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Dynamic transmission effects between the interest rate, the US dollar, and gold and crude oil prices

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ABSTRACT

This paper shows that in the short term both gold and crude oil prices positively influence each other. Interest rates have a negative influence on the future gold prices and a positive influence on the future crude oil prices. In the long run, a relationship exists whereby interest rates influence the US dollar, which in turn influences international crude oil prices. When the Federal Reserve Board (Fed) lowers interest rates to boost the economy, market expectations for oil demand change and, as a result, crude oil prices fluctuate. In addition, there is a price transmission relationship from interest rates to gold prices. A reduction in interest rates influences investor expectations with respect to depreciation of the dollar. Investors then move their capital to the gold market for capital preservation or speculation. Finally, international gold and crude oil prices have feedback effects on interest rates. This paper infers that crude oil prices increasing to a certain level trigger inflation, at which juncture the Fed may tighten monetary policies to downturn the bloom economy.

1. Introduction

International oil prices have always been a leading indicator in the global economy. When oil prices rise, corporations suffer from surging costs and declining profits. Such increases also indirectly change consumer spending. Prices shoot up and, as a result, disposable income declines and inflation occurs. All of this is bad news for economic growth. Nevertheless, looming inflation boosts gold prices because investors believe gold preserves its value.

The US dollar is the major denomination currency for the international crude oil market and fluctuations in dollar exchange rates make it even more difficult to predict the international purchasing power of oil-exporting countries. In the short term, oil-exporting countries may be worried about the US dollar weakening, since they benefit from it being strong. However, overestimation of the US dollar can result in a reverse demand shock over the long run. When the outlook for the US dollar is dim, a large portion of capital goes to the crude oil markets and pushes up oil prices. In contrast, if a large amount of capital flows out of the crude oil market, fluctuations in the US dollar will be fairly noticeable. As long as the denomination and settlement currency for the international crude oil market is the US dollar, this correlation will continue to hold.

Gold and other commodities trend up following the lead of crude oil prices, all under the influence of macroeconomic factors such as inflation, interest rates, and industrial production. Rising commodity prices increase the anticipation of inflation among investors. As a result, the government will likely tighten monetary policies by hiking interest rates. Since interest rates influence the returns of investments on commodities, changes in interest rates indirectly affect returns for gold holders.

In the international market, gold is denominated in US dollars and is the best commodity to preserve capital and to combat recessions. The US dollar is under the direct influence of the interest rate policies set by the Federal Reserve Board (Fed), which depend on the recovery of the global economy. Investors develop certain anticipations regarding the future boom or bust of the economy based on adjustments to interest rates, with rising rates boosting their confidence. If the interest rates in the US are higher than in other countries, appreciation of the US dollar will suppress gold prices. In the meantime, signs of economic recovery also boost oil prices. It is possible for international crude oil and gold prices to move in opposite directions. Rising oil and gold prices both have an important influence on the international financial markets and the global economy.

This paper examines the short- and long-term dynamic interactions between interest rates, oil prices, gold prices, and the US dollar. It explores the following issues. First, what are the short-term interactions between interest rates, the US dollar, gold prices, and oil prices as paired variables? Second, what are the long-term causal relationships between interest rates, the US dollar, gold prices, and oil prices as paired variables? Third, do interest rates and oil prices have opposite influences on international gold prices?

This paper consists of five parts. Section 1 describes the motivations and purposes of the research. Section 2 examines the relevant

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literature. Section 3 outlines the research methodology. Section 4 presents the empirical analysis. Finally, Section 5 offers conclusions.

2. Literature review

Chaudhuri and Daniel (1998) suggest that since Bretton Woods, there has been cointegration between real US dollar-denominated production prices and real oil prices in most industrial nations. This means that the instability of real US dollar exchange rates is, in essence, a reflection of the instability of real oil prices. Chen and Chen (2007) analyze data on G7 countries, world oil prices, and intermediate oil prices and find that real oil prices may be the major factor contributing to fluctuations in real exchange rates.

In addition, there is cointegration between real oil prices and real exchange rates. Regression estimates based on cross-sectional data indicate that real oil prices have significant predictability over real exchange rates. Using monthly data on the effective real exchange rates of the US dollar and real oil prices in the US, Amano and van Norden (1998) demonstrate cointegration between the two. The authors suggest that in the post-Bretton Woods era, oil prices may be the main source of long-lasting impacts. They also indicate that the causal relationship is from oil prices to exchange rates alone and not vice versa.

Holding all other variables constant, Benassy-Quere et al. (2007) argue that from 1974 to 2004, a 10% rise in long-term oil prices resulted in a 4.3% appreciation of the effective exchange rate of the US dollar. Zhang et al. (2008) analyze the impact of US dollar exchange rates on international crude oil prices and results find a significant cointegration relationship in the long-term equilibrium, with one-way mean spillover effects of the US dollar exchange rates on crude oil prices. The depreciation of the US dollar is a major factor determining international crude oil prices and the US dollar exchange rates are one of the main determinants of oil prices in the long run.

Since international gold prices are denominated in US dollars, the dollar's depreciation decreases gold prices for investors compared to other hard currencies. To preserve capital, investors will purchase gold and thus push gold prices up. In addition, given rising economic uncertainties and inflation, gold is considered a safe haven. An empirical study of Sjaastad and Scacciavillani (1996) on the international gold markets from 1982 to 1990 supports the efficient market hypothesis. Goldman (2000) validates the efficient market hypothesis based on US dollar and British pound exchange rates from 1890 to 1906, with findings supporting the weak form of efficiency. Capie et al. (2005) use weekly data over the past 30 years to reveal an inverse relationship between gold prices and exchange rates between British pounds and US dollars, as well as between gold prices and exchange rates between US dollars and Japanese yen.

Gold prices show such relationships with exchange rates because gold is a hedge against exchange rate fluctuations and is thus used to preserve capital. According to Hammoudeh and Yuan (2008), fluctuations in crude oil prices have negative impacts on fluctuations in some metal prices and managers of commodity portfolios can benefit from such volatility in the metal markets with options pricing. The volatility of crude oil prices therefore presents an opportunity to switch to commodity markets to diversify portfolios.

Bernanke and Blinder (1992) suggest that short-term interest rates are predictive of the future economy. Because call rates are almost instant, the impulse on short-term interest rate spreads is regarded as an external impulse on the interest rates set by the Fed. As a response to the impulse on the Fed rates, market participants trade currencies based on their expectations of the future economy. A continued impulse on the Fed rates results in varying interpretations from traders due to unexpected transactions. Meanwhile, traders change their expectations over time. Therefore, high trading volumes in response to exchange rate changes last only a few days.

An empirical study by So (2001) demonstrates that changes in interest rates affect changes in future exchange rates, but that changes in exchange rates do not directly affect future interest rates. This is because interest rates reflect the fundamentals of an economy and this information is transmitted through the exchange value of the US dollar. The empirical study of Kanas (2005) uses a test based on the MS-VAR model to identify a causal relationship from the real interest rate spreads of the lag periods to changes in the real exchange rates. Besides, the causal relationship generated from the spreads of the real exchange rates occurs only in high-volatility periods.

According to Kitamura and Akiba (2006), the external impulse of short-term interest rate spreads influences exchange rates via two trading channels. Changes in short-term interest rate spreads result in changes in exchange rates through uncovered interest-rate parity conditions. Market participants generally acknowledge that unexpected changes in exchange rates should be reflected in short-term interest rate spreads.

Cologni and Manera (2008) employ simulations to estimate the total effects of crude oil impulses in 1990. They suggest that part of the influence of crude oil price impulses in certain countries (e.g., the US) is the result of monetary policy. For other countries (e.g., Canada, France, and Italy), the total effects are at least partly offset by monetary policies.

Hammoudeh and Yuan (2008) consider how sensitive commodities are to good news versus bad news and find that gold is not sensitive to bad news, which is why it is a good investment during bad times, such as crises, wars, and times of high inflation, particularly in the short term. Meanwhile, rising interest rates have dampening effects on metal markets. Economic policymakers should tighten monetary policies to suppress instability.

3. Methodology

3.1. Threshold co-integration

This paper examines the long-term equilibrium relationship among the four variables by using the threshold co-integration technique developed by Enders and Granger (1998) and Enders and Siklos (2001) because of the non-linear relationships involved. It follows a two-step technique. First, this paper estimates the co-integration equation as follows:

$$Y_{1t} = \alpha + \beta Y_{2t} + u_t \tag{1}$$

where Y_{1t} and Y_{2t} are the first-difference stationary I(1) series for interest rates, US dollars, oil prices and gold prices. α and β are the estimated parameters, and u_t represents the interfering items that may result in series correlation. The second step involves validating whether the residual item u_t of the long-term equilibrium regression equation shows stationary convergence. The least minimum square method is applied to estimate $\hat{\rho}_1$ and $\hat{\rho}_2$. The ordinary least squares (OLS) estimates are calculated using the following regression equation:

$$\Delta u_t = I_t \rho_1 u_{t-1} + (1 - I_t)\rho_2 u_{t-1} + \sum_{i=1}^{l} \gamma_i \Delta u_{t-i} + \varepsilon_t \tag{2}$$

where ε_t is a white noise-interfering item. The residual item u_t is obtained in Eq. (1) and again estimated in Eq. (2). I_t is the indicator function. If $u_{t-1} \geq \tau$, then $I_t = 1$, but if $u_{t-1} \leq \tau$, then $I_t = 0$. Let τ be a threshold. The required condition for μ_t to be stationary is $-2 < (\rho_1, \rho_2) < 0$. If the variance of ε_t is sufficiently large, the value of ρ_j may fall between -2 and 0, assuming that other values are equal to zero. Enders and Granger (1998) and Enders and Siklos (2001) indicate in their case studies that under the null hypothesis $H_0: \rho_1 = \rho_2 = 0$, there is no convergence, the F statistic has a non-standard distribution. The critical values of non-standard F statistics are listed in their papers. Enders and

Granger (1998) also indicate that if the series is stationary, the estimated minimum squares of ρ_1 and ρ_2 have an asymptotic multivariate normal distribution.

Eq. (2) is the threshold auto-regression (TAR) model. The threshold test for equilibrium errors is called a threshold co-integration test. If a system converges and $\mu_t=0$, it can be the long-term equilibrium value of the series. If μ_{t-1} is higher than the long-term equilibrium, the adjustment speed is $\rho_1 u_{t-1}$. If μ_{t-1} is lower than the long-term equilibrium, the adjustment speed is $\rho_2 u_{t-1}$. The behavior of error adjustments resembles a threshold auto-regression. This paper thus tests the co-integration relationship to validate the null hypothesis $H_0:\rho_1=\rho_2=0$. If the null hypothesis is rejected, this implies that there is co-integration among variables. If $\rho_1=\rho_2=0$, it should be possible to further test the symmetric adjustments using a standard F test. If the adjustment speed is symmetric, then $\rho_1=\rho_2$. If the null hypotheses $H_0:\rho_1=\rho_2=0$ and $H_0:\rho_1=\rho_2$ are rejected, then there are asymmetric adjustments as well as threshold co-integration.

In Eq. (2), the indicator function "heaviside" hinges on the size of u_{t-1} and depends on changes in u_{t-1} during the previous period. The indicator function "heaviside" is expressed as $I_t=1$ if $\Delta u_{t-1}\geq\tau$ and $I_t=0$ if $\Delta u_{t-1}\leq\tau$. The symbol τ indicates a threshold. According to Enders and Granger (1998), when adjustments are asymmetric, the model is particularly valuable because it carries more momentum as compared to other series. This model is called the momentum threshold auto-regression (M-TAR) model. A TAR model can capture broad patterns, whereas an M-TAR can capture more nuanced changes to series.

Because τ is unknown, it must be estimated using ρ_1 and ρ_2. Enders and Granger (1998) conduct their tests using the sample series mean as the estimated threshold τ. However, the existence of asymmetric adjustments to the sample means leads to a biased estimate of thresholds. The consistency estimate of the threshold τ can be achieved using the method proposed by Chan (1993). Enders and Siklos (2001) apply the method developed by Chan (1993) in their Monte Carlo simulations to compute F statistics for the null hypothesis $H_0:\rho_1=\rho_2=0$. The critical values for non-standard F statistics to test the null hypothesis $H_0:\rho_1=\rho_2=0$ are noted in their papers. Since neither TAR nor M-TAR has clear selection criteria, this paper suggests that the choice should be based on the selection criteria of either Akaike information criterion (AIC) or Schwartz Bayesian information criterion (SBC).

3.2. Threshold error-correction model (TECM)

If there is threshold co-integration among variables, it is possible to test price delivery with a TECM to analyze the short-term and long-term causal relationships and long-term equilibrium trends for different threshold bands. A TECM can be expressed as follows (Enders and Granger, 1998; Enders and Siklos, 2001):

$$\Delta Y_{it}=\alpha+\gamma_1 Z^+_{t-1}+\gamma_2 Z^-_{t-1}+\sum_{i=1}^{k_1}\delta_i\Delta Y_{1t-i}+\sum_{i=1}^{k_2}\theta_i\Delta Y_{2t-i}+\nu_t. \tag{3}$$

Note that $Y_{it}=(lex,lfed)$, $Y_{it}=(lfed,loil)$, $Y_{it}=(lfed,lgold)$, $Y_{it}=(loil,lgold)$, $Y_{it}=(lgold,lex)$ or $Y_{it}=(loil,ex)$, $Z^+_{t-1}=I_t\hat{u}_{t-1}$ and $Z^-_{t-1}=(1-I_t)\hat{u}_{t-1}$ are the error correction items for long-term disequilibrium. Z^+_{t-1} indicates the error correction for the long-term disequilibrium above the threshold, whereas Z^-_{t-1} represents the error correction for the long-term disequilibrium below the threshold. γ_1 and γ_2 denote the adjustment speeds for error corrections above and below the threshold, respectively. δ_i and θ_i are the coefficients for the difference items of the lag periods ΔY_{1t-i} and ΔY_{2t-i}, respectively. If $u_{t-1}\geq\tau$, then $I_t=1$. However, if $u_{t-1}\leq\tau$, then $I_t=0$. The symbol ν_t indicates the white noise-interfering item. The Granger causal relationship test involves using the F test to validate whether the coefficients of ΔY_{1t-i} and ΔY_{2t-i} are statistically different from zero and whether the error correction coefficient γ_j is significant. The F test is used because this causal relationship test is highly sensitive to the selection of lag periods. Let k be the difference for the lag period, where k = 1…N until the residual item becomes white noise. The AIC criteria are used to determine the optimal lag period.

4. Empirical results

4.1. Data

This paper explores the short- and long-term interactions between interest rates, US dollars, and oil and gold prices. The justification for the selection of these four variables and their definitions are detailed below. The data on interest rates are from the Fed and the data on US dollar indices, spot prices for gold in New York, and West Texas Intermediate spot prices are from the AREMOS Taiwan Economic Statistical Databanks in Taiwan. According to Zhang et al. (2008), the nominal price should be regarded as the significant determinant of the final price; therefore this paper performs tests on nominal data.

This paper samples daily data from January 2, 1989, through December 20, 2007. After the elimination of incomplete data, there are 4500 observations. According to Table 1, the volatility of gold prices is the highest, followed by that of oil prices, indicating that gold may be traded due to market anticipation and speculation.

4.2. Threshold cointegration

According to Table 2, the optimal selection criteria for the TAR and M-TAR models are based on the minimum values of the Akaike information and Schwarz Bayesian criteria. These values indicate that the M-TAR model has the best adjustment mechanisms. Table 3 indicates asymmetric adjustments and threshold cointegration for interest rates, gold and oil prices, and US dollars. There are long-term threshold cointegration relationships between these four variables, implying a long-term equilibrium between each pair. Therefore, investors cannot diversify portfolio risks by pairing any two of these four variables.

Panel A of Table 4 shows a lead–lag relationship from the US dollar to gold prices and a long-term lead–lag relationship from gold prices to the US dollar. However, below the threshold, there is no such relationship. Panel B of Table 4 illustrates the long-term relationship between the US dollar and oil prices. There is a lead–lag relationship between US dollars and oil prices. There is a long-term lead–lag relationship between oil prices and the US dollar above the threshold of −0.41.

According to Panel A of Table 4, there is threshold cointegration between the US dollar and gold prices. When the long-term equilibrium relationship between gold prices and the US dollar becomes unstable, a positive adjustment of approximately 28.81% of the price of gold below the threshold restores equilibrium, assuming gold prices as an explained variable. There is no adjustment effect above the threshold. When the long-term equilibrium relationship between

Table 1
Descriptive statistics.

	Interest rate	Dollar	Gold	Oil
Mean	4.65	91.29	383.69	29.98
Standard error	2.10	8.19	106.43	17.21
Maximum	10.71	112.87	841.10	99.03
Minimum	0.86	71.11	252.80	10.82
Skewness	−0.18	0.49	1.77	1.60
Kurtosis	2.84	2.77	6.13	4.71

Table 2
The criterion of TAR and M-TAR.

	TAR		M-TAR	
	AIC	SBC	AIC	SBC
gold-ex	−2384	−2346	−2435	−2396
oil-ex	6383	6421	6243	6281
oil-gold	6379	6398	6232	6251
ex-fed	−11,305	−11,286	−11,315	−11,296
fed-gold	9512	9551	9463	9501
fed-oil	9687	9726	9639	9678

Note: fed: interest rate; gold: gold prices; oil: oil prices; ex: US dollar indexes.

gold prices and the US dollar becomes unstable, a negative adjustment of approximately 0.16% of the value of the US dollar below the threshold restores equilibrium, assuming that the US dollar serves as an explained variable. There is no adjustment effect below the threshold.

According to Panel B of Table 4, there is threshold cointegration between the US dollar and oil prices. When the long-term equilibrium relationship between oil prices and the US dollar becomes unstable, a negative adjustment of approximately 78.99% of the price of oil under the threshold restores equilibrium, assuming oil prices as an explained variable. There is no adjustment effect above the threshold. When the long-term equilibrium relationship between gold prices and the US dollar becomes unstable, a negative adjustment of approximately 0.03% of the value of the US dollar above the threshold restores equilibrium, assuming the US dollar serves as an explained variable. There is no adjustment effect below the threshold.

Panel A of Table 4 shows that the price transfers between gold prices and the US dollar are asymmetric. Panel B of Table 4 indicates that the price transfers between oil prices and the US dollar are also asymmetric. These results from the M-TAR model demonstrate threshold cointegration between oil prices and the US dollar.

In the short term, both gold and oil prices are subject to the negative influence of the gold and oil prices of the previous periods. Gold prices are also subject to the negative influence of the US dollar of the previous periods. This finding supports that the US dollar has a negative impact on gold prices, probably because gold is an important value-conserving commodity. Because the US dollar is an important reserve currency, its depreciation prompts investors who hold other hard currencies to purchase gold, which is denominated in US dollars. These investors thus transfer their capital from the money market to the gold market, raising gold prices. As such, they can preserve the value of their assets and hedge risks at the same time.

Below the threshold, changes in the US dollar lead changes in oil prices over the long run. This finding supports that even though short-term currency rate changes do not immediately affect the oil market, US dollars are one of the key determinants of oil prices in the long term. There are single-direction mean spillover effects from the US dollar exchange rates to oil prices. The depreciation of the US dollar encourages additional speculation in the oil market.

Table 3
Threshold co-integration tests (M-TAR model).

	$\hat{F}_c$	$\hat{F}_A$	l	Threshold value τ
gold-ex	29.43***	54.13***	4	−0.07
oil-ex	75.36***	148.27***	4	−0.41
oil-gold	81.13***	154.09***	1	−0.37
ex-fed	5.96***	11.30***	1	−0.01
fed-gold	28.68***	54.82**	4	0.35
fed-oil	26.64***	51.05***	4	0.34

Notes:
1. fed: interest rate; gold: gold prices; oil: oil prices; ex: US dollar indexes. τ: threshold value.
2. *** denotes significance at the 1%.
3. The notation l is the lag periods of lagged difference term, which is decided by the minimum AIC.
4. $\hat{F}_c$ denotes that the null hypothesis H_0:$\rho_1=\rho_2=0$ is the F stats in the no co-integration relationship. $\hat{F}_A$ denotes that the null hypothesis H_0:$\rho_1=\rho_2$ is the F stats of symmetric adjustments. The critical values are given in Table 1 of Enders and Siklos (2001).

Table 4
Estimates of the threshold error correction model on gold prices, oil prices and US dollar index.

	(A) gold-ex		(B) oil-ex	
	dlgold	Dlex	dloil	dlex
Constant	0.0001	−0.0000	0.0003	−0.0000
	(−1.04)	(−0.69)	(0.77)	(−0.62)
dly(−1)	−0.0666***	0.0095	−0.1278***	−0.001
	(−4.36)	(1.35)	(−8.65)	(−0.48)
dlex(−1)	−0.227***	0.0052	0.0005	0
	(−6.81)	(0.34)	(0.00)	(0.01)
Z^+_{t-1}	0.0006	−0.0016***	−0.0011	−0.0003**
	(0.57)	(−3.49)	(−1.08)	(−2.08)
Z^-_{t-1}	0.29***	0.03	−0.79***	0.01
	(7.42)	(1.62)	(−13.18)	(1.24)
$Ho:\theta_1=\gamma_1=0$	23.26***		0.58	
$Ho:\theta_1=\gamma_2=0$	50.04***		86.91***	
$Ho:\delta_1=\gamma_1=0$		6.71***		2.32
$Ho:\delta_1=\gamma_2=0$		2.08		0.79
$Ho:\gamma_1=\gamma_2$	54.8***		173.32***	
$Ho:\gamma_1=\gamma_2$		2.92*		1.62
AIC	−4391	−11,367	5854	−11,357
SBC	−4359	−11,335	5886	−11,325

Notes:
1. dfed: log(interest rate); dgold: log(gold prices); doil: log(oil prices); dex: log(US dollar indexes).
2. ***, ** and * denote significance at 1%, 5% and 10% levels, respectively. t statistics are in parentheses.

However, changes in oil prices lead changes in the US dollar above the threshold. Chen and Chen (2007) and Benassy-Quere et al. (2007) argue that oil prices have significant predictive power over the US dollar. In the long run, the US dollar leads gold prices near the threshold. It is thus safe to infer that the depreciation of the US dollar makes gold prices attractive to investors holding other hard currencies, who then move their money to the gold market. Above the threshold, gold prices lead the US dollar; that is, gold prices around the world predict the volatility of exchange rates.

According to Table 5, there is two-directional influence between gold and oil prices. In addition, the gold prices of the previous periods significantly influence the current period's gold prices. The oil prices of the previous periods also significantly influence the current period's oil prices.

There is a lead–lag relationship between gold and oil prices. There is thus threshold cointegration between oil and gold prices. When the long-term equilibrium relationship between oil and gold prices becomes unstable, a negative adjustment of approximately 98.95% of the price of oil below the threshold restores equilibrium, assuming oil prices as an explained variable. There is no adjustment effect above the threshold. When the long-term equilibrium relationship between oil and gold prices becomes unstable, a negative adjustment of approximately 0.11% of the price of gold below the threshold restores equilibrium, assuming gold prices as an explained variable. There is no adjustment effect below the threshold. Meanwhile, F-tests shows that the price transfers between gold and oil prices are asymmetric. These results from the M-TAR model show threshold cointegration between gold and oil prices.

In addition to the short-term negative impact mentioned above, the current period's gold and oil prices are also under the positive, two-directional influence of the gold and oil prices of the previous periods, respectively. In the long run, oil and gold prices lead each other around the threshold. Virtually all commodities have shown increasing prices during the past years, possibly because they are generally subject to the influence of macroeconomic factors such as inflation, interest rates, and industrial production.

Table 5
Estimates of the threshold error correction model on oil prices and gold prices.

	dloil	dlgold
Constant	0.0003	0.0001
	(0.75)	(1.07)
dloil(−1)	−0.13***	0.0179***
	(−8.76)	(3.74)
dlgold(−1)	0.0767*	−0.0556***
	(1.66)	(−3.72)
Z^{+}_{t-1}	−0.0021	0.0011***
	(−1.67)	(2.70)
Z^{-}_{t-1}	−0.99***	−0.02
	(−13.20)	(−0.81)
$Ho:\theta_1=\gamma_1=0$	2.66*	
$Ho:\theta_1=\gamma_2=0$	88.45***	
$Ho:\delta_1=\gamma_1=0$		11.16***
$Ho:\delta_1=\gamma_2=0$		7.01***
$Ho:\gamma_1=\gamma_2$	173.55***	
$Ho:\gamma_1=\gamma_2$		0.73
AIC	5849	−4313
SBC	5881	−4281

Notes:
1. dgold: log(gold prices); doil: log(oil prices).
2. ***, ** and * denote significance at 1%, 5% and 10% levels, respectively. t statistics are in parentheses.

Table 6
Estimates of the threshold error correction model on US dollar index and interest rate.

	dlex	dlFed
Constant	−0.0000	−0.0002
	(−0.70)	(−0.33)
dlex(−1)	0.0029	0.0013
	(0.19)	(0.01)
dlFed(−1)	0.0001	−0.34***
	(0.11)	(−24.16)
Z^{+}_{t-1}	−0.0001	−0.01*
	(−0.14)	(−1.73)
Z^{-}_{t-1}	−0.02***	0.03
	(−3.57)	(0.65)
$Ho:\theta_1=\gamma_1=0$	0.02	
$Ho:\theta_1=\gamma_2=0$	6.36***	
$Ho:\delta_1=\gamma_1=0$		1.50
$Ho:\delta_1=\gamma_2=0$		0.21
$Ho:\gamma_1=\gamma_2$	12.30***	
$Ho:\gamma_1=\gamma_2$		0.79
AIC	−11,364	9962
SBC	−11,332	9994

Notes:
1.dfed: log(interest rate); dex: log(US Dollar indexes).
2. ***, ** and * denote significant at 1%, 5% and 10% levels, respectively. t statistics are in parentheses.

According to Hammoudeh and Yuan (2008), gold prices are influenced by fluctuations in oil prices, perhaps due to the expected inflation associated with a rise in oil prices of the current period. Rising oil prices make gold an attractive option to counter inflation and, to maintain purchasing power or to speculate, investors then purchase gold products in the following periods. For example, during the Gulf Crisis of 1990, the oil price surged from US$14 to US$40 per barrel. Meanwhile, the price of gold increased from US$350 to US$420 per ounce, having become attractive due to the war, rising oil prices, and anticipated inflation.

Since 2001, increasing demand from emerging markets for oil and commodities and the continued depreciation of the US dollar have made investors gradually shift their capital into the gold market. Investors may hold gold to preserve the value of assets, hedge risks, or simply speculate. When the future supply of oil is expected to fall far below demand, oil prices are expected to rise and hence investors will continue to purchase gold.

According to Table 6, only interest rates are subject to the negative impact of interest rates during the previous periods. There is a long-term lead–lag relationship between interest rates and the US dollar below the threshold of −0.01. There is no lead–lag relationship between interest rates and the US dollar. There is also no lead–lag relationship between the US dollar and interest rates in the long run. There is threshold cointegration, however, between the US dollar and interest rates. When the long-term equilibrium relationship between interest rates and the US dollar becomes unstable, a positive adjustment of approximately 1.73% of the value of the US dollar below the threshold restores equilibrium, assuming the US dollar as an explained variable. There is no adjustment effect above the threshold. When the long-term equilibrium relationship between interest rates and the US dollar becomes unstable, a negative adjustment of approximately 1.33% of the interest rate above the threshold restores equilibrium, assuming interest rates as an explained variable. There is no adjustment effect below the threshold. Meanwhile, F-tests indicate that the price transfers between interest rates and the US dollar are asymmetric. These results from the M-TAR model show threshold cointegration between interest rates and the US dollar.

In the short term, the interest rates of the current period are subject to the negative influence of the interest rates of the previous periods. However, interest rates lead the US dollar above or below the threshold, as well as over the long term. This result is consistent with those of So (2001) and Kanas (2005), who argue that short-term interest rates are an information variable that predicts the economy. Since interest rates reflect the basic rhythms of the economy, any changes therein affect investor expectations in the US dollar, which is translated into US dollar exchange rates.

From 1994 to 1995, the Fed raised the interest rates seven times to downturn the US economy, which made the US dollar a dominant currency. The US dollar began its long rally in 1995 until early 2002. From 2001 to 2003, the US government adopted expansionary policies, including a total of 13 interest rate cuts, to stimulate the economy after deciding that the US was in recession. This information was quickly transmitted to the monetary market. As a result, the US dollar began to decline in 2004. The downward trend continues today, a reflection of the low expectations that the US will recover soon from the recession.

According to Panel A of Table 7, the interest rates during the previous periods have a significant, negative influence on interest rates and gold prices during the current period. Meanwhile, gold prices from the previous periods exhibit a significant, negative influence on gold prices during the current period. The coefficients of the difference from the previous periods have a significant, negative influence when assuming interest rates as the explanatory variable and gold prices as the explained variable. This means that the rising interest rates of the previous periods should cause the gold prices of the following periods to fall; however, the reverse is true. According to Panel B of Table 7, the interest rates during the previous period have a significant influence on both the interest rates and oil prices during the current periods. The oil prices during the previous periods also show significant influence on the oil prices and interest rates during the current periods. In other words, there are two-way interactions between interest rates and oil prices.

The coefficients of the difference during the previous periods are significantly positive, with oil prices as the explanatory variable and interest rates as the explained variable. In addition, the coefficients of the difference during the previous periods are significant and positive, with interest rates as the explanatory variable and oil prices as the explained variable. This means that interest rates have a positive influence on oil prices and vice versa. A rise in interest rates during the current period raises oil prices during the following periods. A rise in the oil prices during the current periods decreases the interest rates during the following periods and vice versa.

Panel A of Table 7 shows the long-term relationship between gold prices and interest rates. There is a lead–lag relationship between

Table 7
Estimates of the threshold error correction model on gold prices, oil prices and interest rate.

	(A) Fed-gold		(B) Fed-oil	
	dlFed	dlgold	dlFed	dloil
Constant	−0.0001	0.0002	−0.0001	0.0004
	(−0.15)	(1.12)	(−0.19)	(0.99)
dlFed(−1)	−0.3128***	−0.005*	−0.3157***	0.0153*
	(−21.98)	(−1.69)	(−22.24)	(1.66)
dlx(−1)	0.0278	−0.0496***	0.0414*	−0.1681***
	(0.39)	(−3.33)	(1.83)	(−11.43)
Z^{+}_{t-1}	−0.5174***	−0.0009	−0.5629***	−0.0054
	(−8.64)	(−0.08)	(−8.31)	(−0.12)
Z^{-}_{t-1}	−0.0025**	−0.0005*	−0.0024***	−0.0006
	(−2.18)	(−1.93)	(−2.05)	(−0.75)
$Ho:\theta_1=\gamma_1=0$	37.42***		36.07***	
$Ho:\theta_1=\gamma_2=0$	2.48*		3.77**	
$Ho:\delta_1=\gamma_1=0$		1.15		1.4
$Ho:\delta_1=\gamma_2=0$		3.4		1.61
$Ho:\gamma_1=\gamma_2$	73.95***		68.41***	
$Ho:\gamma_1=\gamma_2$		0		0.01
AIC	9886	−4298	9890	6022
SBC	9918	−4266	9922	6054

Notes:
1.dfed: log(interest rate); dgold: log(gold prices); doil: log(oil prices).
2. ***, ** and * denote significance at 1%, 5% and 10% levels, respectively. t statistics are in parentheses.

gold prices and the US dollar and between interest rates and gold prices over the long run. When Granger causality with threshold error corrections is taken into account, a lead–lag relationship between interest rates and gold prices exists below the threshold. Above the threshold value, only gold prices lead interest rates.

Panel B of Table 7 shows the long-term relationship between oil prices and interest rates. There is a lead–lag relationship between oil prices and the US dollar. However, there is no lead–lag relationship between oil prices and interest rates over the long run.

According to Panel A of Table 7, there is threshold cointegration between interest rates and gold prices. When the long-term relationship between gold prices and the US dollar deviates from equilibrium, equilibrium is restored with a negative adjustment of approximately 51.74% of a unit of the gold prices above the threshold, with interest rates as an explained variable. Below the threshold, equilibrium is restored with a negative adjustment of approximately 0.25% of a unit of the interest rates. When the long-term relationship between gold prices and the US dollar deviates from equilibrium, equilibrium is restored with a negative adjustment of approximately 0.05% of a unit of the gold prices below the threshold, with gold prices as an explained variable. There is no adjustment effect above the threshold.

According to Panel B of Table 7, there is threshold cointegration between interest rates and oil prices. At the same time, all the coefficients are negative. When the long-term relationship between oil prices and the US dollar deviates from equilibrium, equilibrium is restored with a negative adjustment of approximately 56.29% of a unit of the interest rates above the threshold, with interest rates as an explained variable. A negative adjustment of approximately 0.24% of a unit of the interest rates below the threshold can also restore equilibrium. There are no adjustment effects above or below the threshold when oil prices are the explained variable.

The F-tests in Panel A of Table 7 indicate the long-term influence of gold prices on interest rates. The tests significantly reject the null hypothesis, which means that the price transfers between interest rates and gold prices are asymmetric. The F-tests in Panel B of Table 7 indicate the long-term influence of oil prices on interest rates. The tests significantly reject the null hypothesis, which means that the price transfers between interest rates and oil prices are asymmetric. These results in the M-TAR model demonstrate that there is threshold cointegration between these two variables.

The interest rates and the crude oil and gold prices of the previous period have negative impacts on gold prices during the current period in the short term. The interest rates of the previous period have negative effects on the gold prices of the previous period. This paper infers that if the Fed lowers interest rates during the current period, investors will expect a depreciation of the US dollar and an economic downturn. To protect their wealth or to speculate on such expectations, investors will shift their capital to the gold market and push up gold prices in the subsequent period.

The interest rates of the previous period have a positive influence on the crude oil prices of the current period and the crude oil prices of the previous period have a positive influence on the interest rates of the current period. Regarding the long-term relationship between interest rates and gold prices, interest rates lead gold prices under the threshold. This result supports the notion that gold prices are subject to the influence of interest rates. This is possibly because when the Fed lowers interest rates to boost the economy, the market interprets such a move as indicating an impending economic recession in the US, investors shift their capital to the gold market to speculate or to protect their wealth. This means interest rates lead gold prices in a certain range. Near the threshold, gold prices also lead interest rates.

According to the Fed, commodity market trends can shed light on policymaking and holds that gold prices are an important determinant of short-term interest rates; indeed, gold prices lead interest rates. Near the threshold, crude oil prices lead interest rates. This may be because the demand for crude oil rises in an economic boom. When prices increase to a certain level, inflation occurs. At that juncture, the Fed may adopt tightening monetary policies to cool down the economy, raising interest rates to restrict the rise in oil prices and resulting inflation. This is why there is a correlation between crude oil prices and interest rates.

5. Conclusion

Gold prices, crude oil prices, and interest rates influence each other's respective levels during the previous period in the short term. Gold and crude oil prices positively influence each other during the previous period, possibly because both prices move in line with inflation, interest rates, and industrial production. While the value of the US dollar during the previous period negatively affects gold prices during the following period, the US dollar during the current period has no significant influence on oil prices during the following period. This paper infers that the depreciation of the US dollar during the current period will drive capital to US-denominated gold products for hedging, speculation, or capital conservation. As a result, the gold price of the following period will rise.

The value of the US dollar during the current period has no impact on the crude oil prices of the following period, possibly because the latter are subject to the influence of factors other than US dollars in the short term, including the predictions of supply/demand and economic situations. Consequently, the value of the US dollar in the current period has no significant influence on the crude oil prices in the following period.

The interest rates in the previous period have a negative impact on gold prices and a positive effect on crude oil prices during the following period. This result is consistent with the previous inference: In the short term, interest rate hikes will push down gold prices but squeeze up crude oil prices. The effects of interest rates during the previous period on the US dollar during the current period are not significant. Only the value of the US dollar during the previous period exhibits a negative effect on gold prices during the following period. This may be because short-term interest rate adjustments directly affect how investors predict the economy. Crude oil prices during the previous period have a positive impact on interest rates during the following period. This is perhaps because high crude oil prices will lead to inflation and prompt the monetary authorities to raise interest rates.

Regarding long-term price transmission effects from interest rates to US dollars and from US dollars to gold prices, interest rates lead the US dollar below the threshold and US dollars lead gold prices. According to the threshold error correction model for interest rates and gold prices, there is correlation between interest rates and gold prices below the threshold. This result supports the notion that gold prices are subject to the influence of interest rates.

In some long-term ranges, interest rates lead gold prices. Since interest rates reflect economic fundamentals, any changes in interest rates affect investor expectations of the US dollar, which will be translated into its exchange value. In this instance, the US dollar will depreciate. At this juncture, investors will swiftly move their capital to the gold market for speculation or capital preservation, resulting in fluctuations in gold prices. Gold prices went up because gold preserve values and provides hedging effects.

In terms of the price transmission effects from interest rates to US dollars and from interest rates to crude oil prices, interest rates lead US dollars and US dollars lead crude oil prices below the threshold. Since interest rates mirror the economic fundamentals, when the Fed lowers them to boost the economy, the market interprets this as indicating an economic recession in the US. This will affect market expectations for crude oil demand. Hence, interest rates have indirect effects on crude oil prices in certain ranges. Cologni and Manera (2008) indicate that the impact of crude oil prices in certain countries (e.g., the US) is partly due to monetary policies. Only in certain ranges do interest rates lead the US dollar and the US dollar leads crude oil prices. In 2001–2003, the Fed lowered interest rates 13 times to respond to the economic recession and the crude oil prices declined only moderately, perhaps due to relative demands. Since 2004, the Fed has begun to hike interest rates to curb an overheating economy and possible inflation. Meanwhile, the emergence of the BRIC nations has created massive demand for crude oil and pushed up oil prices. In 2007, the sub-prime mortgage crisis prompted the Fed to lower interest rates again: While the US dollar depreciated, crude oil prices did not seem to fall during this period. This paper infers that crude oil prices are only subject to the speculative influence of interest rate policies within certain ranges. Over the long run, crude oil prices are mainly determined by demand and supply.

Regarding price transmission effects, gold and crude oil prices lead each other above and below the threshold. In recent years, all commodity and crude oil prices have gone up in tandem, perhaps because they are both subject to the influence of a large number of macroeconomic factors, such as inflation, interest rates, and industrial production. Pindyck and Rotemberg (1990) suggest that the excess comovement of unrelated commodity prices may be due to the significant levels of strategic commodities (e.g., gold, crude oil, silver, and copper) used by different industries. This is why gold and crude oil prices lead each other.

As far as the feedback effects of gold and crude oil prices on interest rates, both gold and crude oil prices lead interest rates below and above the threshold. Since long-term inflation is one of the issues the monetary authorities watch closely, when crude oil prices rise to a certain level, the Fed may adopt tightening monetary policies to cool down the economy, that is, raise interest rates to combat the inflation resulting from rising oil prices. According to the Fed, commodity price information can thus shed light on policymaking. Regarding the feedback effects of gold and crude oil prices on US dollars, both gold and crude oil prices lead the US dollar above the threshold.

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