Estimated Effects of Speculation and Interest Rates in a "Carry Trade" Model of Commodity Prices

Jeffrey A. Frankel*

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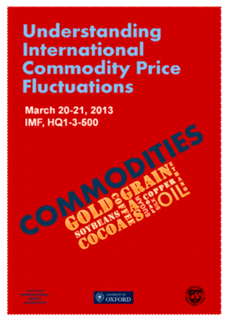

Abstract

This paper attempts econometric estimation of a model of the prices of oil and other storable commodities, a model that can be characterized as reflecting the carry trade. It focuses on speculative factors, here defined as the trade-off between interest rates on the one hand and market participants' expectations of future price changes on the other hand. It goes beyond past research by bringing to bear new data sources: survey data to measure expectations of future changes in commodity prices and options data to measure perceptions of risk. Evidence is found of a negative effect of interest rates on the demand for inventories and thereby on commodity prices and positive effects of expected future price gains on inventory demand and thereby on today's commodity prices.

Keywords: carry trade; commodity; commodities; real; interest rate; oil, petroleum, mineral, volatility; inventory; inventories, monetary, spot price; spread; overshooting, futures; speculation.

JEL Classification Codes: Q11, Q39

*Harpel Professor of Capital Formation and Growth, Harvard Kennedy School, Harvard University,
79 JFK Street, Cambridge MA 02138-5801. jeffrey_frankel@harvard.edu http://ksghome.harvard.edu/~jfrankel/
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This paper presents and estimates a model of macroeconomic determinants of prices of oil and other commodities, with an emphasis on the intermediating role of inventories. It could be called the "carry trade" model in the light it shines on the trade-off between interest rates and speculation regarding future changes in the price of the commodity. Low real US interest rates are a signal that money is plentiful, with the result that funds venture far afield in search of higher expected returns, whether it is in mineral commodities or in foreign currencies. The phrase "carry trade" is today primarily associated with speculation in international fixed-income markets, where the spot price of concern is the price of foreign exchange and the "cost of carry" is the international difference in interest rates. There is perhaps an irony here, because the original intuition comes from more tangible commodities, where the cost of carry includes storage costs (among other variables).

1. Macroeconomic Influences

There are times when so many commodity prices move so much together that it becomes difficult to ignore the influence of macroeconomic phenomena. The decade of the 1970s was one such time. Recent history provides another. It cannot be a coincidence that prices of oil and almost all mineral and agricultural commodity prices rose in unison from 2001 to 2007, peaked jointly and abruptly in mid-2008, plunged together in 2009, and again rose together thereafter. Three theories compete to explain increases in commodity prices in recent years.

First, and perhaps most standard, is the *global growth explanation*. This argument stems from the unusually widespread growth in economic activity after 2000 – particularly including the arrival of China and other entrants to the list of important economies and their rapid recovery from the 2008-09 global recession – together with the prospects of continued high growth in those countries in the future. This growth has raised the demand for, and hence the price of, commodities.

The second explanation -- also highly popular, at least among the public -- is *speculation*. Many commodities are highly storable; a large number are actively traded on futures markets. We can define speculation as the purchases of the commodities, whether in physical form or via contracts traded on an exchange, in anticipation of financial gain at the time of resale. This includes not only the possibility of destabilizing speculation (bandwagon effects), which is what the public often has in mind, but also the possibility of stabilizing speculation. The latter case is the phenomenon whereby a rise in the spot price relative to its long run equilibrium generates expectations of a price decline in the future, leading market participants to sell or short the commodity today and thereby dampen the price increase today.

One kind of evidence that has been brought to bear on this argument is the behaviour of inventories. Krugman (2008a, b) and Wolf (2008), for example, argued that inventories were not historically high at the time of the 2008 price spike and therefore that speculators could not have been betting on price increases and could not have added to the current demand. Others have found evidence in inventory data that they interpret as consistent with an important role for speculation, driven for example by geopolitical fears of disruption to the supply of Mideastern oil. (See Kilian and Murphy, 2013; Kilian and Lee, 2013).

The third explanation is that *easy monetary policy* has contributed to increases in commodity prices, via either high demand or low supply. Easy monetary policy often shows up as low real interest rates.[1] Barsky and Kilian (2002, 2004) and others have argued that high prices for oil and other commodities in the 1970s were not exogenous, but rather a result of easy

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[1] See Frankel (2008a, b), for example.

monetary policy. The same could be argued for other mineral and agricultural commodities. Conversely, a substantial increase in real interest rates drove commodity prices down in the early 1980s, especially in the United States. High real interest rates raise the cost of holding inventories. Lower demand for inventories then contributes to lower total demand for commodities. [2]

After 2000, the process went into reverse. The Federal Reserve cut real interest rates sharply in 2001-2004, and again in 2008. Each time, it lowered the cost of holding inventories, thereby contributing to an increase in demand. The analogy with the carry trade in foreign exchange is clear: low interest rates send investors far afield in their search for yield, whether it is into foreign assets or commodities.

As a preliminary illustration of the monetary influence on commodity markets, Figure 1a shows the time series for real interest rates from 1950 to 2012 together with a time series for the real value of commodity price index (Moody's Commodity price index, deflated). The advantage of looking at an aggregate index, as opposed to prices of individual commodities, is that the host of idiosyncratic factors that influences each individual sector may wash out. Commodity price spikes in the 1970s, 2008 & 2011 coincide with real interest rates that are zero or even negative. Figure 1b presents the same data in the form of a plot, with the real interest rate on the horizontal axis and the real commodity price on the vertical axis. A negative correlation is visible.

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[2] A second effect of higher interest rates is that they undermine the incentive for oil-producing countries to keep crude oil under the ground. By pumping oil instead of preserving it, OPEC countries could invest the proceeds at interest rates that were higher than the return to leaving it in the ground. Higher rates of pumping increase supply; both lower demand and higher supply contribute to a fall in oil prices. The same mechanisms apply to decisions about extracting minerals, logging forests, harvesting crops, etc.

Figure 1a: Real commodity price index (Moody's) and real interest rates; time series

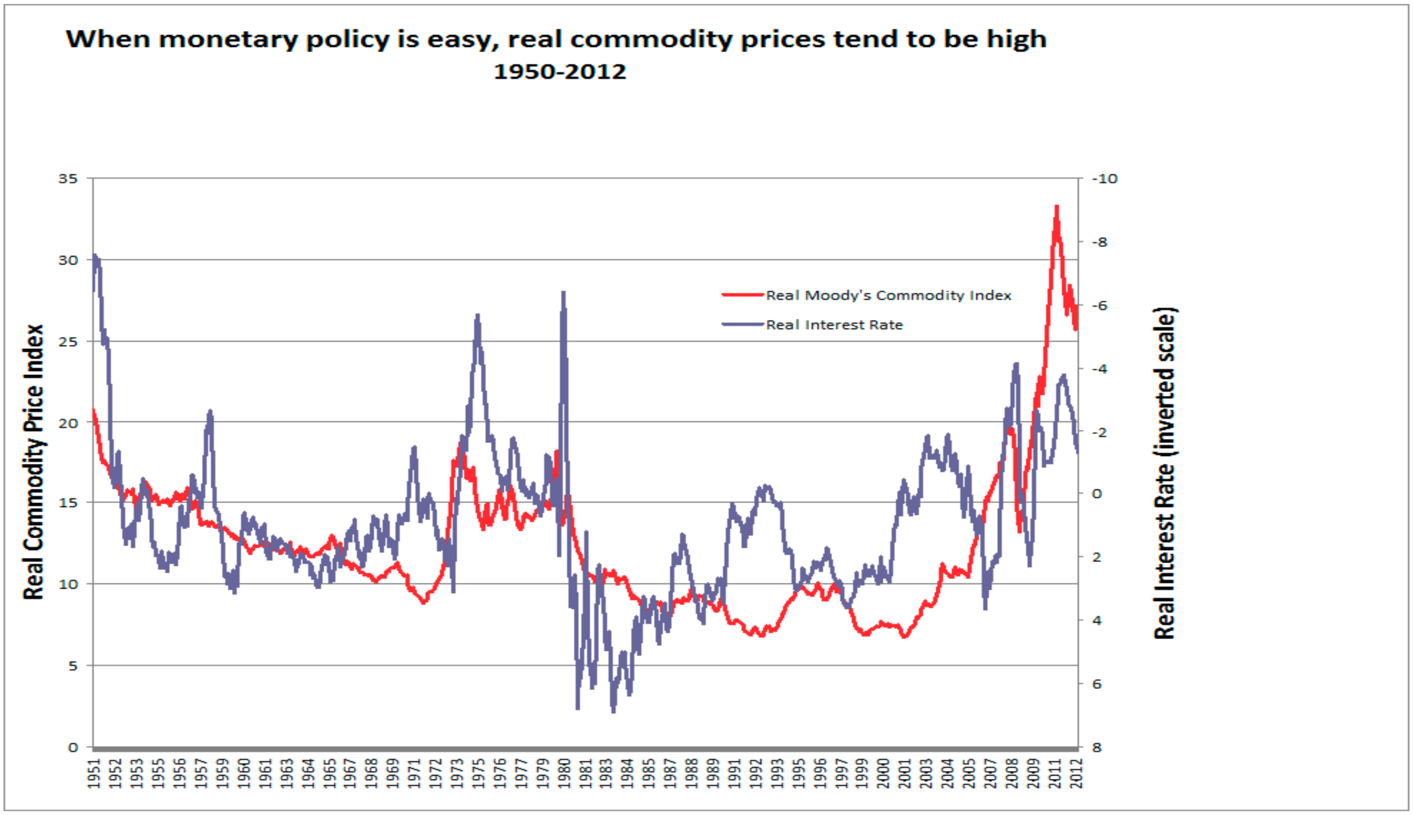
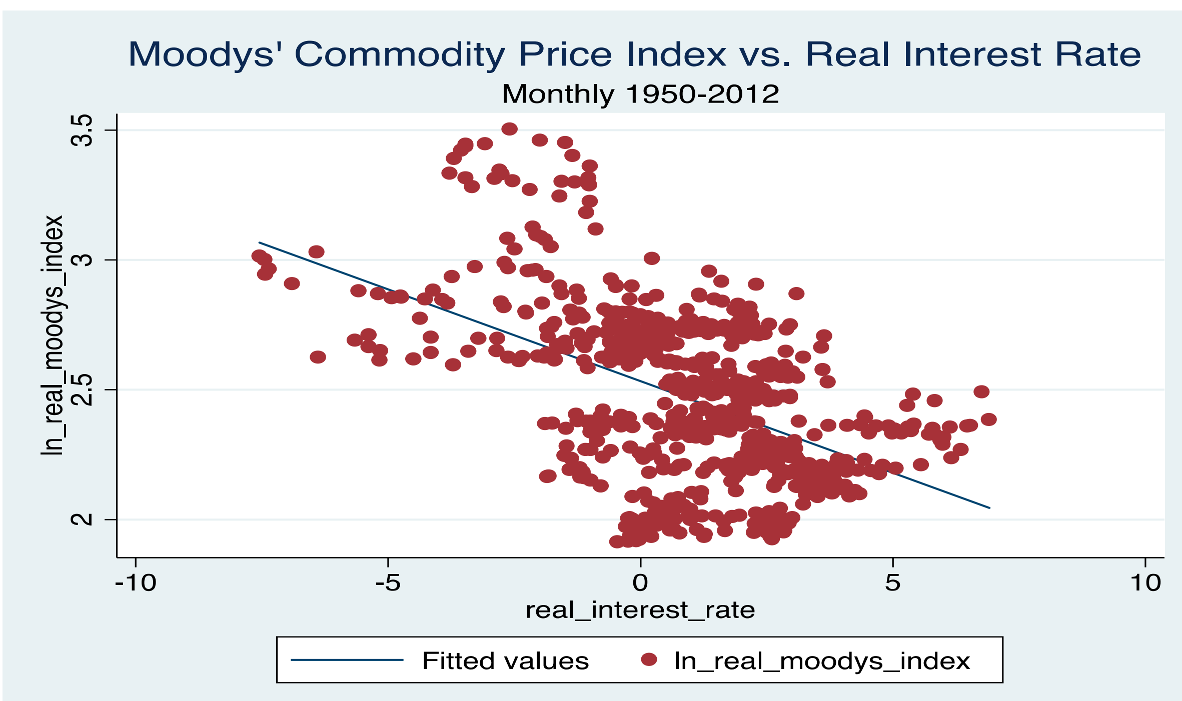


Figure 1b: Real commodity price index (Moody's) and real interest rates; plot



Critics of the interest rate theory as an explanation of increased prices for oil and other commodities over the last decade have pointed out that it implies that inventory levels should have been high and have argued that they were not. This is the same missing link that has been raised in objection to the destabilising speculation theory. For that matter, the missing inventories link objection can be applied to most theories. [3] Explanation number one, the global boom theory, is often phrased in terms of expectations of future growth rates, not just a currently-high income levels; but this factor, too, if operating in the market place, should in theory work to raise demand for inventories.

The price spike in 2008 worked in favour of explanations number two and three, the speculation and interest rate theories, at the expense of explanation number one, the global boom. Previously, rising demand from the global expansion, especially the boom in China, had seemed the obvious explanation for rising commodity prices. But the sub-prime mortgage crisis hit the United States around August 2007. Virtually every month thereafter, forecasts of growth were downgraded, not just for the United States but for the rest of the world as well, including China.[4] Meanwhile commodity prices, far from declining as one might expect from the global demand hypothesis, climbed at an accelerated rate. For the year following August 2007, at least, the global boom theory was clearly irrelevant. That left explanations number two and three. Of course the 2008 spike represents just one data point.[5]

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[3] I am indebted to Larry Summers for this point.
[4] For example, *World Economic Outlook*, International Monetary Fund, October 2007, April 2008 and October 2008. Also OECD and World Bank.
[5] Frankel (2008b), Hamilton (2008, 2009).

In both cases – increased demand arising from either low interest rates or expectations of capital gains – detractors pointed out that the explanations implied that inventory holdings should be high and continued to argue that this was not the case.[6]

This paper attempts econometric estimation of a model of the prices of oil and other storable commodities, a model that can be characterized as reflecting the carry trade. It focuses on speculative factors, here defined as the trade-off between interest rates on the one hand and market participants' expectations of future price changes on the other hand. Inventories are a mediating variable between these factors and commodity prices. Data on inventories are readily available in the case of oil, and to a lesser extent for some other commodities. Previous attempts to estimate the role of oil inventories in mediating speculation, such as Kilian and Murphy, (2013), Killian and Lee (2013), Ye *et al* (2002, 2005, 2006) and Frankel (2008, Table 2), have not had an explicit measure of expectations held by market participants; they thus have had to infer the speculative factor implicitly rather than measuring it explicitly. This paper attempts to capture the speculative factor explicitly by using data on forecasts of future commodity prices from a survey of market participants. Furthermore, where past attempts to capture the role of risk have usually relied on actual volatility measures this paper uses the subjective measure of volatility implicit in options prices.

To preview the results, there is some empirical support for the hypothesized roles of inventories, economic activity, and – most importantly – the two determinants of the carry trade: interest rates and expected future commodity price changes.

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[6] Among others, Krugman (2008) and Kohn(2008).

2. A Carry-Trade Theory of Commodity Price Determination

Most fossil fuels, minerals, and agricultural commodities differ from other goods and services in that they are both storable and relatively homogeneous. As a result, they are hybrids of assets – where price is determined by supply of and demand for *stocks* – and goods, for which the *flows* of supply and demand matter.[7]

The elements of an appropriate model have long been known.[8] The monetary aspect of the theory can be reduced to its simplest algebraic essence as a relationship between the real interest rate and the spot price of a commodity relative to its expected long-run equilibrium price. This relationship can be derived from two simple assumptions. The first governs expectations. Let:

$s \equiv$ the natural logarithm of the spot price,

$p \equiv$ the (log of the) economy-wide price index,

$q \equiv s\text{-}p$, the (log) real price of the commodity, and

$\bar{q} \equiv$ the long run (log) equilibrium real price of the commodity.

Market participants who observe the real price of the commodity today lying either above or below its perceived long-run equilibrium value, expect it to regress back to equilibrium in the future over time, at an annual rate that is proportionate to the gap:

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[7] For example, Frankel (1984) and Calvo (2008).

[8] See Frankel (1986, 2008a) and Frankel and Hardouvelis (1985). The classic Dornbusch (1976) overshooting paper developed the model for the case of exchange rates. The commodities version of the overshooting model essentially substituted the price of commodities for the price of foreign exchange and substituted convenience yield (adjusted for storage costs) for the foreign interest rate.

$$E\,[\,\Delta\,(s-p\,)\,] \equiv E[\,\Delta q] = -\,\theta\,(q-\bar{q}\,) \tag{1}$$

or $$E\,(\Delta s) = -\,\theta\,(q-\bar{q}\,) + E(\Delta p). \tag{2}$$

For present purposes, it may be enough simply to assert that this is a reasonable form for expectations to take: It seems reasonable to expect a tendency for the price of a commodity to regress back toward long run equilibrium in the future. But it can be shown that regressive expectations are also rational expectations, under certain assumptions regarding the stickiness of prices of other goods (manufactures and services) and a certain restriction on the parameter value θ.

The next equation concerns the decision whether to hold commodity inventories for another period or to sell at today's price and use the proceeds to earn interest. The expected rate of return to these two alternatives should be equalized:

$$E\,(\Delta s) + c = i, \qquad \text{where: } c \equiv cy - sc - rp; \tag{3}$$

i ≡ the nominal interest rate;

cy ≡ convenience yield from holding the stock (for example, the insurance value of having an assured supply of some critical input in the event of a disruption or, in the case of a commodity like gold, the psychic pleasure of holding it);

sc ≡ storage costs (for example, feed lot rates for cattle, silo rents and spoilage rates for grains, rental rates on oil tanks or oil tankers, costs of security to prevent plundering by others, etc.);[9]

[9] Fama and French (1987) and Bopp and Lady (1991) emphasise storage costs.

$rp \equiv (f\text{-}s) - E(\Delta s) \equiv$ risk premium,

where *f* is the log of the forward/futures rate at the same maturity as the interest rate. The risk premium (when defined in this way) should be negative if being long in commodities is risky, requiring compensation to those who expose themselves to the risk, but should be positive if commodities offer a natural hedging opportunity because their prices are negatively correlated with the market return on the aggregate asset portfolio.[10]

(f-s) = The Futures-Spot Spread. If one is interested in the derivatives markets, one often focuses on the forward discount or slope of the futures curve, *f-s* in log terms (also sometimes called the "spread" or the "roll"). The spread *f-s* is often negative. This phenomenon, "normal backwardation," suggests that convenience yield outweighs the interest rate and storage costs; it may signal that inventories are running low, so the market is "tight" and pays a premium for prompt delivery.[11] But sometimes *f-s* is positive, which is called "contango," signalling that the market is soft, because inventories are plentiful.

The null hypothesis that the forward spread is an unbiased forecast of the future change in the spot price has been tested extensively.[12] This issue does not affect the questions addressed in this paper, however. Here we note only that one need not interpret the finding of bias in the futures rate as a rejection of rational expectations; it could be due to a risk premium. As just

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[10] Working (1949) and Breeden (1980) are classic references on the roles of carrying costs and the risk premium, respectively, in commodity markets. Yang, Bessler and Leatham (2001) review the literature.

[11] For example, Kolb (1992). See also the discussion of Figure 1.22 in the *World Economic Outlook April 2006*, (International Monetary Fund, Washington, DC) and the discussion of Figures 13 and 32 in Commodity Prices and Volatility: Old Answers to New Questions, Global Economics Paper NO. 194, Goldman Sachs, March 30, 2010 [Jeffrey Currie, Allison Nathan, David Greely and Damien Courvalin].

[12] As in the (even more extensive) tests of the analogous unbiasedness propositions in the contexts of forward foreign exchange markets and the term structure of interest rates, the null hypothesis is usually rejected: the carry trade on average makes money. This literature is reviewed in the Appendix to Frankel and Rose (2009).

defined, the risk premium *rp* is the difference between the spread (*f* – *s*) and the expected increase in the commodity price.

To get our main result, we simply combine Equations (2) and (3):

$$- \theta \, (q - \bar{q}) + E(\Delta p) + c = i$$

$$\Rightarrow q - \bar{q} = - (1/\theta) \, (i - E(\Delta p) - c) \,. \qquad (4)$$

Equation (4) says that the real price of the commodity, measured relative to its long-run equilibrium, is inversely proportional to the real interest rate (measured relative to the term *c*, which could be described as the net convenience yield – that is, the convenience yield after accounting for storage costs and any risk premium). When the real interest rate is high, as in the 1980s, money will flow out of commodities and prices will fall. This will continue until the prices of commodities are perceived to lie sufficiently below their future equilibria, generating expectations of future price *increases*, at which point the quasi-arbitrage or carry-trade condition will be met. Conversely, when the real interest rate is reduced, as in 2001-05 and 2008-11, money will flow into commodities and prices will rise. This will continue until the prices of commodities (or the other alternative assets) are perceived to lie sufficiently above their future equilibria, generating expectations of future price *decreases*, so as to satisfy the carry-trade condition. This is the overshooting model.

If the net convenience yield, *c*, could be treated as constant, equation (4) would give us a simple correlation between the real interest rate, *r*, and real commodity price, *q,* of the sort sketched in Figures 1a and 1b. To see how strong is the inverse relationship that the eye observes, Table 1 presents a bivariate regression of the commodity price indices (in real terms) against the real interest rate (computed very simply with lagged inflation). The relationship is highly significant statistically, regardless which of four standard indices of commodity prices is used. When the dependent variable is the Moody's commodity price index, the estimated coefficient suggests that every 100 basis point increase in the real interest rate lowers real commodity prices by 7 per cent. Similar results hold for the indices calculated by CRB, Dow Jones, and Goldman Sachs.

Table 1: Regression of real commodity price indices against real interest rate (1950-2012)

	Dependent variable: log of commodity price index, deflated by US CPI			
VARIABLES	**CRB index**	**Dow Jones Index**	**Moody's index**	**Goldman Sachs Index**
Real interest rate	**-0.041*** **	**-0.034*** **	**-0.071*** **	**-0.075*** **
	(0.007)	(0.006)	(0.005)	(0.007)
Constant	0.900***	0.066***	2.533***	0.732***
	(0.017)	(0.016)	(0.011)	(0.018)
Observations	739	739	739	513
R-squared	0.04	0.04	0.25	0.18
	*** p<0.01 (Standard errors in parentheses.)			

INFLATION (Month X, Year T) =Log CPI (Month X, Year T) – Log CPI (Month X, Year T-1)
REAL INTEREST RATE (Month X, YEAR T) = [3-TBILL(Month X, YEAR T)/100 - INFLATION (Month X-1, YEAR T)]*100 for months (Feb-Dec) ; for Jan we take INFLATION (Month X-1, YEAR T-1). Source for 3-month treasury bill rates: Federal Reserve Bank of St. Louis

Table 1 thus supports the negative relationship between the real interest rate and real commodity prices of Equation (4). There is no reason for the net convenience yield, *c*, in Equation (4) to be constant, however. Potentially important factors were left out of the equation estimated in Table 1.

Substituting from (3) into (4),

$c \equiv cy - sc - rp \Rightarrow$

$q-\bar{q} = -(1/\theta)[i - E(\Delta p) - cy + sc + rp]$

$$q=\bar{q} - (1/\theta)[i-E(\Delta p)] + (1/\theta)\, cy - (1/\theta)\, sc - (1/\theta)\, rp\,. \quad (5)$$

Thus, even if we continue to take the long-run equilibrium $\bar{q}$ as given by a constant or a trend, there are other variables in addition to the real interest rate that determine the real price: the convenience yield; storage costs; and the risk premium. Furthermore the long-run equilibrium real commodity price $\bar{q}$ need not necessarily be constant. Fluctuations in the convenience yield, storage costs, or the risk premium might also contain a permanent component; all such effects would then appear in the equation.[13]

To translate Equation (5) into empirically usable form, there are several measurable determinants of the real commodity price for which we need to account. We discuss these in turn.

Inventories. How can costs of storage be measured? Storage costs rise with the extent to which inventory holdings strain existing storage capacity: $sc = \Phi$ *(INVENTORIES)*. If the level of inventories is observed to be at the high end historically, then storage costs must be high (absent

[13] An additional hypothesis of interest is that storable commodities may serve as a hedge against inflation. Under this view, an increase in the expected long-run inflation rate would then raise the demand for commodities thereby increasing real commodity prices today. (E.g., Calvo, 2008.)

any large recent increase in storage capacity). This should have a negative effect on commodity prices.[14] Substituting into Equation (5),

$$q = \bar{q} - (1/\theta)\ \Phi\ (\textit{INVENTORIES}) - (1/\theta)\ [i - E(\Delta p)] + (1/\theta)\ cy - (1/\theta)\ rp\ . \qquad (6)$$

An equation for the determination of inventory holdings can be derived as follows: From Equation (3),

$$E\ (\Delta s) + cy - sc - rp = i;$$

$$\text{or}\ \ sc = [E\ (\Delta s)\text{-}i] + cy - rp. \qquad (7)$$

Combine equation (4) with the inverted form of the relationship between the marginal cost of storage and the quantity of the commodity in storage:

$$\textit{INVENTORIES} = \Phi^{-1}\ \{\ sc\ \}$$

$$= \Phi^{-1}\ \{\ [\ E(\Delta s)\text{-}i] + cy - rp\} \qquad (8)$$

We see that low interest rates should predict not only high commodity prices but also high inventory holdings (other things equal). High expectations of future price increases should also be associated with high inventories.[15]

An important innovation of this paper is that expected future changes in spot commodity prices, *E(Δs),* are measured by a survey of market participants conducted by *Consensus Forecasts* (collected from ”over 30 of the world's most prominent commodity forecasters.”). Previous econometric attempts to measure this key variable have generally used one of three

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[14] Ye *et al* (2002, 2005, 2006) emphasise the role of inventories in forecasting oil prices.

[15] As in the arguments of Krugman (2008a,b), Kohn (2008) and Wolf (2008).

approaches. (i) The *rational expectations methodology* substitutes observed ex post changes in the spot rate *(Δs),* for the expectation *E(Δs),* inverts the equation, and relies on the rational expectations proposition that the prediction error *(Δs)-E(Δs)* should be uncorrelated with all variables observed at the time the expectation is formed. Even assuming one is willing to accept the rational expectations hypothesis (unbiased forecasts), we know that the prediction errors are huge (poor forecasts) because so much is not known ahead of time. The ex post realization is such an extremely noisy indicator of the ex ante expectation that its value in a regression to determine the supply and demand for commodities is questionable, especially in short samples. (ii) The *projection approach* regresses price changes on observed macroeconomic variables, e.g., by a Vector Auto Regression, and then uses the fitted values to model expectations. The problems with this approach is that it is hard enough to find a good model of commodity prices ex post; a short list of variables recorded at the time expectations are formed is sure to leave out most of the relevant information that market participants use, such as recent news about political instability in supplier countries or about the macroeconomic outlook in consumer countries. (iii) The *inventory approach* infers from firms' inventory behavior what price changes they must be expecting. The problem here is that, as our equation illustrates, inventory demand is determined by other factors in addition to price expectations: convenience yield and other variables, including in practice omitted factors that go into the regression error. To infer price expectations from inventory data would confound expectations with these other determinants.

There is no reason to think that the relationship *Φ* ( ) is necessarily linear. We assume linearity in our estimation for simplicity, but allowing for non-linearity is a desirable extension of the analysis. Under the logic that inventories are bounded below by zero and above by some absolutely peak storage capacity, a logistic function might be appropriate.

Economic Activity (denoted *Y*) is a determinant of the convenience yield *cy,* since it drives the transactions demand for inventories. Higher economic activity should have a positive effect on the demand for inventory holdings and thus on prices. Let us designate the relationship γ (*Y*). Again we assume linearity, somewhat arbitrarily. We usually measure this with GDP or industrial production. There is a good case for using a measure of global economic activity rather than US activity, especially in the price equation (or in an inventory equation using data for global inventories rather than US inventories alone). There are also grounds for thinking that the contemporaneous level of economic activity might not have a positive effect on inventories and indeed that an unexpectedly high level of economic activity might result in a temporary drawdown of stocks, because firms had not set inventories in anticipation of the higher demand. In that case one might focus on the expected change in economic activity as the variable determining firms' decision whether to add to inventories relative to the level in the previous period.

Risk or *Volatility* (denoted σ), can be measured either by actual observed price volatility or – an innovation in this paper – the subjective volatility that is implied by commodities options prices.[16] The theoretical effect of risk is ambiguous. Risk is another determinant of *cy,* especially to the extent that risk concerns fear of disruption of availability, whereby it should have a *positive* effect on inventory demand and therefore on commodity prices. But it is also a determinant of the risk premium *rp* , whereby it could have a *negative* effect on commodity prices.

Substituting these extra effects into Equation (7), we get

$$q = C - (1/\theta)\Phi(\textit{INVENTORIES}) - (1/\theta)[i-E(\Delta p)] + (1/\theta)\gamma(Y) - (1/\theta)([f\text{-}s - E(\Delta s)]). \quad (9)$$

[16] Frankel and Rose (2009) measured risk (political, financial and economic), in the case of oil for example, by a weighted average of political risk among 12 top oil producers.

It is this equation – augmented by what one hopes is a well-behaved residual term – that we wish to investigate.

Each of the variables on the right-hand side of Equation (9) could easily be considered endogenous. This must be considered a limitation of our analysis. However, we are short of plausibly exogenous variables with which to identify such equations. From the viewpoint of an individual commodity though, aggregate variables such as the real interest rate and GDP can reasonably be considered exogenous.[17]

4. Estimation of the Equation of Commodity Price Determination

We begin in Table 2 by estimating equation (9) for the real price of oil. The estimated coefficients are of the hypothesized sign for each of the three variables where the theory implies a sign: real interest rates have a negative effect on the oil price, economic activity as measured by US GDP has a positive effect, and oil inventories have a negative effect. The trend does not appear statistically significant. When the trend is omitted the effects of the two macroeconomic variables, the real interest rate and real GDP, are highly significant statistically. The coefficient on inventories is not significant.

The risk premium is highly significant statistically. The positive coefficient suggests that commodities offer a natural hedging opportunity with respect to the aggregate market portfolio. Volatility appears with a positive coefficient when measured by means of oil options but with a negative coefficient when measured by lagged actual spot price variability. Neither is statistically significant, but this is not disturbing, since the theoretical effects are ambiguous.

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[17] Also inventories could perhaps be considered pre-determined in higher frequency data, since it takes time to make big additions to, or subtractions from, inventories.

Table 2 (Mar. 4, 2013)	Dependent variable: Log of real oil price	1995-2011, quarterly†		
VARIABLES				
Real interest rate		-3.172	-3.942***	-3.848***
(quarterly)		(2.262)	(1.255)	(1.293)
Log US Real GDP		5.205	6.776***	7.022***
(quarterly, constant 2005 US$); WDI		(4.024)	(1.200)	(1.512)
Stocks of Petroleum		-0.537	-0.042	-0.215
(Millions of barrels)		(1.496)	(0.804)	(0.909)
Risk Premium: log(futures price/spot price)		1.207***	1.073***	1.027***
minus survey-forecast change in log commodity price		(0.385)	(0.308)	(0.315)
Option-Implied volatility		3.048	4.303	6.892
(100% moneyness;first day of month)		(8.469)	(6.773)	(7.215)
Volatility				-4.287
(std. dev of spot price over preceding quarter)				(9.669)
Constant		-82.717	-111.840***	-114.638***
		(74.329)	(20.510)	(23.978)
Trend (per annum)		0.006		
		(0.015)		
Observations		24	24	24
R-squared		0.845	0.843	0.844
F test		14.11	19.25	22.93
P-value of F test		9.01e-06	1.17e-06	2.88e-07

*** $p<0.01$, ** $p<0.05$, * $p<0.1$ (Robust standard errors in parentheses.)

†No data available for 2003. Years 1995, 2002 and 2007 have 2,3,3 data points respectively.

Table 2a extends the estimation to a wider set of mineral and agricultural commodities. To do so, we lose the option-implied volatility measure [which is a small loss to judge from Table 2] and we lose the survey-based forecasts of future commodity prices [which are available only for oil, silver and gold].

The coefficient on the real interest rate is negative for 9 out of 11 commodities and statistically significant for 6 out of the 9. The coefficient on World GDP is positive for 8 out of 11, but significant for only 3 out of the 8. The coefficient on inventories is negative for 7 out of 11, and significant for 4 out of 7. The coefficient on the spread is significantly negative for 5 commodities and actual volatility significantly positive for 5.

Table 2a: Estimation of equations for determination of individual real commodity prices.
1950-2012, annual observations †

Table 2a -- 1st half	(1)	(2)	(3)	(4)	(5)
Commodity:	Copper	Corn	Cotton	Live cattle	Live hogs
VARIABLES					
Real interest rate	-0.066***	-0.046*	0.005	-0.052***	-0.038***
	(0.018)	(0.026)	(0.014)	(0.018)	(0.009)
Log World GDP	-0.465	0.616	0.560	2.260	-2.619**
(constant 2000US$);WDI	(0.570)	(0.574)	(0.578)	(1.475)	(1.119)
Log Inventories	-0.190***	-0.075	-0.134	1.122	0.419*
	(0.056)	(0.172)	(0.117)	(0.784)	(0.245)
Spread, %	0.000	-0.006	-0.001	-0.007***	-0.004***
Future-Spot	(0.002)	(0.003)	(0.001)	(0.002)	(0.001)
Volatility; Std.dev.	3.038***	0.937	0.203	-0.275	-1.017
of log price over past year	(0.720)	(0.909)	(0.527)	(0.778)	(0.609)
Linear trend	-0.002	-0.041**	-0.038*	-0.078*	0.054
	(0.020)	(0.020)	(0.020)	(0.042)	(0.033)
Constant	16.938	-20.259	-14.944	-81.651	74.873**
	(17.288)	(16.542)	(17.291)	(51.771)	(33.004)
Observations	50	51	51	32	39
R-squared	0.549	0.660	0.760	0.511	0.802

Table 2a -- 2nd half	(6)	(7)	(8)	(9)	(10)	(11)
Commodity:	Oats	Petroleum	Platinum	Silver	Soybeans	Wheat
VARIABLES						
Real interest rate	-0.037**	-0.015	0.081***	-0.016	-0.040**	-0.003
	(0.016)	(0.071)	(0.015)	(0.025)	(0.016)	(0.021)
Log World GDP	1.555**	-4.423	3.378***	3.625*	0.377	0.325
(constant 2000US$);WDI	(0.593)	(4.984)	(0.753)	(2.012)	(0.837)	(0.702)
Log Inventories	-0.311**	-2.815	-0.243***	0.005	0.043	-0.453*
	(0.135)	(4.432)	(0.030)	(0.106)	(0.086)	(0.238)
Spread, %	-0.005*	-0.002	-0.000	-0.010**	-0.007**	-0.001
Future-Spot	(0.003)	(0.003)	(0.001)	(0.004)	(0.003)	(0.003)
Volatility; Std.dev.	0.905	-0.082	1.096***	5.148***	1.861**	1.812***
of log price over past year	(0.665)	(0.691)	(0.356)	(0.666)	(0.868)	(0.650)
Linear trend	-0.085***	0.172	-0.123***	-0.119*	-0.036	-0.026
	(0.026)	(0.137)	(0.027)	(0.063)	(0.027)	(0.022)
Constant	-45.541***	156.653	-98.356***	-111.768*	-13.651	-7.089
	(16.331)	(142.648)	(22.409)	(60.573)	(24.707)	(20.177)
Observations	50	29	47	44	48	51
R-squared	0.634	0.336	0.733	0.612	0.709	0.737

*** p<0.01, ** p<0.05, * p<0.1   (Robust standard errors in parentheses.)

† Some commodities have shorter sample periods due to data availability, as indicated in the number of observations.

Table 2b estimates the same equations in terms of first differences, to address concerns of high autocorrelation or nonstationarity. The results are similar, but not quite as strong. First, the coefficient on the real interest rate is negative in 10 out of 11 cases, but significant in only three, and only at the 10% level. Second, for the economic activity variable we try the *Consensus* forecast of the rate of change of industrial production in the year of observation and the subsequent year. The motivation is that expectations of rapid growth might add to the current demand for commodities. The coefficient is positive in 9 cases, and significant in 6 of those 9. Third, the coefficient on inventories is often of the wrong sign; but then we no longer are controlling for forecasts of price increases, and their positive effect could possibly be showing up via inventories.

To summarize the results for individual commodities, the real interest rate often has a significantly negative effect on the prices of copper, platinum, oil, and some agricultural products. But the other variables are not as strong. Analysing commodities one by one might give weaker results than when the data are pooled. For one thing, because we are working with annual data here, each regression has relatively few observations. For another thing, we know that we have not captured the many idiosyncratic forces such as weather events that lead to bad harvests in some agricultural commodities or high demand for fuels. Accordingly we now turn to panel regressions, where the number of observations is much larger and we can hope that some sector-specific idiosyncratic factors will largely wash out.

Table 2b: Estimation of equations for individual real commodity prices (changes)
1950-2012, annual †

Table 2b -- 1st half	(1)	(2)	(3)	(4)	(5)
Commodity:	Copper	Corn	Cotton	Live cattle	Live hogs
VARIABLES					
Δ Real interest rate	0.013	-0.060	-0.024	-0.010	-0.027
	(0.043)	(0.040)	(0.049)	(0.015)	(0.037)
Forecast 2-year change	11.483***	3.719	-0.102	2.851***	3.514*
of U.S. IP, monthly survey	(2.502)	(2.390)	(2.298)	(0.629)	(1.967)
Δ Log of Inventories	0.042	0.642	0.784*	-3.107	-1.086
	(0.069)	(0.421)	(0.411)	(2.073)	(1.222)
Δ Spread	-0.002	-0.005*	-0.004**	-0.004	-0.003*
	(0.003)	(0.002)	(0.002)	(0.002)	(0.001)
Δ Volatility	0.407	-0.041	-1.715*	-0.288	-0.983
	(0.471)	(0.570)	(0.805)	(0.412)	(0.724)
Linear Trend	0.027***	0.013	0.007	0.003	0.007
	(0.008)	(0.008)	(0.007)	(0.003)	(0.005)
Constant	-0.546***	-0.217	-0.106	-0.116**	-0.160
	(0.147)	(0.129)	(0.127)	(0.045)	(0.095)
Observations	19	20	20	20	20
R-squared	0.719	0.413	0.420	0.663	0.550

Table 2b -- 2nd half	(6)	(7)	(8)	(9)	(10)	(11)
Commodity:	Oats	Petroleum	Platinum	Silver	Soybeans	Wheat
VARIABLES						
Δ Real interest rate	-0.072*	-0.093*	-0.038	-0.003	-0.075*	-0.076**
	(0.037)	(0.046)	(0.032)	(0.021)	(0.038)	(0.033)
Forecast 2-year change	3.652	11.337***	7.141**	5.131***	2.342	5.005***
of U.S. IP, monthly survey	(2.593)	(1.950)	(3.132)	(1.287)	(1.626)	(1.478)
Δ Log of Inventories	-1.080***	-2.345	0.001	0.114***	-0.269	-0.822
	(0.280)	(1.567)	(0.071)	(0.036)	(0.174)	(0.475)
Δ Spread	-0.005**	0.000	-0.002	-0.001	-0.002	0.001
	(0.002)	(0.001)	(0.002)	(0.002)	(0.002)	(0.003)
Δ Volatility	0.579	1.020**	0.017	0.505	-0.248	-0.348
	(0.403)	(0.469)	(0.549)	(0.423)	(0.717)	(0.996)
Linear Trend	0.017***	0.013*	0.015***	0.014***	0.007	0.010
	(0.004)	(0.007)	(0.004)	(0.003)	(0.006)	(0.006)
Constant	-0.302**	-0.397***	-0.297**	-0.223***	-0.114	-0.225**
	(0.103)	(0.102)	(0.117)	(0.063)	(0.111)	(0.096)
Observations	19	20	19	19	20	20
R-squared	0.668	0.634	0.707	0.764	0.400	0.471

*** p<0.01, ** p<0.05, * p<0.1 (Robust standard errors in parentheses.)

† Some commodities have smaller periods, as indicated in the number of observations.

In Table 3a, the estimated coefficient on the real interest rate is negative in 6 permutations, and significant in 3 of them. The coefficient on inventories is in all cases negative as hypothesized, and is in all cases highly significant statistically. The coefficient on the forward-spot spread is significantly negative in all cases. This is consistent with the earlier intuition that when the term structure is in contango (i.e., the spread *f-s* is high), the market is soft. The coefficient on actual volatility is significantly positive in all.

Among the economic activity variables, the positive effect of Global GDP is significant when the linear trend time term is supplemented by a quadratic. Consistent with this finding, when world GDP is de-trended by means of a Hodrick-Prescott filter, giving us a variable we call Business Cycle, its positive effect is again highly significant.

In Table 3b, forecasted rate of US growth is significantly positive in the 3 permutations where it is tried, as is H-P-filtered world GDP ("Global Business Cycle") and OECD estimates of the output gap. In both tables, it is reassuring to see that bringing more data to bear at once, through the panel, has led to stronger results for the negative effects of real interest rates and the positive effects of economic activity, the spread, and volatility.

Table 3: Estimation of equations for determination of real commodity prices in a panel

Table 3a: Panel -- real prices of 11 commodities (annual)	(1)	(2)	(3)	(4)	(5)	(6)	(7)
VARIABLES							
Real interest rate	-0.024*	-0.021*	-0.010	-0.010	-0.010	-0.032**	0.009
	(0.013)	(0.011)	(0.010)	(0.013)	(0.012)	(0.014)	(0.010)
Log World GDP	0.011	0.415					3.447***
(constant 2000 US$); WDI	(0.236)	(0.401)					(0.770)
Log Inventories	-0.141***	-0.154***	-0.124***	-0.164***	-0.111***	-0.138***	-0.133***
	(0.026)	(0.027)	(0.037)	(0.023)	(0.024)	(0.024)	(0.022)
Future-Spot Spread, %	-0.003***		-0.003***	-0.003***	-0.004***	-0.003***	-0.003***
	(0.001)		(0.001)	(0.001)	(0.001)	(0.001)	(0.000)
Volatility: Std.dev. of	1.811***	1.640***	0.844*	1.850**	1.325**	1.915***	1.774***
log spot price of past year	(0.520)	(0.468)	(0.402)	(0.585)	(0.424)	(0.510)	(0.468)

Linear Trend	-0.017*	-0.028*	0.015*	-0.021***	-0.002	-0.017***	-0.192***
	(0.008)	(0.013)	(0.008)	(0.002)	(0.004)	(0.002)	(0.041)
Constant	0.006	-11.854	-0.462	0.479*	-0.508*	0.323	-101.896***
	(7.012)	(11.869)	(0.415)	(0.221)	(0.269)	(0.229)	(22.926)
Forecast 2-yr.US GDP growth			-3.726				
(*Consensus Forecasts* monthly)			(2.092)				
Global Business Cycle						7.219***	
(HP-Filtered World GDP)						(1.083)	
Quadratic Trend							0.001***
							(0.000)
Observations	492	536	216	403	293	492	492
R-squared	0.456	0.400	0.365	0.487	0.216	0.486	0.512

Table 3b: Panel—Δ real prices of 11 commodities (annual)	(1)	(3)	(4)	(5)	(6)	(7)
VARIABLES						
Δ Real interest rate	-0.021	-0.0187	0.0062	0.0064	-0.0010	-0.029**
	(0.013)	(0.0135)	(0.0056)	(0.0110)	(0.0063)	(0.012)
Forecast 2-yr.US GDP growth	8.575***	8.6675***				11.365***
(*Consensus Forecasts* monthly)	(1.978)	(1.9029)				(2.178)
Δ Log Inventories	-0.004	-0.0025	-0.0761	-0.0842	-0.0856	-0.008
	(0.061)	(0.0597)	(0.0485)	(0.0728)	(0.0481)	(0.056)
Δ Future-Spot Spread, %	-0.001***		- 0.0020***	- 0.0021***	- 0.0017***	-0.002***
	(0.000)		(0.0004)	(0.0005)	(0.0005)	(0.000)
Δ Volatility: Std.dev. of log spot price of past year	-0.067	-0.0183	0.4892*	-0.1498	0.1919	0.068
	(0.184)	(0.1735)	(0.2556)	(0.1364)	(0.2133)	(0.208)
Linear Trend	0.010***	0.0100***	0.0014*	0.0067***	0.0015***	-0.024***
	(0.002)	(0.0019)	(0.0006)	(0.0009)	(0.0003)	(0.005)
Constant	-0.314***	-0.3136***	-0.0216	- 0.0862***	- 0.0434***	-0.271***
	(0.068)	(0.0659)	(0.0122)	(0.0124)	(0.0092)	(0.071)
OECD Output Gap; 1950-2008			0.0368***			
			(0.0058)			
OECD Output Gap; 1985-2011				0.0208***		
				(0.0059)		
Global Business Cycle (HP-Filtered World GDP)					6.7646***	
					(1.0354)	
Quadratic trend						0.002***
						(0.000)
Observations	216	216	400	293	486	216
R-squared	0.216	0.188	0.182	0.172	0.170	0.270

*** p<0.01, ** p<0.05, * p<0.1 (Robust standard errors in parentheses.)

4. Estimation of the Inventory Equation

We now turn to estimation of equation (8), which is intended to capture the determinants of inventories, in particular the carry-trade factors.

$$INVENTORIES \quad = \quad \Phi^{-1} \{ [E(\Delta s)\text{-}i] + cy - rp\} \qquad (8)$$

We again assume that convenience yield depends on a measure of economic activity and perhaps on a measure of risk.

Unfortunately oil is the only commodity for which we have all the data necessary to estimate the inventory equation. We report the results in Table 4. In two of the four permutations we control for lagged inventories, under the reasoning that firms are only able to adjust actual inventories toward their desired level gradually over time, as in a traditional stock adjustment model.

The most important variable is the speculative term [$E(\Delta s)$-i] . Its coefficient is positive and statistically significant in all four permutations. The expectation of future increases, relative to the interest rate, raises the desired inventory holdings. This finding seems like a major pay-off from having applied the survey data to the analysis of speculation, in that it furnishes what some have considered a missing link (via inventories) in the theories that either easy monetary policy or speculation are responsible for some of the price variation over the last decade.

Table 4: Estimation of the Inventory Equation: Oil (1995-2011, quarterly[†])

Stocks Petroleum; Millions of barrels VARIABLES	(1)	(2)	(3)	(4)
Forecast price rise - Nominal interest rate	0.022*	0.023*	0.117***	0.115***
	(0.012)	(0.012)	(0.027)	(0.030)
Actual IP growth	0.015	0.014	0.564***	0.564***
	(0.084)	(0.085)	(0.150)	(0.151)
Log U.S. Industrial Production; 2005=100, Seasonally Adjusted		0.011		-0.010
		(0.037)		(0.072)
Forecast 2-year rate of change of U.S.IP	0.003	0.000	-0.674**	-0.671**
	(0.146)	(0.146)	(0.318)	(0.318)
Log Stocks petroleum lagged	0.911***	0.912***		
	(0.054)	(0.055)		
Trend	0.000	0.000	0.004***	0.004***
	(0.000)	(0.000)	(0.000)	(0.000)
Constant	0.653	0.600	7.313***	7.356***
	(0.392)	(0.481)	(0.008)	(0.316)
Observations	58	58	58	58
R-squared	0.972	0.972	0.843	0.843

*** p<0.01, ** p<0.05, * p<0.1. (Robust standard errors in parentheses.)

[†] No data available for 2003. Years1995, 2002, 2007 have 2, 3, 3 data points respectively.

5. Summary and Conclusion

This paper has presented a model that can accommodate each of the prominent explanations that were given for recent increases in the prices of oil and most other agricultural and mineral commodities: economic activity, easy monetary policy, and speculation. It has gone beyond past research in using survey data to measure the forecasts of market participants ("speculation") and using options data to measure the implicit variance ("risk").

The theoretical model is built around the 'arbitrage' decision faced by any firm holding inventories. This is the tradeoff between the costs of carrying the inventory on the one hand (the interest rate plus the cost of storage) versus the convenience yield and forward-spot spread (or, if unhedged, the expected capital gain adjusted for the risk premium) on the other hand. A second equation completes the picture: the real commodity price is expected to regress gradually back to its long run equilibrium. The reduced form equation expresses the real commodity price as a function of the real interest rate, storage costs, convenience yield and the risk premium. The level of inventories is a ready stand-in for storage costs.

The empirical significance of the inventory variable suggests that the data and relationship are meaningful, notwithstanding fears that the available measures of inventories are incomplete.[18] Economic activity is an important determinant of the convenience yield and thereby of the demand for inventory holdings and the price of the commodity. Measures of risk based on either actual volatility or option-implied volatility constitute other potentially important determinants of both convenience yield and the risk premium, though there is only rather limited evidence in support of them here.

The significance of the inventories variable in the panel regressions for determination of commodity prices supports the legitimacy of arguments by others who have used observed inventory levels to gauge the roles of speculation or interest rates. There was support in these new results for the hypothesis that low real interest rates are an important source of upward pressure on real commodity prices, via a high demand for inventories (among other channels), beyond any effect that easy monetary policy might have via real economic activity.

A number of possible extensions remain for future research. These include: 1) testing for nonlinearity in the effects of growth, uncertainty and (especially) inventories; 2) more

[18] We are implicitly considering inventories relative to full capacity, but explicit adjustment would improve the measurement, if the appropriate data on storage capacity could be found. We hope that the trend term adequately captures storage capacity.

sophisticated time series treatment of the relationships[19]; and 3) allowing for endogeneity of inventories and speculation, perhaps using the interest rate as an instrumental variable.

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[19] Frankel and Rose (2009) include tests for unit roots and cointegration.

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Data Appendix

Sources:

A. Commodity Spot and Futures Prices

Data on commodity spot and futures prices for Copper, Cotton, Corn, Live Hogs, Live Cattle, Oats, Oil, Platinum, Soybeans, Silver and Wheat are from Global Financial Database. To compute real commodity prices, the deflator was the U.S. GDP chain price index taken from the *Economic Report of the President* 2012. The series are annual and in most cases run from 1950 to 2012.

B. Real Interest Rate

Annual real interest rate was constructed as the difference between the 3-month U.S. Treasury Bill and the percentage change in the U.S. chain price index. The 3-month U.S. Treasury Bill is from the Economic Report of the President 2012.

C. Inventories

Inventories for commodities are from the Foreign Agricultural Service, U.S. Energy Information Administration, The USDA National Agricultural Statistics Service, and the U.S. Geological Survey. World inventories were used when possible and substituted by U.S. inventories when they were missing (specifically for Copper, Live Cattle, Live Hogs, Oats, Platinum and Silver).

D. Real World GDP

Annual Real World GDP is measured as World GDP in constant 2000 US$ from the World Bank's World Development Indicators.

E. Volatility

Volatility was constructed as the standard deviation of monthly commodity spot prices over the past year. Oil's option-implied volatility (for 100 % moneyness level) is from Bloomberg.

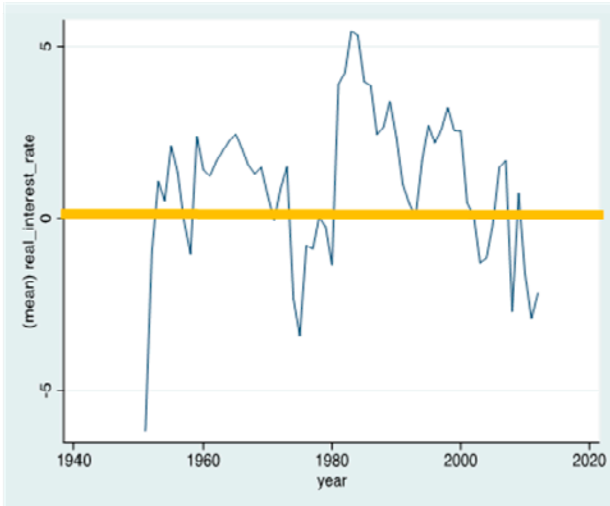
F. Spot –Futures Spread

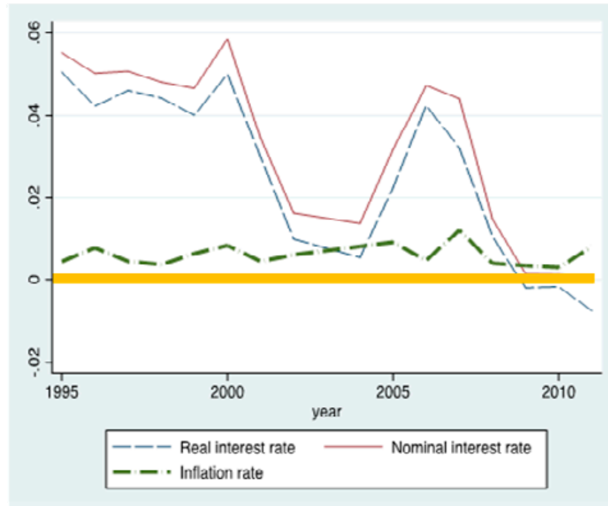
The Spot-Futures Spread is defined as the difference between the futures price and the spot price expressed as percentage of the spot price.

G. GDP, Industrial Production, Inflation and Oil Price Forecasts

Data on Forecasts of U.S. GDP, Industrial Production, Inflation and Oil price were taken from Consensus Economics Inc. Database. Average of 12-month growth rates and forecasts for current year and subsequent year were calculated.

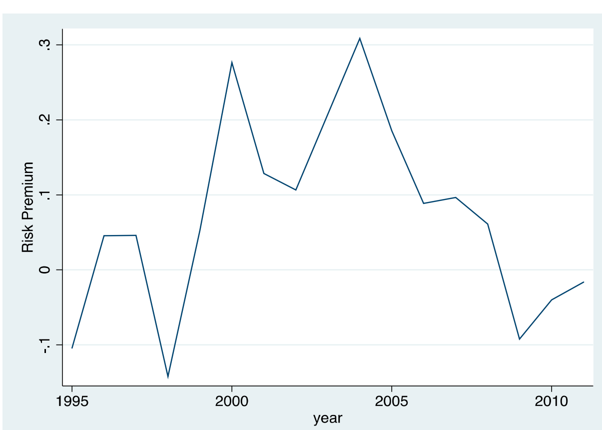
Real interest rate 1950-2012 **1995-2012**



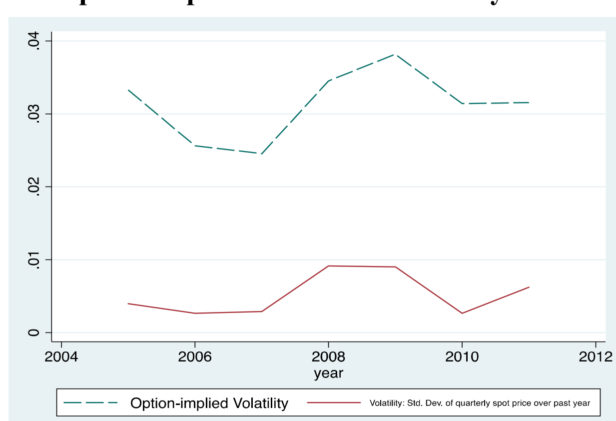


Petroleum inventories

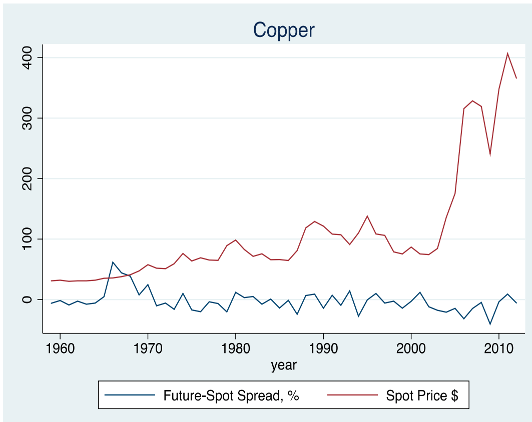
Risk premium

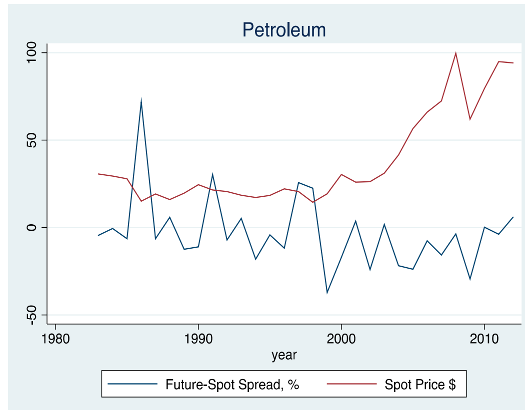


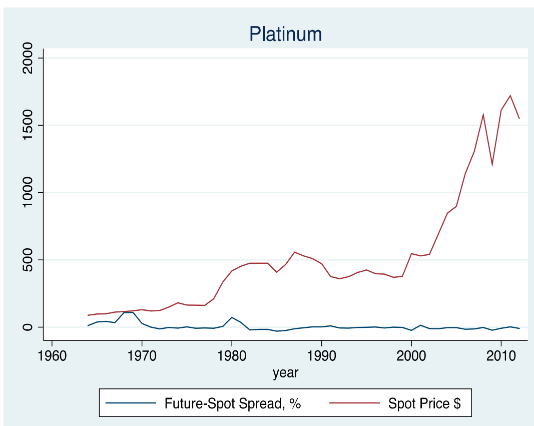
Two measures of volatility:
Option-implied and actual volatility

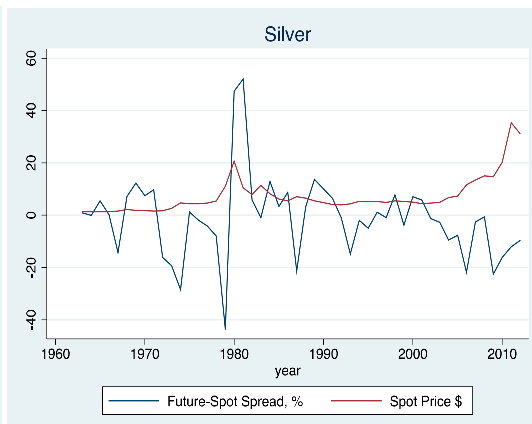


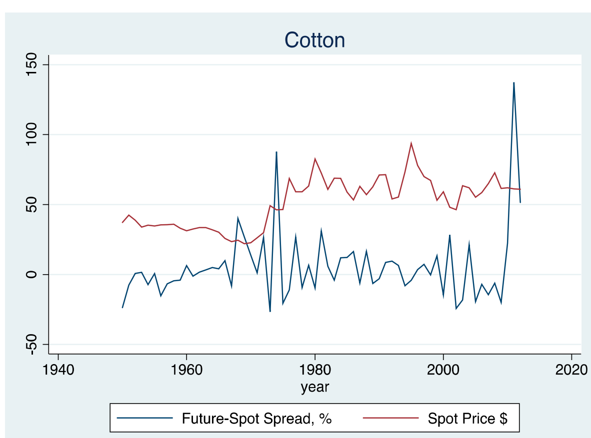
Commodity prices, with future-spot spread

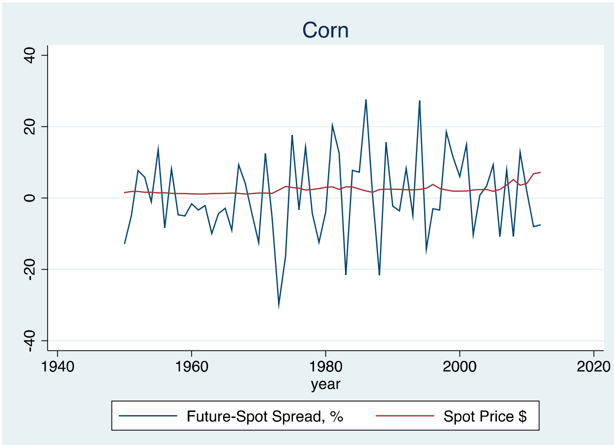


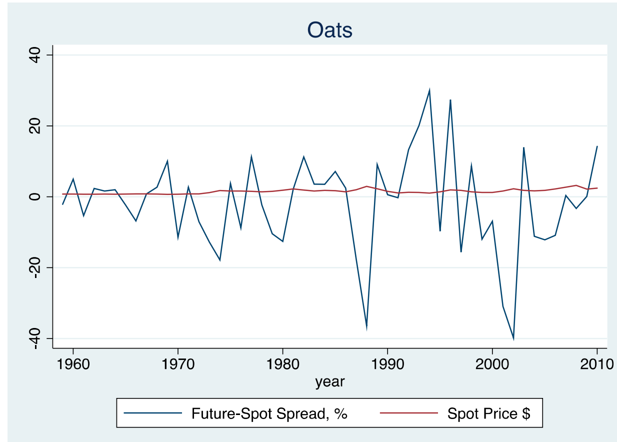


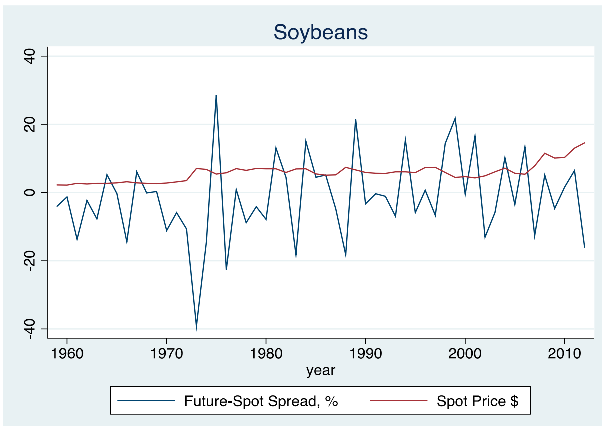


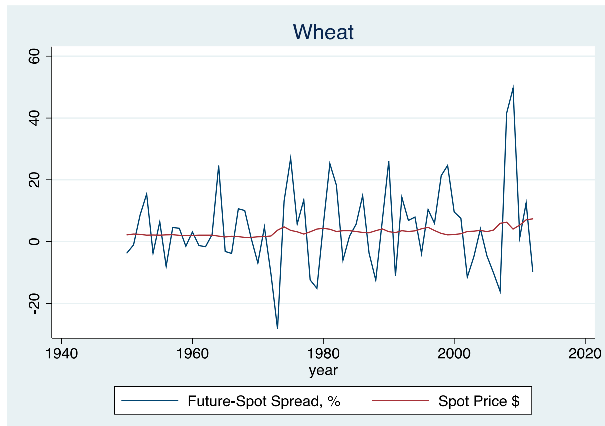


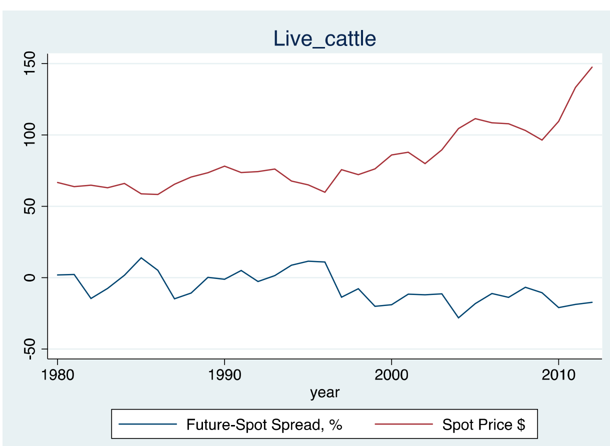


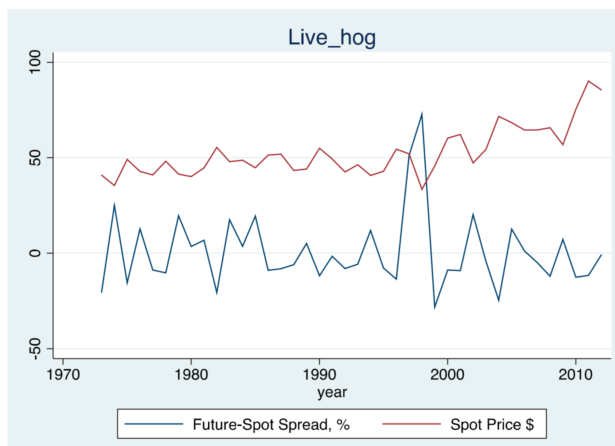

Corn
-40
-20
0
20
40
1940
1960
1980
2000
2020
year
Future-Spot Spread, %
Spot Price $


Oats
-40
-20
0
20
40
1960
1970
1980
1990
2000
2010
year
Future-Spot Spread, %
Spot Price $


Soybeans
-40
-20
0
20
40
1960
1970
1980
1990
2000
2010
year
Future-Spot Spread, %
Spot Price $


Wheat
-20
0
20
40
60
1940
1960
1980
2000
2020
year
Future-Spot Spread, %
Spot Price $


Live_cattle
-50
0
50
100
150
1980
1990
2000
2010
year
Future-Spot Spread, %
Spot Price $


Live_hog
-50
0
50
100
1970
1980
1990
2000
2010
year
Future-Spot Spread, %
Spot Price $