The Simple Economics of Commodity Price Speculation†

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The price of crude oil never exceeded $40 per barrel until mid-2004. By July 2008 it peaked at $145 and by late 2008 it 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* G13, G18, G23, G31, Q35, Q38)

> *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.*
> —*New York Times*, September 4, 2012

> *Federal legislation should bar pure oil speculators entirely from commodity exchanges in the United States.*
> —Joseph Kennedy II, *New York Times*, April 10, 2012

The price of crude oil in the United States 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. By late 2014, it dropped below $60. Were these sharp price changes 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
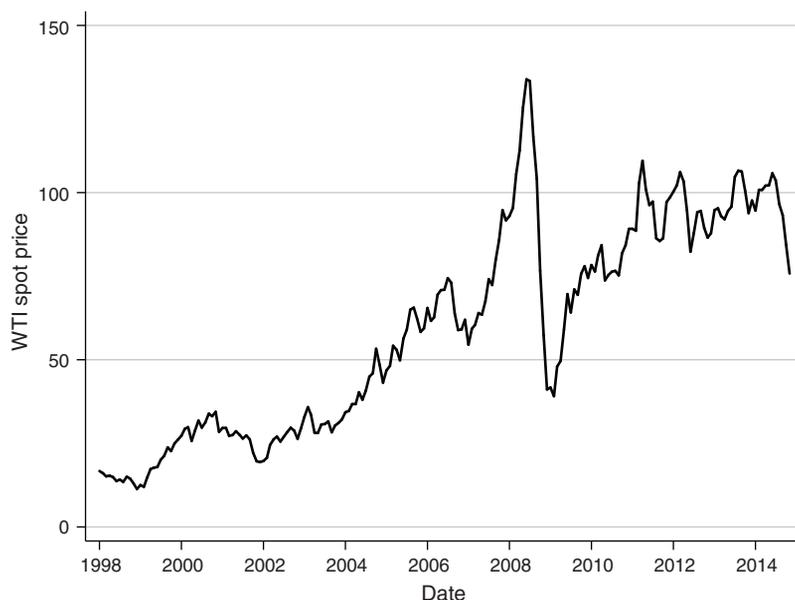
FIGURE 1. MONTHLY SPOT PRICE OF WTI CRUDE OIL, 1990–2014

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 0.74 to 0.89 in levels, and 0.52 to 0.71 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 shocks, e.g., increases in demand from China and other countries?

The claim that speculators are to blame and futures trading should be limited is well exemplified by an 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" ignores the reality of futures markets. 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 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 clarify the mechanisms by which speculators (and investors) affect oil prices, production, and inventories. Then 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, Kilian, and Mahadeva (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 (2014) 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. 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.[1] 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.[2] 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 tell us a good deal about the role of demand versus supply shocks, and inventory changes.

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[1] 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.

[2] 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 (2014) make this point. Kilian (2009) uses a VAR model to distinguish between demand- and supply-side shocks to fundamentals.

However, our aim 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. Also, our simple model confirms the results that Kilian and Murphy (2014); Kilian and Lee (2014); and Fattouh, Kilian, and Mahadeva (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 vehicles for speculation, especially the use of futures contracts. In Section II, we lay out a simple analytical framework that connects production, consumption, inventories, and spot and futures prices. Section III shows 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 IV, we present our empirical results, and show that there is no evidence that speculation contributed to the observed sharp increases in oil prices. Section V concludes.

I. Commodity Price Speculation

To proceed, we first clarify what we mean by "oil price speculation" and how it differs from a hedging operation or an investment to diversify a portfolio. Second, we briefly discuss the main vehicles for speculation.

A. *Speculation versus Investment*

We define oil price speculation as *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 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.[3]

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, 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., 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.

B. *Vehicles for Speculation*

There are a variety of ways an individual or firm could speculate on the price of a commodity, but we will focus on the two most often linked to sharp changes in spot prices: holding a (long or short) position in the futures market or holding physical inventories of the commodity.[4]

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[3] 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.

[4] One could also buy or sell the stocks of oil companies, which is a common way to speculate (or invest) in oil. What would happen to the price of oil if speculators become "bullish" and buy oil company stocks? In the short run (less than two years) it would have no effect on oil production 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, which 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 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 that 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 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 speculators take long positions 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, discussed below. Since the use of futures contracts is the most important means of speculation, we will look at it in detail.[5]

Hold Oil Inventories.—Producers and consumers of oil hold inventories to facilitate production and delivery scheduling and avoid stock-outs. Inventories could also be held to speculate, however, if sufficient storage capacity is available. Were oil companies (or industrial consumers) accumulating "excess" inventories during periods of suspected speculation? Here, "excess" means inventories are held in part because of an expectation of a capital gain. As explained below, we test for this possibility using futures price data.

Speculation via the futures market and speculation via inventory accumulation are intertwined. As we will see, in order for speculative buying of futures to push up the spot price, inventories must also increase, at least temporarily. Likewise, speculative purchases of inventories will affect the "price" of storage and thereby affect the futures price. Thus, we test for speculation by examining the behavior of spot prices, futures prices, and inventories.

In principle, oil companies could also speculate by delaying the development of undeveloped reserves. Of course there could be other reasons for delaying development, e.g., the reserve's option value.[6] There is no evidence (or claim) that companies speculated by delaying investment, but we address this possibility briefly at the end of the paper.

II. 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

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[5] Other 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.

[6] As Paddock, Siegel, and Smith (1988) showed, an undeveloped reserve gives the owner an option to develop the reserve, at an exercise price equal to the cost of development. The greater the uncertainty over future oil prices, the greater is the option value and the incentive to keep the option open by delaying development. See Kellogg (2014) for the effects of uncertainty on drilling activity.

what follows, we present a framework that describes the cash market, the storage market, and the futures-spot spread. 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.

A. *The Cash Market*

In the cash market, purchases and sales for immediate delivery occur at the "spot price."[7] Because inventory holdings can change, the spot price does not equate production (including imports) and consumption (which might include exports). Instead, the spot price determines the change in inventories, i.e., the difference between production and consumption.

Demand (consumption) 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 ϵ_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 ϵ_2 is a random shock.

Letting N_t denote the inventory level, the change in inventories is just

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

We will refer to ΔN_t as *net demand*, so equation (1) says that the cash market is in equilibrium when net demand equals net supply. We can rewrite equation (1) in terms of the following inverse net demand function:

$$(2) \qquad P_t = f(\Delta N_t; z_{1t}, z_{2t}, \epsilon_t).$$

Market clearing in the cash market is therefore a relationship between the spot price and the change in inventories. Figure 2 illustrates how the net demand curve is determined from supply and demand in the cash market. In the figure, at price P_1, $Q = X$ and $\Delta N = 0$. At the higher price P_2, $X > Q$ and $\Delta N > 0$. The opposite holds at the lower price P_3. 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 ΔN.

The left panel of Figure 3 illustrates how a change in fundamentals can cause a shift in net demand. Here, $f_1(\Delta N)$ 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

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[7] 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. The model presented below is an extension of the framework in Pindyck (2001).
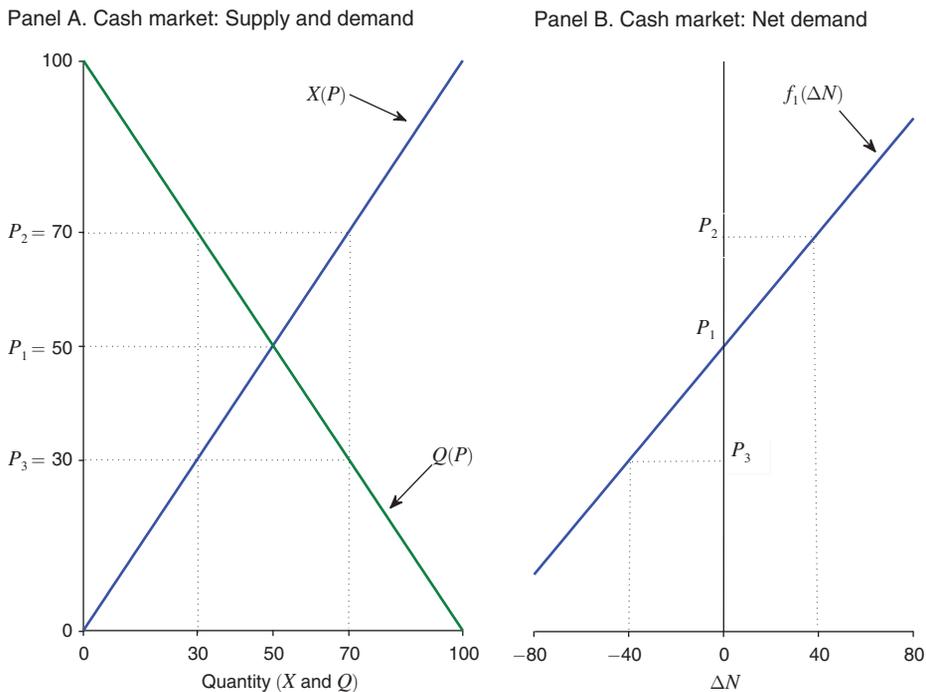
Panel A. Cash market: Supply and demand

Panel B. Cash market: Net demand

FIGURE 2. SUPPLY, DEMAND, AND NET DEMAND
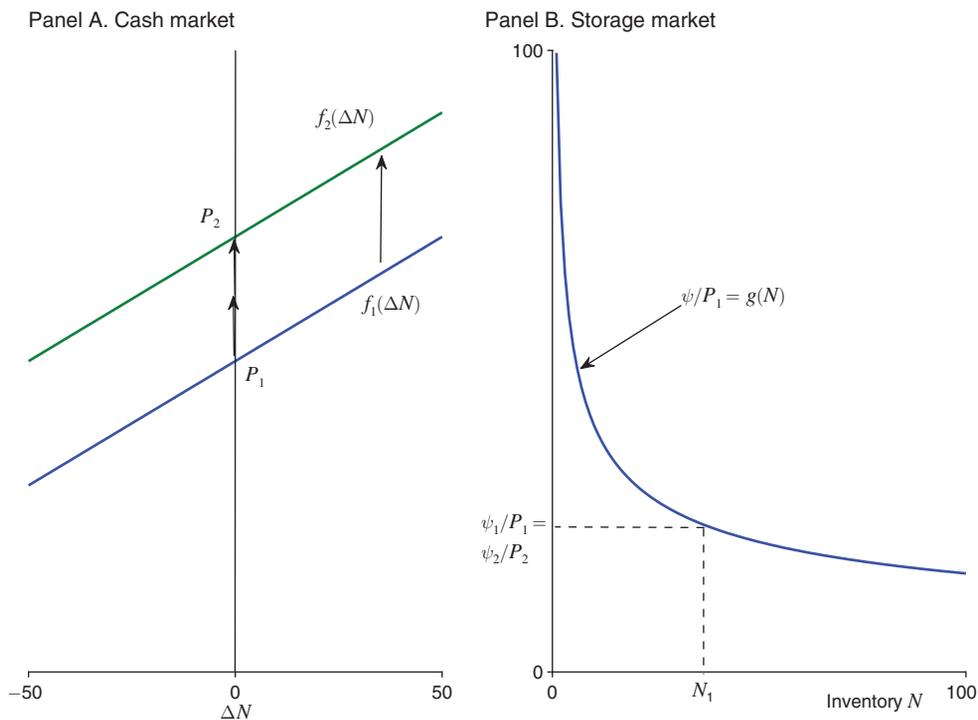
Panel A. Cash market

Panel B. Storage market

FIGURE 3. PERMANENT INCREASE IN DEMAND FOR OIL

upward shift in $f(\Delta N)$ reflects a shift in fundamentals, as opposed to a speculative change in the market. In Figure 3, we assume the shift is permanent.

B. *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 ψ_t, and write the demand for storage as $N(\psi)$.

In addition to the price of storage ψ, the demand for storage will depend on the price P of the commodity itself (one would pay more to store a higher-priced good). As discussed later, statistical studies show that ψ is proportional to P (as one might expect). The demand for storage can also depend on other variables, such as the volatility of price.[8] Letting z_3 denote these other demand-shifting variables and including a random shock, we can write the inverse demand for storage as

$$(3) \qquad\qquad \psi \;=\; Pg(N; z_3, \epsilon_3).$$

The storage market is illustrated by the right-hand panel of Figure 3, where N_1 is the supply of storage and ψ_1 is the corresponding price (convenience yield). We put ψ/P (often referred to as the "percentage net basis") on the vertical axis because this is independent of the price P.

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 $N''(\psi) > 0$.

Suppose oil supply and demand become more volatile, or there is a sudden threat of war in oil producing regions of the world. This could lead producers and industrial consumers of oil to want to hold more inventories. Then the demand for storage curve on the right-hand side of Figure 3 will shift upward, so that if the supply of storage remains fixed at N_1, the convenience yield ψ will increase (as will the ratio ψ/P). The shift in the demand for storage curve would reflect a change in fundamentals, but this time in the market for storage.

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[8] Greater volatility increases the demand for storage by making stock-outs more likely for any given level of inventories. 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.

C. *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.[9] One need not take delivery on a futures contract; 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.

Given the spot price at time t and the futures price for delivery at $t + T$, we can find the convenience yield. Let $\psi_{t,T}$ denote the (capitalized) flow of marginal convenience yield from holding a unit of inventory from t to $t + T$. To avoid arbitrage, $\psi_{t,T}$ must satisfy

$$(4) \qquad\qquad \psi_{t,T} = (1 + r_T)P_t - F_{t,T} + k_T,$$

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 substitute equation (3) for $\psi_{t,T}$ and rewrite equation (4) as follows:

$$(5) \qquad\qquad [1 + r_T - g(N_t)]P_t = F_{t,T} - k_T.$$

Thus, an increase in $F_{t,T}$ requires an increase in P_t—unless there is an increase in N_t (so that $g(N)$ falls) and/or an increase in k_T.

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.

The futures price itself, $F_{t,T}$, is driven by expectations regarding the future spot price, but also depends on the risk-adjusted rate of return from holding the commodity

$$(6) \qquad\qquad F_{t,T} = E_t P_{t+T} + (r_T - \rho_T)P_t,$$

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[9] 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.

[10] To see why equation (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 $F_{t,T} - F_{T,T} = F_{t,T} - P_{t+T}$, 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 nonstochastic, so it must equal the risk-free rate times the cash outlay for the commodity, i.e., $r_T P_t$, from which equation (4) follows.

where E_t denotes the expectation at time t, and ρ_T is the T-period expected return on the commodity, and accounts for systematic risk in its price.[11] Most industrial commodities are pro-cyclical, so $\rho_T > r_T$ and $F_{t,T} < E_t P_{t+T}$, i.e., the futures price is a biased estimate of the future spot price.

In a rational expectations equilibrium, $E_t P_{t+T}$ would reflect expected changes in fundamentals, such as seasonal increases in demand or new production wells expected to come on line. With speculation, however, $E_t P_{t+T}$ can deviate from this equilibrium as speculators bet on higher (or lower) future spot prices. Thus, we can write $E_t P_{t+T}$ as

$$(7) \qquad\qquad E_t P_{t+T} = E_t \bar{P}_{t+T} + s_t,$$

where $E_t \bar{P}_{t+T}$ is the expected future spot price under rational expectations, which might be constant, or, if fundamentals are expected to change, time-varying, and s_t is a shifter that accounts for deviations due to speculation. We treat both $E_t \bar{P}_{t+T}$ and s_t as exogenous, so that $E_t P_{t+T}$ is exogenous.

We will see that 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 attributable to structural shifts in demand and supply, or instead to speculative activity in the futures market.

D. *Summary*

Our analytical framework can be summarized by four equations that describe the evolution of four variables, P_t, N_t, $\psi_{t,T}$, and $F_{t,T}$: equation (2) for P_t, equation (3) for N_t, equation (4) for $\psi_{t,T}$, and equation (6) for $F_{t,T}$.

As illustrated below, given $E_t P_{t+T}$ and a starting inventory level N_0, equations (2), (3), (4), and (6) can be solved forward to generate values of the four variables in each period. We will see how exogenous changes in $E_t P_{t+T}$ can affect these other variables.

As an exercise in comparative statics, Figure 3 uses this framework to illustrate the impact of a change in fundamentals, in this case a (permanent) upward shift in demand. From equation (2), the net demand curve shifts up and the spot price increases from P_1 to P_2. This increase in the spot price is anticipated, so $E_t \bar{P}_{t+T}$ and thus $E_t P_{t+T}$ increase, which, from equation (6) implies an increase in $F_{t,T}$. 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 and the convenience

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[11] To see why equation (6) must hold, consider buying one unit of the commodity at time t to be held until time $t + T$ and then sold. The expected return on this investment is $E_t P_{t+T} - P_t + \psi_{t,T} - k_T$, which must equal $\rho_T P_t$, where ρ_T is the risk-adjusted discount rate for the commodity. Substitute equation (4) for $\psi_{t,T}$ and rearrange to get equation (6).

yield to price ratio remains fixed, i.e., $\psi_1/P_1 = \psi_2/P_2$. From equation (5), the increase in $F_{t,T}$ will equal $[1 + r_T - g(N_1)](P_2 - P_1)$, assuming no change in k_T.

E. *Impact of Speculation*

Now suppose there is no change in fundamentals, but speculators believe the spot price will rise, and "bet" accordingly by buying futures and/or accumulating inventories. This change in beliefs implies an increase in s_t and thus $E_t P_{t+T}$. We can again use equations (2), (3), (4), and (6) to trace out the impact on prices, inventories, and convenience yield.

Speculation via the Futures Market.—Suppose speculators bet on higher prices by buying futures. Consistent with equation (6), the increase in $E_t P_{t+T}$ implies an increase in the futures price $F_{t,T}$. 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 fundamentals-driven shift in the demand for storage.[12]

From equation (5), equilibrium in the spot and futures markets requires an increase in N (so $g(N)$ falls) and/or an increase in the spot price. With no change in fundamentals, both will occur. The spot price will rise (from P_1 to P_2 in the figure), and with $P > P_1$, supply exceeds demand so inventories must rise (from N_1 to N_2) and $g(N) = \psi/P$ will fall, which limits the increase in the spot price. At some point the speculative buying of futures will diminish. The expected future spot price will fall, as will the futures price $F_{t,T}$. Now everything runs in reverse; the spot price falls, inventories are sold off, pushing the spot price down further (to P_3 in Figure 4). Eventually inventories fall back to N_1 and convenience yield increases to ψ_1, at which point ΔN approaches zero, 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 Figure 3? In Figure 3 there is an increase in the spot price, but no change in inventories N or the convenience yield to price ratio ψ/P. 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.

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 ΔN 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.

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[12] 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 $f(\Delta N)$ upward. Because it drives up demand, we will treat this as a change in fundamentals.
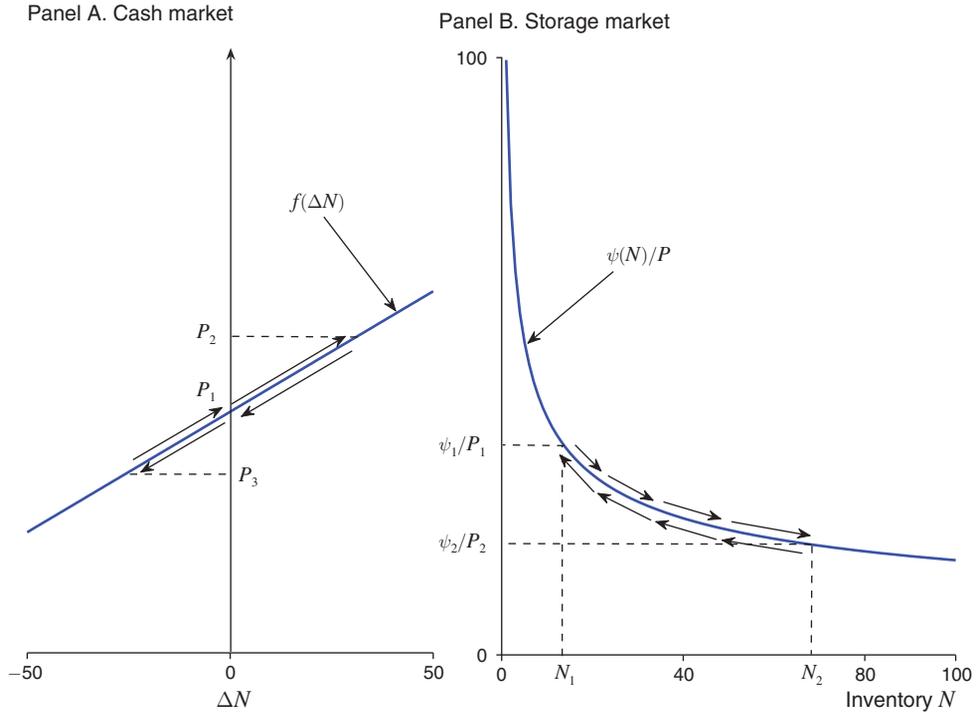
Panel A. Cash market

Panel B. Storage market

FIGURE 4. IMPACT OF SPECULATION ON CASH AND STORAGE MARKETS

Speculative Inventory Holdings.—Suppose oil companies accumulate inventories to speculate on rising prices. With no change in fundamentals, $f(\Delta N)$ and $g(N)$ remain fixed, so Figure 4 again applies. While inventories are increasing (from N_1 to N_2), $\Delta N > 0$, so from equation (2), P must rise (from P_1 to P_2 in the figure), and from equation (3), ψ/P must fall. This inventory accumulation is driven by an increase in $E_t P_{t+T}$, so the futures price $F_{t,T}$ will increase. But from (4), $F_{t,T}$ will increase by more than P_t, consistent with the drop in ψ.

Eventually inventory accumulation stops, so that $\Delta N = 0$ and P returns to P_1. One possibility is that $E_t P_{t+T}$ and thus $F_{t,T}$ fall somewhat, but not to their original levels. A more likely possibility, consistent with Figure 4, is that $E_t P_{t+T}$ and $F_{t,T}$ fall back to their original levels, as do N and ψ/P. Then while $\Delta N < 0$, P drops to P_3, and only returns to P_1 when N reaches N_1 so $\Delta N = 0$. Depending on when they bought and sold, some speculators may have made money, but, on average, speculators will have lost because they will have incurred additional costs of physical storage.

III. Evaluating the Impact of Speculation

The comparative statics exercises above are illustrative, but to take our analytical framework to the data, we must specify functional forms for demand and supply in the cash market, and for the demand for storage. We do that below, and then show how observed changes in the spot price and convenience yield can be
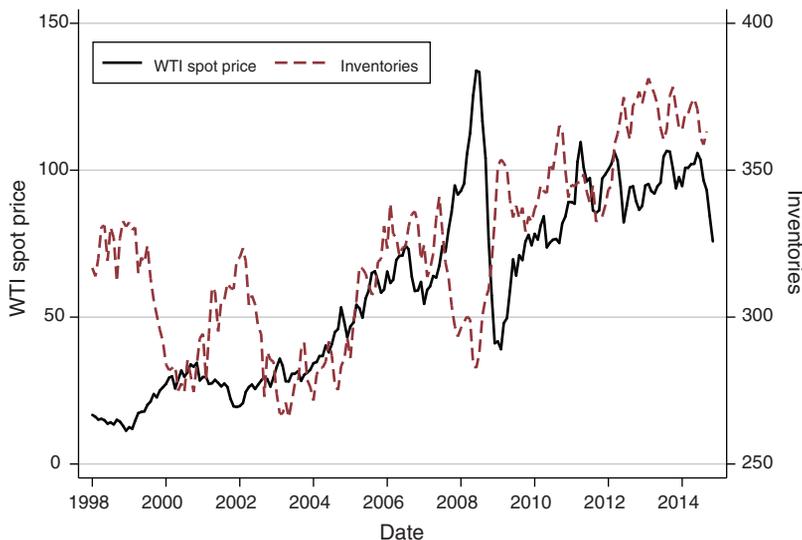
FIGURE 5. MONTHLY SPOT PRICE AND COMMERCIAL INVENTORIES, 1998–2014

decomposed into fundamentals and speculative components. The latter provide a (month-by-month) measure of the impact of speculation.

The previous analysis established a link between speculation and inventories; speculative activity that increases spot prices requires a build-up of inventories. As a first step, we plot spot prices and commercial inventories in Figure 5. There is very little evidence that sharp increases in spot prices were associated with increases in inventory levels. In fact, during the steep increase in oil prices of 2007 and early 2008, inventory levels decreased, while inventories increased during the sharp decline in prices of late 2008.

A. Completing the Model

Equations (4) for $\psi_{t,T}$ and (6) for $F_{t,T}$ are exact (arbitrage-based) relationships. We will take $F_{t,T}$ as given, use equation (4) to obtain a time series for $\psi_{t,T}$, and then use equations (2) and (3) as the basis for our test for speculation. To do so, however, we must say more about supply and demand in the cash market, and the demand for storage.

The Cash Market.—Starting with the cash market, we 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 $X = k_S P^{\eta_S}$ and demand as $Q = k_D P^{\eta_D}$, the change in inventories is:

$$(8) \qquad \Delta N_t = k_S P_t^{\eta_S} - k_D P_t^{\eta_D}.$$

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 η_S and η_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 η_S and η_D, but instead consider a broad range of plausible values for these parameters.

Divide both sides of equation (8) by Q_t:

$$(9) \qquad \frac{\Delta N_t}{Q_t} = \frac{X_t}{Q_t} - 1 = \frac{k_S}{k_D} P_t^{\eta_S - \eta_D} - 1.$$

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

$$(10) \quad \Delta \ln P_t = \frac{1}{(\eta_S - \eta_D)} [\Delta \ln k_D - \Delta \ln k_S] + \frac{1}{(\eta_S - \eta_D)} \Delta \ln(X_t/Q_t).$$

We have assumed that any change in market fundamentals is reflected in a change in k_D and/or k_S. Thus, we can use equation (10) to isolate the speculative component of price changes:

$$(11) \qquad \Delta \ln P_t^S = \frac{1}{(\eta_S - \eta_D)} \Delta \ln(X_t/Q_t).$$

Suppose that over some extended period of time, say $t = 0$ to T, there are no changes in fundamentals, so that the only changes in price are driven by speculation and given by equation (11). Suppose further that for part of the time speculators push the price above its equilibrium fundamental level, and they keep it at this higher level for some interval, say T_1 to T_2. Equation (11) implies that over this interval *inventories must continually increase*. To see this, suppose we start in equilibrium at a price P_0 and with $X_0 = Q_0$ so there is no change in inventories. If speculators drive up the price to $P_1 > P_0$, we must have $X_1 > Q_1$ so that inventories grow. If the price is to stay at this higher level, i.e., $P_2 = P_1$, then we must have $X_2/Q_2 = X_1/Q_1 > 1$ so that inventories again grow. *This growth in inventories must continue as long as the price remains above P_0.* If the price drops back to P_0, inventories will stop growing (because then $X/Q = X_0/Q_0 = 1$), but they will remain at a higher level than when the speculative activity began. This is illustrated in Figure 6—speculators push the price up at time T_1 from \$60 to \$100, it stays at this higher level until T_2, and then it drops back to its original level, where it stays until T_3.

For inventories to return to their original level, the price must drop below, and stay below, P_0 for a sufficient period of time (from T_3 to T_4 in the figure). This
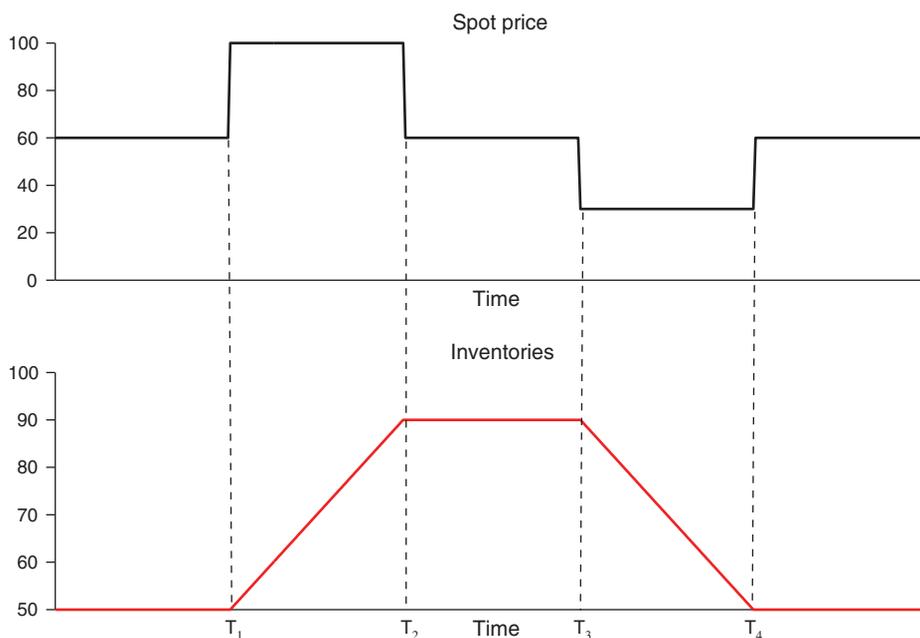
FIGURE 6. SPECULATIVE PRICE CHANGES AND INVENTORY BEHAVIOR

"undershooting" of price is necessary to get back to equilibrium, and is also seen in Figure 4.

The Storage Market.—Next, we specify the demand for storage. We will write the (inverse) demand for storage curve as

$$(12) \qquad \psi(N_t) \ = \ P_t g(N_t) \ = \ k_N P_t N_t^{-1/\eta_N},$$

where $\eta_N > 0$ is the price elasticity of demand for storage. This standard specification for the demand for storage has been estimated in the literature for a variety of commodities. As discussed below, we estimated equation (12) using our data for crude oil and found that $\eta_N \approx 1$, consistent with other studies, and that $\psi(N)$ is indeed proportional to the spot price P_t.

We assume that any change in market fundamentals is reflected in a change in k_N. For example, an increase in market volatility or an increased threat of war in the Persian Gulf would cause an increase in k_N. If oil producers accumulate inventories to speculate on price increases, k_N would remain unchanged and we would observe a movement down the demand for storage curve, as in Figure 4.

Taking logs and first differences of equation (12) gives

$$(13) \qquad \Delta \ln \psi_t \ = \ \Delta \ln k_N + \Delta \ln P_t - (1/\eta_N)\Delta \ln N_t.$$

Now substitute equation (10) for $\Delta \ln P_t$ to eliminate the spot price:

$$(14) \qquad \Delta \ln \psi_t = \Delta \ln k_N + \frac{1}{(\eta_S - \eta_D)} [\Delta \ln k_D - \Delta \ln k_S]$$

$$+ \frac{1}{(\eta_S - \eta_D)} \Delta \ln(X_t/Q_t) - (1/\eta_N)\Delta \ln N_t.$$

We use equation (14) to isolate the speculative component of changes in the convenience yield:

$$(15) \qquad \Delta \ln \psi_t^S = \frac{1}{(\eta_S - \eta_D)} \Delta \ln(X_t/Q_t) - (1/\eta_N)\Delta \ln N_t.$$

B. *Behavior of Price, Inventories, and Convenience Yield*

We use equations (11) and (15), along with alternative "reasonable" values for the sum of the supply and demand elasticities ($\eta_S - \eta_D$), to measure the speculative components of the spot price and the convenience yield. We proceed as follows.

Consider equation (11) for log changes in the speculative component of price, $\Delta \ln P_t^S$. We want to know whether such changes are small and tend to cancel out over time, or instead tend to add up to a sustained increase (or decrease) that could help explain the price movements in Figure 1. For example, if the run-up in price during 2005 to 2008 was partly due to speculation, these log changes would have had to be not just significant in magnitude, but also consistently positive over this period.

Therefore at each point in time, we calculate the *cumulative* change in the speculative component of price, starting with the beginning of our sample, which is January 1998. Thus, we take the price in, say, January 2000 that is due to speculation to be the sum of the these changes over the preceding two years. We do the same thing with the convenience yield. We use equation (15) to get the log change in the speculative component of convenience yield, and then cumulate these changes as we move forward in time.

IV. Were Oil Prices Driven by Speculation?

Can changes in oil prices after 2000 be attributed, even in part, to speculation? Below we discuss the data used to address this question, and the results of our analysis.

A. *Data*

We collected monthly data from the Energy Information Administration (EIA) on US production, commercial stocks, imports, and exports from January 1998 to June 2012. We then construct consumption as US production plus net imports minus

changes in commercial stocks. To eliminate the effects of seasonality in demand, we de-seasonalize stocks by first regressing inventories on a set of month dummies and subtracting the coefficients associated with the 11 dummy variables. Thus, consumption is also de-seasonalized given its construction. 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 US data. Our use of US data is justified as follows. First, speculation is often blamed on people trading US futures. For those futures, delivery (which rarely occurs) must be in WTI crude, so Saudi or Nigerian crude is not relevant. Of course Saudi or Nigerian crude is an imperfect substitute for WTI, so in principle WTI inventories could be "traded" for Saudi inventories, but as a practical matter this would be costly and take considerable 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 US) to analyze speculation. In this sense, the United States 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 US inventory data far exceeds the quality of global data, so the use of global inventory data will likely inject noise into the analysis.[13]

Finally, the US market is indeed connected to and constrained by the world market, but only to a degree. For example, the price of Brent crude has been \$5 to \$20 higher than the price of WTI. If the US price rose sharply, more oil (Saudi, Brent, etc.) would start to flow into the United States, but this would take time. Thus, if speculators push up the futures price, US inventories would increase, as would the US spot price. By the time US inventories stop increasing, the spot price must return to its original level. Could Saudi and other producers arbitrage by selling oil into the United States while US inventories are increasing and the US spot price is high? Possibly, but it would be time consuming, costly, and thus unlikely.

B. *Testing for Speculation*

As discussed above, we use equations (11) and (15) to calculate the speculative components of monthly changes in price and convenience yield, respectively. However, to use equation (11), we need numbers for the 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, Knittel, and Sperling (2008) suggest that the short-run demand elasticity is roughly -0.1, although, Kilian and Murphy (2014) 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. The literature on supply elasticities is more sparse. Dahl and Duggan (1996) summarize that literature and find that many estimates, for both

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[13] We also note that Kilian and Lee (2014) use the same empirical model as Kilian and Murphy (2014), but applied to global supply, demand, and inventory data and find similar results.

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.

The monthly changes in the spot price resulting from speculative activity come directly from equation (11). We are interested in understanding the cumulative effects of speculative activity over our entire time period. Therefore, at each point in time we add the changes in prices resulting from speculative activity in all previous periods. For January 1998, the first month of our sample, we set $\Delta \ln P_t^S = 0$, and then calculate and accumulate values for $\Delta \ln P_t^S$ over the rest of the sample. This yields

$$(16) \qquad \Delta \ln P_T^S = \ln P_T^S - \ln P_0 = \sum_{t=Jan\ 1998}^{T} \Delta \ln P_t^S.$$

To calculate speculation-induced changes in the convenience yield using equation (15), we need the actual convenience yield and an estimate of the price elasticity of the demand for storage, η_N. From equation (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. A rough estimate of the cost of storage (k_T) is $1.50 per barrel per month, although this cost can rise when inventory levels are large and storage facilities fill up.

We use the estimate of $1.50, but note that in 5 of the 162 months in our sample the futures-spot spread was so large that a $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 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, η_N, is $1.0.$[14] However, we estimate this elasticity and also test whether changes in convenience yield are indeed proportional to changes in price. We estimate equation (13) assuming an AR(2) process for the error term. The results, in the first column of Table 1, support our assumption that changes in convenience yields are proportional to changes in spot prices. The estimated coefficient on the log change in price is 0.9784 and is not statistically different from 1 (*p*-value of 0.90). The coefficient on the log change in stocks is 0.1221, but is noisy; we cannot reject a coefficient of -1 (*p*-value of 0.10).[15] Because we are estimating the inverse demand curve for storage, one might be have concerns that price, and potentially stocks, are endogenous, so we reestimate the equation instrumenting for price and stocks. As instruments

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[14] Pindyck (1994) estimated the storage price elasticity to be about 1.1 for copper and 1.2 for heating oil.
[15] This noisy estimate is likely due to the small amount of variation in stocks.

TABLE 1—ESTIMATION OF THE INVERSE-DEMAND FOR STORAGE CURVE

Variables	AR(2) (1)	OLS (2)	GMM-IV (3)
$\Delta \ln P_t$	0.9784*** (0.1725)	0.9576*** (0.1798)	0.8169 (0.9844)
$\Delta \ln N_t$	0.1221 (0.6498)	−0.0263 (0.6494)	3.5369 (4.1600)
AR1	0.1056 (0.0667)		
AR2	−0.3920*** (0.0651)		
Observations	177	177	177

*** Denotes statistical significance at the 1 percent level.

we use macroeconomic variables and lagged values for oil prices and stocks.[16] The results are in column 3 of Table 1.[17] Once again, the coefficient on the log change in price is insignificantly different from 1, and we cannot reject a coefficient of −1 for the log change in stocks (*p*-value of 0.86).

The speculative component of convenience yield is given by equation (15). As with prices, we are interested in the cumulative affect of speculation, so at each point in time we add the changes in convenience yield resulting from speculative activity in all previous periods. The cumulative change in the log of convenience yield due to speculation at any time T is then

$$(17) \qquad \Delta \ln \psi_T^S = \ln \psi_T^S - \ln \psi_0 = \sum_{t=Jan\ 1998}^{T} \Delta \ln \psi_t^S.$$

C. Results

Price Changes.—Figure 7 plots the cumulative change in the log of actual spot prices and the cumulative change in prices coming from speculation. The figure makes clear that speculative activity did not lead to large or sustained changes in price. The cumulative effect from speculation hovers around zero for our entire sample. This is not surprising since over this time period there was no large and sustained growth in inventories.

Suppose one believed that supply and demand are extremely inelastic. Figure 8 shows the actual and speculative component of prices, but with $\eta_S = 0.05$ and $\eta_D = -0.05$. The price changes that can be attributed to speculation are still very small.

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[16] In particular, we use the index of industrial activity, the 3-month T-bill rate, the money supply (M1), and the major currency exchange rate index.

[17] For completeness, we also show (in column 2) the results from a simple OLS regression. We obtain similar results if we omit one set of instruments (i.e., the macroeconomic variables or the lagged variables).
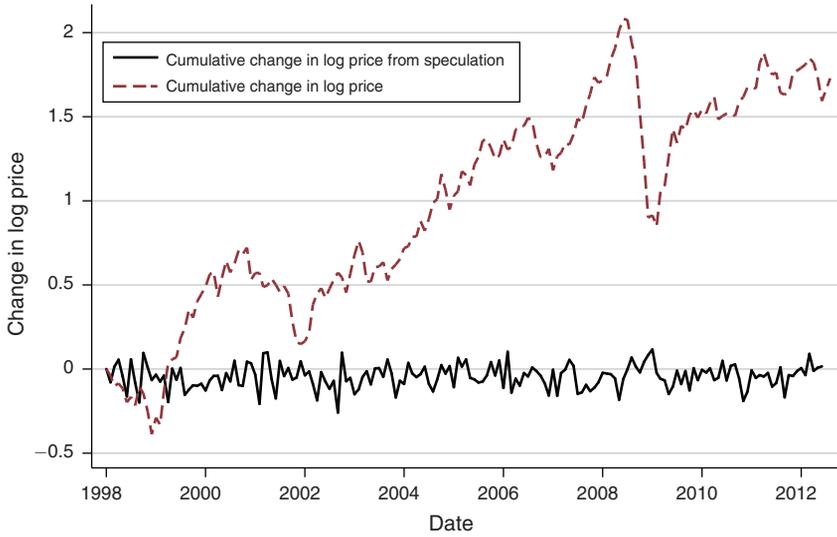
FIGURE 7. ACTUAL MONTHLY CHANGES IN LOG PRICES AND IMPLIED CHANGES FROM SPECULATIVE ACTIVITY: USING INVENTORY CHANGES, $\eta_S = 0.1$ AND $\eta_D = -0.1$
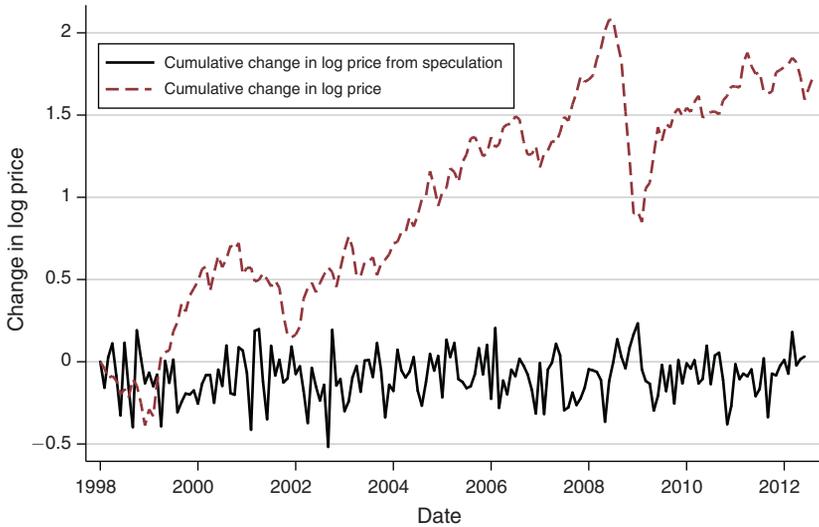

FIGURE 8. ACTUAL MONTHLY CHANGES IN LOG PRICES AND IMPLIED CHANGES FROM SPECULATIVE ACTIVITY: USING INVENTORY CHANGES, $\eta_S = 0.05$ AND $\eta_D = -0.05$

Convenience Yield.—We saw that speculative inventory accumulation would result in a movement down in the demand for storage curve, so that convenience yield would fall as inventories rose. However, as can be seen from equation (13), there is a second effect operating through the impact of speculation on spot prices. As spot prices increase, the demand for storage increases, pushing convenience yields upward. Therefore, the net effect of speculation on convenience yields is
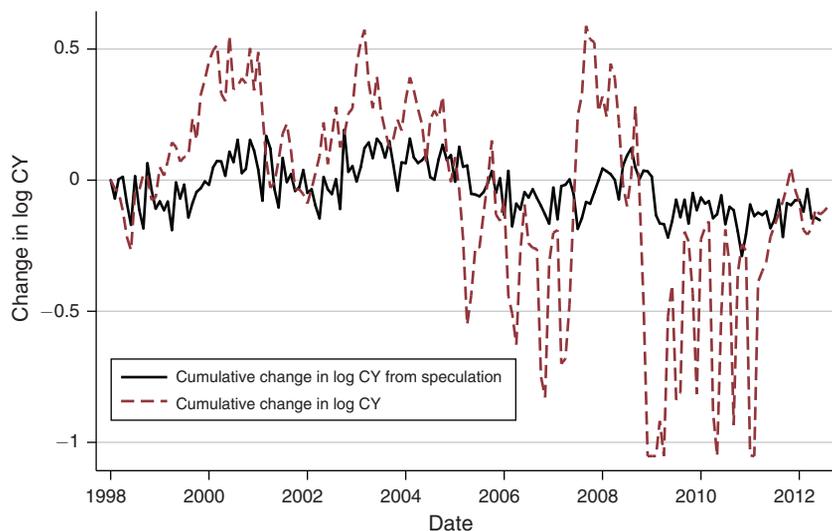
FIGURE 9. ACTUAL MONTHLY CHANGES IN log CONVENIENCE YIELDS
AND IMPLIED CHANGES FROM SPECULATIVE ACTIVITY

ambiguous. We can still compare how changes in convenience yields due to specu-
lation compare to the overall change.

Figure 9 shows the actual cumulative change in the log of convenience yield
and the cumulative change resulting from speculation. As with the spot prices, the
cumulative change resulting from speculation tends to fluctuate around zero. These
results suggest that market fundamentals are the main driver of changes in conve-
nience yield.

D. *Specific Periods*

Next, we focus on specific time periods during which prices increased sharply
and there was intensive public concern over speculation. Figure 10 plots WTI spot
prices and Google search intensity for the term "oil speculation."[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 10 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 price increases as well

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[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 over the entire period. The week with
maximum search intensity is scaled at 100, and all other weeks are a percentage of the maximum week. Figure 10
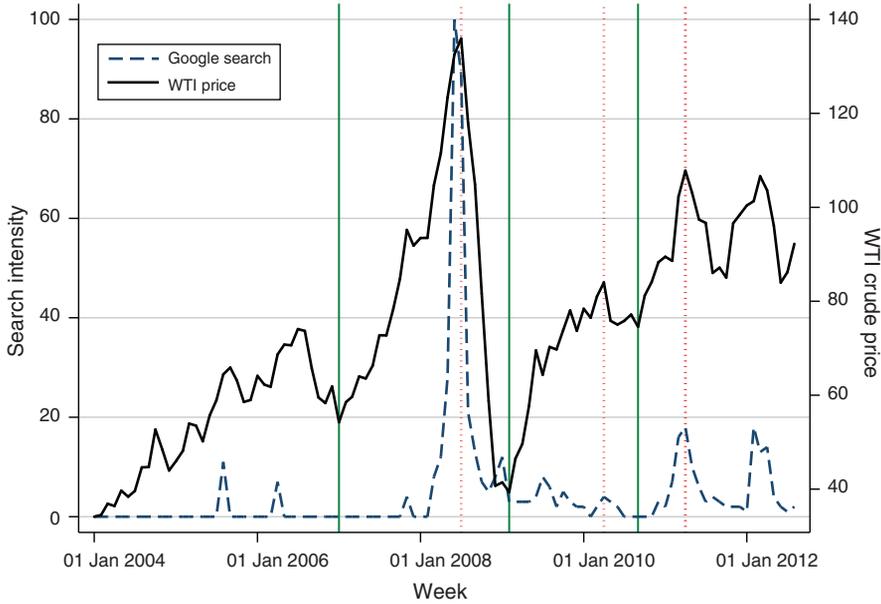plots the weekly average within a particular month.

FIGURE 10. MONTHLY WTI SPOT PRICES AND GOOGLE SEARCH INTENSITY FOR "OIL SPECULATION"

as heavy Google search activity. We split the second into two sub-epochs because prices leveled off 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 over the entire epoch instead of working with monthly changes. In particular: (i) We report the beginning and final price for the epoch; (ii) we calculate the actual change in inventories; and (iii) we calculate the speculative change in prices and the convenience yield and compare it to their actual values. The first three time periods exceed a year in length, suggesting long-run demand and supply elasticities may be more relevant. Therefore, for the first three periods we assume that $(\eta_S - \eta_D)$ equals 0.4, consistent with demand and supply elasticities of 0.2 and -0.2, respectively. We use short-run elasticities (0.1 and -0.1) for the final period, which is 7 months long. The results are in Table 2.

For the first three epochs the share of the price change resulting from speculation is small. Indeed, for all four epochs, speculation led to lower prices, not higher prices. These results are consistent with the previous sets of results which show that speculation had almost no impact on prices, and if anything, dampened price spikes. Table 2 also shows that for every epoch inventory changes were small and negative even though the price changes were large and positive. As Figure 6 illustrates, for speculation to have accounted for even part of these prices increases inventories would have had to increase substantially, not decrease.

We also use equation (17) to calculate the change in convenience yield due to speculation. Once again, this is inconsistent with speculation being a significant factor in the market.

TABLE 2—EPOCH ANALYSIS

Epoch	2007:1–2008:7 (1)	2009:2–2011:4 (2)	2009:2–2010:4 (3)	2010:9–2011:4 (4)
Beginning price (P_0)	$54.51	$39.09	$39.09	$75.24
Ending price (P_T)	$133.37	$109.53	$84.29	$109.53
Beginning X (X_0)	582.867	484.570	484.570	521.087
Beginning Q (Q_0)	577.514	481.923	481.923	509.951
Ending X (X_T)	566.539	519.262	535.992	519.262
Ending Q (Q_T)	562.038	518.881	537.916	518.881
Change in log price due to speculation, $\left(\Delta \ln P_T^S\right)$	−0.31%	−1.19%	−2.27%	−10.43%
Ending inventories (de-seasonalized) (Millions of barrels) (N_T)	286.80	346.50	343.22	346.50
Actual inventory build up over entire Epoch (ΔN_T)	−37.75	−7.49	−10.76	−20.98
Beginning convenience yield (ψ_0)	$3.52	$1.50	$1.50	$1.69
Ending convenience yield (ψ_T)	$3.89	$3.04	$1.77	$3.04
Change in log convenience yield due to speculation, $\left(\Delta \ln \psi_T^S\right)$	12.05%	0.95%	0.82%	−4.56%

Notes: $\Delta \ln P_T^S$ is derived from equation (16), replacing time period T with the end of the epoch and time period 0 with the beginning of the epoch, implying: $\Delta \ln P_T^S = \dfrac{1}{(\eta_S - \eta_D)} \Delta \ln(X_T/Q_T)$. For Epochs 1, 2, and 3 we assume that $(\eta_S - \eta_D) = 0.4$, but for Epoch 4 we asssume that $(\eta_S - \eta_D) = 0.2$.

$\Delta \ln \psi_T^S$ is derived from equation (17), replacing time period T with the end of the epoch and time period 0 with the beginning of the epoch, implying: $\Delta \ln \psi_T^S = \dfrac{1}{(\eta_S - \eta_D)} \Delta \ln(X_T/Q_T) - (1/\eta_N)\Delta \ln N_T$.

V. 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 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 beginning in 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 (2014) and Kilian and Lee (2014).

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.

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.

Finally, might oil companies have contributed to the sharp price increases by delaying the development of undeveloped reserves or reducing production from existing wells? If the former, 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. In Knittel and Pindyck (2013), we show that 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. We also show that oil companies did not appear to reduce production from developed reserves. Production had been falling prior to 2006, but was roughly level during 2006 to 2008.

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