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ABSTRACT

The Role of Speculation in Oil Markets: What Have We Learned So Far?*

A popular view is that the surge in the price of oil during 2003-08 cannot be explained by economic fundamentals, but was caused by the increased financialization of oil futures markets, which in turn allowed speculation to become a major determinant of the spot price of oil. This interpretation has been driving policy efforts to regulate oil futures markets. This survey reviews the evidence supporting this view. We identify six strands in the literature corresponding to different empirical methodologies and discuss to what extent each approach sheds light on the role of speculation. We find that the existing evidence is not supportive of an important role of speculation in driving the spot price of oil after 2003. Instead, there is strong evidence that the co-movement between spot and futures prices reflects common economic fundamentals rather than the financialization of oil futures markets.

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1. INTRODUCTION

The unprecedented surge in the spot price of crude oil during 2003-08 has sparked a heated public debate about the determinants of the price of oil. A popular view is that this surge cannot be explained by changes in economic fundamentals, but was caused by the increased financialization of oil futures markets, which in turn allowed speculation to become a major determinant of the spot price of oil. The financialization of oil futures markets has been held responsible for a variety of phenomena including changes in price volatility, increased co-movement between oil futures prices and other financial asset and commodity prices, a breakdown of the statistical relationship between oil inventories and the price of oil, and an increased influence of the decisions of financial investors such as swap dealers, hedge funds and commodity index traders on the oil futures price. Most importantly, there is a perception that oil futures markets no longer adequately perform their function of price discovery and risk transfer. The view that the entry of financial investors such as index funds has somehow distorted oil prices has been driving policy efforts to regulate oil futures markets as part of a larger effort by the G20 governments to impose more control on commodity market participants.

This survey reviews the evidence in the academic literature supporting this interpretation. We identify six strands in the literature corresponding to different empirical methodologies. We discuss to what extent each approach sheds light on the role of speculation in the spot market and in the futures market for crude oil. We find that the existing evidence is not supportive of an important role of speculation in driving the spot price of oil after 2003. Instead, there is strong evidence that the co-movement between spot and futures prices reflects common economic fundamentals rather than the financialization of oil futures markets. To what extent this conclusion may have to be refined in light of recent evidence for time-varying risk premia in the oil futures market after 2005 is still unclear, but there is no reason to expect the answer to change fundamentally. Not only was the surge in the real price of oil well underway by 2005, but the ability of economic fundamentals such as unexpectedly strong demand for crude oil from emerging Asia to explain fluctuations in the real price of oil since 2003 does not depend on how the oil futures market is modeled. This is a robust finding across a wide class of models and methodologies.

2. WHAT IS SPECULATION?

One of the reasons why discussions about the role of speculation often degenerate into blanket generalizations is that it is rarely clear how speculation is defined. The most general economic definition of speculation is provided in Kilian and Murphy (2011) who note that anyone buying crude oil not for current consumption, but for future use is a speculator from an economic point of view. What is common to all speculative purchases of oil is that the buyer is anticipating rising oil prices. Speculative buying may involve buying crude oil for physical storage leading to an accumulation of oil inventories, or it may involve buying an oil futures contract, provided an oil futures market exists. Either strategy allows one to take a position on the expected change in the price of oil. Standard theoretical models of storage imply that there is an arbitrage condition ensuring that speculation in one of these markets will be reflected in speculation in the other market (see, e.g., Alquist and Kilian 2010).

It is immediately clear that speculation defined in this manner need not be morally reprehensible. In fact, speculation may make perfect economic sense and indeed is an important aspect of a functioning oil market. For example, it seems entirely reasonable for oil companies to stock up on crude oil in anticipation of a disruption of oil supplies because these stocks help oil companies smooth the production of refined products such as gasoline. The resulting oil price response provides incentives for additional exploration and helps alleviate future shortages. Hence, it would be ill-advised for policymakers to prevent such oil price increases.

In the public mind speculation has a negative connotation because it is viewed as excessive. Excessive speculation sometimes may be defined as speculation that is not required for the oil market to function properly. Excessive speculation might also be defined as speculation that is beneficial from a private point of view, but would not be beneficial from a social planner's point of view. It follows naturally that the public has an interest in preventing this form of speculation. The broad definition of speculation in Kilian and Murphy (2011) makes no distinction between socially desirable and undesirable speculation. Indeed, determining whether speculative trading is excessive is difficult. For example, it does not depend on who engages in speculation.

One strand of the literature defines speculation in terms of who is buying the oil. Traditionally, traders in oil futures markets with a commercial interest in or an exposure to a physical commodity have been called hedgers, while those without a physical position to offset have been called speculators. The distinction between hedging and speculation in futures markets is less clear than it may appear, however. First, the oil futures market cannot function without speculative traders providing liquidity and assisting in the price discovery. The presence of speculators defined as noncommercial traders tells us nothing about whether speculation is excessive. Second, in practice, commercial traders may take a stance on the price of a commodity or may not hedge in the futures market despite having an exposure to the commodity. Both positions could be considered speculative (see Büyükşahin and Harris 2011). Likewise, there is nothing that prevents oil companies from acting as speculators in the physical market. Nor is there anything excessive about a hedge fund, for example, storing crude oil in a tanker in anticipation of rising oil prices, as long as the hedge fund bears the risk of the price of oil not increasing enough to compensate for the costs of this holding strategy. These examples illustrate the futility of defining excessive speculation by classifying different types of traders.

Likewise, efforts to detect speculators on the basis of high ex-post profits are not compelling. After all, speculators take risky positions and the return on holding oil must reflect that risk. Speculators who end up losing their bets rarely attract public attention. Yet another argument has been based on the relative size of the oil futures market and the physical market for oil. For example, it is often asserted that the daily trading volume in oil futures markets is three times as high as daily physical oil production, fueling the suspicion that speculators are dominating this market. Ripple (2008), however, shows that this ratio – after taking account of the number of days to delivery for the oil futures contract - is a fraction of about one half of daily U.S. oil usage rather than a multiple, invalidating this argument.

An alternative approach has been to quantify speculation following Working (1960) as an index measuring the percentage of speculation in excess of what is minimally necessary to meet short and long hedging demand (see, e.g., Büyükşahin and Harris 2011). A high Working index number, however, does not necessarily indicate excessive speculation. One benchmark in evaluating this index are historical values of this index for other commodity markets. By that standard the index numbers for the oil market even at their peak remain in the midrange of historical experience. Moreover, there does not appear to be a simple statistical relationship between this index of speculation and the evolution of the price of oil. For example, although the index for near-term contracts for the most part increased from 2001 until 2005, it remained roughly constant between early 2006 and early 2009, while the average price of oil first rose from $60 to $147 and then fell to $35. The correlation between the speculative index and daily price changes is near zero (see, e.g., Büyükşahin and Harris 2011; Alquist and Gervais 2011).

Often excessive speculation is equated with market manipulation. For example, it has been asserted that financial traders are herding the market into positions from which they can profit, resulting in excessively high oil prices in the spot market. It is important to stress that market manipulation and speculation are economically distinct phenomena. For example, the increased financialization of oil markets does not by itself mean that market manipulation is on the rise. Nor is there widespread evidence of market manipulation, notwithstanding some isolated cases in recent years.[1]

We conclude that there is no operational definition of excessive speculation. Rather the public has tended to conflate several recent developments in oil futures markets and in the spot market for crude oil. Oil futures contracts are financial instruments that allow traders to lock in today a price at which to buy or sell a fixed quantity of the commodity on a predetermined date in the future. Futures contracts can be

[1] While recognizing the difficulty of defining manipulation in a precise manner, Pirrong (1994) emphasizes the 'corner' or 'squeeze' as the main form of manipulative activities. A squeeze refers to a situation in which the trader goes long in the futures market by an amount that exceeds the actual barrels that can be delivered during that month. The squeezer can then demand the 'shorts' to deliver the barrels. The shorts have to secure the barrels often at a higher cost because they have to bid for these barrels from far away markets. This cost increases with the number of deliverable barrels and hence the bigger the position, the higher the premium that the squeezer can extract. Alternatively, the shorts can agree to cash settle at a price above the competitive price. A successful squeeze will have important effects on prices and the flow of the underlying commodity increasing the spot price both in absolute value and relative to the price of oil for forward delivery. Also the price of oil in the delivery market will rise relative to other locations. Thus, manipulation undermines the two main functions of the futures markets: (1) the price discovery function by distorting absolute and relative prices; and (2) the risk shifting function by reducing the effectiveness of hedging. There is a general consensus that policymakers must protect the integrity of futures market against such manipulative strategies. The debate focuses on whether the government should adopt harm-based rules or preventive measures and whether the existing regulations regarding manipulation are effective.

retraded between inception and maturity on futures exchanges such as the CME Group (formerly the New York Mercantile Exchange) or the Intercontinental Exchange (ICE). Exchanges offer institutional features that allow traders to transact anonymously, reduce individual default risk and ensure homogeneity of the traded commodity, making the futures market a low-cost and liquid mechanism for hedging against and for speculating on oil price risks.

As documented in Alquist and Kilian (2007) and Fattouh (2010a), starting in 2003, there was an influx of traders from outside the oil industry (often collectively and somewhat imprecisely referred to as hedge funds) into oil futures markets and other commodity futures markets. This phenomenon is referred to as the financialization of oil futures markets. The presumption is that these new financial traders were attracted by the prospect of high returns. At about the same time, both spot and futures prices of crude oil began to surge, soon reaching unprecedented levels. A natural conjecture is that this price surge was caused by the financialization of oil futures markets. In this interpretation, initially proposed by non-academics such as Masters and Soros testifying before Congress, hedge funds took speculative positions that resulted in rising oil futures prices, which in turn caused a similar increase in the spot price of oil.

As we will discuss in more detail below, the veracity of this view is not obvious at all and much of the academic debate centers on the evidence, if any, supporting Masters' (2008, 2010) interpretation. For example, what should matter is not only the number of financial investors, but also what net positions they take and how their presence changes the risk aversion, horizon, and risk-bearing capacity of traders overall.[2] Moreover, an exogenous shift in the composition of traders is not the only possible explanation for the surge in the price of oil. An alternative interpretation of the same evidence is that financial investors merely responded to the same market forces as other market participants and that both spot and futures prices were driven by the same economic fundamentals. Identifying cause and effect in financial markets requires a structural model such as the model we will discuss in section 7. Causality cannot be inferred from predictive correlations.

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[2] For example, Etula (2010) attributes the evolution of the risk premium in oil futures markets during 2008 to the arrival of institutional investors with a greater capacity to bear short-term price volatility.

One reason that the Masters hypothesis has received disproportionate attention among policymakers is that it seems to provide an obvious remedy to the problem of rising oil and commodity prices. This problem in policy circles often is mistakenly described as a problem of price volatility. To the extent that so-called financial speculation is the cause of the problem of rising oil prices, policies aimed at controlling trades in oil futures markets can be expected to prevent increases in the spot price of oil. This interpretation has informed recent policy efforts to regulate oil futures markets as part of a larger effort by the G20 governments to impose more control on financial markets. While these policy measures are perhaps understandable within the broader context of the global housing and banking crisis, they are not based on solid evidence. The following sections review the evidence in support of this hypothesis from a variety of angles, mirroring the evolution of the academic literature on this subject.

3. EVIDENCE FOR THE INCREASED FINANCIALIZATION OF OIL FUTURES MARKETS

While the definition of the term financialization remains vague, it captures the increasing acceptance of oil derivatives as a financial asset by a wide set of market participants including hedge funds, pension funds, insurance companies, and retail investors. Financial innovation provided easy and inexpensive access to financial instruments such as futures, options, index funds, and exchange-traded funds. The most obvious candidate explanation for this shift toward the use of energy derivatives is a secular change in investor preferences, involving increased reliance on market-based instruments for consumption smoothing, insurance and diversification, perhaps spurred by lower transaction costs or lower risk aversion. Other possible explanations are more temporary in nature and include that risk-free interest rates were low; that there was excess liquidity in financial markets; that returns in other financial markets were low or too volatile; or that crude oil was seen as a good hedge against inflation risks and a weak U.S. dollar.

There is clear evidence of increased involvement of financial investors in oil futures markets starting in 2003 (see Alquist and Kilian 2007; Tang and Xiong 2011; Hamilton and Wu 2011). Much of the initial analysis of the speculation hypothesis focused on documenting changes in the co-movement of oil prices and financial asset prices during 2003-08. For example, Silvennoinen and Thorp (2010) show that the conditional correlation between commodity futures returns and U.S. stock index returns has increased in recent years, especially in periods of high volatility. Büyükşahin and Robe (2011) report increased equity-energy price co-movements which can be explained in part by the entry of hedge funds that take positions in both equity and energy markets. Specifically, holding other things equal, they find that a 1% increase in the overall share of hedge funds in energy futures is associated with 5% increase in the dynamic correlation between energy and equity returns. This result, however, does not hold for other types of traders such as commodity index traders and swap dealers. They also find that the correlation is weaker in periods of financial market stress. Other studies examine the impact of the entry of index investors on the price co-movement between energy and other commodities. Tang and Xiong (2010) find that prices of non-energy commodities became increasingly correlated with oil prices. They also find that this result is more pronounced for commodities that are included in the commodity indices. In a similar vein, Silvennoinen and Thorp (2010) conclude that the correlation between crude oil future returns and other commodities such as agriculture has increased. There also is evidence of increased correlation between returns in foreign exchange and returns on oil (see, e.g., Akram 2009).

Other researchers have studied so-called commodity index funds and shown that the correlation is higher among returns within the index than among returns outside the index and that the correlation between energy-based indices and non-energy indices has increased. This has been taken as evidence of financial market integration driven by the rapid growth of commodity index funds (see Tang and Xiong 2010). Commodity index funds obtain price exposure by entering long positions in futures contracts. In order to maintain the long exposure, they need to unwind the maturing contracts before they expire and initiate new long positions in contracts that have later maturity dates. Because the funds have to roll their entire positions forward on a regular basis, the potential pressure on the prices of contracts involved can be very large, given the size of investment. Mou (2010) shows that the profitability of trading strategies designed to exploit this market anomaly increases in the share of index fund investment in oil futures markets.

The implications of increased co-movement between oil prices, financial asset prices and other commodity prices on social welfare are not clear. Büyükşahin and Robe (2011) in recognition of this point stress that "additional work is needed, if one is to ascertain whether the impact of financialization on cross-correlations represents a welcome improvement in market efficiency or, instead, is a worrisome development". Some studies argue that the increased co-movement of prices enhances spillover effects from other financial markets and from other commodity markets (see Tang and Xiong 2010). Others suggest that the increased co-movement had the effect of eroding the diversification benefits in commodity markets, one of the main motives for investors to include commodities in their portfolios in the first place (Silvennoinen and Thorp 2010). On the other hand, Fattouh (2010b) shows that the emergence of highly liquid crude oil futures markets has helped physical crude oil markets become more integrated by reducing transaction costs and facilitating arbitrage across geographically distant markets and across crude oils of different quality. Similarly, Büyükşahin et al. (2009) find that increased financialization is associated with more efficient derivatives pricing methods and Pirrong (2011) shows that greater financial market integration may reduce the market price of risk and increase the level of inventories by reducing the cost of hedging. While this mechanism induces an increase in the spot price, the higher level of oil inventories reduces the chances of future price spikes.

Most importantly, evidence of increased comovement between the spot price of oil, oil futures prices and other asset prices does not imply that the surge in the spot price was caused by financial speculators. First, economic theory tells us that both spot prices and futures prices are determined simultaneously and respond to the same economic forces (see Alquist and Kilian 2010). To the extent that global macroeconomic fundamentals have changed in recent years, for example, that fact could provide an alternative explanation of the observed comovement in spot and futures prices.

Second, there are other pieces of evidence that are inconsistent with the view that financialization is driving the price of oil. For example, Stoll and Whaley (2010) stress that the price of commodities not traded on futures exchanges rose as much as or more than the price of exchange-traded commodities. Indeed, the evolution of the price of crude oil is broadly similar to that of an index of non-exchange traded commodities (see Figure 1). The same point has been made by Irwin, Sanders, and Merrin (2009). This evidence is consistent with research quantifying broad-based shifts in the demand for all industrial commodities during 2003-08 (see, e.g., Kilian 2009a,b; Kilian and Hicks 2012). There also are persistent deviations between oil futures prices and natural gas futures prices that suggest a more important role for supply constraints in individual commodity markets. The development of shale gas in particular decoupled price developments in the natural gas market from the price of oil. The view that the supply side matters is also consistent with evidence in Kilian (2009a) who studies the evolution of oil and non-oil commodity prices in recent years and documents systematic differences between oil and other more elastically supplied industrial commodities.

4. DO INDEX FUND FLOWS PREDICT THE PRICE OF OIL FUTURES?

Subsequent studies have focused on the question of whether the increased importance of index funds helps predict higher returns on oil futures contracts. On the basis of such predictive correlations, Singleton (2011), for example, concluded that financial flows affect the return on crude oil. This prompted Reuters to assert that "Stanford University's Professor Kenneth Singleton has mounted the most wide-ranging and influential assault so far on the orthodoxy among policymakers and academics that speculation does not affect commodity prices" (Kemp 2011). This conclusion is remarkable in several respects. First, it had been academics that were reluctant to embrace Masters' hypothesis rather than policymakers. In fact, the prevailing orthodoxy among policymakers has been precisely the position Singleton advocates, not the position that speculation does not affect commodity prices. Second, the only evidence presented by Singleton is that financial flows precede changes in the oil futures price, but predictability does not necessarily imply causality. Third, the central question not answered by Singleton is how financial flows explain the corresponding increase in the spot price of oil. Fourth, Singleton's evidence is based on a very short estimation period. There is little controversy about the fact that the price of oil futures rose when index fund investments increased starting in 2003. The question is whether these index funds moved endogenously in response to economic incentives or exogenously shifted the oil futures price. In this sense, Singleton's analysis raises more questions than it answers.

Quite apart from these issues of interpretation there are concerns with the nature of the evidence provided by Singleton (2011). His empirical analysis like that of Masters (2008, 2010) is based on highly aggregated CFTC data on the positions of index funds (see Figure 2). Büyükşahin in a series of coauthored papers since 2009 has shown that this heavily aggregated data set is unsuitable for studying the question of speculation and that very different conclusions about the role of speculation are obtained when alternative proprietary CTTC data sets are used that include individual traders' positions. Moreover, Singleton's measure of index fund positions in oil futures is in fact inferred from CFTC data on agricultural futures, which subsequent research has shown to have little relation to the index funds' actual positions regarding oil (see, e.g., Irwin and Sanders (2012). Based on an alternative CFTC data set that is superior to that used by Singleton in terms of coverage and accuracy, Irwin and Sanders show that the WTI crude oil futures positions computed by Masters and by Singleton are grossly misleading. The imputed data used by Singleton and several other researchers not only contain large absolute errors, but have near zero correlation with the best available estimates of actual positions taken by index funds. Irwin and Sanders conclude that the data used by Singleton at best suffer from severe measurement error and at worst lead to highly misleading statistical estimates and inference.

The same point has been illustrated by a large number of papers. Brunetti and Büyükşahin (2009), for example, examine the same question as Singleton with a data set showing individual positions taken by traders. Unlike Singleton, they find no evidence that financial investor flows predict movements in oil futures prices or price volatility. Rather such speculative trading was associated with reduced volatility. Likewise, Büyükşahin and Harris (2011) find no evidence that the positions of hedge funds or other non-commercial investors predict changes in the futures price; rather futures price changes precede changes in positions. Brunetti, Büyükşahin, and Harris (2011) study specific categories of traders and test whether positions taken by speculators such as hedge funds and swap dealers cause changes in oil futures prices or price volatility. Their results are consistent with speculators providing valuable liquidity to the market and with speculators reacting to market conditions rather than vice versa. Similarly, Irwin and Sanders (2011) show that there is no statistically significant relationship between growth in the volume of oil futures contracts on the one hand and oil futures returns, their realized volatility and their implied volatility on the other hand. When a relationship is found at all, it is negative rather than positive, which is at odds with the results in Singleton (2011). Similar results are also reported in Stoll and Whaley (2011) and Sanders and Irwin (2011) based on a different data set.

Finally, even if we were to accept the results in Singleton (2011), his evidence is not necessarily evidence of speculation. It is equally consistent with the existence of frictions in the processing of information. This point has been stressed in a more general context by Hirshleifer (1988, 1989). Given the presence of setup costs (possibly related to informational costs) that limit the participation of non-commercial traders in the futures market, the risk premium depends both on systematic risk and on a residual risk linked to hedging pressure, with increased hedging pressure increasing the size of the risk premium and affecting oil futures and spot prices. Chang (1985) and De Roon el al. (2000) provide evidence that in many markets producers' hedging positions are correlated with commodity futures price changes, consistent with the existence of such frictions. In related work, Hong and Yogo (2012) document that the open interest in the oil futures market contains information about future economic activity and inflation expectations that is not immediately reflected in asset prices. The change in the open interest is a more reliable predictor of higher economic activity (and hence higher asset prices) than oil futures prices. It also helps predict changes in the spot price of oil. Hong and Yogo interpret this evidence as an indication that the anticipation of higher economic activity raises demand for hedging, which in turn drives up open interest.

5. DO FUTURES PRICES PREDICT SPOT PRICES?

An alternative strand of the literature has focused on the link between futures prices and the spot price. It is sometimes argued that higher futures prices cause increases in the spot price, simply because long-term oil contracts often use the oil futures price as a reference price. This argument is not compelling because the oil futures price reflects expectations about future demand and supply conditions in the oil market.

Theoretical models of storage imply that these same expectations must be reflected in the spot price by construction. For example, Peck (1985) emphasized that “expectations are reflected nearly equally in current and in futures prices. In this sense cash prices will be nearly as good predictions of subsequent cash prices as futures prices”, echoing in turn the discussion in Working (1942) who was critical of the “general opinion among economists that prices of commodity futures are … the market expression of consciously formed opinions on probable prices in the future” whereas “spot prices are not generally supposed to reflect anticipation of the future in the same degree as futures prices”. Working specifically criticized the error of “supposing that the prices of futures … tend to be more strongly influenced by these anticipations than are spot prices”.

Nevertheless, there has been a presumption in the public debate that the evolution of oil futures prices at a minimum helps predict changes in the spot price of oil. This is not the case. Alquist, Kilian and Vigfusson (2012) examine the out-of-sample accuracy of daily and monthly oil futures prices and show that there is no compelling evidence that oil futures prices help forecast the spot price of oil. Although this evidence does not address the central question of what caused the surge in the price of oil after 2003, it invalidates one of the arguments to which proponents of the Masters hypothesis about the role of index funds appeal to.

6. CRUDE OIL INVENTORY DATA

Another strand of the literature has aimed to provide evidence for speculation on the basis of data on crude oil inventories (see, e.g., Hamilton 2009a). Often rising levels of crude oil inventories are interpreted as a sign of speculative pressures in oil markets. Figure 3 plots the relationship between U.S. commercial stocks of crude oil held above the ground and the nominal West Texas Intermediate (WTI) price of crude oil during 1994-2011. The plot shows that there is little systematic relationship. It is sometimes claimed that the negative relationship between these variables that used to prevail during 1994-2004 has been overturned by speculators entering the oil futures market after 2003. Indeed, there is evidence of an upward slope in post-2004 data. The data in Figure 3 may seem to support this interpretation at first sight, but there are several problems with this argument.

First, to the extent that there is a systematic relationship driven by speculative demand for inventories, economic theory tells us that this relationship should be between the speculative component of the real price of oil (or equivalently the negative of the oil futures spread) and the change in global crude oil inventories (see Alquist and Kilian 2010). In this sense, both axes in Figure 3 are mismeasured and the lack of a systematic relationship is not surprising. Second, such a relationship would only be expected to hold in the absence of other oil demand and oil supply shocks. Third, the conventional economic argument for a positive relationship between oil prices and inventories after 2003 relies on a static model in which speculators exogenously drive the futures price above its equilibrium level, which all else equal encourages new production and discourages consumption. This in turn causes an unplanned accumulation of inventories, resulting in positive co-movement between the spot price of oil and crude oil inventories. This model is not realistic because it takes as given the premise that the increase in the futures price is exogenous with respect to the oil market. It rules out by assumption that these speculators were responding endogenously to expectations of future shortages. Standard theoretical models of storage tell us that all relevant model variables will respond endogenously to shifts in expectations about future oil supply shortfalls, violating the ceteris paribus assumption in the static model. In these models, oil inventories, the spot price of oil and the futures price are jointly and simultaneously determined rather than the futures price being exogenously given.

A detailed analysis of such a dynamic rational expectations model can be found in Alquist and Kilian (2010) who study the relationship between changes in oil inventories, the oil futures spread and changes in the real price of oil driven by precautionary demand shocks. Their focus is on the effects of increased uncertainty about future oil supply shortfalls, modeled as an exogenous mean-preserving spread. Similarly, Pirrong (2008) advocates the use of a dynamic rational expectations model for analyzing the commodity storage problem. In his model, there is a random shock to economic fundamentals with a stochastic variance that reflects increased uncertainty about future oil supply shortfalls. As in Alquist and Kilian, forward-looking agents respond to an exogenous increase in this variance by increasing inventory holdings which requires the spot price of oil to increase. If the variance is sufficiently high, the reduced-form relationship between inventories and the real spot price becomes unstable.

In related work, Dvir and Rogoff (2010) study exogenous shocks to the demand for oil in the form of exogenous shifts in world income. In their model agents increase storage optimally in response to an income shock, causing the real spot price of oil to increase in equilibrium because expectations of higher growth in the future amplify the demand for storage. This means that the volatility of the price of oil increases due to storage contrary to the notion that storage necessarily reduces oil price volatility. Dvir and Rogoff note that their model is particularly applicable to modern oil markets since 1973.

The absence of a stable relationship between inventories and the real price of oil is also a central feature of structural oil market models of the type proposed in Kilian and Murphy (2010). Their analysis focuses on the post-1973 period. Unlike Dvir and Rogoff's theoretical analysis, the empirical model of Kilian and Murphy treats all observables as fully endogenous. A popular argument in the literature, building on the static model with exogenous shifts in the oil futures price that we discussed earlier, has been that a persistent accumulation of oil inventories implies the presence of speculators. Kilian and Murphy show that this argument can be misleading once all variables are treated as endogenous. An observed increase in inventories, for example, is equally consistent with an increase in inventory demand driven by speculative demand shocks and an unexpected slowing of the global economy or an unanticipated increase in oil production. Kilian and Murphy also illustrate that historically different demand and supply shocks in the global oil market often resulted in offsetting changes in oil inventories, while reinforcing changes in the real price of oil in the same direction, so the absence of changes in oil inventories does not imply the absence of speculation. This evidence reinforces the point that one should not expect a stable relationship between the real price of oil and inventories. Indeed, the current consensus in the literature is that "those searching for evidence of speculative excess need look elsewhere than the price-inventory relation" (Pirrong 2008).

7. STRUCTURAL ECONOMIC MODELS OF OIL MARKETS

The discussion in section 6 highlights that there is no substitute for a structural model of the oil market in thinking about the evidence for speculation. Theoretical models of storage such as Alquist and Kilian (2010) or Pirrong (2008, 2011) make it clear that the notion that the real price of oil is no longer driven by demand and supply, but by speculation, as is often asserted in the media, is economic nonsense because speculative demand is one component of the demand for oil. The challenge is how to model speculation within an empirical model that nests different explanations of the surge in the real price of oil.

7.1. THE KILIAN AND MURPHY MODEL

Kilian and Murphy (2011) proposed the first empirical model designed to quantify the effect of speculative demand shocks on the real price of oil. Their model builds on a growing literature using structural vector autoregressive (VAR) models to disentangle demand and supply shocks in global oil markets (see, e.g., Kilian (2009a,b); Kilian and Murphy 2012; Baumeister and Peersman 2012). The set of variables in Kilian and Murphy (2011) consists of monthly data for the percent change in global oil production, a measure of global real activity (in deviations from trend), the real price of crude oil, and the change in above-ground global crude oil inventories. The model is identified based on a combination of sign restrictions and bounds on the short-run price elasticities of oil demand and oil supply.

The key identifying assumptions for the purpose of this discussion are restrictions on the signs of the impact responses of the four observables to each structural shock. There are four structural shocks. First, conditional on past data, an unanticipated disruption in the flow supply of oil causes oil production to fall, the real price of oil to increase, and global real activity to fall on impact. Second, an unanticipated increase in the flow demand for oil associated with unexpected changes in the global business cycle causes global oil production, global real activity and the real price of oil to increase on impact.[3] Third, a positive speculative demand shock, defined as an increase in inventory demand driven by expectations

[3] The response of above-ground oil inventories to flow demand and flow supply shocks is left unrestricted in the model because the price responses to these shocks could potentially trigger an accumulation of inventories due to speculation, while refiners are likely to smooth their production of refined products, resulting in lower inventories. Which effect dominates is not clear ex ante, but the model estimates indicate a negative response on balance.

shifts not otherwise captured by the model, will in equilibrium cause an accumulation of oil inventories and will raise the real price of oil (see, e.g., Alquist and Kilian 2010). The accumulation of inventories requires oil production to increase and oil consumption to fall (associated with a fall in global real activity). The focus on above-ground crude oil inventories is consistent with conventional accounts of speculation involving the accumulation of inventories in oil-importing economies. An alternative view is that speculation may also be conducted by oil producers who have the option of keeping the oil below the ground in anticipation of rising prices (see Hamilton 2009b). Such an accumulation of below-ground inventories by oil producers in this model would be reflected in a reduction in flow supply. No attempt is made to distinguish such speculative supply shocks from other supply shocks. Finally, the model also includes a residual oil demand shock designed to capture idiosyncratic oil demand shocks driven by a myriad of reasons that cannot be classified as one of the first three structural shocks. The latter demand shock has little systematic effect on the real price of oil.

The Kilian and Murphy model is designed to remain valid even if there are limits to arbitrage between oil futures and spot markets. In fact, one of its advantages is that the identification strategy does not require the existence of an oil futures market, but remains valid in the presence of an oil futures market. This allows the use of data back to 1973 in estimating the model. Indeed, it can be shown that the oil futures spread is redundant in this model because all the information about expectations is already captured by the data on oil inventories. This interpretation is consistent with the fact that the oil futures spread, when it is available, does not Granger cause the four model variables, which may be viewed as a test of the model specification (see Giannone and Reichlin 2006).

The estimates of the Kilian and Murphy model show that indeed there were several historical episodes in which speculation moved the real price of oil including 1979, 1986, 1990 and late 2002. This evidence is important because it illustrates that the model has the power to detect speculation when it exists according to anecdotal evidence (see, e.g., Yergin 1992). With regard to the surge in the real price of oil between 2003 and mid-2008, in contrast, the model estimates unambiguously show that there is no evidence to support the notion that this surge was caused by speculation. If so, one would have expected positive speculative demand shocks to have driven up the real price of oil in the spot market. This is not what the model estimates imply. To the extent that there is unlimited arbitrage these estimates also imply that there was no speculation in the oil futures market because by arbitrage such speculation would have caused speculative demand for inventories to shift. While the latter implication is necessarily more tentative, it is consistent with evidence based on disaggregate CFTC data that index funds did not drive up the oil futures price.

Likewise there is no evidence for speculation by oil producers or for other negative oil supply shocks causing the price surge. Negative flow supply shocks during 2003-08 raised the real price of oil slightly, but the increases were minor compared with the observed surge in the real price of oil. Nor is there evidence for the peak oil hypothesis having affected the real price of oil. Instead the model indicates that a sequence of positive flow demand shocks, none of which was particularly large individually, is perfectly capable of explaining the observed surge in the real price of oil, even during 2007/08. This empirical result is also consistent with independent evidence in Kilian and Hicks (2012) based on an analysis of professional real GDP forecasts, which highlights the role of increased demand for crude oil and other industrial commodities from emerging Asia, and with evidence based on dynamic stochastic general equilibrium models of the world economy in Bodenstein and Guerrieri (2011). The same type of flow demand shock in the VAR model also explains the partial recovery of the real price of oil after 2009. This evidence implies that both oil futures prices and spot prices were driven up by the same economic fundamentals. In short, the Kilian and Murphy model provides the most decisive and most formal evidence on the question of speculation to date.[4]

7.2. OTHER STUDIES

Recently, two studies have argued that the Kilian and Murphy model does not explicitly allow for

[4] It also has been shown that this model may be used to construct more accurate real-time out-of-sample forecasts of the real price of oil than alternative models including the random walk model and forecasts based on oil futures prices (see Baumeister and Kilian 2012). The latter evidence is instructive in that it suggests that the linear VAR model is a good first-order approximation even in the presence of structural changes such as fluctuations in the risk premium (see section 8).

"financial speculation" and hence may be misleading (see Juvenal and Petrella 2011; Lombardi and Van Robays 2011). For example, Juvenal and Petrella (2011) introduce an additional shock into the Kilian and Murphy model designed to capture speculation by oil producers, while retaining the original speculative demand shock in that model. Their analysis relies on a static theoretical model in which there is an exogenous upward shift in oil producers' expectations of the real price of oil. Oil producers expecting a higher price for future deliveries, as a result, will withhold oil from the market and accumulate inventories. This accumulation takes the form of an accumulation of below-ground inventories, resulting in a reduction in flow supplies, associated with a higher spot price and lower oil consumption and hence lower real activity.[5] Juvenal and Petrella's first crucial identifying assumption is that the impact response of above-ground oil inventories to an oil producer speculation shock is positive. This assumption is inconsistent with the underlying economic model which predicts an accumulation of below-ground inventories. The second crucial identifying assumption is an additional sign restriction on the inventory response to flow supply shocks, for which there is no theoretical justification. The failure of either of these two sign restrictions invalidates the estimates of their model. Moreover, leaving aside the question of identification, this additional speculation shock is not designed to capture financial speculation, but rather speculative supply shocks of the type described by Hamilton (2009a). In short, the analysis in Juvenal and Petrella is not informative about the role of financial speculation.

In related work, Lombardi and Van Robays (2011) propose to augment the Kilian and Murphy model with data on the oil futures price and to re-estimate the model on data since the late 1980s.[6] Their key innovation is the introduction of an additional 'nonfundamental' financial speculation shock. The intuition underlying their model is similar to that in the static model of speculation we reviewed in section 6. The financial speculation shock is identified as a shock that raises both the oil futures spread and the oil

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[5] The inventory accumulation also could take the form of an accumulation of above-ground inventories by oil producers, but the latter form of storage is more costly than keeping the oil below the ground, making it implausible.

[6] Their model is misspecified in that they model spot and futures prices in differences and in nominal terms, rendering all estimates inconsistent. A more appropriate specification would have involved the oil futures spread and the real price of oil in the spot market. Here we abstract from this and other modeling choices in the interest of focusing on the identification.

futures price on impact. All other impact responses to this shock are left unrestricted. The key identifying assumption is the positive response of the spread. This is in contrast with the negative response of the spread to a speculative demand shock in standard models of storage. However, they fail to impose other restrictions implied by economic theory such as the restriction that the impact responses of oil production and of global real activity should be negative and that of the real price of oil should be positive. Likewise, the authors fail to impose the other restrictions on oil inventories implied by the analysis in Kilian and Murphy and the additional restrictions on the spread implied by the analysis in Alquist and Kilian (2010). This invalidates the model estimates for the reasons discussed in Kilian and Murphy (2012). Moreover, their interpretation of the speculative demand shock of Kilian and Murphy (2011) as an oil-specific demand shock is incorrect, as is the assertion that this shock is designed to reflect expected changes in fundamentals only and cannot capture other expectations shifts. We conclude that Lombardi and Van Robays' analysis does not shed light on the role of financial speculation shocks.[7]

A very different approach was taken by Hamilton (2009b) who observes that speculation in oil markets indeed will have to involve a response of above-ground inventories unless the short-run price elasticity of gasoline demand is literally zero, allowing increases in the real price of oil to be passed on to consumers without a reduction in consumption causing an involuntary accumulation of inventories. The empirical relevance of this limiting case depends on the magnitude of the elasticity in question. Kilian and Murphy (2011) show that under reasonable assumptions this gasoline demand elasticity is approximately the same as the short-run price elasticity of oil demand. They also show that traditional estimates of the short-run price elasticity of oil demand based on reduced-form models are not identified, causing these estimates to be biased toward zero. Alternative structural estimates that correct for this problem are consistently far from zero. For example, the preferred estimate of the short-run price elasticity of oil demand in Kilian and Murphy is -0.26. Similar results have been obtained using many other econometric

[7] An additional problem common to both Juvenal and Petrella (2011) and Lombardi and Van Robays (2011) is that the interpretation of the empirical results is based on median response functions. It has been shown that median response functions are not a valid summary measure of the central tendency of the impulse response estimates nor do they have an economic interpretation, making it difficult to interpret the results in these papers (see, e.g., Fry and Pagan 2011; Inoue and Kilian 2011; Kilian and Murphy 2012).

methodologies that address the central issue of identification (see, e.g., Serletis, Timilsina and Vasetsky 2010; Bodenstein and Guerrieri 2011; Baumeister and Peersman 2012). This conclusion also is consistent with recent structural estimates of the short-run price elasticity of gasoline demand based on instrumental variable regressions (see, e.g., Davis and Kilian 2010). An unresolved question is to what extent the price elasticity of gasoline demand may have declined in magnitude in very recent years and at what time (see, e.g., Hughes, Knittel, and Sperling 2008). It would take a substantial decline, however, to make the limiting case of a zero elasticity discussed in Hamilton (2009b) empirically relevant.

8. MODELS OF TIME-VARYING RISK PREMIA

Buying a futures contract involves risk that is compensated for in equilibrium by a risk premium. Standard theoretical and empirical models of oil markets treat this risk premium as constant over time. Indeed, Alquist and Kilian (2010) provide empirical evidence that the risk premium in oil markets is on average not significantly different from zero. This evidence would also be consistent with time-varying risk premia which alternate in sign depending on the state of the economy, however. A number of recent studies have developed models in which the risk premium evolves over time. Of particular concern is the possibility that the risk premium may have decreased in recent years during the time of the surge in the real price of oil. A time-varying risk premium could potentially undermine the usefulness of existing empirical and theoretical models based on a constant risk premium.

Standard models of speculation such as Alquist and Kilian (2010) focus on refiners' use of oil inventories to hedge oil price risks, building on the notion of a convenience yield. In other words, oil storage is valuable because it provides insurance against supply disruptions or against unexpected increases in demand. In these models, the oil futures market merely provides an additional financial instrument that serves much the same purpose as accumulating crude oil inventories. Acharya et al. (2010) propose an alternative model of oil futures markets in which speculators allow oil producers to hedge. The model highlights the role of the capital constraints faced by speculators for the determination of futures and spot prices. The key difference is that this model focuses on oil producers' inventories rather than refiners' inventories, as in conventional models.

Acharya et al. (2010) show that tighter capital restrictions faced by commodity investment funds or increased hedging pressures increase the price of oil futures and raise the cost of hedging for producers who are naturally short. This induces producers to scale back their above-ground oil inventory holdings, releasing the oil to the market and thus putting downward pressure on the spot price. They also show that an increase in hedging pressures and/or a decline in the speculators' ability to bear risk affect the risk premium in oil futures markets and helps predict changes in the spot price. Specifically, increases in risk aversion (proxied by the default risk facing producers) predict an increase in the excess return on short-term futures. Moreover, the fraction of the futures risk premium attributable to default risk is higher in periods when broker-dealer balance sheets are contracting. One reason to be concerned with their model is that the model has direct implications for regulators. In particular, efforts intended to increase the cost of hedging may reduce the risk-bearing capacity of speculators and hence may raise the spot price of oil.

A key implication of Acharya et al. (2010) is that a decrease in the futures risk premium causes an increase in the spot price of oil, as producers are willing to hold higher inventory levels when the cost of hedging is low. In closely related work, Etula (2010) shows that the effective risk aversion of brokers who are highly leveraged and who tend to play an important role in matching parties in over-the-counter markets is an important determinant of risk premia in commodities markets. Etula (2010) derives an asset pricing model in which the risk premium depends both on systematic and non-marketable risk with the latter increasing in the economy's effective risk aversion. Etula (2010) shows that risk aversion varies over time with brokers' risk bearing capacity. Using aggregate balance sheet data for broker-dealers to construct an empirical proxy of risk aversion, he finds that changes in risk aversion predict expected futures returns for crude oil. However, the indicator of effective risk aversion fails to explain oil price fluctuations during 2008-2009. Etula attributes the break in the relationship to the inadequacy of the constructed measure of risk aversion to reflect the broader appetite for risk as it does not capture the various types of financial investors such as hedge funds, index investors and pension funds. He also shows that changes in risk aversion help predict one-quarter ahead excess returns in crude oil futures out of sample, although the extent of the reductions in the mean-squared prediction error cannot be inferred from his results.

These results on time-varying risk aversion are encouraging, but hardly dispositive. For example it is difficult to tell from the analysis in Acharya et al. (2010) which of the many regressors is responsible for how much improvement in predictive accuracy and it is unclear how the out-of-sample forecast accuracy of these models compares to that of alternative forecasting models based on economic fundamentals (see, e.g., Alquist et al. 2012; Baumeister and Kilian 2012). Moreover, Acharya et al. (2010) readily acknowledge that their alternative theory is unlikely to explain the full magnitude of the rise and fall in oil prices witnessed recently. Indeed, it is not a theory of global oil markets, but of U.S. oil producers and the available firm data are not rich enough to infer the aggregate hedging position even for U.S. oil producers, not to mention global oil producers. Hence, Acharya et al. view this mechanism as a likely contributing factor to recent price movements at best. In contrast, existing empirical oil market models are capable of explaining much of the observed surge in the real price of oil based on unexpected changes in global real activity without relying on changes in the risk premium (see, e.g., Kilian 2009a,b).

The logical next step would be an evaluation of the empirical content of models of time-varying risk premia within the context of a more general model that embeds the notion of time-varying risk premia along with other explanations of oil price fluctuations. It is not clear, however, how to construct such a model or how to compute global measures of risk-bearing capacity or, for that matter, how to obtain disaggregate global crude oil inventory holdings for oil producers.

The idea of time-varying risk premia also plays a central role in recent work by Hamilton and Wu (2011) who provide evidence of large shifts in the risk premium after 2005. Figure 4 shows that, following a long period of stability, the risk premium on the 8-week oil futures contract became highly volatile after 2005. An initial surge in the risk premium to an unusually high positive level in 2005/06 is followed by subsequent equally negative spikes in 2007/08 and 2010. Hamilton and Wu associate these shifts with index funds and other financial investors having become natural counterparties for commercial hedgers. They provide a formal theoretical model and improved econometric techniques for the estimation of time-varying risk premia. It is noteworthy that the date of the apparent break in the process governing the risk premium in Figure 4 does not occur in 2003, but much later, illustrating that the volume of speculative trading is not necessarily the best indicator of structural changes in oil futures markets. The implications of this evidence for the evolution of the spot price of oil are not clear.

Changes in estimated risk premia are not the only sign of possible structural change in oil futures markets in recent years. In related work, Büyükşahin et al. (2009) note large changes in the term structure of oil futures after about 2002 (including a lengthening of the term structure), and Fattouh and Scaramozzino (2011) provide evidence that the front end and the back end of the term structure of oil futures has shifted, with the back-end price adjusting to the front-end price. Such a shift could be explained by a model of Bayesian updating in which the probability distribution about the future price of oil shifts. Whether this shift is caused by financial investors or more fundamental shocks is a different question.

All this evidence is suggestive of the interpretation that the arrival of financial investors may have changed the behavior of oil futures markets. There is no consensus, however, that this increased financialization has been detrimental. For example, Büyükşahin et al. (2009) emphasize that increased efficiencies in derivatives pricing have caused futures prices at different maturities to become more closely linked. In related work, Boyd et al. (2010) find evidence of herding in oil futures markets, resulting in common trading strategies, but conclude that this herding actually stabilized the price.

One of the least understood aspects of financialization is how the entry of new classes of investors affects the formation of market expectations. Singleton (2011), for example, building on Allen, Morris, and Shin (2006), stresses that market participants may form expectations not only in terms of expected fundamentals, but also in anticipation of other market participants' actions. Likewise, there is a concern that some market participants may overreact to public information or signals that do not reflect large changes in underlying fundamentals. This concern seems particularly pertinent when new market participants lack the expertise to understand oil market developments. Another possibility is that market participants coordinate on a small number of easily observable signals such as data on oil inventories, the dollar exchange rate, shortages of supply, or concerns over peak oil. Many of these concerns arise in similar form in other financial markets. In this sense, we may say that oil futures markets have matured and have become an integrated part of the financial market system.

9. CONCLUSION

The key question addressed in this survey is whether there is evidence that speculation has been driving the recent fluctuations in the spot price of oil. The academic literature allows several conclusions. First, there is clear evidence of the increased financialization of oil futures markets. Whether this financialization also was responsible for increased co-movement among different asset prices continues to be debated. Although there is some evidence of increased co-movement across asset classes, that co-comovement is also found in markets in which index funds do not operate and for which there are no futures exchanges, which is suggestive of an explanation based on common economic fundamentals.

Second, there is no compelling evidence that changes in financial traders' positions predict changes in the price of oil futures. Conflicting results in the literature in this regard can be traced to the use of data sets in some studies that are too aggregated to be informative about these predictive relationships. To the extent that any evidence of predictive power from index fund holdings to oil futures prices has been found, that evidence has not been based on rigorous real-time analysis and the extent of the out-of-sample gains has yet to be quantified. Finally, it cannot be ruled out that this predictive power, if any, arises from traders' positions responding to the underlying fundamentals of the oil market.

Third, contrary to widely held beliefs that increases in oil futures prices precede increases in the spot price of oil, there is no evidence that oil futures prices significantly improve the out-of-sample accuracy of forecasts of the spot price of oil. This result holds whether one is forecasting the nominal price or the real price of oil. There is evidence that models based on economic fundamentals help forecast the spot price of oil out of sample, however.

Fourth, we observed that the simple static model that has been used to explain how an influx of financial investors may cause an increase in the spot price of oil is inconsistent with dynamic models of storage. As a result, the oil price-inventory relationship tells us nothing about the quantitative importance of speculation in oil markets. In particular, the absence or presence of speculative pressures in the oil market cannot be inferred from studying oil inventory data without a fully specified structural model.

Fifth, structural VAR models that nest alternative explanations of the evolution of the real price of oil (including speculative demand) provide strong evidence of speculation in 1979, 1986, 1990 and late 2002, but are not supportive of speculation being an important determinant of the real price of oil during 2003 and mid-2008. Instead these models imply that both spot and futures prices were driven by a common component reflecting economic fundamentals. Alternative structural VAR studies that claim to have found evidence of financial speculation suffer from identification problems and are uninformative. Nor is there empirical evidence that the short-run price elasticity of gasoline demand is literally zero, as required for the theoretical model discussed in Hamilton (2009a) to explain increases in the spot price based on speculation in oil futures markets.

Sixth, recently developed theoretical and empirical models of time-varying risk premia may help enhance our understanding of fluctuations in oil prices, but it is not clear how representative these models are for the global market for crude oil, and their ability to explain fluctuations in the price of oil has yet to be explored in full detail.

Finally, the absence of evidence in favor of speculation does not mean that the financialization of oil futures markets does not matter. There is clear evidence of structural instability in the term structure of oil futures and in the risk premium, for example, that could be related to the financialization of these markets. We discussed existing research as well as some avenues for future research that may help us understand these facts. We highlighted in particular the role of heterogeneous expectations and of the limits to arbitrage in these markets.

One of the problems in this literature and, more importantly, in the public debate about speculation is that it is rarely clear how speculation is defined and why it is considered harmful to the economy. For example, the aim of recent regulatory changes in oil futures markets is to reduce price volatility, when increased oil price volatility was never the problem, but the persistent increases in the price of oil after 2003. Moreover, the literature has shown that the presence of index funds has, if anything, been associated with reduced price volatility. This view is also supported by historical analyses on the relationship between futures markets and price volatility (see, e.g., Jacks 2007). Nor is there sufficient attention to the possibility that some forms of speculation may be more harmful than others. One strategy for evaluating the consequences of speculation would be to quantify the social welfare costs of speculation. This approach will require the developments of more fully articulated economic models than the current generation of theoretical and empirical models.

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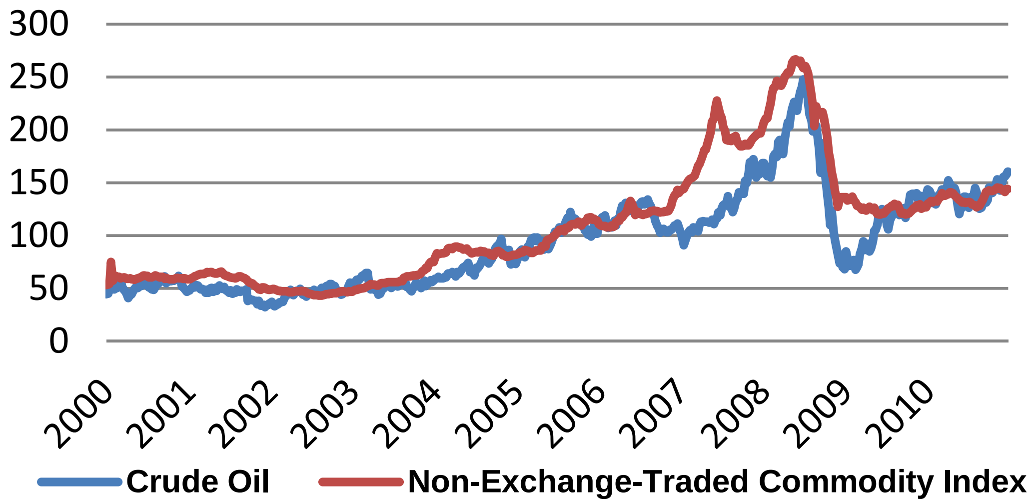
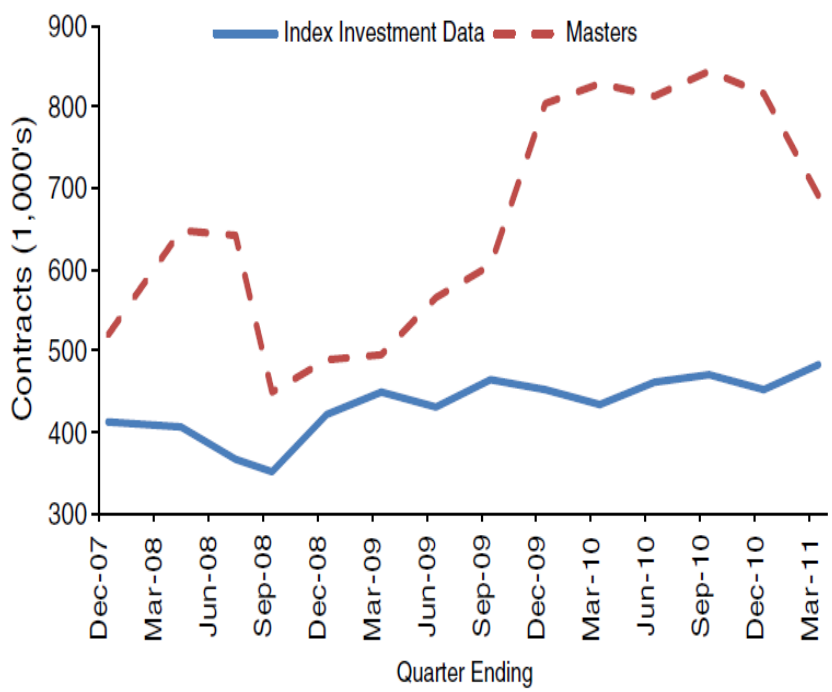
Figure 1: Price of Non-Exchange Traded Commodities and Price of Crude Oil



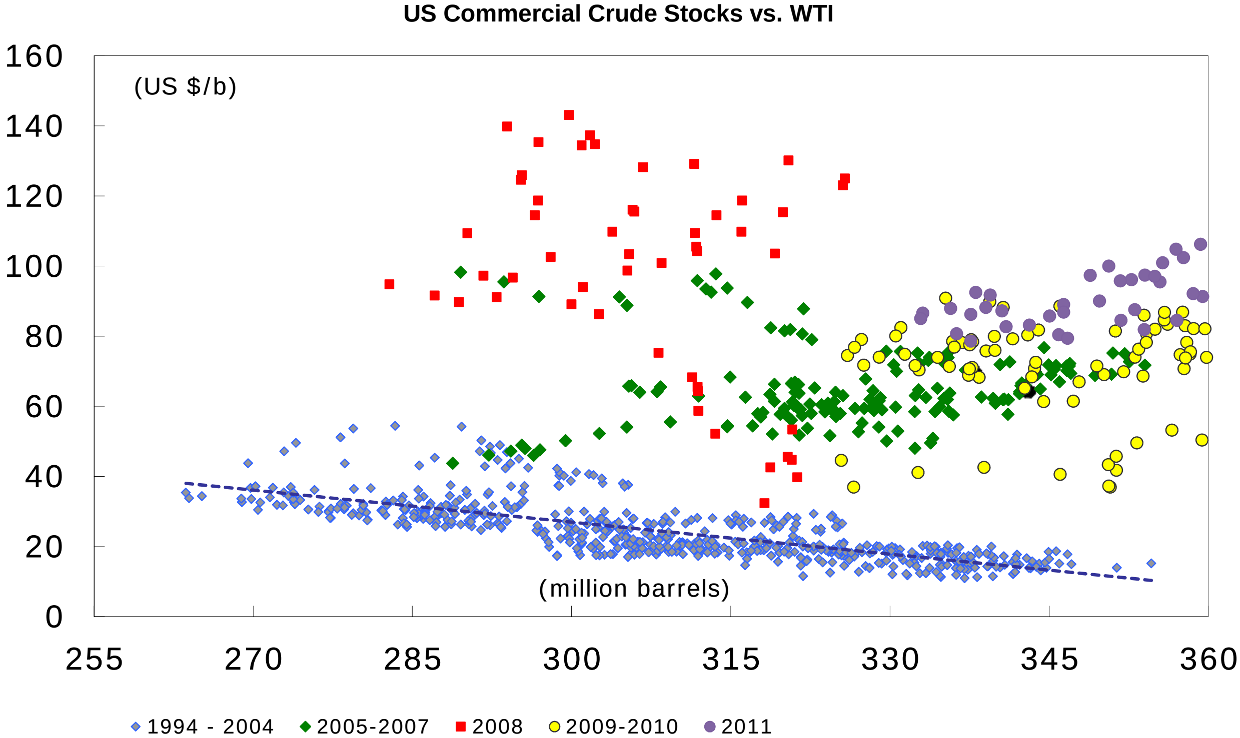
Source: Computations of the authors based on data in the *IEA Oil Market Report*, March 15, 2011.

Figure 2: Comparison of WTI Crude Oil Net Long Positions based on Index Investment Data and Masters' Estimates



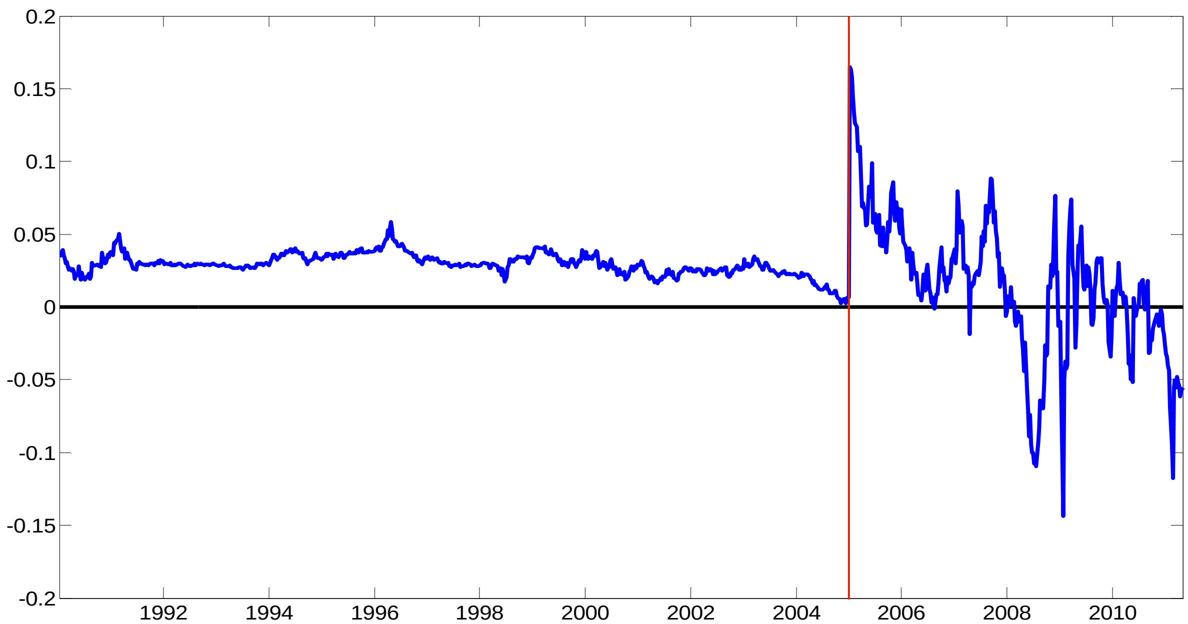
Source: Irwin and Sanders (2012). Reproduced with permission of the authors.

Figure 3: The Crude Oil Inventory-Oil Price Relationship



Source: Computations of the authors based on EIA data.

Figure 4: 8-Week Risk Premium Estimated from Hamilton and Wu (2011) Model with Sample Split in 2005



Source: Hamilton and Wu (2011).