And then according to the PT model, a joint equation group is established to figure out  $\alpha_1$  and  $\alpha_2$ . Furthermore, the common factor of the crude oil market and gold market can be gotten through the equation  $\alpha_1 P_t^O + \alpha_2 P_t^G$  (see Figure 4), from which it can be roughly seen that the crude oil price accounts for a larger part in the common factor, i.e. the common effective price.

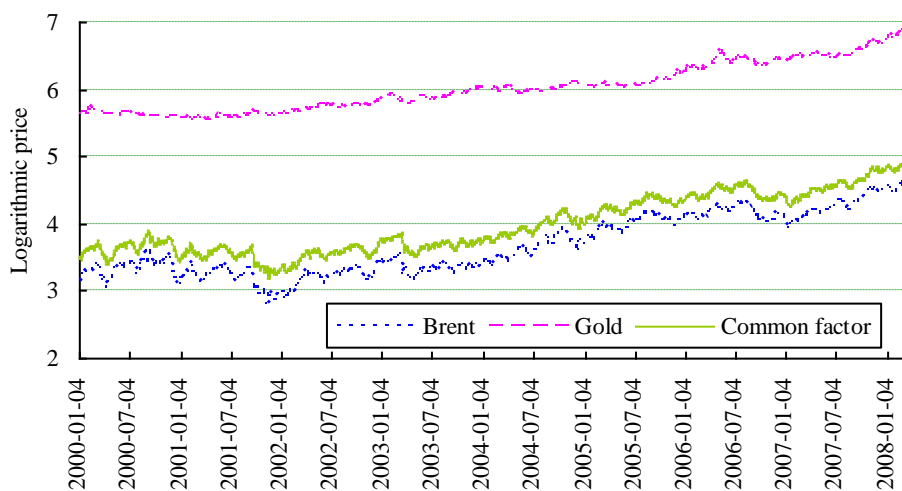


Fig. 4. Oil price, gold price and their common effective price.



Then based on the Equation (14) of the IS model, information share coefficients can be obtained (see Table 6). From the estimated results, it can be noted that as for the price discovery using the PT model and the IS model, the contribution of the crude oil price and the gold price proves (86.50% versus 13.50%) and (50.28% versus 49.72%) respectively. Therefore, we may see whether with the PT or IS models, the contribution of the crude oil price is greater than that of the gold price, which implies that the influence of the crude oil on the whole large commodity market may be larger than that of the gold.

Table 6

Estimated results of price discovery models

Markets Parameters	Crude oil market	Gold market
Vector error correction coefficient $\alpha$	-0.0065 (-1.9784)	0.0413 (2.3179)
$\Gamma$ coefficient in the PT model	0.8650	0.1350
Information share coefficients in the IS model	0.5028	0.4972

Note: t statistic values are reported in parentheses.

In order to check the robustness of price discovery results above, we also introduce the G-S model by Moosa (2002) to examine the contribution to price discovery between the crude oil market and the gold market. The G-S model is developed as follows.

$$\begin{aligned}
 P_t^O &= c_G + (1 - d_G)P_{t-1}^O + d_G P_{t-1}^G + \lambda_{t1} \\
 P_t^G &= c_O + d_O P_{t-1}^O + (1 - d_O)P_{t-1}^G + \lambda_{t2}
 \end{aligned} \tag{16}$$

Then let  $\tau = d_G / (d_O + d_G)$ , which is used to explain the importance extent of the crude oil market and the gold market in price discovery. Specifically, if  $\tau$  is larger than 0.5, the role of the gold price in price discovery outweighs that of the crude oil price; otherwise, we may argue the role of the crude oil price proves more important.

After implementing the OLS approach in Equation (16), estimated results can be found in Table 7.

Table 7

Estimated results of the G-S model

	Coefficient	R squared	DW
$d_G$	0.0002 (0.0574)	0.9978	1.9892
$d_o$	-0.0015 (0.0611)	0.9990	1.8768

*Note:*  $p$ -values are reported in parentheses. DW means the Durbin-Watson statistic.

According to the estimated values of  $d_o$  and  $d_G$ , we may get the value of  $\tau$ , which is -0.1592 and less than 0.5. Therefore, we may say the role of the crude oil price in commodity market seems more important than that of the gold price, which means the importance of the crude oil price movement should be attached more attention. This validates the results from the PT and IS model above, and also keeps in line with the aforementioned empirical research statement that the crude oil price volatility Granger causes the change of the gold price but not vice versa.

This may arise from the fact that crude oil is considered to be an essential raw material of industrial production. As a result, compared with the gold, the influence of crude oil on global economic development appears more direct and extensive, hence its price change turns out to be more attractive and important to investors concerned.

Indeed, in the wake of global industrialization and market-oriented process, crude oil futures, as the largest commodity futures in the world, has a profound influence on other futures. For instance, due to the rapid development of alternative energy, America uses a great deal of corn and white sugar to produce bioethanol and employs soybean to generate biodiesel oil; as a result, there can be seen a close relation between the crude oil price and the prices of grease products, soybean and corns. Additionally, given the extensive usage, the crude oil has become one of the most important and fundamental lifelines of global economy, and its price is supposed to be of great significance to the prices of other commodities. In brief, there has been some growing evidence that the influence of crude oil price has become increasingly crucial for world economic development, and the fluctuation of the whole large commodity market prices, for the most part, depends on the rise-and-fall of the crude oil price.

### **Concluding remarks and future work**

This paper conducts a comprehensive empirical study on the interaction between the crude oil market and

the gold market from three perspectives, i.e. price cointegration, price causality and price discovery, so as to provide some rewarding support for recognizing and analyzing the dynamics of the crude oil market, gold market and even the whole large commodity market. To recap what we have done above, several main conclusions and policy implications can be obtained as follows.

(1) Overall, the crude oil price volatility magnitude proves greater than that of the gold price in the sampling period. From the value of Coefficient of Variance (CV), it can be found that the fluctuation of crude oil price is 2 times stronger than that of gold price. Moreover, due to the rampant speculating activities of index funds, from 2004 to 2008, the volatility magnitude of both crude oil price and gold price has almost doubled. It also should be noted that there is a high positive correlation between the crude oil price and the gold price with the correlation coefficient 0.9295 in the sampling period, which implies the two markets take very similar price trends and contain some common effective price information.

(2) Significant cointegration relationship can be identified between the crude oil price and the gold price. Put it another way, there exists long-term equilibrium relationship between the two markets, which results from the fact that the two markets tend to be influenced by some common factors, such as the US dollars exchange rate, economic fundamentals, geopolitical events. Besides, as for their short-term interaction, we find that their mutual influence appears statistically significant at 1% level on the same day, and the influence of the gold price on the crude oil price is about 5 times stronger than that of the crude oil price on the gold price. However, the stronger influence of the gold price on the crude oil price can exist only on the same day, but the smaller influence of the crude oil price on the gold price can last until the next day. Furthermore, we find that the long-term equilibrium across the crude oil and the gold markets can only adjust their short-term change in a fairly limited manner. Therefore, when we analyze the main factors driving the crude oil price short-term change, the volatility of the gold market is necessary to be considered as a dominant factor and can only provide a supplementary reference.

(3) There can be found significant unilateral linear Granger causality between the crude oil market and the gold market. Specifically, the crude oil price return change linearly Granger causes the movement of the gold price return, but not vice versa, which means in the first few years of the 21<sup>st</sup> century, the surging crude oil price has driven up the gold price, but it is not the case in the opposite direction. Additionally, they do not have any significant nonlinear Granger causality. Therefore, it can be argued that the interaction between the crude oil market and the gold market proves fairly direct and concise.

(4) Based on the common effective price information between the crude oil price and the gold price, we find that the contribution of the crude oil price appears larger than that of the gold price, which implies that

among the price trends of the large commodity market, the role of crude oil outweighs that of the gold. This displays that, in the sampling period, the crude oil, as an important raw material of industrial production, has gained a remarkable soaring market position and extensive acknowledgement of investors.

As for the future work, with respect to the relationship between the crude oil and the gold markets, at least two things have to be conducted further. For one thing, in this paper, we are focused on their overall relationship, so the results here are relatively static with an average meaning; in the future, attention can be paid to their dynamic and time-varying interaction. For another, this paper sheds light upon their relationship in the mean perspective, while other perspectives also can be considered in the future, such as the volatility, risk spillover etc., in order to foster a more holistic comprehension about the crude oil and the gold markets even the whole large commodity market.

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