

The Links between the Price of Oil and the Value of US Dollar

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ABSTRACT: Using monthly data, this paper studies the cointegration between the real price of oil and the real effective exchange rate of US dollar allowing for structural breaks. Contrary to the conclusion from previous literature, this paper finds that the cointegration between the oil price and the value of US dollar does not significantly exist unless the effects of two structural breaks in the past, November 1986 and February 2005, are controlled for.

Keywords: Oil price; Exchange rate; Cointegration

JEL Classifications: C32; F31; Q43

1. Introduction

The US dollar is typically used as the invoicing currency in international crude oil trading. Therefore, the dollar crude oil price is believed to be influenced by fluctuations in the value of US dollar. At least since 2002, the dollar price of oil has tended to rise at the same time that the US dollar has depreciated, in terms of real effective exchange rate (hereinafter referred to as the 'US dollar exchange rate'). This raises the possibility that co-movements between the price of oil and the US dollar exchange rate exist in the long run, and a depreciation of the US dollar should be associated with a rise in the dollar price of oil. Depreciation of dollar makes oil relatively cheaper in countries with appreciating currencies such as the euro and yen (Alhajji 2004). If the US dollar exchange rate really matters in setting the price of oil, it is appropriate to raise the question of the choice of currency for oil invoicing. Therefore, it is interesting and important to investigate the linkage between the dollar oil price and the US dollar exchange rate. With a longer and more up-to-date data, I do not find a long-run relationship between the price of oil and US dollar exchange rate, which is also found by Ferraro et al. (2011), and Chen et al. (2013). However, in this paper, I show that the long-run relationship significantly exists with the consideration of two breakpoints. One is in November 1986, when the oil pricing system changed from the refinery margin netback to formula netback pricing. The other one is in February 2005, when the world oil demand increased, particularly coming from the emerging economies.

A lot of papers have studied the long-run relationship between the price of oil and the US dollar exchange rate, and most of them only find causality moving from the price of oil to the exchange rate, not vice versa, which is not consistent with the analysis mentioned above. Some have studied the theory underlying the links between the price of oil and the US dollar exchange rate. For the effect of the oil price on the dollar exchange rate, Krugman (1983) and Golub (1983) explain such effects through the balance of payments. They both argue that a rise in the oil price will bring a wealth transfer from oil-importing countries to oil-exporting countries, and its impact on the exchange rate will depend on the portfolio preferences of oil-exporting countries in the short run, but will depend on their import preferences in the long run. They find that oil-exporting countries, typically OPEC countries, have a preference for US dollar-denominated assets. When the oil price rises, it increases the income of oil-exporting countries. Then, in the short run, these countries use the higher income to purchase more US dollar-denominated assets, which causes the US dollar to appreciate. In the long run, higher income will transfer into higher expenditure. For example, suppose these countries use the higher income to purchase European goods. Then they have to exchange US dollars for Euros, which eventually leads to a depreciation of the US dollar.

The effect of the dollar exchange rate on the price of oil can be found in Haughton (1989) and Alhajji (2004). An exogenous exchange rate change will bring about an oil price adjustment separately on the oil demand and oil supply sides. On the demand side, once the dollar depreciates, oil in other countries is cheaper in local currencies, which means a higher quantity demanded for oil, and hence a higher world demand for oil. Then the oil price rises. On the supply side, the oil exporting countries lose purchasing power when the dollar depreciates, and in order to defend losing purchasing power, they may curtail supply, which will increase the oil price.

Other researchers have used econometric techniques to investigate the link between the price of oil and the US dollar exchange rate. Some of them just focus on the bilateral linkage between these two by employing cointegration tests and error correction models to explore the long-term relationship, and the direction of causality between them over time. They all find that these two series are cointegrated, and the oil price causes subsequent changes in the US dollar exchange rate (Amano and Norden, 1998a; Amano and Norden, 1998b; Benassy-Quere et al., 2007; Chaudhuri and Daniel, 1997).

Chen and Chen (2006) use panel data covering G7 countries from 1972 to 2005 to explore the relationship between the real oil prices and the real exchange rate. Using a panel cointegration test and panel prediction regression, they show that the real oil price may have been the dominant source of real exchange rate movements during this period.

Olomola and Adejumo (2006) investigate the relationship between the real oil prices and real exchange rate by including other important macroeconomic variables such as output, inflation, and the money supply, especially in Nigeria, in a cointegrated Vector Autoregressive (VAR) model. They examine the effect of an oil price shock on Nigeria's currency against the US dollar exchange rate, output, inflation and the money supply. They find that an oil price shock does have a significant effect on the exchange rate as well as the money supply in the long run, but not on the output and inflation in Nigeria.

Lizardo and Mollick (2010) use the same method to explore the oil price-exchange rate relationship. They consider the US dollar exchange rate against the currencies of oil-importing countries and oil-exporting countries, respectively; they also add the US relative money supply and relative industrial production into their cointegrated VAR model. They find that increases in real oil prices lead to a significant depreciation of the USD against net oil exporter currencies, such as Canada, Mexico, and Russia, but an appreciation against oil importers, such as Japan.

Huang and Guo (2007) construct a structural VAR model to study the effects of oil price shocks, demand shocks, supply shocks and monetary shocks on China's real exchange rate. They find that real oil price shocks would lead to a minor appreciation of the long-term real exchange rate due to China's lesser dependence on imported oil than its trading partners included in the RMB basket peg regime and rigorous government energy regulations.

Narayan et al. (2008) use daily data on oil prices and the Fiji-US dollar exchange rate for the period 2000-2006, to study the links between the volatility of oil prices and the volatility of the Fiji-US dollar exchange rate, employing a GARCH model. They find that a rise in the oil price leads to an appreciation of the Fijian dollar vis-à-vis the US dollar.

Most of the above literature also investigates the direction of causality between the price of oil and the US dollar exchange rate. All the above-mentioned empirical studies only find an effect of the price of oil on the exchange rate, but not vice versa, which is not consistent with the analytical consensus. Still, there is some research focusing on the effect of the exchange rate on the price of oil.

Novotny (2012) investigates the effect of nominal effective exchange rate of the US dollar on the Brent oil price, by including the US dollar industrial production, short-term real interest rates, oil inventories and rate of use of oil refineries in the USA in the model. The findings provide evidence of an inverse relationship between the US dollar exchange rate and the Brent crude oil price, which may be due to the additional speculative demand for oil as an alternative investment instrument.

Using cointegration tests and error correction models, Sadorsky (2000) investigates the relationships among futures prices for crude oil, heating oil, and unleaded gasoline, and the US dollar exchange rate. The results show a long-run equilibrium relationship between these four variables, and the causality is from exchange rate to those energy futures prices.

Zhang et al. (2008) investigate the volatility spillover effect of the US exchange rate on the price of oil, using cointegration and ARCH-type models as well as the methodology of Granger causality in

risk that is employed by Hong (2002) for risk effects. They mainly find that US dollar depreciation is a key factor in driving up the international crude oil price.

In summary, most previous papers find a cointegrated long-term relationship between the price of oil and the US dollar exchange rate, with the causality running mostly from the price of oil to the exchange rate. In this paper, I pay attention mainly to the price of oil as a dependent variable, and study further the interaction between the spot price of oil and the US dollar exchange rate in the long term by employing a cointegration test and error-correction model, with consideration for possible structural breaks. Since the sample is over a long time period, from 1973, it is quite likely that the relationship between the oil price and the exchange rate may have had some structural breaks during the sample period. One approach to identify the break points is to run Chow-type tests using some of the well-known historic events or shocks as the potential break points. However, the oil market is complicated, and there are various shocks in the history of the crude oil price, and there is no easy way of judging which of them are relatively more important and thus need to be considered as the potential break points. Moreover, the oil prices and the exchange rates are likely to be non-stationary time series, which means that the usual Chow tests may not provide reliable test results.

This paper follows that data-driven approach proposed by Gregory and Hansen (1996). This method allows us to identify unknown break points in the cointegration relationship without exogenous information on potential break points. Once a significant cointegrating relationship is found, then I use the error correction model to investigate the dynamics of the response of the price of oil to a deviation from the long-term relationship. With a longer and more up-to-date dataset than those in previous studies, this paper re-examines the linkages between the real WTI (West Texas Intermediate) spot oil price and the real trade-weighted US dollar exchange index. In contrast to the previous empirical studies, I fail to find any significant cointegration between those two variables when structural breaks are not allowed. Once structural breaks are allowed by the method of Gregory and Hansen (1996), however, I find a significant cointegration with two break points. It turns out that these two break points coincide with important historic events.

The remaining part of the paper is organized as follows. Section 2 introduces the background of the crude oil market. Section 3 introduces the methodology - the standard cointegration tests, the cointegration test with a structural break, and the error correction model. Section 4 describes the data selection. Section 5 presents the empirical findings. Section 6 discusses findings. Section 7 concludes.

2. Background of the Crude Oil Market

During the 1800s, one of the main sources of light was whale oil. But by 1859, overfishing substantially decreased the whale population, which made whale oil very expensive. Then crude oil emerged as a substitute for whale oil. The world's first oil well was developed in Pennsylvania, which is often considered as the beginning of the modern oil industry. From then until 1870, when the Standard Oil Company was founded, the price of crude oil dropped from \$375 to only \$2.60 per barrel in 2009 dollars because of overproduction.

In the early twentieth century, crude oil was even more overproduced and oversupplied since more discoveries were made in Texas and Oklahoma in the US, as well as in other parts of the world.¹ During that period, crude oil was not only used for lighting lamps, but also for transportation fuel and other oil products such as asphalt, plastics, and petrochemicals. The price stayed low due to the overproduction (Downey 2009).

In order to prevent the price going down continually, the major oil companies² had a meeting in 1928 and signed the As-Is Agreement. In this agreement, they agreed to collude instead of compete, to assure that each of them could earn a profit in the crude oil business. But that agreement did not last long because those oil companies had different market shares and strong incentives to cheat for a higher profit. Later, the price was truly stabilized when the US government required the Texas Railroad Commission (TRC) and the oil producing states to restrict production in the 1930s.

¹ Those parts include the shores of the Caspian Sea, Baku, Russia, etc.

² The major oil companies were Royal Dutch Shell, Anglo-Persian Oil (now BP), Standard Oil of New Jersey (now ExxonMobil), Gulf Oil (now part of Chevron and BP), and Standard Oil of Indiana (now part of BP).

Until the 1970s, the world oil industry was mainly controlled by The Seven Sisters,³ who made a deal with non-US oil producing countries on a 50/50 profit sharing rule. Under this rule, The Seven Sisters bought the crude oil from those oil producing nations at a posted price determined by The Seven Sisters, and shared the profit half and half with the nation. However, the 50/50 rule did not satisfy some oil-producing countries. During the 1950s, Iran argued about increasing its share to about 55%.

The 50/50 rule finally crashed when US oil production reached a peak in 1970 and OPEC⁴ began to take the control of world oil production in the early 1970s (Downey 2009). But it only succeeded in raising the profit share of producing countries from 50% to 55% (the Tehran Agreement in 1971). The posted oil price was still determined by the major oil companies and fixed stably in US dollars even though the currency depreciated after the gold-dollar standard system broke down in 1971.

But such fixed pricing system eventually collapsed in 1973 with the Yom Kippur War⁵. The Arab OPEC members proclaimed an oil embargo, cutting the oil supply to the US, which caused the crude oil price to jump from \$14 to over \$50 per barrel in 2009 dollars. Since then, OPEC has realized its power to affect the world oil price. This was the first oil crisis.

The second oil crisis occurred between 1979 and 1981, following a strike by Iranian oil workers in 1978. This event curtailed the oil production of Iran. And also due to the outbreak of the Iran-Iraq War, oil production in these two countries declined dramatically, which pushed the oil price up to over \$90 per barrel in 2009 dollars.

During the early 1980s, Saudi Arabia cut its production in order to bring production back to more optimal rates. But other OPEC countries realized that they had spare production capacity, and cheated on their quotas by increasing their oil production. In 1984, Saudi Arabia changed its official posted prices to a netback pricing formula⁶, which connects the crude oil price directly to finished oil products like gasoline and diesel, at the same time, increased their production. The reformed pricing system and greater oil production made the oil price drop to \$28 per barrel in 2009 dollars. Particularly after the futures exchange for crude oil⁷ came out in 1983, the pricing mechanism became more transparent between sellers and buyers.

However, OPEC's spare production capacity disappeared after 1990, which indicated it was not as easy as before to keep oil production at a steady pace in order to satisfy world oil demand. The invasion of Kuwait by Iraq in 1990 led the oil price to rise to \$33 per barrel. In the 1990s, the price of crude oil became more volatile. The price even dropped to around \$10 per barrel in 1997 in the wake of the Asian Financial Crisis. Since 2000, the price has climbed steadily mainly due to the increasing demand from emerging economies. It reached its peak, which was \$145 per barrel, around 2008⁸. Some researchers argued that some of the rise of oil price was due to speculation in the futures exchanges market and investment behaviors by using crude oil as an investment asset to diversify the risk of the depreciation of the US dollar (Novotny 2012). Table 1 summarizes the events in the history that had significant impacts on the oil price.

As described below, since the oil industry has been experiencing series of events, the price of oil has been volatile over a long time period. It is reasonable to re-examine the relationship between the oil price and US dollar exchange rate by considering any structural breaks from 1973.

³ The Seven Sisters were Standard Oil Company of New Jersey, Standard Oil Company of New York, Standard Oil of California, Texas Company, Royal Dutch Shell, Anglo-Persian Oil Company, and Gulf Oil.

⁴ OPEC (the Organization of Petroleum Exporting Countries) was initially founded by Saudi Arabia, Kuwait, Iran, Iraq, and Venezuela. Later nine more countries joined it. They are the United Arab Emirates, Qatar, Libya, Algeria, Indonesia, Nigeria, Angola, Ecuador and Gabon. Gabon and Indonesia subsequently left. So there are a total of 12 countries remaining nowadays.

⁵ The war was between Israel and Arab states led by Egypt and Syria. The US was the main supporter of Israel.

⁶ Under this pricing rule, oil producers link the selling price of oil to a free market oil benchmark price. Benchmark prices are usually set when business closes every day on futures exchanges based on spot trading of physical crude oil at different locations around the world.

⁷ An oil futures exchange market is a place that people can purchase or sell the crude oil for delivery at a certain date in the future given a fixed price.

⁸ Source: The New York Merchantile Exchange

Table 1. History of oil price shocks between 1970s and 2000s

Year	Event	Oil Price Change (in 2009 dollars)
1973	The Yom Kippur War OPEC embargo	Increased from \$14 to over \$50
1979-1981	Iranian Revolution Iran-Iraq War	Increased to over \$90
1981-1983	Netback pricing formula The futures exchange market emerges	Decreased to \$28
1990	The invasion of Kuwait	Increased to \$33
1997	Asian financial crisis	Decreased to \$10
2008	World financial crisis Speculative behavior	Increased to \$145

3. Methodology

This paper mainly uses an Engle-Granger (1987) residual-based cointegration test to examine the long-run equilibrium relationship, between January 1973 and June 2010, between the price of oil and the price of the U.S. dollar. The Johansen and Juselius (1990) rank cointegration test is also employed for confirmation.

The procedure for the Engle-Granger technique has three parts: (1) unit root test; (2) cointegration test; (3) ECM (error correction model). I now consider each in turn.

3.1. Unit Root Test

One of the basic properties of time series data is nonstationarity. Therefore, checking for a unit root must be done before the cointegration test. If both series are nonstationary and integrated of the same order, a cointegration test can then be employed. In this paper, augmented-Dickey-Fuller (ADF) and Phillips-Perron (PP) tests are used to check for unit roots.

3.2. Standard Residual-based Cointegration Test

The second step is to explore the cointegration relationship between the oil price and the US dollar exchange rate. A cointegration regression in levels for the two time series is performed using the simple equation below.

$$Y_t = \alpha + \beta * X_t + \varepsilon_t, \quad (1)$$

where Y_t is the real price of oil, X_t is the real trade-weighted US dollar exchange rate index, and ε_t is the residual.

This regression is estimated by OLS. After the estimation, the residuals from Equation (1) are checked for stationarity. If the test results show that the residuals are stationary, I may conclude that these two time series are cointegrated and the linear combination of them is stationary. Then the error correction model may be used to examine for Granger causality in the third step.

3.3. Error Correction Model

The general error correction model is shown in the following:

$$\Delta Y_t = c_1 + c_2 * \Delta X_t - \lambda * \varepsilon_{t-1} + u_t, \quad (2)$$

where ΔY_t and ΔX_t are the first differences of the oil price and the US dollar exchange rate, respectively, ε_{t-1} is the first lagged residual from the cointegration regression, and u_t is an error term, which should be white noise.

From Equation (2), if the coefficient of ΔX_t is significant, or the coefficient of the lagged residual series (λ) is significant, the null hypothesis that ΔX_t does not Granger cause ΔY_t is rejected. The coefficient on the lagged residual series, $-\lambda$, helps determine whether a time series that has deviated will return to the long-run equilibrium.

3.4. Residual-Based Cointegration Test with a Structural Break

Gregory and Hansen (1996) consider the idea of testing for cointegration allowing for the existence of a possible structural break. Their method is a residual-based technique. They suggest three models, namely:

Model 1: Cointegration with a level shift

$$Y_t = \alpha + \beta * X_t + \gamma * dum_t + \varepsilon_t \quad (3)$$

Model 2: Cointegration with a level shift and trend

$$Y_t = \alpha + \beta * X_t + \gamma * dum_t + \mu * t + \varepsilon_t \quad (4)$$

Model 3: Cointegration with a regime shift

$$Y_t = \alpha + \beta X_t + \gamma dum_t + \mu t + \delta X_t dum_t + \varepsilon_t \quad (5)$$

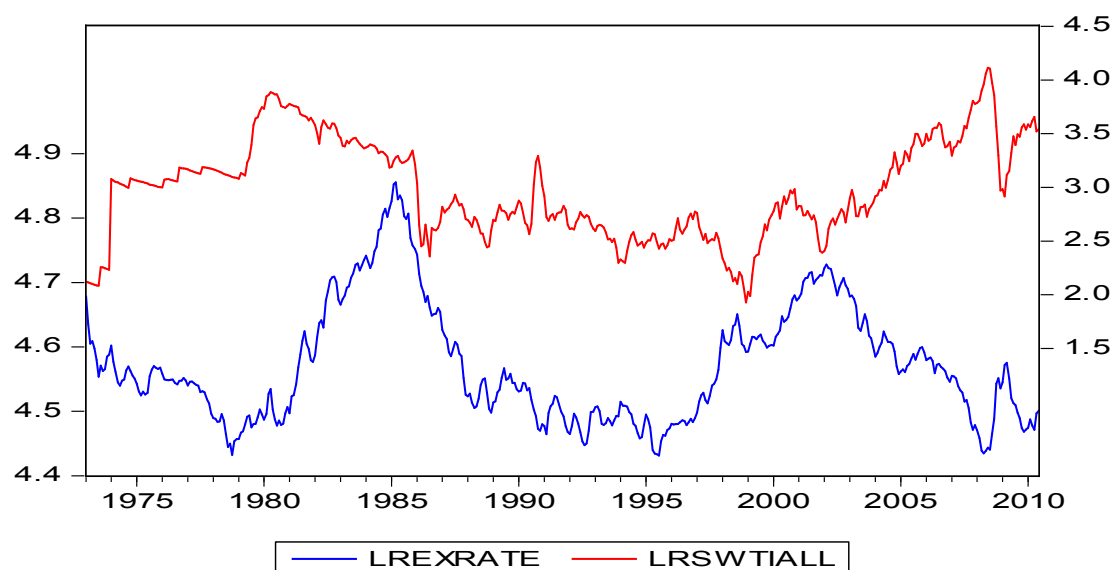
Here dum_t is a dummy variable that is equal to 1 if $t > T_b$, and zero otherwise, where T_b is the structural breaking point.

I need to estimate models 1 – 3 by OLS and get the residuals for every suspected breaking point, then pick the one with the smallest value of the conventional ADF test statistic, denoted by $ADF^* = \inf ADF(\tau)$ ⁹, to compare with the critical value given by Gregory and Hansen (1996). If ADF^* is greater than the critical value, I reject the null of a unit root, that is, the residuals are stationary, and a long-run equilibrium relationship between the two series exists.

4. Data Selection

The data are monthly observations from January 1973 to June 2010. The real effective US dollar exchange rate (*lrexrate*) is defined as the real trade-weighted value of the US dollar against the currencies of a broad group of major US trading partners, and comes from the Federal Reserve.¹⁰ The real price of crude oil (*lrswtiall*) is the US dollar spot price per barrel of West Texas Intermediate Crude Oil deflated by the US CPI. The oil price data are provided by the Federal Reserve Bank of St. Louis. Both variables are used in logarithmic form. Figure 1 shows both series during the whole time period, in logarithmic form. Several observations can be made. First, compared with the real effective exchange rate of the dollar, the real oil price is more volatile¹¹, with some significant breakpoints over time. Second, generally both series seem to move in the opposite directions, most obviously since 2004: the increase in the oil price was associated with a decrease in the value of the dollar (dollar depreciation).

Figure 1: Real WTI oil price (right axis) and real effective US dollar exchange rate (left axis) in logarithm



5. Empirical Analysis

From an inspection of Figure 1, it is not easy to tell whether the two time series are cointegrated or not. But it is clear that the price of oil is more volatile than the US dollar exchange rate. The real US dollar exchange rate seems stationary with no deterministic trend during the whole time period. The first step is to check formally whether the time series are stationary or not. In this paper, I use the ADF

⁹ inf: infimum of a subset of some set is the greatest element that is less than or equal to all elements of the subset. For finite sets, the infimum and the minimum are equal. So here, it indicates the minimum of the ADF statistics.

¹⁰ The broad currency index includes the euro area, Canada, Japan, Mexico, China, United Kingdom, Taiwan, Korea, Singapore, Hong Kong, Malaysia, Brazil, Switzerland, Thailand, Philippines, Australia, Indonesia, India, Israel, Saudi Arabia, Russia, Sweden, Argentina, Venezuela, Chile, and Columbia.

¹¹ The standard deviation of the real oil price is 10.41, the standard deviation of the real effective exchange rate is 9.14.

and PP tests to check for unit roots in each time series. From the results contained in Table 2, I can conclude that both series are integrated of order one, which implies that they are not stationary in levels, but stationary in the first difference. This means that I can employ a cointegration test to explore the long-run relationship between these two in the second step.

Table 2. Unit root tests (Jan 1973 – June 2010)

	lrexrate (p-value)		lrswtiall (p-value)	
	Level (with constant)	First difference (without constant)	Level (with constant)	First difference (without constant)
ADF	0.244	0.000*	0.072	0.000*
PP	0.252	0.000*	0.112	0.000*

Note: * means rejection of the null hypothesis of a unit root at 5% significance level.

5.1. Standard Cointegration Test

In this paper, I use a residual-based cointegration test to check if both series are cointegrated, and then use the Johansen Trace and Max-Eigen cointegration tests for confirmation. According to the residual-based cointegration test methodology, first I need to run a linear regression of the oil price on the US dollar exchange rate, and test the unit roots for the residuals from the regression. The estimated equation is

$$lrswtiall_t = 3.301 - 0.069 * lrexrate_t + \varepsilon_t, \quad (6)$$

It is found that the real US dollar exchange rate has a negative relationship with the real oil price. Table 3 below shows the unit root test of the residual series from Equation (3).

Table 3. Unit root test of the residual series

	ADF test statistic	Critical value		
		1%	5%	10%
Residual series	-2.712	-3.921	-3.350	-3.054

Note: The critical values are for cointegrating relations (with a constant in the cointegrating vector) estimated using the Engle-Granger methodology. Critical values are interpolated using the response surface in MacKinnon (1991).

From Table 3, I fail to reject the null of a unit root for the residuals, which indicates that the residuals are not stationary. This seems to imply that there is no cointegration relationship between the price of oil and the US dollar exchange rate. But for confirmation, I also use the Johansen Cointegration test to recheck this relationship. Table 4 shows the statistics. It is found that both the trace and max-Eigen statistics are not significant for the null hypothesis of rank being zero, which also implies that there is no cointegration between those two variables. Thus a simple long-term relationship between the oil price and the US dollar exchange rate did not exist in the period in question, which was from January 1973 through June 2010.

Table 4. Johansen Cointegration test (Jan 1973 – June 2010)

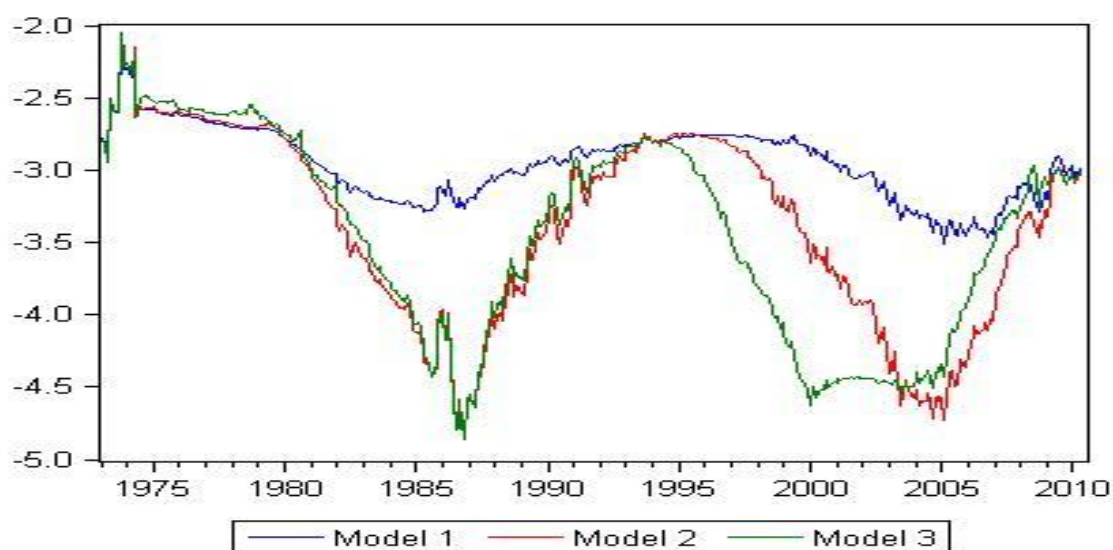
Number of Lags = 1

Hypothesized No. of CE (s)	Trace statistic (p-value)	Max-Eigen statistic (p-value)
R=0	0.109	0.336
R<=1	0.030	0.030

5.2. Cointegration Test with Structural Break

I now take every observation as a possible breakpoint, except the first and last ones. Thus I have a total of 448 possible dummy variables for those possible breakpoints, and need to estimate Models 1 – 3 for each dummy variable. The values of the ADF test statistic of each model are then calculated by assuming no intercept and time trend for the residuals. Hence, I can get three ADF-value series for my three models with every possible breakpoint. Figure 2 shows the values of ADF test statistic of each model.

Figure 2. Values of ADF test statistic of residuals



Note: From Model 1 (M1), $lrswtiall$ is a function of constant, $lrexrate$, and a dummy variable representing the breakpoint in February 2005 (Feb05); from Model 2 (M2), $lrswtiall$ is a function of constant, $lrexrate$, $trend$, and a dummy variable representing the breakpoint in November 1986 (Nov86); from Model 3 (M3), $lrswtiall$ is a function of constant, $lrexrate$, $trend$, a dummy variable representing the breakpoint in November 1986 (Nov86), and an interaction between the dummy and $lrexrate$ ($lrexrate86$).

From Figure 2, I can get the value of $ADF^* = infADF(\tau)$. According to the ADF^* values, for Model 1, the breakpoint is in February 2005 (Feb05). For Model 2 and Model 3, the breakpoint is in November 1986 (Nov86). The estimated models are shown in Table 5:

Table 5. Estimated regressions of Models 1-3

	const	lrexrate	trend	Nov86	Feb05	lrexrate86	BIC	R-square
M1	0.902	0.435	-	-	0.641	-	1.040	0.23
M2	10.209	-1.595	0.004	-1.307	-	-	0.654	0.48
M3	8.884	-1.306	0.004	1.542	-	-0.622	0.660	0.49

Note: $lrexrate86$ is the interaction between “Nov86” and “lrexrate”.

Table 6 shows the ADF^* values of the residuals from the above three models. From Table 6, the ADF^* value of Model 1 is absolutely smaller than all the critical values, which implies that I fail to reject the null of a unit root for the residuals. In other words, there is no cointegration between those two variables even with a breakpoint in February 2005. However, from Models 2 and 3, I can reject the null at the 10% confidence level. Of the three models, Model 2 has the lowest value of BIC, suggesting that Model 2 is the most appropriate one.

Table 6. ADF^* values of cointegrating residuals with structural breaks

Model	ADF^* test statistic	Breakpoint	Critical value		
			1%	5%	10%
1	-3.510	Feb 2005	-5.13	-4.61	-4.34
2	-4.860	Nov 1986	-5.45	-4.99	-4.72
3	-4.864	Nov 1986	-5.47	-4.95	-4.68

5.3. Error Correction Model

Since a cointegration relationship allowing for a structural break is found from the above step, I can estimate an ECM equation. According to Equation (2), the ECM from a residual-based analysis is represented as follows:

$$\Delta lrswtiall_t = 0.002 - 0.420*\Delta lretrate_t + 0.228*\Delta lrswtiall_{t-1} - 0.044*e_{t-1} + u_t \quad (7)$$

(0.538) (0.169) (0.000) (0.000)

where $\Delta lrswtiall$ and $\Delta lretrate$ are the first differences of $lrswtiall$ and $lretrate$, and e_{t-1} is the first lagged residual from Model 2. The coefficient of e_{t-1} represents the speed of adjustment, which measures the response of the dependent variable in the short term to the previous period's deviation from long-run equilibrium. The coefficient of $\Delta lretrate$ is not significant, while the estimated coefficient of the lagged residuals from the cointegration relationship is significant at the 1% level. Hence, the short-run real price of oil is significantly affected by the deviation from long-run equilibrium in the previous period. Also, Granger causality from real exchange rate to real price of oil could not be rejected. If the coefficient of $\Delta lretrate_t$ and the coefficient of e_{t-1} are both equal to zero, the real exchange rate does not Granger cause the real price of oil. Since the coefficient of e_{t-1} is quite significant, Granger causality could not be rejected. The speed of adjustment parameter measures how fast the short-term dynamics of the real price of oil respond to a deviation from the long-term relationship. Here the speed value is very small (0.044), suggesting that about 4% of the deviation from equilibrium is corrected per month.

5.4. Cointegration with two dummy variables

The Gregory and Hanson method only considers one structural break in the cointegration. But from Figure 2, it is clear that two possible breakpoints exist, which are in November 1986 and February 2005, if I take Model 2 as our best model. Meanwhile, the cointegration test statistic for model 2 is only significant at the 10% level, which is not strong evidence for the existence of cointegration. For confirmation, I incorporate those two possible breakpoints into Model 2 with two dummy variables. The estimated equation is as follows:

$$lrswtiall_t = 6.663 - 0.788*lretrate_t - 0.941*Nov86 + 0.544*Feb05 + 0.002*t + \varepsilon_t \quad (8)$$

The test statistic and critical values for cointegration are shown in the following table:

Table 7. Cointegration test with two dummy variables

	ADF test statistic	Critical value		
		1%	5%	10%
Residual series	-4.689	-5.249	-4.621	-4.300

Note: The critical values are from Zhang, Dickinson and Barassi (2006) who report the critical values obtained by Monte Carlo Simulations with two dummy variables.

The ADF statistic for residuals is significant at the 5% level. Therefore, I can reject the null hypothesis of no cointegration. In other words, considering two breakpoints, at November 1986 and February 2005, there is a significant long-term equilibrium relationship between the real price of oil and the real US dollar exchange rate.

5.5. ECM with two dummy variables in the cointegration relationship

With two possible breakpoints, I have a different error correction model. The estimation result is as follows:

$$\Delta lrswtiall_t = 0.002 - 0.358*\Delta lretrate + 0.232*\Delta lrswtiall_{t-1} - 0.052*e_{t-1} + u_t \quad (9)$$

(0.527) (0.241) (0.000) (0.000)

Table 8. Residual (u_t) Diagnostic Tests

LM(1)	0.4136	ARCH(1)	0.0649
LM(4)	0.5757	ARCH(4)	0.4859
LM(8)	0.5727	ARCH(8)	0.8832

Note: Reported values are p-values. LM(k) represents Lagrange Multiplier tests for autocorrelation of order k. ARCH(k) represents autoregressive conditional heteroskedasticity tests of order k.

The coefficient of the first-differenced US dollar exchange rate is not significant, but does have the expected sign. The coefficient of the lagged residuals is significant at the 1% level, indicating that the real exchange rate Granger causes the real price of oil. Still, it is noteworthy that the value of the speed

of adjustment parameter is small. Table 8 shows the diagnostic tests on residuals. The results indicate little evidence of autocorrelation and autoregressive conditional heteroskedasticity.

6. Further Discussion

I now return to the two significant break points within the full sample period to investigate how each of them is related to major events in the oil market. The first breakpoint was in November 1986. In August 1985, as Downey (2009) explains, Saudi Arabia linked the sale price of its crude oil to open market prices for finished products such as gasoline and diesel. Saudi Arabia had been restricting its output to maintain the price of oil. When it stopped restricting its production, the price of oil collapsed more than 70% by 1986. This change moved the pricing system of crude oil from the refinery margin netback to formula netback pricing, which is much more transparent as it is based on an openly-traded free-market crude oil benchmark. This pricing mechanism is still in use today. Therefore, this can be important evidence of a possible break in the long-run relation between the price of oil and the US dollar exchange rate.

As for the other breakpoint, in February 2005, Downey (2009) mentions that OPEC's excess capacity disappeared, especially after about 2000. And by 2005, world oil demand had caught up, especially from emerging economies, so OPEC's excess capacity could not satisfy the rapidly-increasing demand around the world¹². The increasing demand was mostly caused by the fast growth of emerging economies, especially China, where the rapid expansion of industry, and transportation required more oil (Novotny 2012; EIA 2012¹³). However, China's increasing demand for oil did not suddenly come up just in 2005. From Figure 2, the lowest points of Model 2 and Model 3 are not exactly consistent. Contrarily, the whole period between 2000 and 2006 is lower than the other parts, indicating that there might be a structural break *period* during that time, which affects the long-term relationship between the price of oil and US dollar exchange rate. Since late 1990s and early 2000s, China has showed a gradual increase of the oil consumption mainly because of more automobile purchases and faster industry constructions. Between 1995 and 2004, China accounted for one-fourth of world incremental oil demand, and one-third in 2004. China has seen oil consumption grow by 8% yearly since 2002, doubling from 1996–2006. Meanwhile, China has also amassed the second largest official reserves in foreign currencies (Benassy-Quere et al. 2007). Even though, in July 2005, the Chinese government officially moved its exchange-rate regime to a managed float based on a basket of foreign currencies, the Chinese currency is still practically pegged to the US dollar. Hence, a depreciation of the US dollar positively affects Chinese economic activity. Benassy-Quere et al. (2007) consider the role of China in the oil-exchange rate relationship. By constructing a theoretical model, they demonstrate that China plays a significant role in influencing the relationship.

7. Conclusion

In this paper I have analyzed the relationship between the price of oil and the US dollar exchange rate. Extending the standard cointegration procedure, I consider possible structural breaks in the full sample. Using an extended cointegration test allowing a single breakpoint, I cannot reject the null of no cointegration in the underlying model. However, I do find some evidence of a significant cointegration relationship when allowing for two structural breaks, by extending the standard cointegration test to include two dummy variables. In the full sample period, the first possible event is the change in the crude oil pricing mechanism associated with institutional innovations from Saudi Arabia around 1986. The second break is associated with the shortage of capacity in OPEC, coupled with increasing demand from China, around 2005. Both breakpoints are statistically significant, and the extended model suggests the existence of a long run relationship between the price of oil and the US dollar exchange rate. The implication is that although there is a stable relationship between the price of crude oil and the value of the US dollar in real terms, the relationship is subject to structural breaks over time.

¹² World crude oil demand grew an average of 1.76% per year from 1994 to 2006, with a high of 3.4% in 2003-2004. (World Energy Outlook 2009)

¹³ U.S. Energy Information Administration:

http://www.eia.gov/finance/markets/reports_presentations/correlation_paper_final.pdf

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