Abstract

The price of crude oil never exceeded $40 per barrel until mid-2004. By July 2008 it peaked at $145 and by late 2008 fell to $30 before increasing to $110 in 2011. Are speculators partly to blame for these price changes? Using a simple model of supply and demand in the cash and storage markets, we determine whether speculation is consistent with data on production, inventory changes, and convenience yields. We focus on crude oil, but our approach can be applied to other commodities. We show speculation had little, if any, effect on oil prices.

JEL Classification Numbers: Q40; L71; G13

Keywords: Commodity prices, crude oil, speculation, futures markets, storage markets, inventories.
Commodities have become an investment class: declines in their prices may simply reflect the whims of speculators.

The Economist, June 23, 2012.

Tens of billions of dollars went into the nation’s energy commodity markets in the past few years, earmarked to buy oil futures contracts. Institutional and hedge funds are investing increasingly in oil, which has prompted President Obama and others to call for curbs on oil speculation.


Federal legislation should bar pure oil speculators entirely from commodity exchanges in the United States.


1 Introduction.

The price of crude oil in the U.S. had never exceeded $40 per barrel until mid-2004. By 2006 it reached $70 and in July 2008 it peaked at $145. As shown in Figure 1, by the end of 2008 it had plummeted to about $30 before increasing to $110 in 2011. Were these sharp changes in oil prices due to fundamental shifts in supply and demand, or are “speculators” at least partly to blame? This question is important: the wide-spread claim that speculators caused price increases has been the basis for attempts to limit—or even shut down—trading in oil futures and other commodity-based derivatives.

Other commodities also experienced large price swings. Several times during the past decade the prices of industrial metals such as copper, aluminum, and zinc more than doubled in just a few months, often followed by sharp declines. And price changes across commodities tend to be correlated; from 2002 to 2012, the correlation coefficients for crude oil and aluminum, copper, gold, and tin range from .74 to .89 in levels, and .52 to .71 in monthly first differences. Should we infer from the volatility and correlations of prices that commodities have indeed “become an investment class?” Or might commodity prices have been driven by common demand shocks, e.g., increases in demand from China and other developing countries?

The claim that speculators are to blame and futures trading should be limited is well exemplified by a recent Op-Ed piece in the New York Times by Joseph P. Kennedy II. He wrote that “the drastic rise in the price of oil and gasoline” is at least partly attributable
to “the effect of pure speculators—investors who buy and sell oil futures but never take physical possession of actual barrels of oil.” He argues that “Federal legislation should bar pure oil speculators entirely from commodity exchanges in the United States. And the United States should use its clout to get European and Asian markets to follow its lead, chasing oil speculators from the world’s commodity markets.”

Was Kennedy on to something? Unfortunately there is considerable confusion over commodity price speculation and how it works. Even identifying speculators, as opposed to investors or firms hedging risk, is not simple. Claiming, as Kennedy did, that anyone who buys or sells futures but does not take possession of the commodity is a “pure speculator” is nonsensical. Hardly any person, firm, or other entity that buys or sells futures contracts ever takes possession of the commodity, and we know that a substantial fraction of futures are held by producers and industrial consumers to hedge risk.

This paper attempts to clarify the potential and actual effects of speculators, and investors in general, on the prices of storable commodities. We focus on the price of crude oil because it has received the most attention as the subject of speculation. More than other commodities, sharp increases in oil prices are often blamed, at least in part, on speculators. (Interestingly, speculators are rarely blamed for sharp decreases in oil prices.) But our theoretical and empirical approach can be applied equally well to other commodities.

We begin by addressing what is meant by “speculation,” and how it relates to investments in oil reserves, inventories, or derivatives (such as futures contracts). We also outline the ways in which one could engage in speculation. We clarify the mechanisms by which speculators (and investors) affect oil prices, production, and inventories, and thereby provide a “simple” explanation of the economics of price speculation. Finally, we turn to the data, and answer the questions raised in the first paragraph: What role did speculation have in the sharp changes in oil prices that have occurred since 2004?

Others have also investigated the causes of oil price changes and the possible role of speculation. Fattouh et al. (2013) summarize the literature and conclude that “the existing evidence is not supportive of an important role of financial speculation in driving the spot price of oil after 2003.” Kilian and Murphy (2013) note (as we do) a connection between speculative activity and inventory changes, and estimate a vector-autoregressive (VAR) model
that includes inventory data to identify the “asset price component” of the real price of oil.\footnote{Kilian (2009) uses a VAR model to distinguish between demand- and supply-side shocks to fundamentals.} They find no evidence that speculation increased prices. Hamilton (2009a,b) examines possible causes of oil price changes and concludes that speculation may have played some limited role in the price increase during 2007-2008.\footnote{Hamilton and Wu (2014), however, show that index fund and related investments in the futures markets for oil and agricultural commodities had little or no impact on futures prices.} In a more qualitative study, Smith (2009) does not find any evidence that speculation increased prices between 2004 and 2008, noting that inventories were drawn down during this time and there is no evidence that non-OPEC producers reduced output.\footnote{In a more dynamic model, inventories may be drawn down in the presence of speculation on net, if shocks to the market would have led to increases in inventories in the absence of speculation. Pirrong (2008) and Kilian and Murphy (2013) make this point.} Likewise, Alquist and Gervais (2013) use Granger causality tests to argue that financial speculation had little or no impact on prices.

We put the word “simple” in the title of this paper because speculation and its impact can be understood and assessed with a relatively basic economic model. We do not mean to suggest that recent econometric studies of oil prices (such as those mentioned above) do not provide useful information about the causes of price movements. Those studies indeed tell us a good deal about the role of demand versus supply shocks, and inventory changes. In any case, our focus is not to explain why prices moved as they did, but rather to determine whether speculation was a significant driver of prices. As we will show, we can do this with a simple model of supply and demand in the cash and storage markets for a commodity. In addition, our simple model confirms the results that Kilian and Murphy (2013), Kilian and Lee (2013), and Fattouh et al. (2013) obtained in their structural VAR-based studies.

Using our model, we can determine whether speculation as the driver of price changes is consistent with the data on production, consumption, inventory changes, and spot and futures prices, given reasonable assumptions about elasticities of supply and demand. We show that although we cannot rule out that speculation had any effect on oil prices, we can indeed rule out speculation as an explanation for the sharp changes in prices since 2004. Unless one believes that the price elasticities of both oil supply and demand are close to zero, the behavior of inventories and futures-spot spreads are inconsistent with speculation.
as a significant driver of spot prices. Across our sample, speculation decreased prices on average or left them essentially unchanged, and reduced peak prices by roughly 5 percent.

In the next section we clarify the meaning of speculation (versus “investment”), and discuss ways in which speculation can occur. We note that the simplest and lowest-cost way to speculate on the price of a commodity is to buy or sell futures contracts. In Section 3 we lay out a simple analytical framework that connects production, consumption, inventories, and spot and futures prices. Sections 4 and 5 show how this framework can be used to distinguish the effects of speculation from the effects of shifts in fundamental drivers of supply and demand. In Section 6 we present our empirical results, and show that there is no evidence that speculation contributed to the observed sharp increases in oil prices.

2 Some Basics.

We begin with two basic issues. First, what is meant by “oil price speculation,” and how does it differ from a hedging operation or an investment to diversify a portfolio? Second, how can does speculation occur?

2.1 What is Meant by “Oil Price Speculation?”

Oil price speculation is the purchase (or sale) of an oil-related asset with the expectation that the price of the asset will rise (or fall) to create the opportunity for a capital gain. A variety of assets can be instruments for speculation; oil futures, oil company shares, and oil above or below ground are examples. Thus a speculator might take a long position in oil futures because she believes the price is more likely to rise than fall. (But for every long futures position there is an off-setting short position, held by someone betting the other way.)

In principle, speculation differs from an oil-related investment, which we define as the purchase or sale of an asset such that the expected net present value (NPV) of the transaction is positive. One example of such an investment is the purchase or sale of oil futures (or other derivatives) not to “beat the market” but instead to hedge against price fluctuations that, if large enough, could lead to bankruptcy. Another example is the purchase of oil-related
financial assets, such as futures or oil company shares, to diversify a portfolio.\footnote{Note that in this example the expected return on the asset would account for systematic risk and thus would equal the opportunity cost of capital, making the expected NPV of the investment just zero. However, by helping to diversify the portfolio, purchasing the asset would reduce the portfolio's risk.}

As a practical matter, it is usually impossible to distinguish a speculative activity from an investment. For example, mutual funds, hedge funds, and other institutions often hold futures as well as oil company shares, and might do so to make a “naked” (unhedged) bet on future prices, or instead to diversify or hedge against oil-related risks. Sometimes it is possible to identify a hedging activity, but more often it is not. So in most cases, what we call an “investment” and what we call “speculation” are likely to be the same thing, or at best ambiguous. Thus when we examine the impact of, e.g., purchases of futures contracts, we will not be concerned about whether the purchase is an investment or pure speculation.

Although we will not try to distinguish among motivations for purchases of oil-related financial assets, we can be clear about what speculation is not: a shift in fundamentals. This could include a shift in consumption demand (e.g., a short-term shift resulting from unusually cold weather, or a long-term shift resulting from increased use of oil in China) or a shift in supply (e.g., because of a strike or hurricane that shuts down some output). A shift in fundamentals can certainly cause a change in price, and we want to distinguish that from a price change caused by speculators or investors.

What about the purchase or sale of oil-related assets in response to anticipated changes in price resulting from widely-held beliefs regarding expected changes in fundamentals? Examples would include seasonal fluctuations in demand, and the expected impact of a forecasted hurricane. We will treat examples of this kind as shifts in fundamentals.

When speculation is blamed for pushing oil prices up or down, it is usually the spot price that is being referred to; i.e., the price for immediate delivery. By contrast, the futures price is the market price of a futures contract for oil to be delivered at some future point in time. When speculators (or investors) buy and sell futures contracts, the futures price may change, and we want to know whether and how much that change can affect the spot price.
2.2 Vehicles for Speculation.

There are several ways an individual or firm could speculate on the price of oil. Here we discuss how each would affect prices, production, and inventories. Blaming speculators for price changes usually occurs when price has been rising, not falling. But one can speculate in either direction, and market equilibrium requires equal “long” and “short” positions. For simplicity we will focus on the “long” side, i.e., speculating that prices will rise.

Buy Stocks of Oil Companies. Holding oil company shares is a common way to speculate (or invest) in oil, and is done by mutual funds, hedge funds, and individual investors. Suppose speculators become “bullish” and buy oil company stocks. What would this do to the price of oil? In the short run (less than two years), it would have no effect on oil production or consumption and thus no effect on price. In the longer run, by pushing up oil companies’ stock prices, it would lower the companies’ cost of capital. This would encourage more exploration and development, leading to more production and lower prices. But this would take several years, and certainly cannot explain the sharp price changes since 2004.

Hold Oil in Situ. An owner of in-ground oil reserves can speculate on higher prices by keeping the oil in the ground rather than producing it. How easily an oil company can speculate this way depends on whether the reserves are undeveloped or developed.

Undeveloped reserves contain oil that cannot be produced until large sunk cost investments in development are made. Normally, development (construction of production wells, offshore platforms, etc.) takes at least a year or two. Thus an oil company that wants to “bet” on higher prices could simply delay development—although there could be other reasons for delaying development, e.g., the reserve’s option value.\footnote{An undeveloped reserve gives the owner an option to develop the reserve, the exercise price for which is the cost of development. If there is considerable uncertainty over future oil prices, the option value will be high, so that there is an incentive to keep the option open by delaying development. \textit{Paddock et al.} (1988) were among the first to calculate the option value of an undeveloped reserve. See \textit{Dixit and Pindyck} (1994) for a discussion of “real options,” including a treatment of the option to develop an oil reserve.} Suppose around 2004 or 2005, oil companies withheld development of undeveloped reserves. What would happen? Production would fall and prices rise—but only after one or two years had passed, given the time to develop a reserve. How could we identify such an activity? Normally rising oil prices increase returns from development, and lead to rising rig rental rates and rig utilization.
If rig rates and utilization were instead falling, it might suggest companies were delaying development. We examine this possibility later.

*Developed reserves* have the production wells, pipelines, platforms, and other infrastructure needed to produce oil. But once production begins, the rate cannot be easily varied. Production usually follows a decline path largely determined by the internal pressure and other physical characteristics of the reserve, the size of the wells, etc. Reducing or temporarily stopping production can reduce the total quantity of oil that can potentially be produced, and thus is usually not economical. Nonetheless, we will examine whether production has fallen below trend during periods of suspected speculation.

**Hold Oil Above Ground.** Producers and consumers of oil hold inventories to facilitate production and delivery scheduling and avoid stockouts. In principle, however, inventories could be held to speculate. This form of speculation is feasible for oil companies if sufficient storage capacity is available. Were oil companies (or industrial consumers) accumulating “excess” inventories during periods of suspected speculation? Here, “excess” means that a speculative motive raises the value of the marginal unit of inventory. As explained in Section 5.2, we test for this possibility using futures price data.

**Hold Oil Futures.** This is the easiest, lowest cost, and most common way to speculate on oil prices. One would hold a long (short) futures position to speculate on prices going up (down). (Note every long position must be matched by a short position.) Holding futures involves very low transaction costs, even for an individual investor. This is an important means of investment for hedge funds, some ETFs, mutual funds, and also individuals. It is also the most common explanation for how speculation takes place, and is usually the focus of those who criticize the activities of speculators (and investors).

If more people want to go long than short at the current futures price, the futures price will rise. What would that do to the spot price, which is the price we care about? In principle it could push the spot price up, but only under certain conditions. Since the use of futures contracts is the most important means of speculation, we will look at it in detail.6

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6Other derivatives can be used to speculate, e.g., call or put options on futures prices. Those and more complex derivatives are sometimes held by hedge funds, but their impact on oil prices is closely related to the impact of futures contracts, so we will ignore them and focus below on futures.
3 Analytical Framework.

There are two interrelated markets for a storable commodity: a *cash market* for immediate, or “spot,” purchase and sale, and a *storage market* for inventories. The price of storage is not directly observed, but it can be determined from the spread between futures and spot prices, and is termed the *marginal convenience yield*. In what follows, we present a framework that describes the cash market, the storage market, and the futures-spot spread.\(^7\) We then use this framework to show how speculative activity in the futures market—as well as fundamental shifts in supply or demand—can affect spot prices, inventories, and convenience yield.

3.1 The Cash Market.

In the cash market, purchases and sales for immediate delivery occur at the “spot price.”\(^8\) Because inventory holdings can change, the spot price does not equate production (which might include imports) and consumption (which might include exports). Instead, the spot price determines “net demand,” i.e., the difference between production and consumption. To see this, note that demand in the cash market is a function of the spot price, other variables such as the weather and aggregate income, and random shocks reflecting unpredictable changes in tastes and technologies: \(Q = Q(P; z_1, \epsilon_1)\), where \(P\) is the spot price, \(z_1\) is a vector of demand-shifting variables, and \(\epsilon_1\) is a random shock.

Supply in the cash market is also a function of the spot price, a set of (partly unpredictable) variables affecting the cost of production (e.g., wage rates and capital costs), and random shocks reflecting unpredictable changes in operating efficiency, strikes, etc.: \(X = X(P; z_2, \epsilon_2)\), where \(z_2\) is a vector of supply-shifting variables, and \(\epsilon_2\) is a random shock.

Letting \(N_t\) denote the inventory level, the change in inventories is just:

\[
\Delta N_t = X(P_t; z_{2t}, \epsilon_{2t}) - Q(P_t; z_{1t}, \epsilon_{1t}) .
\]

We will refer to \(\Delta N_t\) as *net demand*, i.e., the demand for production in excess of consumption.

\(^7\)This framework is presented in more detail in Pindyck (2001).

\(^8\)The spot price is a price for immediate delivery at a specific location of a specific grade of the commodity, with the location and grade specified in a corresponding futures contract. The “cash price” is an average transaction price, and might include discounts or premiums resulting from relationships between buyers and sellers. We will ignore this difference for now, and use “spot price” and “cash price” interchangeably.
Thus eqn. (1) says that the cash market is in equilibrium when net demand equals net supply. We can rewrite eqn. (1) in terms of the following inverse net demand function:

\[ P_t = f(\Delta N_t; z_{1t}, z_{2t}, \epsilon_t) \]  

(2)

Market clearing in the cash market is therefore a relationship between the spot price and the change in inventories.

Because \( \partial X/\partial P > 0 \) and \( \partial Q/\partial P < 0 \), \( f(\Delta N_t; z_{1t}, z_{2t}, \epsilon_t) \) is upward sloping in \( \Delta N \). This is illustrated by the left panel of Figure 2, where \( f_1(\Delta N) \) is the inverse net demand function for some initial values of \( z_1 \) and \( z_2 \), and \( f_2(\Delta N) \) is the inverse net demand function following an increase in demand (an increase in \( z_1 \)) or decrease in supply (a decrease in \( z_2 \)). This upward shift in \( f(\Delta N) \) reflects a shift in fundamentals, as opposed to a speculative change in the market. For oil, it might occur because of an increase in Chinese demand, or a disruption that reduces supply. In Figure 2, we assume the shift is permanent.

### 3.2 The Market for Storage.

At any instant of time, the supply of storage is the total quantity of inventories held by producers, consumers, or third parties, i.e., \( N_t \). In equilibrium, this quantity must equal the quantity demanded, which is a function of price. The price of storage is the implicit “payment” for the privilege of holding a unit of inventory. As with any good or service sold in a competitive market, if the price lies on the demand curve, it is equal to the marginal value of the good or service, i.e., the utility from consuming a marginal unit. In this case, the marginal value is the value of the flow of services accruing from holding the marginal unit of inventory, and is referred to as marginal convenience yield. We denote the price of storage (marginal convenience yield) by \( \psi_t \), and write the demand for storage as \( N(\psi) \).

The storage market is illustrated by the right-hand panel of Figure 2, where \( N_1 \) is the supply of storage and \( \psi_1 \) is the corresponding price (convenience yield). Note that the marginal value of storage is small when the total stock of inventories is large, because in that case an extra unit of inventory will be of little value, but it rises sharply when the total stock becomes small. Thus \( N'(\psi) < 0 \) and \( N''(\psi) > 0 \).

In addition to the price \( \psi \), the demand for storage can depend on other variables, e.g.,
expected future rates of consumption or production; if a seasonal increase in demand is expected, the demand for storage will increase because producers will want greater inventories to avoid sharp increases in production cost and to make timely deliveries. The demand for storage also depends on the spot price (one would pay more to store a higher-priced good), and on the volatility of price.\(^9\) Letting \(z_3\) denote these demand-shifting variables and including a random shock, we can write the inverse demand function as:

\[
\psi = g(N; z_3, \epsilon_3) .
\]  

(3)

Suppose oil supply and demand become more volatile. Then the demand for storage curve on the right-hand side of Figure 2 will shift upwards, so that if that supply of storage remains fixed at \(N_1\), the price (convenience yield) \(\psi\) will increase. The demand for storage curve could also shift for reasons related to speculation, as we explain later.

### 3.3 Spot Price, Futures Price, and Convenience Yield.

Because speculation usually occurs via the futures market, it is important to clarify how the futures price can affect the spot price. A futures contract is an agreement to deliver a specified quantity of a commodity at a specified future date, at a price (the futures price) to be paid at the time of delivery. Because most futures contracts are traded on organized exchanges, they tend to be more liquid than forward contracts, which are also agreements to deliver a specified quantity of a commodity at a future date, at a price (the forward price). The two contracts differ only in that the futures contract is “marked to market,” i.e., there is a settlement and corresponding transfer of funds at the end of each trading day.

It is not necessary to take delivery on a futures (or forward) contract; in fact, the vast majority of contracts are “closed out” or “rolled over” before the delivery date, so the commodity does not change hands. The reason is that these contracts are usually held for hedging, investment, or speculation, so there would be no reason to take delivery.

\(^9\)Greater volatility increases the demand for storage by making scheduling and stock-out avoidance more costly. Pindyck (2004) estimates the impact of changes in volatility on inventories and price for crude oil, heating oil, and gasoline. In related work, Alquist and Kilian (2010) developed a theoretical model that links volatility (and uncertainty over future supply shortfalls) to spot prices, futures prices, and inventories.
Once we know the spot price at time \( t \) and the futures price for delivery at time \( t + T \), we can determine the convenience yield. Let \( \psi_{t,T} \) denote the (capitalized) flow of marginal convenience yield from holding a unit of inventory over the period \( t \) to \( t + T \). To avoid arbitrage, \( \psi_{t,T} \) must satisfy:

\[
\psi_{t,T} = (1 + r_T)P_t - F_{t,T} + k_T.
\]

(4)

where \( P_t \) is the spot price at time \( t \), \( F_{t,T} \) is the futures price for delivery at \( t + T \), \( r_T \) is the risk-free \( T \)-period interest rate, and \( k_T \) is the \( T \)-period per-unit cost of physical storage.\(^{10}\)

We are interested in how changes in the futures price affect the spot price, so it is useful to rewrite eqn. (4) with the spot price on the left-hand side:

\[
P_t = \frac{1}{1 + r_T}[F_{t,T} + \psi_{t,T} - k_T].
\]

(5)

Thus an increase in \( F_{t,T} \) will lead to an increase in \( P_t \)—unless there is a equivalent decrease in \( \psi_{t,T} \) and/or increase in \( k_T \). The drop in \( \psi_{t,T} \) could occur if \( N_t \) increases. But what if \( N_t \) increases to the point that there is almost no more storage capacity? Then \( k_T \) would increase sharply, again limiting the impact of the higher futures price on the spot price.

As we will see, an increase in the futures price can lead to an increase in the spot price of a commodity, but any impact will be limited by activity in the market for storage. In addition, we can look to the storage market (i.e., the behavior of inventories and convenience yield) to determine whether changes in the spot price are due more to structural shifts in demand and supply, or instead to speculative activity in the futures market.

3.4 Example: Permanent versus Seasonal Shifts in Demand.

The interaction of the cash and storage markets can be seen in Figures 2 and 3, which illustrate the impact of an upward shift in demand. In Figure 2, the shift in demand is expected to be—and is—permanent. The net demand curve shifts up and the spot price

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\(^{10}\)To see why eqn. (4) must hold, note that the (stochastic) return from holding a unit of the commodity from \( t \) to \( t + T \) is \( \psi_{t,T} + (P_{t+T} - P_t) - k_T \), i.e., the convenience yield (like a dividend) plus the capital gain minus the physical storage cost. If one also shorts a futures contract at time \( t \), which would yield a return \( F_{t,T}T = F_{t,T}P_{t+T} \), one would receive a total return over the period of \( \psi_{t,T} + F_{t,T} - P_t - k_T \). The futures contract requires no outlay and this total return is non-stochastic, so it must equal the risk-free rate times the cash outlay for the commodity, i.e., \( r_T P_t \), from which eqn. (4) follows.
increases from $P_1$ to $P_2$. The demand for storage curve remains fixed, and assuming the shift in the net demand curve occurs slowly, there would be no reason for producers or consumers to change their inventory holdings, so total inventories remains fixed at $N_1$.

Figure 3 illustrates an anticipated shift that is expected to be—and is—temporary, e.g., a seasonal increase in demand. Because the increase is anticipated, inventories are accumulated ahead of time (so $N$ increases from $N_1$ to $N_2$) and the spot price increases (from $P_1$ to $P_2$), before there is any shift in the net demand curve. When the net demand curve does shift up, inventories are drawn back down, as producers and consumers anticipate that net demand will shift down again. Thus the spot price stays at or near $P_2$, rather than rising to $P_3$, the level that would have been reached had there been no changes in inventories. Finally, the net demand curve shifts back down and the spot price returns to $P_1$.

The spot price changes illustrated in Figures 2 and 3 and the inventory changes in Figure 3 are the result of structural shifts in the cash market for oil, as opposed to speculation. In the next section we examine the impact of speculative activity.

4 The Impact of Speculation.

We focus mostly on futures contracts as the instrument of speculation. They are easily used, and they receive the most attention from those claiming that price changes are caused by speculators. However, we will also consider what happens if producers and/or consumers of the commodity accumulate inventories for speculative purposes.

4.1 Speculation via the Futures Market.

Suppose speculators buy futures, driving up the futures price $F_{t,T}$. What will this do to the spot price, inventories, and convenience yield? As shown in Figure 4, although $F_{t,T}$ increased, there is no shift in net demand $f(\Delta N)$ because there has been no change in the fundamentals driving demand and supply. Nor is there any shift in the demand for storage.\(^{11}\)

From eqn. (5), equilibrium in the spot and futures markets requires a reduction in $\psi(N)$

\(^{11}\)Sockin and Xiong (2013) show how an increase in the futures price could signal (correctly or incorrectly) an increase in global economic activity, which could cause an increase in demand for the commodity, shifting $f(\Delta N)$ upwards. Because it drives up demand, we will treat this as a change in fundamentals.
and/or an increase in the spot price. Given that $F_{t,T}$ is now high relative to $P_t$, the payoff from holding inventories is large, so inventories increase. Thus $\Delta N > 0$, and as shown in Figure 4, the spot price increases from $P_1$ to $P_2$. Eventually inventories reach $N_2$ and convenience yield falls from $\psi_1$ to $\psi_2$. At that point, with no further inventory buildup, $\Delta N$ falls to zero so $P_t$ must fall back to $P_1$. This is consistent with a higher futures price because $\psi_2 < \psi_1$, so the futures price can remain high even though the spot price falls.

As the futures contracts reach expiration, the future price must approach the spot price. If speculators remain optimistic, they might “roll over” their contracts, i.e., sell the near-term futures and buy longer-term futures. Then inventories and convenience yield will remain at $N_2$ and $\psi_2$, keeping the spot price at $P_1$. But it is likely that speculative buying of futures will eventually diminish, so that the futures price falls, reducing the expected payoff from holding inventories. Inventories are then sold off, pushing the spot price down (to $P_3$ in Figure 4). Eventually inventories fall back to $N_1$ and convenience yield increases to $\psi_1$, at which point $\Delta N$ approaches 0, and the spot price returns to $P_1$.

How does this speculative scenario differ from what we would observe with the fundamental shifts illustrated in Figures 2 and 3? In Figure 2 there is an increase in the spot price, but no change in inventories or convenience yield. In Figure 3 there is a temporary increase in the spot price and the inventory level, but those changes follow seasonal patterns. Thus if we deseasonalized the data we would observe no change in either the price or inventories.

The situation in Figure 4 is quite different. First, the increase in the spot price requires a large increase in inventories, and the spot price would fall back to its original level once the inventory buildup stopped. Second, as speculative buying of futures slowed or reversed, the spot price would fall below its original level, as inventories fall back to $N_1$. Third, there would be no seasonal pattern in either price or inventories.

If demand and supply are very price-inelastic, the impact of speculative buying of futures on the spot price can be larger. The net demand curve $f(\Delta N)$ will then be much steeper, so a small $\Delta N$ will be sufficient to cause the spot price to rise considerably. Then inventories will increase only slowly and the higher spot price can be sustained longer. But as before, once inventories stop growing the price will have to return to its original level.
4.2 Speculative Inventory Holdings.

In principle, oil companies (and some oil consumers) could speculate by accumulating inventories. This would cause an upward shift in the demand for storage curve because it would add a speculative benefit from holding inventories to the usual benefits of stock-out avoidance, etc. Suppose oil companies accumulate inventories to speculate on rising prices. As Figure 5 shows, the demand for storage curves shifts upward. Assuming no change in holdings of futures contracts, as inventories increase (from \( N_1 \) to \( N_2 \)), eqns. (2) and (4) imply that the spot price will increase (from \( P_1 \) to \( P_2 \)) because \( \Delta N_t > 0 \), and therefore the convenience yield must increase (to \( \psi_2 \)). In the figure, inventories peak at \( N_3 \), and as \( \Delta N_t \) drops to zero, the spot price returns to \( P_1 \) and the convenience yield returns to \( \psi_1 \).

If the high inventory level \( N_3 \) is maintained, there will be no further changes in \( P_t \) or \( \psi_t \). If, on the other hand, this speculative episode ends with companies selling off part of their inventories, \( P_t \) and \( \psi_t \) will fall (to \( P_3 \) and \( \psi_3 \) in Figure 5) as inventories decline. Eventually the inventory sell-off ends as \( N_t \) returns to \( N_1 \), and both price and convenience yield return to their original levels. Depending on when they bought and sold, some speculators may have made or lost money. But on average speculators will have lost, because they will have incurred additional costs of physical storage.

5 Evaluating the Impact of Speculation.

In this section, we lay out a simple framework for decomposing price changes into fundamentals and speculative components. We do this in two ways. The first uses the relationship between supply and demand elasticities, changes in inventories, and prices. The second relies on the relationship between convenience yields, changes in inventories, and prices.

5.1 Speculative Changes in Spot Prices.

To begin, we focus on the cash market, and maintain two simplifying assumptions: (i) the supply of oil includes imports, and domestic production and imports are indistinguishable; and (ii) the supply and demand functions are isoelastic. (We also assume demand includes exports, which in any case are negligible.) Writing supply as \( X = k_S P^{ns} \) and demand as
$Q = k_D P^{nd}$, the change in inventories is:

$$\Delta N_t = k_S P_t^{ns} - k_D P_t^{nd}.$$  \hfill (6)

Furthermore, we assume that market fundamentals are incorporated in the supply and demand parameters $k_s$ and $k_D$, so that a shift in supply or demand would imply a change in one or both of these parameters, rather than in the elasticities $\eta_S$ and $\eta_D$.

Is this model too simple? Clearly we could have specified more complex (and perhaps more realistic) supply and demand functions. However, unlike the recent structural VAR literature, our objective is not to precisely estimate the sources of price changes, but rather to determine whether speculation can be ruled out as a significant driver of price. To that end, we do not estimate the supply and demand elasticities $\eta_S$ and $\eta_D$, but instead consider a broad range of plausible values for these parameters.

Dividing both sides of eqn. (6) by $Q_t$:

$$\frac{\Delta N_t}{Q_t} = \frac{X_t}{Q_t} - 1 = \frac{k_S}{k_D} P_t^{ns-nd} - 1.$$  \hfill (7)

Now rearrange and take logs and then first differences of both sides:

$$\Delta \log P_t = \frac{1}{(\eta_S - \eta_D)} [\Delta \log k_D - \Delta \log k_S] + \frac{1}{(\eta_S - \eta_D)} \Delta \log \left( \frac{\Delta N_t}{Q_t} + 1 \right)$$

$$= \Delta \log P_{Ft} + \Delta \log P_{St}.$$  \hfill (8)

Thus price changes can be broken up into fundamental and speculative components.

Suppose a fraction $\pi$ of the price changes is due to speculation and a fraction $(1 - \pi)$ is due to fundamentals. If demand and supply are stable over the period the price is changing, i.e., there is no change in fundamentals, then $k_S$ and $k_D$ are constant. Thus the speculative component of price changes could be written as:

$$(\eta_S - \eta_D) \pi \Delta \log P_t = \Delta \log \left( \frac{\Delta N_t}{Q_t} + 1 \right).$$  \hfill (9)

Since $\Delta N_t = X_t - Q_t$, eqn. (9) can be written equivalently as:

$$(\eta_S - \eta_D) \pi \Delta \log P_t = \Delta \log (X_t/Q_t).$$  \hfill (10)

This explains the portion of price changes resulting from speculation, as opposed to changes in fundamentals. We use eqns. (9) and (10) to test for speculation in two ways.
Price Behavior. Beginning with a set of plausible values for the sum of the supply and demand elasticities, $\eta_S - \eta_D$, we can decompose a price change over any period of time into fundamental and speculative components: $\Delta \log(P_T) = \Delta \log(P_S) + \Delta \log(P_F)$. Consider any three-month period, for example. Summing the monthly inventory changes over the three months and dividing by the initial consumption $Q_0$, eqn. (9) gives the price change that can be attributed to speculation/investment. Subtracting that from the total price change gives the portion that is due to a shift in fundamentals. A comparison of the two components provides a picture of the relative importance of speculation as a driver of price.

Inventory Behavior. We again begin with plausible values for the sum of the supply and demand elasticities, $\eta_S - \eta_D$. Suppose a percentage $\pi$ of the price change over a period of $j$ months is due to speculation. Rearranging eqn. (9), this would imply:

$$\frac{\Delta N_t}{Q_t} + 1 = \left(\frac{\Delta N_{t-j}}{Q_{t-j}} + 1\right) \left(\frac{P_t}{P_{t-j}}\right)^{\pi(\eta_S - \eta_D)}. \quad (11)$$

Taking logs and including an error term, we re-write this as:

$$\log \left(\frac{\Delta N_t}{Q_t} + 1\right) - \log \left(\frac{\Delta N_{t-j}}{Q_{t-j}} + 1\right) = \pi(\eta_S - \eta_D) \log \left(\frac{P_t}{P_{t-j}}\right) + \epsilon_t. \quad (12)$$

If speculation accounted for $\pi$ percent of the price changes, eqn. (12) should hold on average. To test this, we first run a regression of eqn. (12) to obtain an estimate of $\pi(\eta_S - \eta_D)$. Next, given plausible values for $\eta_S - \eta_D$ and a range of values for $\pi$, we calculate RMS errors to measure how well the left-hand side of eqn. (12) replicates the right-hand side. We determine the value of $\pi$ that yields the smallest RMS error.

5.2 Speculative Inventory Holdings and Convenience Yield.

The tests described above are based on equilibrium in the cash market. They rely on the link between price changes, inventory changes, and the sum of the supply and demand elasticities. Speculation via inventory accumulation manifests itself in the market for storage.

To see this, write the (inverse) demand for storage curve as:

$$\psi(N_t) = P_t g(N_t) = k_N P_t N_t^{-1/\eta_N}. \quad (13)$$

where $\eta_N > 0$ is the price elasticity of demand for storage. This is a standard specification for the demand for storage, and has been estimated in the literature for a variety of commodities.
As discussed below, we estimated this equation using our data for crude oil and found that $\eta_N \approx 1$, consistent with other econometric studies. Note that the marginal value of storage is proportional to the price, $P_t$, of the commodity being stored.

The parameter $k_N$ captures other factors that might affect the demand for storage. Those factors might reflect fundamentals; for example, an increase in market volatility or an increased threat of war in the Persian Gulf would cause an increase in $k_N$. But a change in $k_N$ might also (or instead) reflect speculation. If oil producers accumulate inventories to speculate on price increases, it would cause a shift in the demand for storage because there would now be a speculative benefit from holding inventories beyond the usual benefit. This speculative benefit would be reflected by an increase in $k_N$.

Taking logs and first differences of eqn. (13) gives:

$$\Delta \log \psi_t = \Delta \log P_t - (1/\eta_N)\Delta \log N_t + \Delta \log k_N .$$

(14)

Absent any substantial change in volatility or the threat of war (which we will assume to be the case), the last term in eqn. (14) would reflect a shift in the demand for storage attributable to speculation. By measuring marginal convenience yield from the spot-futures spread, we can use eqn. (14) to compare the behavior of the actual convenience yield with what it would be in the absence of speculation.

To do this comparison, we use eqn. (14), with $\Delta \log k_N = 0$, to compute a counterfactual series for $\psi_t$, i.e., values of $\psi_t$ that would we would observe if there were no speculation-induced changes in $P_t$, $N_t$, and in the demand for storage curve. We compare this to the actual series for $\psi_t$ to assess the possibility of speculation-driven inventory accumulation.

6 Were Oil Prices Driven by Speculation?

Can changes in oil prices after 2000 be attributed, even in part, to speculation. Although speculation is most easily done using futures contracts, in principle oil companies could speculate on rising prices by slowing development of undeveloped reserves (which would result in a drop in the rental and utilization rates of drilling rigs), or by reducing production from developed reserves. We examine these last two possibilities first, and then turn to the use of futures contracts and inventory accumulation as vehicles for speculation.
We collected monthly data from the Energy Information Administration (EIA) on U.S. production, commercial stocks, imports and exports from January 1998 to June 2012. We construct consumption as the change in U.S. production plus net imports minus changes in commercial stocks. The EIA also reports monthly averages for WTI spot and futures prices. (We use the WTI price but the results change little if we use Brent prices.)

One might argue that there is a world market for oil, so we should use world, rather than U.S. data on production, consumption and inventories. Our use of U.S. data is justified as follows. First, speculation is often blamed on people trading U.S. futures. For those futures, delivery (which rarely occurs) must be in WTI crude as specified in the contract, so Saudi or Nigerian crude is not relevant. Of course Saudi or Nigerian crude is a substitute for WTI (though not a perfect one), so in principle WTI inventories could be “traded” for Saudi inventories, but as a practical matter this would be costly and takes time.

Second, even for a “bath tub” style world market, unless the three elasticities (demand, supply, and demand for storage) are very different across regions, we can look at the behavior of inventories and prices in any one region (in our case the U.S.) to analyze speculation. In this sense, the U.S. serves as a microcosm of the global market. Since our analysis relies only on “plausible” elasticity values (e.g., $\eta_S - \eta_D \approx 0.2$ or $0.4$), regional differences are unlikely to matter much. Third, the quality of U.S. inventory data far exceeds the quality of global data, so the use of global inventory data will likely inject noise into the analysis.\footnote{We also note that Kilian and Lee (2013) use the same empirical model as Kilian and Murphy (2013), but applied to global supply, demand, and inventory data and find similar results.}

Finally, the U.S. market is indeed connected to and constrained by the world market, but only to a degree. For example, the price of Brent crude has recently been $20 higher than the price of WTI. If the U.S. price rose sharply, more oil (Saudi, Brent, etc.) would start to flow into the U.S., but this would take time. Thus if speculators push up the futures price, U.S. inventories would increase, as would the U.S. spot price. By the time U.S. inventories stop increasing, the spot price must return to its original level. Could Saudi and other producers arbitrage by selling oil into the U.S. while U.S. inventories are increasing and the U.S. spot price is high? Possibly, but it would be time-consuming, costly, and thus unlikely.
6.1 Speculation by Oil Companies.

Might oil companies have contributed to the sharp price increases by delaying the development of undeveloped reserves? If so, we would expect to see a drop in the utilization of drilling rigs in advance of the observed price increases. That is not the case. Rig utilization rates were roughly level during 2004–2007, increased in early 2008 as the price increased, and then dropped shortly after the steep plunge in the price, inconsistent with the view that development delays drove price increases.\(^\text{13}\)

Might oil companies have contributed to price increases by reducing production from developed reserves? We addressed this possibility by looking at the behavior of production, which had been falling prior to 2006. However, as shown in Knittel and Pindyck (2013), production stopped falling by 2006, well before the 2008 price spike, and was roughly level during 2006 to 2008. This is also inconsistent with speculation by oil companies.

6.2 Speculation via the Futures Market.

As discussed above, we decompose observed prices changes into components attributable to speculation and to changes in market fundamentals. Using eqn. (9) and numbers for supply and demand elasticities, we also calculate the inventory changes required if some fraction of the observed price changes are due to speculation.

We examine price and inventory changes for non-overlapping three-month and 12-month intervals. Each price and inventory change is calculated on a moving month-to-month basis. For example, for three-month intervals, we compare the average price for April, May, and June 2005 to the average price for January, February, and March 2005, the average price for May, June, and July 2005 to February, March, and April 2005, and so on. Thus we have price and inventory changes for each month in our sample. We use intervals of varying length because speculation might have short-term effects that dissipate over longer periods.\(^\text{14}\)

For each time interval, we calculate the consumption-weighted spot price, average con-

\(^{13}\)See Knittel and Pindyck (2013). We purchased the data from RigZone, which reports utilization of jackups, semi-subs, and drill-ships in the Gulf of Mexico.

\(^{14}\)We have also done the analysis using monthly intervals and obtained similar results, but the counterfactual prices are much more volatile.
sumption, average stock levels, and the change in inventories over the interval. For $X$-month intervals, the differences in eqns. (9) and (14) are defined as $X$-month differences. To eliminate the effects of seasonality in demand, we de-seasonalize inventories by first regressing changes in inventories on a full set of month dummies and taking the residuals as our measure of inventory changes. (We observe no seasonality in the convenience yield.)

Generating counterfactual prices using eqn. (9) requires supply and demand elasticities, which will vary depending on the amount in time over which supply and demand can adjust to price changes. Studies by Dahl (1993), Cooper (2003), and Hughes et al. (2008) suggest that the short-run demand elasticity is roughly $-0.1$, although, Kilian and Murphy (2013) estimate a short-run elasticity of roughly $-0.25$. Dahl (1993) and Cooper (2003) find that the long-run demand elasticity is in the range of $-0.2$ to $-0.3$. (But note that estimating long-run elasticities is challenging.) The literature on supply elasticities is more sparse. Dahl and Duggan (1996) summarize that literature and find that many estimates, for both short- and long-run elasticities, are noisy and have the wrong sign. Hogan (1989) estimates a short-run elasticity of $0.09$ and a long-run elasticity of $0.58$. (It is easy to see how short-run supply elasticities could be small.) Note, however, that what matters for our analysis is the sum of the elasticities. Furthermore, we will see that our results are robust to any reasonable set of elasticity estimates or assumptions.

We show results based on $\eta_S - \eta_D = 0.2$, consistent with a supply and demand elasticity of $0.1$ and $-0.1$ respectively, for the three-month intervals. For the 12-month intervals we use $\eta_S - \eta_D = 0.4$. We use these same numbers to construct the inventory changes required for speculation to have accounted for a percentage of the observed price changes.

To calculate a counterfactual series for the convenience yield using eqn. (14), we need the actual convenience yield and an estimate of the price elasticity of the demand for storage, $\eta_N$. From eqn. (4), we use the 3-month T-bill rate for the risk-free rate of interest, and the price of the three-month futures contract to get a three-month gross convenience yield. There is little data on the cost of storage ($k_T$); a rough estimate is $\$1.50$ per barrel per month, but the cost can rise when inventory levels are large and storage facilities fill up. We begin with the estimate of $\$1.50$. However, in 5 of the 162 months in our sample the futures-spot spread was so large that the $\$1.50$ cost would imply a negative net convenience yield, violating the
arbitrage condition. (For example, in December 2008, the gross monthly convenience yield is −$6.08.) These large negative values may result from the EIA’s aggregation of the futures and spot prices up to a monthly level, or may reflect actual changes in storage costs. To take logs, we truncate the net convenience yield below at $1.50. The truncation applies only during the rapid drop in oil prices following 2008, so it should not affect our results.

A reasonable value for the price elasticity of demand for storage, $\eta_N$, is $1.0$.\textsuperscript{15} However, we estimate this elasticity and also test our assumption that changes in the convenience yield are proportional to changes in prices. We estimate eqn. (14) for both the three-month and 12-month intervals over our sample (1999 to 2012) assuming an AR(2) process for the error term. Table 1 reports the results, which support our assumption that changes in convenience yields are proportional to changes in spot prices; we cannot reject a coefficient of 1 at any conventional level (p-values of 0.18 and 0.64). In addition, we cannot reject a coefficient of $-1$ for the change in the log of stocks (p-values of 0.78 and 0.61).\textsuperscript{16}

6.3 Results: Prices and Inventories.

**Price Changes.** We first calculate the counterfactual spot prices that would have prevailed had no speculative (or investment) activity occurred. Figure 6 plots actual and counterfactual prices using changes in inventories over three-month intervals. Note that the two price series are very close to each other; the correlation is 0.88. The average spot price over this period was $55.37 per barrel, and the average counterfactual price is $55.34. The peak counterfactual price is 7 percent higher than the actual price, $144.90 compared to $130.85, and the volatilities of the counterfactual and actual prices are almost the same (the standard deviations $29.04$ and $28.79$ respectively). Thus (i) speculation can account for very little of the observed price changes; (ii) speculation did not cause an increase in price volatility; and (iii) price spikes would have been slightly higher absent speculation.

Using 12-month intervals, the resulting counterfactual prices are even closer to the actual prices. The average spot and counterfactual prices were both $53.06, with a standard devia-

\textsuperscript{15}Pindyck (1994) estimated the storage price elasticity to be about 1.1 for copper and 1.2 for heating oil.

\textsuperscript{16}It is clear, however, that the confidence intervals around the change in the log of stocks are quite wide. This is likely due to the small amount of variation in stocks.
tion of $27.05. The peak counterfactual price is slightly lower, $107.50 compared to $107.85. The correlation between the two price series is 0.9997; the average change in inventories across 12-month intervals is only 1.01 million barrels (compared to an average commercial stock of 319 million barrels), so counterfactual prices will mirror actual prices.

Suppose one believed that supply and demand are extremely inelastic. Figure 7 shows actual and counterfactual prices, again for three-month intervals, but with $\eta_S = 0.05$ and $\eta_D = -0.05$. The counterfactual prices are still quite close to the actual prices.

**Inventory Changes.** Eqn. (12) describes a relationship between inventories and prices that must hold if $\pi$ percent of the observed changes in actual prices were due to speculation rather than changes in fundamentals. Thus, given a value for $\eta_S - \eta_D$, we can estimate $\pi$ from a regression of this equation. We ran the regression (with a constant term) for $j = 3$ and 12, and calculated Newey-West standard errors allowing up to 12 lags. The estimate of $\pi(\eta_S - \eta_D)$ is $-0.013$ with a $t$-statistic of $-3.02$ for $j = 3$, and $-0.0005$ with a $t$-statistic of $-0.19$ for $j = 12$. (The constant is insignificant in both regressions.) These results are inconsistent with speculation having any role in price changes.

Next, given plausible values for $\eta_S - \eta_D$, we determine how well the left-hand side of eqn. (12) replicates the right-hand side for different values of $\pi$. Table 2 shows the RMS errors and corresponding Theil Inequality Coefficients for values of $\pi$ ranging from 0 to 100%, and for $\eta_S - \eta_D = .10, .20, \text{ and } .40$. Note that in each case, $\pi = 0$ yields the smallest RMS error, which suggests that speculation had no impact on prices during our sample.

### 6.4 Results: Convenience Yields.

Suppose speculators drove up oil prices by accumulating inventories. This would imply a change in $k_N$ in eqn. (13). Thus by holding $k_N$ fixed, we can generate a counterfactual “no speculation” series for convenience yield and compare it to the actual series.

A one-time increase in the speculative demand for above-ground inventories will shift the demand for storage curve $\psi(N)$ upwards, so that both inventories and the convenience yield increase. Thus if speculative inventory accumulation was at work, we would observe counterfactual convenience yields below the actual ones. Figure 8 shows the actual and
counterfactual convenience yields (the latter implied by eqn. (13)) for three-month intervals.\textsuperscript{17}

These results are inconsistent with speculative inventory accumulation. In fact, the average fundamentals-only convenience yield is higher than the actual: about 5 percent higher for three-month intervals, and 19 percent higher for 12-month intervals. Also, the standard deviation of the counterfactual series exceeds the actual by 16 and 46 percent for the three- and 12-month periods, respectively. Thus if anything, speculation decreased the demand for storage and reduce the volatility of convenience yields.

### 6.5 Specific Periods.

Next, we focus on specific time periods during which prices increased sharply and there was intensive public concern over speculation. Figure 9 plots WTI spot prices and Google search intensity for the term “oil speculation.”\textsuperscript{18} Because search may occur with some lag, we begin the “epochs” at the beginning of the price run-up and end at the maximum price.

We analyze four epochs, for which the beginning and end points are shown in Figure 9 by solid and dotted lines respectively. Note that the last two epochs are subsets of the second one. The epochs are (1) January 2007 to July 2008, (2) February 2009 to April 2011, (3) February 2009 to April 2010, and (4) September 2010 to April 2011. These epochs encompass periods of sustained prices increases as well as heavy Google search activity. We split the second into two sub-epochs because prices leveled o\textsuperscript{19} in the middle of the interval.

We examine the behavior of price, inventories, and convenience yield as we did before, but now calculating the components of eqn. (8) over the entire epoch instead of over 3-month intervals. In particular: (a) We generate a counterfactual final price for the epoch, i.e., the price that would prevail absent speculation; (b) we calculate the required inventory changes for speculation to have caused $\pi\%$ of the observed price increase; and (c) we calculate the no-speculation change in the convenience yield and compare it to the actual. We use our

\textsuperscript{17}Note that the actual and counterfactual series differ more than do the actual and counterfactual prices shown in Figure 6. This is partly due to our assumption that any change in $k_N$ is due to speculation, i.e., we ignore any fundamentals-based shifts in $k_N$, e.g., the likely reduction in $k_N$ due to the recession in 2009-2010.

\textsuperscript{18}Google Insights data allow one to track the intensity of search for a particular term. Within the time period specified, the Insights data report the relative intensity of search for that term. So, the week with maximum search intensity is scaled at 100, and all other weeks are a percentage of the maximum week. Figure 9 plots the weekly average within a particular month.
long-run supply and demand elasticity assumptions for the first three periods (0.2 and -0.2), since they exceed a year in length. We use our short-run elasticities (0.1 and -0.1) for the final period, which is seven months long. The results are in Table 3.

For all four epochs, the counterfactual “fundamentals-only” prices are extremely close to the actual ending prices. The fundamentals-only peak price is six percent higher than the actual peak price in the first epoch, while in the other three it is within four percent of the actual price. This is consistent with the previous sets of results which show that speculation had almost no impact on prices, and if anything, dampened price spikes.

The next panel of Table 3 shows the inventory change required if speculation caused $\pi\%$ of the observed price increase. For every $\pi \geq 10\%$, very large inventory increases would have been required, whereas the actual inventory changes were very small.

Finally, we calculate the fundamentals-only changes in convenience yield. Had there been speculative inventory accumulation, the observed convenience yield would be larger than that justified by fundamentals. Instead, the actual increase in the convenience yield was smaller than what is justified by fundamentals. Again, these results are inconsistent with the notion that speculation drove up spot prices through the storage market.

7 Conclusions.

We have shown how a simple model of equilibrium in the cash and storage markets for a commodity can be used to assess the role of speculation as a driver of price changes. With reasonable assumptions about elasticities of supply and demand, the model can be used to determine whether speculation is consistent with the data on production, consumption, inventory changes, and spot and futures prices. Given its simplicity and transparency, we believe that our approach yields results that are quite convincing. We have focused on the price of crude oil because sharp increases in oil prices have often been blamed on speculators, but our approach can be applied equally well to other commodities.

We found that although we cannot rule out that speculation had any effect on oil prices, we can indeed rule out speculation as an explanation for the sharp changes in prices since 2004. Unless one believes that the price elasticities of both oil supply and demand are close
to zero, the behavior of inventories and futures-spot spreads are simply inconsistent with the view that speculation has been a significant driver of spot prices. If anything, speculation had a slight stabilizing effect on prices. These results are consistent with the structural VAR results of Kilian and Murphy (2013) and Kilian and Lee (2013).

The simplicity of our approach to speculation is a benefit, but also a limitation. For example, we assume that demand and supply in the cash market are isoelastic functions of price, and that the elasticities do not change over time. We also assume that imports can be combined with domestic supply and respond to price changes in the same way. Finally, we assume that apart from shifts in the multiplicative parameter $k_N$, the demand for storage is stable. We believe these assumptions are reasonable and similar in nature to functional form assumptions that are required in related econometric studies.

Finally, as we explained at the outset, it is difficult or impossible to distinguish “speculation” from an “investment.” The latter might involve buying or selling futures, not to “beat the market,” but instead to hedge against large price fluctuations. Mutual funds, hedge funds, and other institutions often hold futures positions, but it is usually impossible to know whether they are doing so to make a “naked” (unhedged) bet on future prices, or instead to diversify or hedge against other commodity-related risks. Thus when we examined the impact of increased purchases of futures contracts, we were not concerned with whether this represented an investment or pure speculation, and our use of the word “speculation” should always be interpreted as including investment activities—but not a shift in fundamentals.
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Figure 1: Monthly Spot Price of WTI Crude Oil, 1990–2012

Figure 2: Permanent Increase in Demand for Oil
Figure 3: Seasonal (and Anticipated) Changes in Demand

Figure 4: Impact of Speculation on Cash and Storage Markets
Figure 5: Speculation via Inventory Accumulation

Figure 6: Actual Prices and Implied Prices with No Speculative Activity: Using Inventory Changes and Three-Month Intervals
Figure 7: Actual Prices and Implied Prices with No Speculative Activity: Using Inventory Changes, Three-Month Intervals, $\eta_S = 0.05$ and $\eta_D = -0.05$

Figure 8: Actual Convenience Yields and Implied Convenience Yields with No Speculative Activity: Three-Month Intervals
Figure 9: Monthly WTI Spot Prices and Google Search Intensity for “Oil Speculation”

Table 1: Estimation of the Inverse-Demand for Storage Curve

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<th>VARIABLES</th>
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<td></td>
<td>Three-Month</td>
<td>Twelve-Month</td>
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<tr>
<td>Δ ln(Spot)</td>
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<td>0.5698**</td>
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<td>(0.2755)</td>
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<td>Δ ln(Stock)</td>
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<td>1.7890***</td>
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Observations 162 162
### Table 2: Inventory-Based Test for Speculation

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<th>Speculation share ($\pi$)</th>
<th>$(\eta_s - \eta_d) = 0.10$</th>
<th>$(\eta_s - \eta_d) = 0.20$</th>
<th>$(\eta_s - \eta_d) = 0.40$</th>
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<td>Theil Coeff</td>
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<td>0.84</td>
<td>31.72</td>
</tr>
<tr>
<td>100%</td>
<td>31.72</td>
<td>0.87</td>
<td>51.42</td>
</tr>
</tbody>
</table>

*Let $Y_{at}$ and $Y_{pt}$ be actual and predicted inventory changes in time $t$, respectively, the Theil Coefficient is defined as:

$$\text{Theil Coefficient} = \sqrt{\frac{1}{T} \sum_{t=1}^{T} (Y_{at} - Y_{pt})^2} \div \sqrt{\frac{1}{T} \sum_{t=1}^{T} (Y_{at})^2 + \frac{1}{T} \sum_{t=1}^{T} (Y_{pt})^2}.$$*

### Table 3: Epoch Analysis

<table>
<thead>
<tr>
<th>Epoch</th>
<th>1/07-7/08</th>
<th>2/09-4/11</th>
<th>2/09-4/10</th>
<th>9/10-4/11</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beginning Price</td>
<td>$54.51$</td>
<td>$39.09$</td>
<td>$39.09$</td>
<td>$75.24$</td>
</tr>
<tr>
<td>Ending Price</td>
<td>$133.37$</td>
<td>$102.86$</td>
<td>$81.20$</td>
<td>$102.86$</td>
</tr>
<tr>
<td>Fundamental-Only Price*</td>
<td>$140.99$</td>
<td>$98.31$</td>
<td>$77.67$</td>
<td>$99.02$</td>
</tr>
<tr>
<td>Ending Inventories (Millions of Barrels)</td>
<td>295.23</td>
<td>360.21</td>
<td>359.25</td>
<td>360.21</td>
</tr>
<tr>
<td>Actual Inventory Build up</td>
<td>-0.54</td>
<td>11.75</td>
<td>-0.54</td>
<td>11.75</td>
</tr>
<tr>
<td>Implied Inventory Build up, $\pi=100%$</td>
<td>261.47</td>
<td>121.16</td>
<td>183.46</td>
<td>74.47</td>
</tr>
<tr>
<td>Implied Inventory Build up, $\pi=50%$</td>
<td>125.71</td>
<td>61.26</td>
<td>88.63</td>
<td>37.92</td>
</tr>
<tr>
<td>Implied Inventory Build up, $\pi=20%$</td>
<td>55.18</td>
<td>28.00</td>
<td>38.03</td>
<td>17.06</td>
</tr>
<tr>
<td>Implied Inventory Build up, $\pi=10%$</td>
<td>33.30</td>
<td>17.34</td>
<td>22.13</td>
<td>10.28</td>
</tr>
<tr>
<td>Ending Convenience Yield</td>
<td>$2.39$</td>
<td>$1.50$</td>
<td>$2.17$</td>
<td>$1.50$</td>
</tr>
<tr>
<td>Actual Change in Convenience Yield</td>
<td>$0.37$</td>
<td>$0.00$</td>
<td>$0.67$</td>
<td>$0.00$</td>
</tr>
<tr>
<td>Fundamentals-Only Change in Conv. Yield</td>
<td>$5.42$</td>
<td>$3.92$</td>
<td>$3.10$</td>
<td>$2.07$</td>
</tr>
</tbody>
</table>

* Consistent with speculation causing the price change.