Nonlinear Oil Price Dynamics and the Impact of Heterogeneous Agents*

Chung-Wei Kao**, David Kleykamp***, and Jer-Yuh Wan****

Abstract

This study uses a nonlinear agent-based model to examine the impact of speculative behaviors on WTI oil prices since 2000. The purpose is to find the consequences of 'financialization' of the oil market, especially after oil prices exhibited roller-coaster dynamics in recent years. The major conclusions are: (1) A structural break exists during the sample period from 2000/01/04 to 2012/03/27 and oil dynamics can be divided into two distinct periods constituting quite different investment environments. (2) The first period is characterized as a 'high return, low risk' period, while the second is a 'low return, high risk' state. The breakpoint is supported by existing literature which claims that huge flows of index-funds have change the oil market generating increasingly large trading volumes. (3) In the first period, oil price is basically driven by agent behavior. Fundamentalists play a crucial role in market stabilization. Price follows closely to its long-run equilibrium level. (4) In the

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second period, financial market conditions appear to explain oil price fluctuations. Fundamentalists lose confidence and stop trading when price deviations increase. Chartists' chase-and-sell strategies cause a wider range of surge and slump. Evidence shows that ‘financialization’ has generated greater speculation in oil and larger departures from fundamental pricing.

Keywords: Heterogeneous Agent Models, Nonlinear Modeling, WTI Oil Price, Chartist and Fundamentalist

JEL Classification: G15, O13, Q43

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I. Introduction

The world oil market experienced dramatic price changes during the past decade, stimulating an enormous amount research devoted to explaining such large fluctuations. One strand of these studies claims that the bulk of increases in oil prices can be attributed mainly to changes in fundamental factors. For example, the significant increase in world oil demand, disruptions in oil supplies, and (perhaps) the depreciation of the US dollar can explain the oil surge during 2005-2007.[1] The slow economic growth following the 2007-08 crisis caused continuous falls in oil price. Yet another strand of research argues that the substantial variations in oil price cannot be satisfactorily explained by economic fundamentals alone. Kaufmann and Ullman (2009) contend that oil prices respond to fundamentals, but their volatility is nevertheless exacerbated by speculation. Coleman (2012) finds a positive link between oil price and speculative activity. Cifarelli and Paladino (2010) conclude that a speculation-driven model may better fit oil prices than one that uses fundamental factors alone. These results have induced debate on such questions as whether financial investors have increased their interest in commodity markets, and whether these interests have caused commodity prices to disconnect from their fundamentals. In short, researchers are increasingly

[1] Hamilton (2009) examines the oil spikes between 2005 and 2007 and concludes they were primarily due to the failure of global production to increase sufficiently. The strong demands from China, the Middle East, and other newly industrialized nations encourage oil peak. Kesicki (2010) elaborates on details of the oil price crises 30 years ago and suggests that high demand growth, low investments in new oil fields, and a weak US dollar explains the oil surge.

asking whether or not the oil market has been so ‘financialized’ that the structure of the market for oil has substantively changed. Many now believe that crude oil should no longer to be regarded as a commodity to be used, but has come to be regarded instead as financial asset for hedging against adverse conditions (Bhar and Malliaris, 2011).

A conference organized by the Research Department of the International Monetary Fund and University of Oxford was held on 2013/09/20-21, in which an in-depth discussion of the ‘financialization of commodity markets’ was addressed. The main conclusion arrived at by participants was an acceptance of the financialization of commodity markets as a welcome development. But the conclusions also recognized that the ‘financialization of commodity markets’ might open up the possibility for noisy trading and momentum strategies which might significantly affect prices. It remains a matter of debate whether such trading behavior played a role in the acceleration of commodity prices between 2005 and 2008 (Arezki et al., 2014).

There are various methods proposed in the literature to measure the extent and consequence of speculative activities. For example, Coleman (2012) uses the ratio of turnovers of oil futures to physical sales as the proxy for speculative activities. Fan and Xu (2011) and Büyükşahin and Robe (2014) use position report of the Commodities Futures Trading Commission (CFTC). The CFTC report was widely challenged owing to the failure to distinguish active speculators from non-reporting traders and reporting noncommercial traders (Cifarelli and Paladino, 2010; Hamilton and Wu, 2014). In particular, Hamilton and Wu (2014) estimated risk premium changes in order to trace the impact of speculative activities. Cifarelli and Paladino (2010) used an asset-pricing model and related the excess return of oil to the risk premiums on stock and US dollar exchange rate markets. In such models the presence and degree of speculation is noted by a positive coefficient on lagged oil return. Kilian and Lee (2014) model speculative activities by assessing above-ground crude oil inventory changes.[2]

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[2] Kilian and Lee’s model depends crucially on the quality of the oil inventory data which is notoriously difficult to secure accurately for global crude oil inventories. In lieu of reliable open source global data, Kilian and Lee resort to using data provided by a private sector company.

In this study, we use a nonlinear, agent-based model, i.e. the heterogeneous agent model (HAM), to examine the influences of speculation on oil price. Our model is not novel; the HAM approach was introduced roughly forty years ago.[3] By specifying the behavior of two types of agents (viz., chartists and fundamentalists) the HAM model has proven to be capable of replicating a number of important stylized facts of financial markets, such as mean reversions, bubbles and crashes, excess volatility and volatility clustering (Hommes, 2006). The price impact of agents and their respective contributions to market stabilization can be explicitly evaluated.

Recent developments in nonlinear mathematics and computer science have encouraged an increasing volume of empirical studies using HAM (Westerhoff and Reitz, 2003; Reitz and Westerhoff, 2007; Reitz and Slopek, 2009). Among these studies, Reitz and Slopek (2009) were the first to apply HAM to the WTI oil market. Their main conclusion suggests chartists are extrapolative, bringing momentum to the oil market during the period of 1986/01-2006/12. Fundamentalists, by contrast, prevent price explosions by employing a mean-reversion strategy. Oil price can move back to its equilibrium level under the presence of active fundamentalist behavior. Following Reitz and Slopek's framework, this study employs smooth transition functions to specify the nonlinear nature of chartist's and fundamentalist's behaviors. However, we amend two assumptions in Reitz and Slopek's (2009) model. First, in addition to the existence of a trend-following strategy, we allow chartists to use a negative feedback rule – a contrarian strategy. As a portion of chartists are aware of price overshooting, they switch their trend-following strategy to a reverse trade. Second, we consider the possibility that fundamentalists may sometimes lose their confidence in a mean-reversion strategy. A rise of uncertainty may encourage fundamentalists to leave the oil market once they are sufficiently uncertain about the profitability of fundamental-based forecasts. By virtue of these amendments, we find new evidence on the relationship between speculative behavior and oil price dynamics.

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[3] The first HAM is found in Zeeman (1974), who describes the temporary bull and bear trends in stock market.

Our main conclusions can be listed as follows:

(1) Within the sample period from 2000/01/04 to 2012/03/27, we find a structural break in WTI nearby futures prices. The breakpoint, as detected by a sequence of sup Wald type tests (proposed by Bai and Perron, 1998), is pinpointed to be 2005/06/16. Agents' behavior and their impact on oil prices are quite different in the period before and after the breakpoint.

(2) Oil investors enjoy an ideal investment environment before the breakpoint due to the existence of the relatively higher returns and lower risks observed. In the meanwhile most chartists are found to be trend-followers. Fundamentalists, by contrast, restrain deviations from fundamental prices by adopting a mean-reverting strategy. This result is in line with Reitz and Slopek (2009) who suggest that fundamentalists have important contributions to market stabilization.

(3) By employing two indicators to control for currency and financial market conditions, we find changes in US dollar exchange rates, changes in stock price index, and changes in gold prices have no statistically significant impact on oil price during the period before the breakpoint. This implies the oil market is mainly driven by the interaction of heterogeneous agent behaviors in this period.

(4) When the oil market moves across the breakpoint mentioned above, oil investors are subjected to a tough period characterized by relatively low returns and high risks. During this difficult period, chartists are actively employing chase-and-sell strategies. In stark contrast to this, fundamentalists display low confidence in fundamental-based analysis, and tend to withdraw their orders when the price discrepancy (actual vs. fundamental) increases. The oil market lacks sufficient force to drive price back to its equilibrium level, resulting in large deviations from fundamentals in this period.

(5) The oil market appears to be more affected by changes in currency and financial market conditions during the period after the breakpoint. At the same time, changes in US dollar exchange rates have a positive influence on short-term oil prices, while both financial variables (i.e., gold and stock prices) significantly affect oil prices. The price of gold has an especially strong effect on the long-term oil price contract. Stock prices, on the other hand, produce a larger impact on the short-term oil price contract. These results underscore the fact

that as the oil market integrates closely with global financial markets; ‘financialization’ of oil markedly changes traders’ behavior, fostering speculation and exacerbating price deviations.

The rest of this paper is organized as follows. Section 2 constructs our empirical model, proceeding with an elaboration of the rationale motivating the behavior of agents. Section 3 describes our data and the process of specifying our STAR-GARCH model. Reasons for splitting samples and details of the BP method are introduced in section 3, part A, and results of model specifications are in part B. Section 4 provides estimation results of the two sub-periods; results for period 1 are reported in part A, and results for period 2 in part B. Section 5 states our conclusions.

II. An empirical model based on the HAM approach

Two important types of agents are usually included in HAM studies. The first group is composed of fundamentalists who know the ‘true’ value of asset and usually expect a price reversion to the fundamental equilibrium level. They buy (sell) when the price is below (above) the true value. Their investment decision is based on a combination of (long run) economic fundamentals. However, such rational and well-informed assumptions often imposed on agents might not be realistic. Traders are more likely to have bounded rationality, using simple, but satisficing, rules of thumb for their decision-making under uncertainty. One group of traders incorporated into the model are chartists, who are distinguished by their rejection of fundamentals in favor of complicated analyses of past price trends and patterns. Chartists base their expectations about futures prices (and their trading strategies) on observed historical patterns in past prices, and therefore rely exclusively on historical price dynamics. While there are several available rules for chartists,[4] a trend-following strategy is most popular. When the

[4] For example, the double crossover method, in which a buy (sell) signal is given when a short-term moving average of past asset prices crosses a long-term moving average of past asset prices from below (above), see Westerhoff (2003).

chartist acts as a trend-follower, he/she has a linear and positive reaction function to previous price changes, thus introducing momentum in price. The excess demands of both chartists and fundamentalists are residually absorbed by a market maker who clears the market by taking an offsetting long or short position. Price will go up (down) if there is an excess demand (supply) of agents.

Mean reversion price dynamics follows from the fundamentalist-based convictions of traders. Westerhoff and Retiz (2003) and Reitz and Westerhoff (2007) develop a STAR (smooth transition autoregressive) model to illustrate the smoothly changing nature of fundamentalist behavior, where traders are attracted to fundamental-based analysis as price deviations increase. Confidence in mean-reversion dynamics rises with the increasing magnitude of the price discrepancy. However, this assumption of smoothly increased confidence is doubted by Westerhoff and Retiz (2003) and Reitz and Taylor (2008), who propose that fundamentalists might stop trading under large discrepancies in order to avoid potentially substantial losses. That is, there is the possibility of agents losing confidence in the mean reversion process. To illustrate the event of price reversal under circumstances of low fundamental trading activities, Wan and Kao (2009) add a contrarian strategy to chartist's behavior. The extent of price reversal triggered by the contrarian strategy depends on chartist's awareness of price overshooting, and is therefore nonlinear in nature. Following Wan and Kao (2009), this study specifies two smooth transition variables to describe the nonlinear behavior of chartists and fundamentalists, respectively. In addition, we consider the impacts of financial market conditions on agent's expectations about future oil movements, and attach two variables to the demand functions of each agent. These variables include a currency variable, denoting changes in the US dollar exchange rate market, and a financial variable, represented by returns in the stock market and/or gold market. Westerhoff and Reitz (2003), as well as others, note that such financial market conditions, despite not being captured by agent's trading rules, may still have an impact on asset prices. Following these assumptions, our empirical model is constructed as below.

The movement in oil prices is driven by the excess demands of agents. In this study, agents refer to trend-followers, contrarians, and fundamentalists. Prices adjust in the next period as a function of observed excess demand (Day and Huang, 1990):

$$P_{t+1} = P_t + a^M (D_t^T + D_t^C + D_t^F) + \varepsilon_{t+1}, \quad a^M > 0 \tag{1}$$

where P_t is oil price at time *t*. Parameter a^M is the speed of adjustment, determined by the market institution (for example the New York Mercantile Exchange where the WTI oil futures contracts are traded). We set $a^M > 0$, meaning a net buying (selling) order drives the next period's oil price up (down). D_t^T denotes orders from trend- followers, and D_t^C is orders from the contrarians, D_t^F is from the fundamentalists.

The impact on oil price of a trend-following strategy is $D_t^T = a^T (P_t - P_{t-1})$, where a^T is a constant coefficient and $a^T > 0$, meaning a price rise attracts trend- followers to take a long position; otherwise they sell. Since we assume that 'oil financialization' might introduce separate financial influences on oil prices, the influences of currency and financial variables are taken into consideration. Market order of trend-followers at time *t* can be generalized as:

$$D_t^T = a^T (P_t - P_{t-1}) + b_{USD}^T (USD_t - USD_{t-1}) + b_{FIN}^T (FIN_t - FIN_{t-1}) \tag{2}$$

The variable $(USD_t - USD_{t-1})$ represents changes in the US dollar exchange rates, while the variable $(FIN_t - FIN_{t-1})$ denotes price changes of a financial asset (e.g., stock market returns and/or gold market returns in this study). The use of US dollar exchange rates, stock prices, and gold prices to summarize the condition of markets will be elaborated at the end of this section, as will be detailed discussion of the signs of b_{USD}^T and b_{FIN}^T.

The impact on oil price of contrarian traders is $D_t^C = a^C A_t (P_t - P_{t-1})$. With the addition of currency and financial market conditions, the market order of contrarians can be written as:

$$D_t^C = a^C A_t (P_t - P_{t-1}) + b_{USD}^C (USD_t - USD_{t-1}) + b_{FIN}^C (FIN_t - FIN_{t-1}) \tag{3}$$

where $a^C < 0$, demonstrating the nature of a contrarian strategy; namely contrarians take a long (short) position when price falls (rises). The variable A_t is nonlinear and time-varying measure, rooted in the overreaction hypothesis of De Bondt and Thaler (1985), who assert that the contrarian effect will increase with the magnitude of initial price change. Atkins and Dyl (1990) suggest using a large 1-day price change as the trigger for contrarian activity. However, the identification of a 'large' price change in Atkins and Dyl (1990) is arbitrary, making the contrarian behavior discrete and abrupt. Wan and Kao (2009) propose using an exponential smooth transition function (ESTAR) to operationalize the gradually changing character of contrarian orders that expand with an increasing magnitude of the previous 1-day price change. Variable A_t is thus specified as:

$$A_t = 1 - \exp\left[-\gamma \left(\frac{P_{t-s} - P_{t-s-1}}{\sigma_{t-s}} \right)^2 \right] \tag{4}$$

Since $\gamma > 0$, Eq. (4) implies A_t increases smoothly from 0 to 1 as the previous 1-day price change ($P_{t-s} - P_{t-s-1}$) increases. When $P_{t-s} = P_{t-s-1}$, A_t reduces to zero, implying no contrarian trades are active. Parameter γ measures the sensitivity of contrarian traders to the magnitude of the 1-day price change. Given the value of ($P_{t-s} - P_{t-s-1}$), a larger γ produces a larger value for A_t. In other words, when contrarian traders have higher sensitivities to previous price changes, A_t is greater, as is the magnitude of the price reversal. The 1-day price change ($P_{t-s} - P_{t-s-1}$) is normalized by its conditional standard deviation (σ_{t-s})[5] to account for the time-varying volatility in high-frequency data. The parameter *s* allows for a delayed response for chartists when executing their strategies.[6] Ideally, the value of the delay parameter should be one, representing an immediate response to market change. However, as suggested in

[5] The standard deviation is specified as a GARCH(1,1) process and is obtained by estimating it simultaneously with the mean equation defined in Eq. (7).

[6] The use of delay parameters in empirical applications of nonlinear models has been stressed by Teräsvirta and others (Teräsvirta and Anderson, 1992; Granger and Teräsvirta, 1993; Teräsvirta, 1994; Tsay, 1998).

Teräsvirta (1994), the response delay has to be determined from the data, and may be different from one. The signs on b^C_{USD} and b^C_{FIN} will be discussed later.

The impact on oil price of fundamental activities is contained in $D^F_t = a^F W_t (F_t - P_t)$. As we consider the possible influences of financial asset returns on agent demands, orders from the fundamentalists can be written as:

$$D^F_t = a^F W_t (F_t - P_t) + b^F_{USD}(USD_t - USD_{t-1}) + b^F_{FIN}(FIN_t - FIN_{t-1}) \quad (5)$$

In Eq. (5), $a^F > 0$. Fundamentalists will buy (sell) as the current price is below (above) its fundamental equilibrium value. The effective order of fundamentalists is measured by $a^F W_t$ where W_t is a nonlinear, STAR type variable. The value of W_t changes smoothly with the extent of fundamentalist's belief in a mean reversion strategy, which is in turn determined in part by the parameter φ in Eq. (6) and by the magnitude of fundamental discrepancies (i.e. $|F_{t-d} - P_{t-d}|$). It should be noted that the changing pattern of W_t is contradictory in the literature and needs further clarification.

In Reitz and Westerhoff (2007) and Reitz and Slopek (2009), fundamentalists are assumed deeply convinced of the truth of mean reversion dynamics. When price deviates further from its equilibrium, more fundamentalists will enter the market and conduct a mean-reverting strategy. These studies set a minimum level on the ratio of active fundamentalists, which is at 50%, leading W_t to be bounded within the interval [0.5, 1]. Yet, Reitz and Taylor (2008) and Wan and Kao (2009), on the other hand, argue for the possibility that some of the fundamentalists exit the market.[7] They contend the variable W_t may sometimes reduce to 0 if no fundamentalists are active in market implying that the value of W_t can theoretically vary between [0, 1] given the attendant circumstances. Considering this widened scope of behavior,

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[7] Fundamentalists will leave market when they are not sure of the profitability of fundamental analysis.

we therefore specify W_t as:

$$W_t = \frac{\kappa}{\kappa + \exp\left(-\varphi \frac{\left|F_{t-d} - P_{t-d}\right|}{\sigma_{t-d}}\right)} \tag{6}$$

where $\kappa > 0$ and $\varphi \in \{R\}$.[8] Variable κ determines the ratio of active fundamentalists at a fundamental market equilibrium price. That is, when the actual price equals its fundamental value ($F_t = P_t$), W_t reduces to $\kappa/(\kappa+1)$. The difference between the ratio $\kappa/(\kappa+1)$ at a fundamental market equilibrium and the ratio of actual W_t indicates the extent of price deviation at each time period.

The absolute value of φ determines the transition speed that fundamentalists may enter (or leave) the market, given the value of the absolute price discrepancy, $\left|F_{t-d} - P_{t-d}\right|$. The sign on φ may be positive or negative. If $\varphi > 0$, W_t approaches 1 under extreme price discrepancies. Fundamentalists become more confident in a mean reversion process when this deviation expands. Since fundamentalists believe that price will eventually revert to its fundamental equilibrium level, they consider the extent of mispricing as an opportunity for potential profits. In the case of $\varphi > 0$, more fundamentalists will enter the market as the price deviation widens. The strength of mean reversion increases as a result. On the other hand, if $\varphi > 0$, W_t approaches 0 for extreme price deviations. This suggests that fundamentalists are uncertain about mean-reversion price dynamics. They doubt whether persisting with fundamental analysis is correct and profitable. If the misalignment in price continues and becomes larger, betting against the current trend would likely result in substantial losses. As more fundamentalists abandon the fundamental-base forecasts and decided to leave the market, W_t

8 Reitz and Westerhoff (2007) and Reitz and Slopek (2009) assume $\varphi > 0$ and κ = 1 to ensure the value of W_t varies between 0.5 and unity.

reduces to zero. Since there are possibilities of both cases, we leave the sign of φ to be determined by actual data.

The fundamental price gap in Eq. (6) is normalized by the conditional standard deviation of oil price (σ_{t-d}), which follows a GARCH(1,1) process and is simultaneously estimated with the mean equation. The delay parameter *d* allows for a response delay for the fundamentalists to execute their strategies. The value of *d* is selected by a LM test suggested in Teräsvirta (1994).[9]

Variable F_t denotes the fundamental equilibrium oil price at time *t*. In most economic theories, fundamentalists are considered well-informed. However, it is not easy to compute a measure of "market fundamentals" (Hommes, 2006). Various proxies have been proposed in empirical studies, among which a moving average model is the most widely used (for example, Reitz and Westerhoff, 2007; Reitz and Slopek, 2009; Ellen and Zwinkels, 2010; Fan and Xu, 2011). Since the level of global economic activities is well-accepted as a major factor accounting for the supply-demand conditions in oil market (Hamilton, 2009; Kesicki, 2010; Kaufmann, 2011; Fan and Xu, 2011 and Tverberg, 2012),[10] we apply the Hodrick-Prescott (HP) filter to the nearby WTI futures price to derive the fundamental value of oil price (F_t). The HP filter has been widely used in studies of macroeconomics, especially in real business cycle theory to decompose a time series into its trend and cyclical components.[11] The

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[9] Details are reported in section 3 (part B) of the model specification process.

[10] Global economic activities are considered the most critical factor affecting supply-demand conditions in oil market. Since some events, such as political/financial crises, military/terrorist attacks, changes in under-ground oil reserves or strategic petroleum reserve (SPR), etc., may exert thei influences on the changes of global economies, we consider the oil market fundamentals are linked to the variations of the global economic activities.

[11] Recent studies employing the HP filter for deriving a long-term trend include Artis and Okubo (2009), Uebele and Ritschl (2009), Ghate et al. (2013), Heer and Süssmuth (2013) and among others.

smoothed-curve obtained is more sensitive to long term than to short term fluctuations, and may represent the growth component of a time series. The growth component derived is taken as the proxy for the fundamental price in the market.

Substituting Eq.'s (2) ~ (6) into Eq. (1), and expressing the result as a first order difference in P_t, we obtain the reduced form of oil price changes, which is affected by the orders of trend-followers D_t^T, contrarians D_t^C, and fundamentalists D_t^F, as well as by variations in currency and financial asset markets:

$$\Delta P_t = \alpha_1 \Delta P_{t-1} + \alpha_2 A_{t-1} \Delta P_{t-1} + \alpha_3 W_{t-1}(F_{t-1} - P_{t-1}) + \lambda_1 \Delta USD_{t-1} + \lambda_2 \Delta FIN_{t-1} + \varepsilon_t \tag{7}$$

The price impact of a trend-following strategy is measured by the constant α_1 where $\alpha_1 = a^M a^T > 0$. The effective price impact of a contrarian strategy is measured by $\alpha_2 A_{t-1}$ where $\alpha_2 = a^M a^C < 0$. Variable A_{t-1} varies smoothly between 0 and 1. The aggregated (net) impact of chartists is derived by summing up the impacts of trend-following strategy and contrarian strategy, and is measured by $\alpha_1 + \alpha_2 A_{t-1}$. The effective impact of a fundamentalist strategy is $\alpha_3 W_{t-1}$, where the constant coefficient $\alpha_3 = a^M a^F > 0$, and where W_{t-1} varies smoothly between 0 and 1. The coefficient $\lambda_1 = a^M (b_{USD}^T + b_{USD}^C + b_{USD}^F)$, measures the aggregated influence of US dollar on oil price. Similarly, the coefficient λ_2 measures the influence of financial asset returns on oil price changes, i.e. $\lambda_2 = a^M (b_{FIN}^T + b_{FIN}^C + b_{FIN}^F)$. The signs and statistical significance of estimated λ_1 and λ_2 are discussed later in this section.

A GARCH (1,1) process is introduced in order to cope with the heteroscedastic properties of daily returns:

$$\sigma_t^2 = \beta_0 + \beta_1 \varepsilon_{t-1}^2 + \beta_2 \sigma_{t-1}^2 \tag{8}$$

where $\varepsilon_t = v_t \sigma_t$ and $v_t \overset{iid}{\sim} N(0,1)$. The conditional standard deviation in Eq.(4) and (6) are explicitly modeled as the GARCH (1,1) process. To be specific, our empirical system consists of a mean equation and a standard GARCH (1,1) volatility. Two smooth transition variables are contained in the mean. The empirical model is specified as:

$$\begin{aligned}
&\Delta P_t = \alpha_1 \Delta P_{t-1} + \alpha_2 A_{t-1} \Delta P_{t-1} + \alpha_3 W_{t-1}(F_{t-1} - P_{t-1}) + \lambda_1 \Delta USD_{t-1} + \lambda_2 \Delta FIN_{t-1} + \varepsilon_t \\
&A_{t-1} = 1 - \exp\left[-\gamma \left(\frac{P_{t-s-1} - P_{t-s-2}}{\sigma_{t-s-1}} \right)^2 \right] \\
&W_{t-1} = \frac{\kappa}{\kappa + \exp\left(-\varphi \frac{|F_{t-d-1} - P_{t-d-1}|}{\sigma_{t-d-1}} \right)} \\
&\sigma_t^2 = \beta_0 + \beta_1 \varepsilon_{t-1}^2 + \beta_2 \sigma_{t-1}^2
\end{aligned} \tag{9}$$

The inclusion of variable ΔUSD_{t-1} and ΔFIN_{t-1} in the HAM system is to capture factors that are influential on oil price, but are nevertheless not a matter of chartist and fundamentalist speculation.[12] Variable ΔUSD_{t-1} is measured by changes in the nominal effective exchange rate of US dollar, where $\Delta USD_{t-1} > 0$ denotes an appreciation of US dollar, and $\Delta USD_{t-1} < 0$, a depreciation. Because the US dollar serves as the settlement currency in the global oil market, changes in the US dollar exchange rate may affect supply-demand conditions of oil. The price of oil is affected consequently. Consider the demand side of oil first. A domestic appreciation against the dollar lowers the price of oil measured in the domestic currency. That increases demand and a general rise in oil prices (Akram, 2009). A negative relation is suggested between oil and dollar. However, the effect of the US dollar is not so clear-cut on the supply side. Coudert et al. (2008) assert that a depreciation of the domestic currency (i.e. an appreciation of US dollar) reduces purchasing

[12] Considering the chartists rely exclusively on price history and the fundamentalists speculate on price deviations, there are studies suggesting additional variables be attached to the HAM system. For more on this, please see the studies of Westerhoff and Reitz (2003), Reitz and

power and shift resources away from oil producing countries, which results in a decrease in supply and a rise in oil price. Yet, Yousefi and Wirjanto (2004) analyze five OPEC countries and provide evidence that crude oil export prices respond positively to US dollar depreciations for the purpose of stabilizing export revenues.

According to these studies, it is clear that changes in the US dollar exchange rate may affect oil demand and supply conditions, yet the net effect depends on the currencies used in the different transactions linked to oil activities. We suggest US dollar exchange rates have influence on demand orders of fundamentalists because their activities hinge exclusively on market fundamentals. However, the US dollar has no significant impact on the orders of chartists because their trading strategy depends exclusively on past realizations of oil prices. We therefore set b_{USD}^{T} and b_{USD}^{C} to zero, and treat coefficient b_{USD}^{F} as having an indeterminate sign. The sign on the coefficient λ_1, which is obtained by summing up the three effects, is similarly *a priori* inconclusive.[13]

Variable ΔFIN_{t-1} measures the returns of a financial asset which is relevant to oil investors for serving as an indicator of bull/bear market conditions. The condition $\Delta FIN_{t-1} > 0$ indicates a positive development for the financial market, and $\Delta FIN_{t-1} < 0$, a poor development. In this study, two proxies are used for ΔFIN_{t-1}. The first is changes in the stock market index (denoted as ΔSTK_{t-1}) because large turnovers in stock market make it a reasonable gauge of global financial conditions. The second is the change in the price of gold ($\Delta GOLD_{t-1}$) because a substantial body of literature claims a significant co-movement

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Taylor (2008, 2012), Wan and Kao (2009) and Reitz et al. (2011).

[13] The reduced form of Eq. (9) has a limit on assessing individual agent's response to changes of US dollar. As conducted in Reitz and Taylor (2008, 2012), Wan and Kao (2009), Reitz et al. (2011) and Kao and Wan (2012), we report an aggregated response λ_1 to describe the overall impacts of US dollar on oil price, instead of estimating the respective values on b_{USD}^{T}, b_{USD}^{C} and b_{USD}^{F}.

between oil and gold markets.

The relation between stock and oil markets has been empirically examined by many authors, but these studies have yet to reach a consensus. For example, Cifarelli and Paladino (2010) suggest oil and stock are negatively related through their use of an asset-pricing model, which is augmented with stock and currency returns. Yet, other researchers believe the oil and stock markets are positively related because both are affected by business cycles. Expansionary periods (usually signaled by increasing stock prices) are closely associated with rising oil prices (Narayan and Narayan, 2010; Arouri and Rault, 2012). Zhu et al. (2011) attribute the positive link to the rise in leveraged investment in the stock market. There is another branch of research contending an insignificant relation between oil and stock markets is the norm (Henriques and Sadorsky, 2008; Apergis and Miller, 2009; Al Janabi et al., 2010).

Oil and gold co-movements are supported on several counts, such as both oil and gold are (1) denominated in US dollar, (2) the most widely traded commodities, (3) closely related to inflation and (4) influenced by common macroeconomic factors (Beckmann and Czudaj, 2013). Yet, there are empirical studies refute the presence of oil-gold co-movements. For example, Soytas et al. (2009) find gold prices do not provide information in forecasting oil prices. Zhang and Wei (2010) agree with that opinion because the gold return does not Granger cause oil return. Sari et al. (2010) also give evidence showing that the gold return does not explain much of the oil return. They attribute the weak relation to the fact that oil and gold have different hedging strategies. Gold is a reserve currency, a safe haven and the number one choice for jewelry, while oil is mainly used in industrial productions.

Based on the argument that returns on oil, stock and gold markets are influenced by macroeconomic factors, we treat stock and gold prices as being closely observed by fundamentalists. A positive move in stock and gold prices signals a prosperous expectation for the global economy. Fundamentalists would expect oil price to rise in such circumstance, implying $b_{FIN}^{F} > 0$. In addition, we consider stock and gold prices are relevant to chartists, provided oil is an alternative in a well-diversified portfolio. Chartist may switch between oil and financial assets if they believe the two asset groups are negatively related. Chartist may also regard trends in stock or gold market as an indicator of future oil price movements if they consider oil is positively related to those assets. The latter implies $b_{FIN}^{T} > 0$ and $b_{FIN}^{C} < 0$, while the former predicts a reverse outcome, respectively. The overall effect of ΔFIN_{t-1} on oil returns is indeterminate because of opposing effects among different agents. This countervailing clash of effects leads to *a priori* indeterminate sign and significance for λ_2.

Since gold and stock prices exhibit divergent moving patterns during our investigation period, variable ΔSTK_{t-1} and $\Delta GOLD_{t-1}$ enter Eq. (9) alternatively to check the robustness of our empirical results.[14] The empirical model of Eq. (9) is labelled as the 'stock model' if ΔSTK_{t-1} is employed, and 'gold model' for the case of $\Delta GOLD_{t-1}$ being employed.

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[14] In addition to stock and gold returns, there are multiple indicators that may describe the situation in financial markets, (e.g. changes in bond yields). The use of stock and gold returns as proxies in this study is supported by the sheer volume of works asserting the presence of oil-stock and oil-gold links. However, incorporating ΔFIN_{t-1} into the HAM system is not being made to determine which factor contributes the most to oil price movements, but rather to control for financial conditions not expressly accounted for in agent strategies. According to evidence on the spillover effects among global financial markets, a prosperous /or volatile environment affects agents' expectations on future prices. The gold and stock markets exhibit divergent evolutions during the sample period. For example, gold's price kept rising throughout, whereas stock's price oscillated substantially. These different price patterns no doubt generated contradictory expectations among oil investors. To accommodate the disparate scenarios, we use stock and gold returns alternatively for serving as a proxy for financial market conditions.

III. Data and model specification

A. Data splitting process and basic properties of oil returns

The investigation period spans from 2000/01/04 to 2012/03/27. Daily oil prices in the WTI market are employed in this study because of quick transmission of information between the oil and financial markets. Dorsman et al. (2013) have noted that crude oil may serve as a hedge against declines in the value of other assets such as bonds and stocks. Trading skills normally applied to financial markets can now be employed in trading oil. News is transmitted faster than before. Sari et al. (2010) find significant price co-movements among oil, precious metals, and US dollar markets. Their evidence shows the oil market can revert to its steady state within 1 day only after experiencing shocks. Using daily data in a HAM framework make it possible to capture the prompt reactions of agent behavior.[15]

WTI oil prices are obtained from the website of US Energy Information Administration (EIA). Three price series, namely the spot price, nearby futures price, and price of a four-month contract, are used to test the consistency of our results. The S&P 500 stock index, gold price, and US dollar index are obtained from the Federal Reserve Bank of St Louis's Federal Reserve Economic Database (FRED). The US dollar is measured by the foreign exchange value of the U.S. dollar against a subset of major currencies (including the Euro Area, Canada, Japan, United Kingdom, Switzerland, Australia, and Sweden). An increase in the index suggests an appreciation of the US dollar. All series are log-transformed. The percentage

[15] Many studies use daily data in a HAM model. For example, Reitz and Taylor (2008), Wan and Kao (2009) and Reitz et al. (2011) use daily returns to analyze interactions between chartist and fundamentalist. Kao and Wan (2012) and Reitz and Taylor (2012) use daily yen/dollar exchange rate to examine the effectiveness of central bank's foreign exchange market intervention.

daily returns are expressed as $100(\Delta P_t)$. Variable WTI_0, WTI_1, and WTI_4 denote oil returns with subscripts showing month(s) to delivery. The percentage changes in the US dollar are labeled as ΔUSD. Variables ΔSTK and $\Delta GOLD$ represent the daily returns on stock market and gold market, respectively.

Figure 1 graphs the price of the WTI nearby futures contract during the sample period. This graph shows oil price rising smoothly in the first half of the sample, but then turning to volatile fluctuations in the second half of the sample. This provides descriptive evidence for the existence of important structural breaks. Empirical studies in the past have reported several episodes of structural breaks in the oil market. For example, Fan and Xu (2011) use monthly data to find three stages during the period of 2000/01 to 2009/09. Each stage corresponds to liquidity changes in the WTI nearby market.[16] Oil prices are driven by different factors across stages.[17] Prat and Uctum (2011) apply the Bai and Perron (1998) sequential estimation method (BP method, hereafter) to the Consensus Forecast survey data on WTI price, and find four segments within 1989/11 to 2008/12. The latest breakpoint is at 2006/08 when Israel and Hizbollah in Lebanon began a ceasefire. Liao et al. (2008) study the conditional volatility of the series on daily Brent oil prices from 2003/06/01 to 2006/09/30 and find two breakpoints

[16] These periods can be loosely classified as a relative calm market period (2000/01/07 - 2004/03/12), a bubble accumulation period (2004/03/1 - 2008/06/06), and a global economic crisis period (2008/06/13 - 2009/09/11). The first breakpoint occurs when there is a vast amount of global hedge funds pouring into energy futures beginning in 2003. The second breakpoint corresponds to the deterioration from the US financial crisis and the consequent global liquidity shortage in 2008.

[17] During the 'relatively calm market' period, speculative and episodic events dominate oil price movements. In the 'bubble accumulation' period, speculation became the major driving factor, while market fundamentals played less of a role. In the 'global economic crisis' period, supply-demand fundamentals and recovery of the world economy reasserted their influence over movements in oil prices.

(on 2004/05/25 and 2005/03/24). Liao et al. (2008) assert these breaks are related to the date (2005/04/07) when the Intercontinental Exchange (ICE) shut down its open outcry trading floor and shifted to an all-electronic format. Hamilton and Wu (2014) contend that the market structure of NYMEX has changed since 2005 as the volume of futures trading surged. All these studies point to the fact that the oil market has experienced several episodes where dissimilar factors dominate prices. Therefore, it is interesting to ask “Will the behavior of heterogeneous agents remain consistent across these stages?”

To answer this question, the first step is to examine if breakpoints exist within our sample period. We apply the BP method to the WTI_1 series to test for the existence of breaks.[18] If the answer is ‘yes’, we divide the whole sample according to the dates of each breakpoint. Impacts of heterogeneous trading behaviors are investigated according to each sub-period in order to discuss the differences across breaks.[19]

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[18] Several reasons support using the WTI_1 series to detect the existence of breakpoints. First, prices on WTI nearby futures contracts are regarded as an indicator of an immediate-delivery since it is the contract with the last month to delivery. In contrast to this, spot prices face significant challenges because of limited trading (Dorsman et al., 2013). In addition, the benchmark status of WTI nearby futures contract is underpinned by having the greatest market liquidity. Therefore, we choose the WTI_1 series to test the existence of structure breaks.

[19] There are studies advising segmentation of the investigation period because of the short-lived nature of the influential factors. Miller and Ratti (2009) find a negative relationship between oil price and international stock returns is not stable across breakpoints. Arouri et al. (2011) divide their investigation period into a tranquil period with low volatility and a crisis period with high volatility. The hedge effectiveness between oil and stock markets are different across periods, suggesting the oil-stock relation has changed.

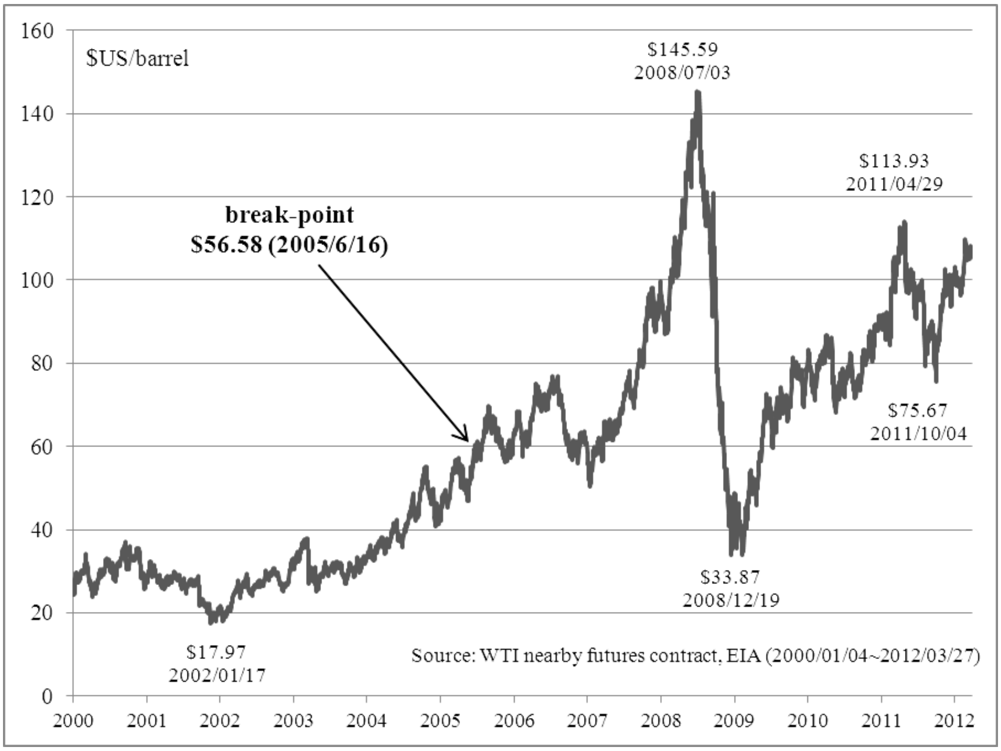

Figure 1 WTI oil price dynamics

The BP method evaluates a univariate linear model to find both the number and location of structural breaks.[20] It is an approach different from the traditional models.[21] Three sequential test statistics (and procedures) are suggested in Bai and Perron (1998): First, there is the $\sup F_t(m)$ test for the null hypothesis of no breaks versus an alternative containing an arbitrary number (m) of breaks. We set $m \in [1,5]$ in this study. Rejecting the null hypothesis

[20] The empirical application procedures are provided by Bai and Perron (2003).

[21] Traditional models choose a possible break-date first, based on one's judgment, and test its significance. The traditional approach has been criticized for its practical applications as one faces continuous fluctuations where multiple breaks cannot be discerned with one's vision.

suggests there is at least one break in the time series. Second, we have the double maximum tests $-UD\max$ and $WD\max$ statistics. These tests have the null hypothesis of no breaks against an unknown number of breaks, given an upper bound of M. Rejecting the null hypothesis confirms the results of the $\sup F_t(m)$ test, and suggests the presence of at least one break in the time series. When the above two tests (i.e. the $\sup F_t(m)$, the $UD\max$ and $WD\max$ tests) reject the null hypothesis of no breaks, we proceed to the final test, which is a sequential test for the null hypothesis of ℓ breaks versus the alternative hypothesis of $\ell+1$ breaks; this test is labeled $\sup F_T(\ell+1|\ell)$. This test is used to determine the exact numbers of break. The value of ℓ starts from 1 because the former tests have statistically verified the existence of at least one break. The sequential test stops at an insignificant result. Bai and Perron (2003) recognize that the above three tests have advantages and disadvantages, and suggest combining all three tests.

The results of BP tests applied to the WTI_1 series are reported in Table 1. It shows the $\sup F_t(m)$ statistics are all significant in a range of m where $m \in [1,5]$. The null hypothesis of no breaks is rejected.[22] The UDmax and WDmax test statistics with the upper bound M = 5 confirm the presence of at least one break in WTI_1 series. The $\sup F(2|1)$ statistics with the value 2.6301 is not significant at traditional levels, indicating only 1 break in WTI_1 series.[23] The breakpoint is found to be located at 2005/06/16, which is close to the date when the Intercontinental Exchange (ICE) shut down its open outcry trading floor and shifted to an all-electronic format. The results lend credence to Liao et al. (2008) and Hamilton and Wu (2014), who have asserted that the structure of the oil market changed beginning in 2005

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[22] Table 1 provides the critical values at 5% level in the brackets under each test result.

[23] The hypotheses here are H_0: one break versus H_1: two breaks. The right-tail critical values of sup F(2|1) statistics are 7.04, 8.58 and 12.29 at 10%, 5% and 1% significance levels, respectively. It shows the sup F(2|1) statistics are not significant at all levels. The null hypothesis of one break is not rejected.

because of the large amount of funds that flowed into commodities futures for purposes of portfolio diversification. According to the BP result, we divide our sample into two sub-periods. Period 1 covers from 2000/01/04 to 2005/06/15 while period 2 is from 2005/06/16 to 2012/03/27.

Table 1 Test results for structural change

Structural changes in returns				
$\sup F_T(1)$	$\sup F_T(2)$	$\sup F_T(3)$	$\sup F_T(4)$	$\sup F_T(5)$
9.4716**	25.4375***	35.4089***	69.4294***	55.4792***
[8.5800]	[7.2200]	[5.9600]	[4.9900]	[3.9100]
UDmax	*WDmax*	Sup $F(2\|1)$	**Estimated date of break**	
69.4294***	121.7421***	2.6301	**2005, 6, 16**	
[8.8800]	[9.9100]	[8.5800]		

Note:

a. The sup $F_T(m)$ statistics denotes the results of test on the null hypothesis of no structural break against the alternative of m breaks (where $m \in \{1,5\}$).

b. The U Dmax statistics and the W Dmax statistics denote the results of test on the null of no break against an unknown number of breaks given the upper bound *M* (*M* = 5 in this case).

c. The Sup F(2|1) statistics denotes the result of test on the null of 1 break versus the alternative of 2 breaks.

d. Numbers in the brackets are critical values at the 5% level.

e. *, **, *** denote significance at 10%, 5% and 1% level respectively.

Table 2, Panel A reports the basic statistics on oil returns in each period. The means of the returns in period 2 are consistently lower than those in period 1. Judging from the standard deviation of the oil price contract, it is evident that except for WTI_0, all other oil price contracts show higher returns and lower risks in period 1 than in period 2. However, if one evaluates the risk in terms of the coefficient of variation (CV) which is useful as one compares data with different means, all series have higher investment risks in period 2.[24] The risk-return relation shows no apparent difference between series. This suggests that most oil investors did well during period 1, but experienced a tough time in the latter period. The significant excess kurtosis in all returns indicates the outliers may occur with a probability higher than that of a normal distribution. The Jarque-Bera test statistics strongly reject the null hypothesis of normality in all series. The Ljung-Box statistics applied to squared returns for testing serial correlation of up to 5th order, i.e. the ARCH(5) statistics, provides evidence of the existence of conditional heteroskedasticity. This result confirms the appropriateness of GARCH modeling for capturing the persistence of volatility in daily returns.

Table 2, Panel B reports the unconditional correlations between returns on oil-US dollar, oil-S&P 500 index, and oil-gold markets. The oil-US dollar correlation is negative in both periods, showing that a rise in oil price often linearly associates with a US dollar depreciation. The oil-S&P 500 correlation is negative in period 1, but turns to positive in period 2. The correlations between oil and gold returns are consistently positive in two periods. In addition, period 2 shows an increased level of correlation for these two variables in period 1. This indicates that the oil market experiences a closer linear association with currency and financial markets in period 2. Collinearity between currency (USD) and financial (STK or GOLD) variables in the regression is not particular serious, judging from the low correlation coefficients of USD-STK and USD-GOLD return pairs during the investigation period.[25] The

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[24] The coefficient of variation (CV) is defined as the ratio of the standard deviation to the mean. It is known as unitized risk. The CV is useful because the standard deviation of data must always be understood in the context of the mean of the data. For comparison between data sets with different means, one should use the CV instead of the standard deviation. The CV pairs of each series are: WTI_0(46.49, 66.11), WTI_1(43.42, 66.09), and WTI_4(30.30, 58.16) where the first number in parentheses is the CV in period 1, while the second is for period 2.

[25] The correlation coefficient between USD-STK is 0.0835 in period 1 and -0.2457 in period 2. The correlation coefficient between USD-GOLD is -0.1757 in period 1 and -0.2510 in period 2. Both argue that the possibility of collinearity is low.

variance-inflating factor (VIF), which measures the degree of collinearity, suggests no such problem between currency and financial variables, according to the values of VIF being close to 1 in each pairs of both periods.[26]

The ADF test in Panel C is applied to the levels of oil price (i.e. the log-transformed price) and the preponderance of evidence suggests not rejecting the null of unit root in price. However, considering the presence of nonlinearities in the behavior of oil prices, we apply unit root tests that account for two types of nonlinearities: (1) the KSS test (Kapetanios et al., 2003) with the unit root null against the alternative of nonlinear ESTAR but globally stationary process, and (2) the Bierens (1997) test with a nonlinear deterministic trend under the alternative hypothesis. Results (not reported but available upon request) show limited evidence of stationarity in the level terms of oil price.[27] Finally, the ADF test is applied to the first difference of oil prices (i.e. the returns series) and the evidence shows that the returns series are all stationary, validating the use of oil returns in our system.

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[26] VIF shows how the variance of an estimator is inflated by the presence of collinearity. It is defined as the inverse of $(1-R_{ij}^2)$, where R_{ij}^2 is the coefficient of determination in the regression of variable i on variable j that are suspected to have collinearity. If there is no collinearity, VIF will be 1. As the extent of collinearity increases, the VIF increases and approaches to infinity in the limit (Gujarati and Porter, 2009). In our sample, the VIF is 1.00702 for USD-STK pair in period 1 and 1.06422 in period 2. The VIF for USD-GOLD pair is 1.03186 in period 1 and 1.06726 in period 2.

[27] The KSS (Kapetanios et al., 2003) test is applied on the raw, de-meaned, and de-meaned and de-trended oil prices. The number of lags is selected using the AIC. The order P in Bierens (1997) test is determined by the AIC. The t(m), A(m) and F(m) statistics are obtained using EasyReg International by Bierens where m denotes the Chebyshev polynomials order. As Bierens argues that there is no unique way to select the order of m, we use m=2, 4, 8 and 12 in the test. Details of the two types of nonlinear unit root tests are given in Kisswani and Nusair (2013). We thank an anonymous referee for providing this reference.

Table 2 Statistical properties of return series

A. Basic Statistics	WTI_0		WTI_1		WTI_4	
	Period 1	Period 2	Period 1	Period 2	Period 1	Period 2
Mean (%)	0.05694	0.03894	0.05745	0.03891	0.06723	0.03759
Max. (%)	12.44253	16.41370	8.11295	16.40973	9.78606	11.46845
Min. (%)	−17.09179	−12.82672	−16.54451	−13.06537	−12.59890	−10.13036
Std. dev.	2.64724	2.57431	2.49447	2.57145	2.03697	2.18616
Skewness	−0.63402***	0.03938	−0.63024***	0.06886	−0.49091***	−0.26540***
ExcessKurtosis	3.90205***	4.77348***	2.98018***	4.79119***	3.16820***	2.91909***
Jarque-Bera	946.0029***	1606.8380***	588.3201***	1619.6590***	618.2554***	620.7147***
ARCH(5)[(a)]	69.806***	623.780***	18.380***	562.330***	66.142 ***	458.377***
B. Correlations with						
USD index	−0.06860	−0.35735	−0.06305	−0.36233	−0.05704	−0.39217
S&P 500	−0.03486	0.32638	−0.05634	0.32106	−0.04626	0.37462
Gold price	0.02380	0.12476	0.00964	0.11933	0.00839	0.12001
C.Augmented Dickey-Fuller unit root test for price series in [(b)]:						
Levels	−2.49	−2.24	−2.32	−2.26	−1.78	−2.20
1st difference	−38.17***	−41.43***	−36.68***	−42.90***	−37.90***	−42.84***

Note:

a. The ARCH(5) is the Ljung-Box test statistic for serial correlation of up to 5th order for squared returns.

b. The Augmented Dickey-Fuller unit root tests are performed under the regression with drift and trend. Maximum lags for the Augmented Dickey-Fuller test is 24.

c. *, **, *** denote significance at 10%, 5% and 1% level respectively.

B. Results of model specification

Eq. (9) contains two smooth transition variables, A_t and W_t, and these variables introduce nonlinearities into our system. To test the existence of nonlinearity and to determine the appropriate value of the delay parameters (s and d), we follow the testing procedures suggested by Granger and Teräsvirta (1993) and Teräsvirta (1994). According to Teräsvirta's procedure, the first step in the process of specification, estimation and evaluation of a STAR model is to determine a linear AR(k) model. Based on the Bayesian information criterion (BIC), we select the lag order k = 1 and use an AR(1) model for this study.[28] The second step is to test linearity of the conditional mean with the AR(1) linear model as the null hypothesis. In this step, different values of (s, d) pairs are employed in the alternative hypothesis. An auxiliary regression is derived via a Taylor approximation, and in this case a third-order approximation applies to variable W_t and a second-order approximation is necessary for A_t (Teräsvirta, 1994, Escribano and Jordá, 1999). Using a joint-significance test, an auxiliary regression helps in determining the significance of the nonlinear variables. We use a range of positive integers with $s \in \{1,5\}$ and $d \in \{1,5\}$ in the auxiliary regression to specify the value of (s, d) pairs. When the null hypothesis of the linear model is rejected, a STAR model is confirmed. In the case that more than one pair of (s, d) is suggested, we select the one with the highest significance (i.e. the smallest p-value) on the LM-type statistics (Teräsvirta, 1994).

The third step in Teräsvirta’s procedure is to appropriately decide between the ESTAR and LSTAR (logistic STAR) functions. However, we need not concern ourselves with this step because both the ESTAR and LSTAR functions are employed in our system. In particular, variable A_t is defined as an ESTAR function, which is commonly specified as $F(y_{t-d};\gamma,c)=1-\exp[-\gamma(y_{t-d}-c)^2]$. The F(.) function is a bounded function of y_{t-d} and continuous everywhere in the parameter space for any value of y_{t-d}. Parameter c can be interpreted as the threshold between the two regimes corresponding to F(.) = 0 and F(.) = 1. With respect to variable A_t, we set the threshold parameter c = 0 and set y_{t-d} to equal the

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[28] Teräsvirta (1994) suggests using an AR(k) model as the null for his nonlinearity test. Therefore, an EST-ARMA model in the null hypothesis is not entertained in this study. Besides, the HAM approach discusses cyclical movements in asset price. The smooth transition functions are usually introduced in the mean equation for illustrating the gradual changes of agent response to asset returns. We do not consider an STGARCH model, which typically describes a smooth transition process in the conditional volatility.

1-day price change. The parameter γ is assumed to be strictly positive and determines the smoothness of the change in the value of the function. This means F(.) will increase smoothly from one regime to the other as $(y_{t-d}-c)^2$ increases. A larger value for γ causes the F(.) function to change more abruptly. If $\gamma = 0$, the model is linear. In contrast to this, variable W_t belongs to the family of an LSTAR model. The LSTAR function is governed by $F(y_{t-d};\ \varphi, c) = \{1+\exp[-\varphi(y_{t-d}-c)]\}^{-1}$, which increases smoothly from 0 to 1 as $(y_{t-d}-c)$ varies from $-\infty$ to $+\infty$. The speed of transition depends on φ. The nonlinear variable W_t in our system is a modified LSTAR function when we set κ = 1 and c = 0. Therefore, our system contains both the ESTAR and LSTAR functions and there is no need to apply the sequence of F tests suggested in Teräsvirta (1994) to decide between the ESTAR and LSTAR family of models.[29] Nevertheless, the nonlinearity test for Eq. (9) and the choice of delay parameter (suggested as the first and second steps by Teräsvirta) are performed. Results are reported in Table 3.

Table 3 Results of model specification

Return Series	Period 1		Period 2	
	(s, d) pairs,	Signif. Level	(s, d) pairs,	Signif. Level
WTI_0	(1, 1)	0.0000306	(2, 4)	0.0000000
WTI_1	(1, 1)	0.0005405	(1, 2)	0.0000000
WTI_4	(1, 5)	0.0001335	(2, 4)	0.0000000

Note: The (s, d) pairs denotes the response delay for traders to execute their strategies, where s represents the delays of contrarian traders, and d refers to delays of fundamentalists. Results are selected from estimating a range of positive integers of $s \in \{1,5\}$ and $d \in \{1,5\}$ with the smallest p-value.

[29] Analogous arrangements can be found in Reitz and Westerhoff (2007) and Reitz and Taylor (2008, 2012) who do not perform the third step because of theoretical reasons supporting their choice of an LSTAR function.

Table 3 reports the (*s, d*) pairs with the most significant LM statistics. It is clear that the LM statistics in each return series are highly significant, strongly rejecting the null hypothesis of a linear model. Nonlinearity in our system is then confirmed. We note that the (*s, d*) pairs are slightly different among series and periods. For example, the (*s, d*) pair is found to be (1, 1) for WTI_0 and WTI_1 series in period 1, and changes to (1, 5) for the WTI_4 series. This means fundamentalists with a distant futures contract do not react as quickly as those dealing with a short-term contract. Fundamentalists who deal with a four-month contract need 5 days to make responses. In addition, the reaction delay is (2, 4) in WTI_0 and WTI_4 series in period 2, but is (1, 2) in WTI_1 series. This implies traders in the nearby futures contract (WTI_1 series) react more quickly, compared to traders in the spot (WTI_0) and four-month contract (WTI_4). Table 3 confirms the nonlinearity in Eq.(9), and helps reveal the (*s, d*) pairs for the next step of parameter estimation.

IV. Estimation Results

The highly significant statistics for excess kurtosis, along with the Jarque-Bera test in Table 2, suggest that the conditional normality assumption is not maintained. To get a robust estimate of the covariance matrix of the parameter estimates, we use the BFGS (Broyden-Fletcher-Goldfarb-Shanno) algorithm of Bollerslev and Wooldridge (1992) and then use this to maximize the respective log-likelihood functions. The estimation results are reported in Table 4 and Table 5 for each period. Since returns of stock and gold prices enter our system alternatively, the corresponding empirical models are labeled as ‘stock model’ or ‘gold model’ depending on the regressor employed. The appropriateness of using our STAR-GARCH model is assessed by the residual-based diagnostic results in Panel C of Table 4 and Table 5. The Ljung-Box Q statistics for an AR(5) suggests there is no linear dependence in the standardized residuals up to the 5th lag, and the Ljung-Box Q statistics for ARCH(5) shows no linear dependence in the squared standardized residuals. The lack of significance in the AR(5) and ARCH(5) statistics shows our STAR-GARCH model can reasonably fit the data by capturing the serial dependence of the conditional mean and variance processes.

A. Results for Period One

Table 4 reports the estimation results for period 1, during which time the oil market enjoys an investor friendly environment characterized by relatively “higher returns and lower risks”. The price impact coefficients (α_1, α_2 and α_3) are quite consistent across both stock and gold models, except for the magnitude of α_3 on WTI_0.[30] Next, we focus our attention on the significance levels and signs for each coefficient. The coefficient α_1 is positive and significant as expected. It supports the existence of a trend-following strategy in the oil market. The presence of a contrarian strategy is confirmed by the negative estimate on α_2, which is also significant at traditional levels. The mean-reversion strength of fundamentalists is illustrated by the positive and significant estimate on α_3 for each series. Transition parameter γ determines the smoothness of changes of A_t. The marginally significant estimates on most γ*’s* suggest the contrarians are relatively insensitive to price changes and this in turn implies a weak contrarian activity in this period.[31] By contrast, fundamentalists are very active in this period, as evidenced by the highly significant and positive estimates on φ across series. Positive φ indicates W_t will increase from zero to one monotonically as price deviation increases. This result means that more fundamentalists enter the market at large discrepancies, producing greater pressure for mean-reversion and driving oil price’s back to its fundamental

[30] Disparities in the magnitude of α_3 are of less concern to us here since we focus on the effective price impact of fundamentalists, which is instead measured by the value of $\alpha_3 W_t$ and which is quite similar in magnitude between stock and gold models (See Panel B in Table 4). This provides evidence that the effective price impacts of fundamentalists on WTI_0 are consistent across different models.

[31] There are four out of six γ estimates are marginally significant at 10% level. As γ approaches zero, A_t reduces to its minimum (= 0). Therefore, the effective price impact of contrarian strategy is zero.

equilibrium level. Judging from the fact that most φ's are larger in the short-term series (except for that on WTI_0 in the gold model), one may conjecture that fundamentalists in the short-term market are more convinced of the usefulness of fundamental-based analyses. Coefficient κ is positive and significant, denoting a positive ratio of fundamentalists at market equilibrium.

Panel B, Table 4 illustrates the estimated values of A_t and W_t, as well as the effective price impacts of chartists (measured by $\alpha_1 + \alpha_2 A_t$) and fundamentalists ($\alpha_3 W_t$). Considering the time-varying nature of A_t and W_t, we report the mean, the minimum value, and the maximum value for each variable. The t-statistics in brackets is meant to test the hypothesis of a zero mean. It is clear that both A_t and W_t are highly significant, confirming the existence of both contrarian and fundamental strategies in the WTI market. The smooth changes in A_t and W_t underlie the nonlinear nature of our system. Since the effective price impact of chartists, $\alpha_1 + \alpha_2 A_t$, oscillates between positive and negative, an interchangeable use of trend-following strategy and contrarian strategy among chartists is implied. The fraction of positive $\alpha_1 + \alpha_2 A_t$ is commonly above 70% in this period. The trend-following strategy appears more frequently used among chartists. This evidence suggests the fact that most chartists in period 1 are trend chasers.

The effective price impact of fundamentalists $\alpha_3 W_t$ is positive in each series, with the average value ranging from about 0.05 in near-term contracts to 0.037 in the distant contract. This result is consistent to the finding on φ that fundamentalists are more active in the short-term markets. The ratio of active fundamentalists at market equilibrium, measured by (κ/κ + 1), is above 0.9 in most short-term contracts, and much lower in the longer one. The MSD statistics measures the mean of price deviations during this period, and is quite small in magnitude.[32] This result implies the oil price in period 1 traces closely its fundamental equilibrium value.

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[32] The MSD is small as we compare to those reported in Table 5.

Table 4 Results for Period One (2000/01/04 ~ 2005/06/15)

	Stock model			Gold model		
Series	WTI_0	WTI_1	WTI_4	WTI_0	WTI_1	WTI_4
Panel A: Regression coefficients with standard deviations in parentheses						
α_1	0.15144***	0.22558*	0.15073**	0.12922**	0.22327**	0.15647***
	(0.0488)	(0.1211)	(0.0715)	(0.0531)	(0.1094)	(0.0143)
α_2	−0.18988**	−0.23301*	−0.23147**	−0.16896*	−0.23191**	−0.24001***
	(0.0838)	(0.1285)	(0.1099)	(0.0884)	(0.1165)	(0.0508)
α_3	0.05061***	0.05215***	1.13609***	7.46544***	0.05237***	0.76485***
	(0.0100)	(0.0085)	(0.3172)	(0.1172)	(0.0082)	(0.0894)
γ	1.49789*	1.62852*	0.62125*	1.22409*	1.58571**	0.62740***
	(0.8569)	(0.9007)	(0.3449)	(0.7372)	(0.7670)	(0.1368)
φ	49.34409***	32.63652***	0.09796***	0.02034***	28.99903***	0.09798***
	(17.6588)	(2.7656)	(0.0105)	(0.0033)	(7.4403)	(0.0056)
κ	97.14163***	15.36198***	0.02423**	0.00618***	13.83549***	0.03676***
	(34.4438)	(1.2460)	(0.0095)	(0.0011)	(0.9324)	(0.0051)
λ_1-ΔUSD	0.03702	0.03833	−0.01644	−0.01129	0.00248	−0.04052
	(0.1204)	(0.1377)	(0.1191)	(0.1495)	(0.1518)	(0.0988)
λ_2-ΔSTK	0.02876	0.02507	0.03543	--	--	--
	(0.0443)	(0.0494)	(0.0369)			
λ_2-$\Delta GOLD$	--	--	--	−0.07664	−0.09732*	−0.08431
				(0.0639)	(0.0557)	(0.0399)
Panel B: Derived outputs with *t*-statistics in brackets						
A_t	0.4595[47.18]	0.4849[49.64]	0.3133[38.12]	0.4237[44.71]	0.4804[49.30]	0.3153[38.23]
(min, max)	(0.000,1.000)	(0.000,1.000)	(0.000,1.000)	(0.000,1.000)	(0.000,1.000)	(0.000,1.000)
W_t	0.99[1.6E+05]	0.99[7.7E+03]	0.0328[64.67]	0.0066[143.1]	0.99[6.8E+03]	0.0490[65.53]
(min, max)	(0.000,0.996)	(0.939,1.000)	(0.024,0.367)	(0.006,0.036)	(0.933,1.000)	(0.035,0.525)]
$\alpha_1+\alpha_2 A_t$	0.0642[34.71]	0.1126[49.46]	0.0782[41.11]	0.0576[35.99]	0.1119[49.50]	0.0807[40.82]
(min, max)	(−0.038,0.151)	(−0.007,0.226)	(−0.081,0.151)	(−0.040,0.129)	(−0.009,0.223)	(−0.084,0.156)
$\alpha_3 W_t$	0.05[1.6E+05]	0.05[7.7E+03]	0.0373[64.67]	0.0491[143.1]	0.05[6.8E+03]	0.0375[65.53]
(min, max)	(0.050,0.051)	(0.049,0.052)	(0.027,0.417)	(0.046,0.270)	(0.049,0.052)	(0.027,0.402)]
$\kappa/(\kappa+1)$	0.9898	0.9389	0.0237	0.0061	0.9326	0.0355
MSD	1.03E-04	3.68E-03	3.73E-04	2.86E-06	4.47E-03	7.97E-04
Fractions of positive value of statistics, $(\alpha_1+\alpha_2 A_t)$ and $(\alpha_3 W_t)$, in the investigation period						

Table 4 Results for Period One (2000/01/04 ~ 2005/06/15) (continue)

	Stock model			Gold model		
Series	WTI_0	WTI_1	WTI_4	WTI_0	WTI_1	WTI_4
$\alpha_1+\alpha_2 A_t$	73.57%	86.04%	82.28%	75.58%	85.75%	81.98%
$\alpha_3 W_t$	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
Panel C: Diagnostic checks						
AR(5)	0.8732	0.4437	0.7098	0.9283	0.4491	0.7433
ARCH(5)	0.6058	0.9452	0.3487	0.7266	0.9493	0.3451

Note:

a. Numbers in parentheses in Panel A denote the standard errors of the estimated coefficients.

b. The average values of two transition variables (A_t and W_t) are reported in Panel B. Since A_t and W_t are time-variant, we report the range (shown in parentheses) of each variable during the investigation period. Numbers in brackets are *t*-statistics testing for the null hypothesis of mean = 0. The net effects of chartists ($\alpha_1 + \alpha_2 A_t$) and fundamentalists ($\alpha_3 W_t$) are reported as the format of A_t and W_t.

c. Numbers in panel *C* are *p*-values of the residual based diagnostic tests. Statistics AR(5) and ARCH(5) denote the Ljung-Box Q statistics respectively applied to 5 lags of standardized residuals and squared standardized residuals.

d. *, **, *** denote significance at 10%, 5% and 1% level respectively.

Coefficient λ_1 measures the influences of US dollar exchange rate changes (ΔUSD). The insignificant estimates in both the stock and gold models strongly suggest the US dollar has no significant impacts on oil price during this period. Coefficient λ_2 measures the influences of financial variables, where $\lambda_2 - \Delta STK$ is result of the stock model and $\lambda_2 - \Delta GOLD$, the gold model. Most estimates of λ_2 are insignificant, except that on WTI_1 in the gold model. It suggests that the influences from current financial markets are negligible, and implies the WTI oil price in this period is mainly driven by heterogeneous agent strategies.

The estimate of $\lambda_2 - \Delta GOLD$ on WTI_1 series is negative with marginal significance at 10% level, while estimates on WTI_0 and WTI_4 are not significant. This result suggests a weak correlation between oil and gold, and is consistent with evidence in Sari et al. (2010). Since gold is considered a safe haven, market participants invest in gold to hedge against uncertainty. However, period 1 is noted as an ideal investment period with low risks and less uncertainty. As investors ease their risk perception and regain their confidence, energy consumption is expected to boost with gradual economic recovery. Investors move from gold to crude oil market. That explains the negative estimate of $\lambda_2 - \Delta GOLD$ on WTI_1 series.

The dissimilar estimates between stock and gold models of WTI_0 series on the parameters relating to fundamental behavior (i.e. α_3, φ, and κ) do not induce large differences for the effective price impact of fundamentalists (measured by $\alpha_3 W_t$). Nevertheless, it reminds one to be cautious when dealing with the spot price of the oil market. The irregular trades in the spot contract prohibit prices from reflecting sufficient information timely. The discreteness of information flows might distort the estimation results. As a consequence, some researchers suggest not using spot oil prices for empirical studies (Fattouh, 2006).

B. Results for Period Two

Table 5 provides estimation results for period 2, during which time the oil market experiences a tough period (i.e. one characterized as having ‘lower returns and higher risks’ as in Table 2). The coefficients representing price impacts (α_1, α_2 and α_3) remain significant with expected signs, supporting the presence of heterogeneous strategies in the oil market. The trend-followers bring momentum into the market, and contrarian traders curtail the trend. However, in contrast to the result in period 1, estimates on the smooth transition parameter γ are highly significant in each series. It shows an obvious interest of chartists in conducting contrarian trades.[33] The estimates for α_3 are significant and positive, demonstrating the existence of a mean-reversion strategy. Nevertheless, most estimates of φ are negative (except WTI_1 in stock model), and are contrary to those in Table 4 for period 1. A negative value of φ means W_t will decrease to zero as price deviation increases without bound. It implies most fundamentalists in this period do not believe in the fundamental-based analysis. They lose their confidence and tend to leave oil market when price discrepancies increase.

Table 5, Panel B portrays the time-variant nature of A_t and W_t. Effective price impacts of chartists and fundamentalists are reported by the values of ($\alpha_1 + \alpha_2 A_t$) and ($\alpha_3 W_t$) respectively. Unlike to results in Table 4, the average value of ($\alpha_1 + \alpha_2 A_t$) are negative in most series. Meanwhile, the fraction of positive ($\alpha_1 + \alpha_2 A_t$) reduces to below 50%.[34] These results suggest an infrequent use of trend-following strategy in this period. Most chartists turn to a contrarian strategy instead. This shift from trend- following strategy to contrarian strategy suggests the fact that most chartists in this period have scented out overshooting in price.

The contrarian strategy is expected to be more profitable once the oil market exhibits reversions. Most estimates on ($\alpha_1 + \alpha_2 A_t$) fluctuate in a wider range in period 2 (except WTI_4 in the gold model). It indicates chartist's behavior causes larger rises and falls in oil price, portraying a picture of heavy speculation in this period. Estimates on $\alpha_3 W_t$ are insignificant (or marginally significant at 10% level) in most series. One exception is that in WTI_1 for the

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[33] A notable estimates on γ in WTI_1 of both stock and gold models suggest chartists in the nearby market are highly interested in contrarian strategy. A tentative explanation can be attributed to the benchmark place of the WTI nearby futures contract in oil market. The large trading volumes on the nearby contract speed information transmission and promote price discovery, which encourages chartists to express their forecasts about future oil price movements.

[34] A remarkably low level is observed for the near-term contract. That is 5.98% in the stock model and 9.31% in the gold model.

stock model, which can be attributed to the positive value on φ, indicating a strengthening of belief in fundamental analysis. Judging from the fact that most $\alpha_3 W_t$ are not significant, the level of fundamentalist activities is quite low in general. The weak fundamentalist behavior explains the larger MSD in this period. Table 5 shows all series report a larger MSD in this period as compared to those in Table 4, despite a little group of fundamentalists who trade on the nearby futures contract believing in the mean-reversion process. The increased MSD suggests the WTI oil market meets with larger discrepancies in this period.

The influences of US dollar and financial market conditions are reported by λ_1 and λ_2. Unlike those in Table 4 (in which the impacts from currency and financial markets are negligible), estimates on λ_1 are significant in most near-term contracts. It indicates US dollar exchange rates have positive influence on short-term oil prices. Estimates on λ_2 in the stock model are positive and highly significant for all series. This supports the conclusions in Narayan and Narayan (2010), Arouri and Rault (2012) and Zhu et al. (2011), and implies shocks in the stock market will pass to the oil market comprehensively. In particular, short-term oil prices are more influenced by fluctuations in the stock market. The estimates of λ_2 in the gold model display a different picture. It shows the gold price has more effect on long-term oil prices, and its impacts on the short-term oil price are negligible at 5% level of significance. Evidence suggests the fact that the oil market is more closely linked to the currency and financial markets in this period. Variations in the US dollar exchange rates, stock prices, and gold prices clearly appear to introduce shocks to the oil market. The oil market is no longer isolated from global financial conditions. Our evidence shows that the turbulence in recent financial markets is one of the factors, along with the interactions between chartists and fundamentalists, in explaining the large price fluctuations in the WTI oil market.

Table 5 Results for Period Two (2005/06/16~2012/03/27)

	Stock model			Gold model		
Series	WTI_0	WTI_1	WTI_4	WTI_0	WTI_1	WTI_4
Panel A: Regression coefficients with standard deviations in parentheses						
α_1	0.04268***	0.42837***	0.02331***	0.08039***	0.40106***	0.05175***
	(0.0087)	(0.0685)	(0.0041)	(0.0261)	(0.0102)	(0.0122)
α_2	–0.20225***	–0.45352***	–0.29212***	–0.18332***	–0.41505***	–0.17759***
	(0.0280)	(0.0692)	(0.0185)	(0.0477)	(0.0101)	(0.0656)
α_3	0.20020***	0.04459***	0.73753***	0.15422***	1.46693***	0.49500***
	(0.0033)	(0.0074)	(0.0104)	(0.0025)	(0.2095)	(0.0679)
γ	0.84322***	508.67732***	0.28932***	1.61798***	259.02392***	0.84417***
	(0.2041)	(111.01)	(0.0428)	(0.0742)	(3.2362)	(0.0246)
φ	–18.39818***	0.28566***	–8.32057***	–16.99106***	–6.59901***	–13.28843***
	(0.3051)	(0.0258)	(0.1215)	(0.0951)	(0.4820)	(1.6371)
κ	4.14970***	0.38057***	2.20753***	4.75580***	10.04994***	7.66522***
	(0.1508)	(0.1454)	(0.0539)	(0.1037)	(0.0718)	(0.1628)
λ_1-ΔUSD	0.15502**	0.15467	0.05183	0.16156***	0.12189**	0.07155
	(0.0751)	(0.1028)	(0.0326)	(0.0579)	(0.0590)	(0.0830)
λ_2-ΔSTK	0.16782***	0.14225***	0.12611***	--	--	--
	(0.0367)	(0.0437)	(0.0060)			
λ_2-$\Delta GOLD$	--	--	--	0.05412*	0.05509*	0.07633**
				(0.0285)	(0.0287)	(0.0302)
Panel B: Derived outputs with t-statistics in brackets						
A_t	0.3780[47.97]	0.971[283.9]	0.2004[37.5]	0.5007[57.1]	0.958[238.2]	0.3799[47.87]
(min, max)	(0.000,1.000)	(0.000,1.000)	(0.000,0.999)	(0.000,1.000)	(0.000,1.000)	(0.000,1.000)
W_t	4.40E-04[1.62]	0.520[129.7]	1.22E-56[1.3]	4.68E-04[1.24]	9.93E-04[1.8]	0.0013[2.033]
(min, max)	(0.000,0.390)	(0.276,0.998)	(0.0,1.34E-53)	(0.000,0.630)	(5.6E-308,0.7)	(0.000,0.876)
$\alpha_1+\alpha_2 A_t$	–0.0338[–21.2]	–0.012[–7.73]	–0.036[–22.6]	–0.0114[–7.1]	0.0035[2.12]	–0.016[–11.15]
(min, max)	(–0.160,0.043)	(–0.025,0.428)	(–0.268,0.023)	(–0.103,0.080)	(–0.014,0.401)	(–0.126,0.052)
$\alpha_3 W_t$	8.80E-05[1.62]	0.023[129.7]	9.02E-57[1.3]	7.20E-05[1.24]	0.0015[1.84]	6.44E-04[2.03]
(min, max)	(0.000,0.078)	(0.012,0.045)	(0.0, 9.85E-54)	(0.000,0.097)	(0.000,1.043)	(0.000,0.433)
$\kappa/(\kappa+1)$	0.8058	0.2757	0.6882	0.8263	0.9095	0.8846
MSD	0.6487	0.0865	0.4737	0.6822	0.8259	0.7809
Fractions of positive value of statistics, $(\alpha_1+\alpha_2 A_t)$ and $(\alpha_3 W_t)$, in the investigation period						

Table 5 Results for Period Two (2005/06/16~2012/03/27) (continue)

	Stock model			Gold model		
Series	WTI_0	WTI_1	WTI_4	WTI_0	WTI_1	WTI_4
$\alpha_1+\alpha_2 A_t$	42.36%	5.98%	42.31%	46.64%	9.31%	49.20%
$\alpha_3 W_t$	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
Panel C: Diagnostic checks						
AR(5)	0.8353	0.5033	0.4487	0.9695	0.7044	0.6569
ARCH(5)	0.5499	0.9165	0.6007	0.2892	0.7928	0.8609

Note:

a. Numbers in parentheses in Panel A denote the standard errors of the estimated coefficients.

b. The average values of two transition variables (A_t and W_t) are reported in Panel B. Since A_t and W_t are time-variant, we report the range (shown in parentheses) of each variable during the investigation period. Numbers in brackets are t-statistics testing for the null hypothesis of mean=0. The net effects of chartists ($\alpha_1 + \alpha_2 A_t$) and fundamentalists ($\alpha_3 W_t$) are reported as the format of A_t and W_t.

c. Numbers in panel C are *p*-values of the residual based diagnostic tests. Statistics AR(5) and ARCH(5) denote the Ljung-Box Q statistics respectively applied to 5 lags of standardized residuals and squared standardized residuals.

d. *, **, *** denote significance at 10%, 5% and 1% level respectively.

V. Conclusions

As the oil market becomes ever more connected with global financial markets, oil prices appear to be no longer fully subject to supply-demand conditions. The consequence of ‘financialization’ of the oil market has raised considerable attention in recent studies. This study uses an agent-based model, i.e. the HAM approach, to examine the impacts of speculative behavior on the WTI oil price since 2000. The investigation period covers the period 2000/01/04 to 2012/03/27, during which a structural break is found. The oil market in the period before breakpoint provides an ideal trading environment for investors because of its relatively higher returns and lower risks. However, the period after the breakpoint proves to be a tough time for investors because of relatively lower returns and higher risk. The break-date in this study is estimated to be pinpointed to 2005/06/16. This is in line with Liao, et al. (2008) and Hamilton and Wu (2014), who claim that large inflows of index-funds to oil futures markets substantially changed the structure of the oil market beginning in 2005.

Two smooth transition variables are employed in this study for describing the nonlinear nature of the trading behaviors of chartists and fundamentalists. Proxies for financial circumstances, including changes in the US dollar exchange rates, returns on corporate stock, and changes in gold prices are included in the model in order to better understand the linkage between the oil market and financial assets. Our evidence shows the behavior of agents and their impact on oil prices are different across the two periods. Chartists in the first period are mainly trend-followers. Their entry brings momentum to the oil market. Fundamentalists are confident of their abilities to identify mispricing and are active in exploiting that mispricing. However, oil price discrepancies are insignificant in this earlier period. This result is consistent with Reitz and Slopek (2009), who claim that fundamentalists are important to oil market stabilization. Changes in US dollar exchange rates, stock prices, and gold prices have no significant influences on oil price dynamics during this period. This implies that oil's price is mainly driven by agent behavior (i.e. no discernable and independent financial markets effect) in the period before breakpoint.

However, as the oil market moves to period 2, changes in oil prices can no longer be explained by agent behavior alone. Financial market variations may positively affect oil price dynamics. In particular, the US dollar has a significant impact on the short-term price of oil. The coefficient between the stock variable (STK) and the short-term oil price is significant and higher than that associated with the long-term oil price. The coefficient relating the gold variable (GOLD) and the long-term oil price is significant and higher than that on the short-term oil price. Based on these facts, stock and gold variables possess different levels of impact on short- and long-term oil prices. Beyond this, chartists in this period have increased inclination to utilize contrarian trades, instead of simply chasing trends. This chase-and-sell strategy induces the oil market to experience a larger set of fluctuations than would otherwise be the case. Fundamentalists, unfortunately, have a weak and fragile ability to correct mispricing. Most fundamentalists appear to distrust the view that the oil market will revert to its fundamental equilibrium level. They lose their confidence in fundamental-based analysis, and will stop trading as the (actual versus fundamental) price gap advances. Such trading attitudes of fundamentalist explain the recent persistent and expanding price discrepancies in the oil market.

It is worth mentioning that our reduced form model still is limited in its ability to evaluate the influence of currency and financial variables in terms of specific agent behaviors. A structural model considering financial impacts on respective agent behaviors would be an important aim of further research.

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異質交易行為與原油價格之非線性動態分析*

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摘　要

本文以非線性異質交易者模型分析美國原油價格在 2000 年 1 月至 2012 年 3 月的起伏變化，希望瞭解當原油市場「金融化」後，影響油價走勢的因素是否有所改變。研究顯示，交易者行為具非線性特性且存在結構變化。分界點位於 2005 年中，時間接近文獻記載國際投資人大量進入原油期貨交易市場的時點。在分界點之前，油價走勢顯現「高報酬、低風險」特性，但分界點後轉變成「低報酬、高風險」特性。交易者策略在分界點前後出現明顯差異。在「高報酬、低風險」時期，油價由基本分析者的行為主導，並對價格安定貢獻顯著。而來自金融面的影響，包括美元漲跌、股價變化、黃金價格變化等因素並不顯著。在「低報酬、高風險」時期，基本分析者因缺乏信心退出市場交易，油價走勢由技術分析者的追漲殺跌策略主導，並且也受到美元、股價、黃金等價格變化的正面影響。此結果隱含當原油市場湧進大批國際投資人後，油價變化已不再完全由基

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本面主導，市場投機行為升高，價格偏離程度擴大。

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