University of Texas at Austin

McCombs School of Business

A Financial Economics-Based Approach to Forecasting Oil Prices

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OVERVIEW

- Efficient Financial Markets as Purveyors of the "Message from Markets"
- Example: Where is the "Risk" (is the risk in upside or downside) in Oil-Price Movements?
  - The Volatility "Smile" in the Oil Markets
  - *Quantifying* Jump-Risk in Oil Markets
  - Reflecting Current Events — Spring 2011
- Whither Crude Oil Prices? While there is an *abundance* of prognosticators, consider a Financial-Economics Approach to Forecasting Spot Prices:
  - Demand- and Supply-Side Effects in Crude-Oil Futures Markets: Comovement (Correlation) of Oil and Equity Markets
  - Modeling the Equity Sharpe Ratio
  - A CAPM-Based Forecast of Oil Prices
  - On the "Financialization of Oil Markets"
- Empirical Results on Oil-Price Futures: Equity Market-Adjusted Returns
- Hence: The Need for a Model of Forward-Looking Oil Betas

The "Message from Markets"

- Brealey, Myers and Allen, **Principles of Corporate Finance** (page 350):

  "If [financial markets are] efficient, prices impound all available information. Therefore, if we can only learn to read the entrails, security prices can tell us a lot about the future."

- Financial markets in general, and *derivative* markets in particular, are highly informative. The challenge is:

  Can We Use the Q-Measure from Derivative Markets to Say Something Meaningful about the P-Measure's *Risk Premium?*

The Risk Premium in Oil Markets

- The "Internal Dynamics" of the Specific Commodity Market. Hirshleifer (1988): Commodity returns vary with the holdings of hedgers
- Modeling the Time-Series Processes of the Commodity Market. One-, Two- and Three-Factor Models of Commodity Returns: Gibson and Schwartz (1990), Brennan (1991), Schwartz (1997), Hilliard and Reis (1998), Schwartz and Smith (2000), Richter and Sørensen (2002), Nielsen and Schwartz (2004), Casassus and Collin-Dufresne (2005), Kolos and Ronn (2007) and more recently Trolle and Schwartz (2008)
- Impact of the "Financialization of Commodity Markets": Singleton (2012)

As regards *observable empirical data,* note the close relationship between "Financialization of Commodity Markets" on the one hand, and "Integrated Capital Markets" on the other. Hence the desirability of examining the *CAPM* approach

The Merton (1976) Jump-Diffusion Model

The Merton (1976) option pricing model is given by:

$$v_T\left(K_T\right) = \sum_{n=0}^{\infty} \frac{e^{-\lambda' T}\left(\lambda' T\right)^n}{n!}\, c_n\left(F_T,\, X,\, T,\, r_n,\, q,\, \sigma_n\right) \tag{1}$$

where

$v_T\left(K_T\right) =$ European call option

$\lambda' = \lambda\left(1 + \overline{k}\right)$

$T =$ option expiration

$c_n\left(F_T,\, X,\, T,\, r_n,\, q,\, \sigma_n\right) =$ Black-Scholes call option value with parameters $\left\{F_T,\, X,\, T,\, r_n,\, q,\, \sigma_n\right\}$, where q is the *dividend yield*

$$\begin{aligned} c_n\left(F_T,\, X,\, T,\, r_n,\, q,\, \sigma_n\right) &= F_T\, e^{-qT} N(d) - K e^{-r_n T} N(d - \sigma_n \sqrt{T}) \\ d &\equiv \frac{\ln\left(F_T / K\right) + \left(r_n - q\right) T}{\sigma_n \sqrt{T}} + \tfrac{1}{2}\,\sigma_n \sqrt{T} \end{aligned}$$

$\sigma_n^2 = \sigma^2 + n\delta^2 / T$

$r_n = r - \lambda \overline{k} + n \ln\left(1 + \overline{k}\right) / T$

$q = r$

Notes:

1. Although in principle (1) requires a summation over an infinite number of terms, in practice the option value converges after a summation over the first ten terms.

2. The parameters of the jump process are:

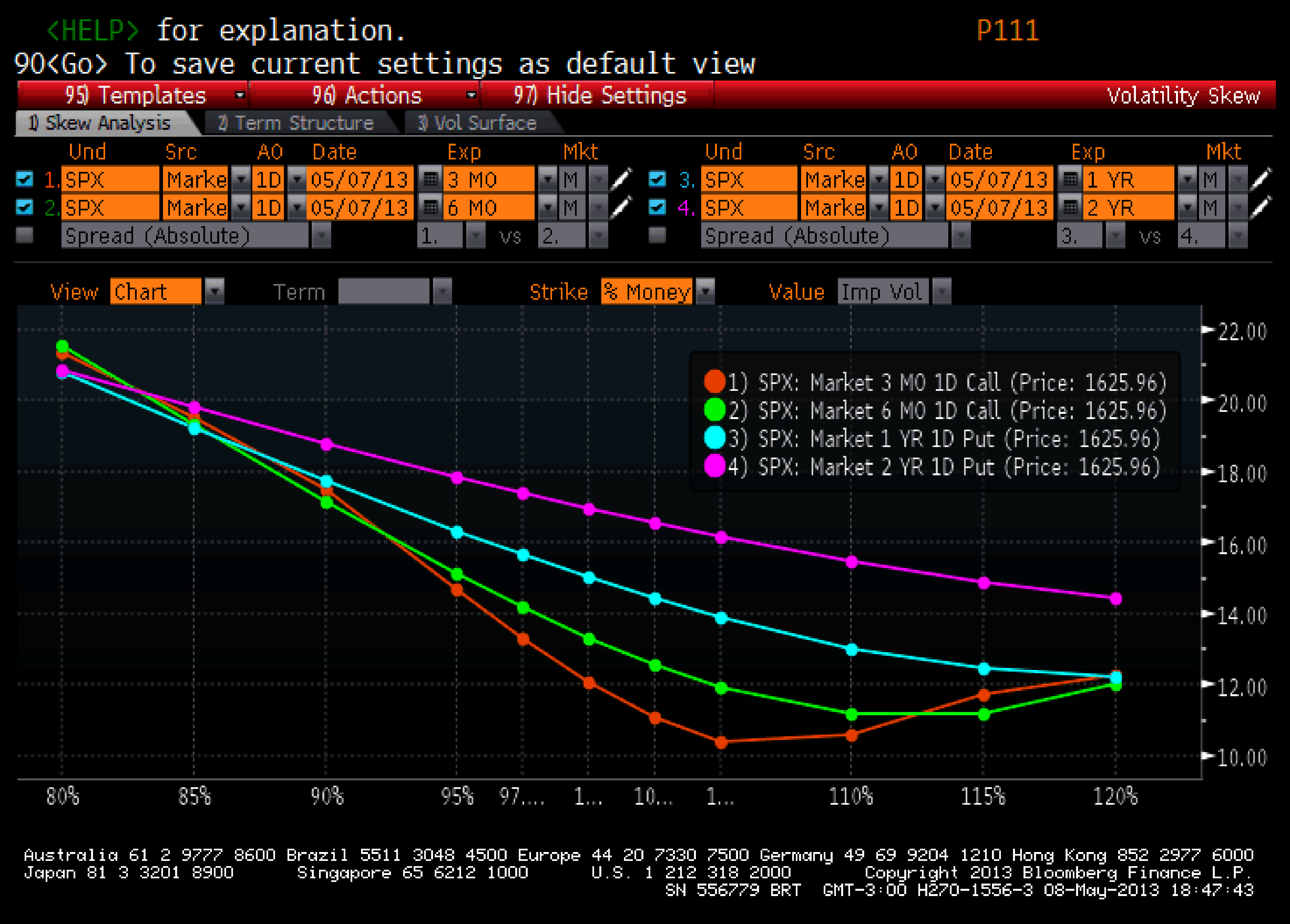
   $\lambda =$ Intensity of the jump process

   $\overline{k} =$ Average amplitude of the jump process

   $\delta^2 =$ Variance of the jump process amplitude

   $\sigma^2 =$ Variance of the diffusion process

3. $q = r$ in this case, since the F_T's are futures contracts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95) Templates
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Volatility Skew
1) Skew Analysis
2) Term Structure
3) Vol Surface
Und Src AO Date Exp Mkt
1. SPX Marke 1D 05/07/13 3 MO M
2. SPX Marke 1D 05/07/13 6 MO M
Spread (Absolute) 1. vs 2.
3. SPX Marke 1D 05/07/13 1 YR M
4. SPX Marke 1D 05/07/13 2 YR M
Spread (Absolute) 3. vs 4.
View Chart
Term
Strike % Money
Value Imp Vol
1) SPX: Market 3 MO 1D Call (Price: 1625.96)
2) SPX: Market 6 MO 1D Call (Price: 1625.96)
3) SPX: Market 1 YR 1D Put (Price: 1625.96)
4) SPX: Market 2 YR 1D Put (Price: 1625.96)
22.00
20.00
18.00
16.00
14.00
12.00
10.00
80%
85%
90%
95%
97....
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10...
1...
110%
115%
120%
Australia 61 2 9777 8600 Brazil 5511 3048 4500 Europe 44 20 7330 7500 Germany 49 69 9204 1210 Hong Kong 852 2977 6000
Japan 81 3 3201 8900 Singapore 65 6212 1000 U.S. 1 212 318 2000 Copyright 2013 Bloomberg Finance L.P.
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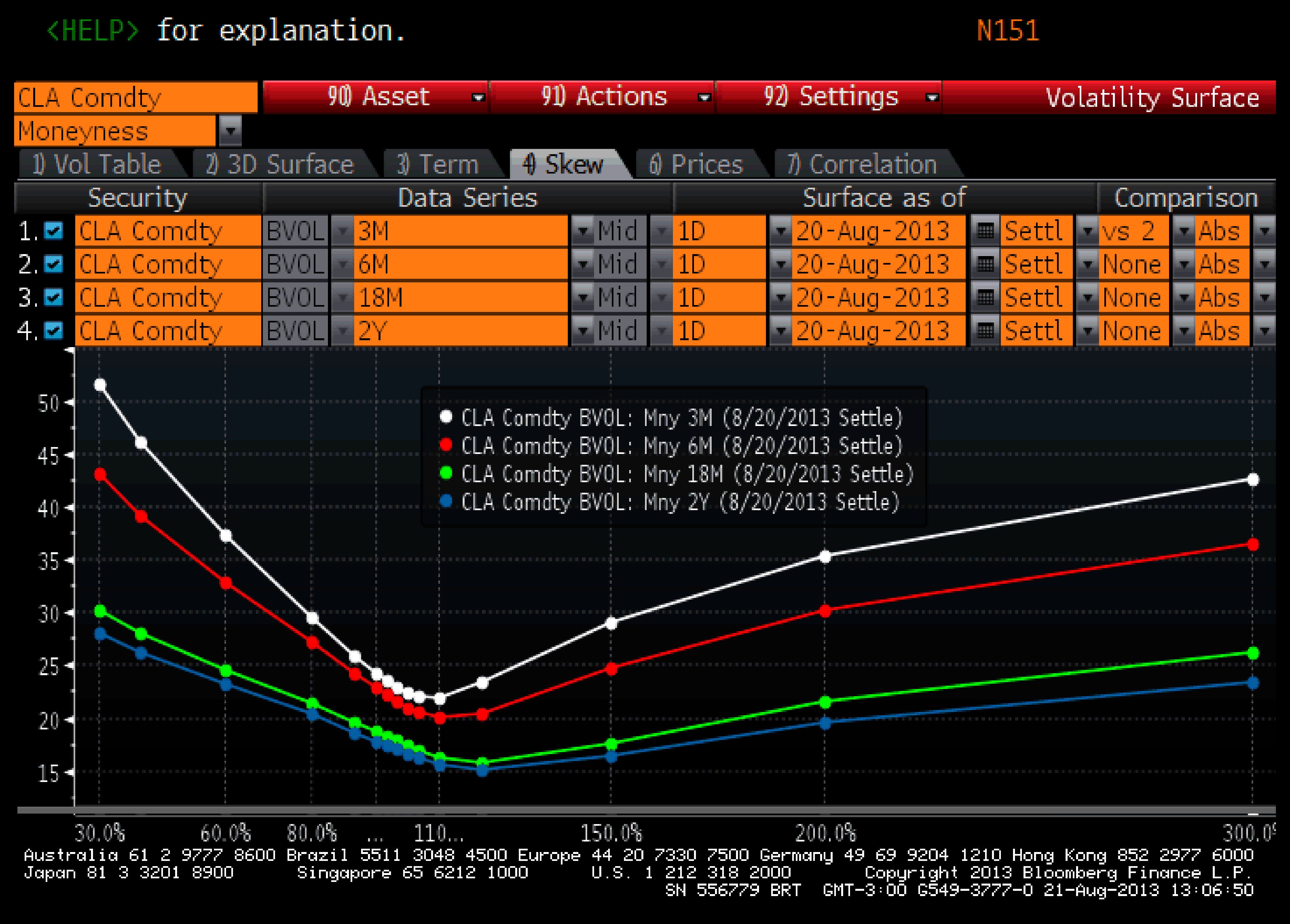

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N151
CLA Comdty
90) Asset
91) Actions
92) Settings
Volatility Surface
Moneyness
1) Vol Table
2) 3D Surface
3) Term
4) Skew
6) Prices
7) Correlation
Security
Data Series
Surface as of
Comparison
1. CLA Comdty BVOL 3M Mid 1D 20-Aug-2013 Settl vs 2 Abs
2. CLA Comdty BVOL 6M Mid 1D 20-Aug-2013 Settl None Abs
3. CLA Comdty BVOL 18M Mid 1D 20-Aug-2013 Settl None Abs
4. CLA Comdty BVOL 2Y Mid 1D 20-Aug-2013 Settl None Abs
CLA Comdty BVOL: Mny 3M (8/20/2013 Settle)
CLA Comdty BVOL: Mny 6M (8/20/2013 Settle)
CLA Comdty BVOL: Mny 18M (8/20/2013 Settle)
CLA Comdty BVOL: Mny 2Y (8/20/2013 Settle)
50
45
40
35
30
25
20
15
30.0%
60.0%
80.0%
...
110...
150.0%
200.0%
300.0%
Australia 61 2 9777 8600 Brazil 5511 3048 4500 Europe 44 20 7330 7500 Germany 49 69 9204 1210 Hong Kong 852 2977 6000
Japan 81 3 3201 8900 Singapore 65 6212 1000 U.S. 1 212 318 2000 Copyright 2013 Bloomberg Finance L.P.
SN 556779 BRT GMT-3:00 G549-3777-0 21-Aug-2013 13:06:50

Fitting the Merton Model to Crude-Oil Futures and Option Prices — Murphy and Ronn (2013)

- With observed option prices given by $c_T\left(K_T\right)$, and their theoretical (1) counterparts given by $v_T\left(K_T\right)$, the objective function is:

$$\min_{\{\mathbf{x}\}} \sum_T \sum_K \left[\, c_T\left(K\right) - v_T\left(K\right) \right]^2 \tag{2}$$

where

$$\mathbf{x} \equiv \{\overline{k}_T,\ \delta_T,\ \sigma_T\} \quad \text{for all maturities } T$$

and using all options with Open Interest > 0 satisfying

$$c_T\left(K\right) \geq \max\{.05,\ F_T - K + .05\}$$

- Key Assumptions

  1. Given the relevant data's principal-components, set $\lambda = 0.3$ for all T and t
  2. Jump's average amplitude $\overline{k}_T$ and volatility δ_T vary by maturity

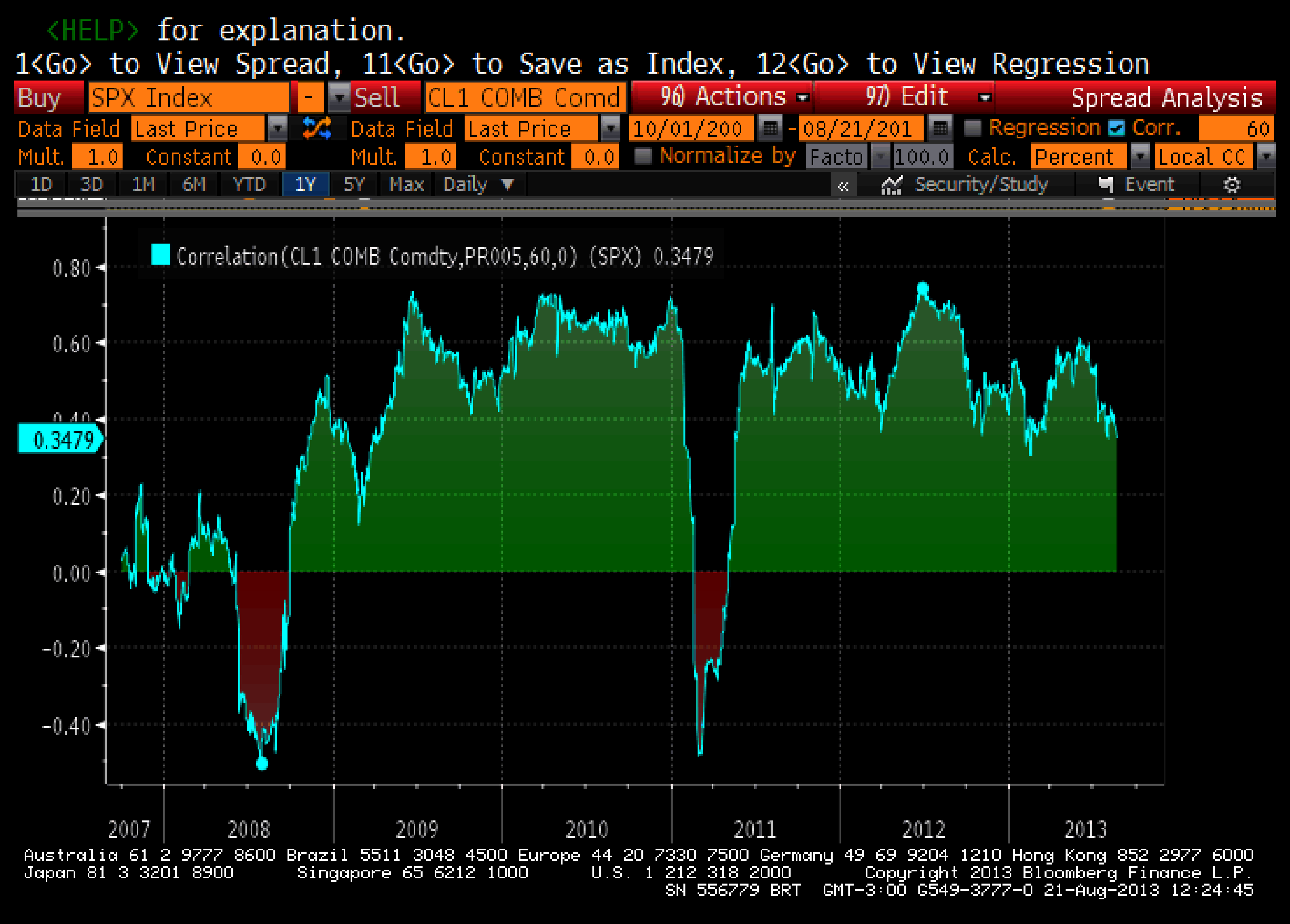
The Magnitude of $\widehat{k}_2$ during the "Arab Spring of 2011"

Date	Event	Country	Value of $\widehat{k}_2$
Dec. 18, 2010	Self-immolation	Tunisia	-25.6%
Jan. 25, 2011	Protests in Tahrir Square	Egypt	-29.6%
Feb. 11, 2011	President Mubarak resigns	Egypt	-2.76%
Feb. 14, 2011	First contagion to Persian Gulf	Bahrain	$-.26\%$
Feb. 19, 2011	Resignation of prime minister	Kuwait	9.44%
March 2, 2011			55.7%
March 11, 2011	Economic concessions by king	Saudi Arabia	43.2%
April 5, 2011			-5.3%

Source for Timeline: Article on the "Arab Spring," `http://en.wikipedia.org/wiki/Arab_Spring`

Economics and Financials of Oil Prices

- On the *Demand* side:
  - In *normal* times: Strong demand growth from Eastern and Southern Asia; Economic growth in Europe, Japan and North America
  - July 2008 – March 2009, severe recessionary conditions
  - Post-March 2009: Recovery, but with Aftershocks ...
- On the *Supply* side:
  - Geopolitical: Middle East (Iraq, Iran, Eastern Mediterranean), Nigeria, Venezuela
  - Meteorological: Gulf of Mexico
- Crude-Oil Market Indicator for Demand or Supply Shock: The Correlation of Oil Market with Equity Market
- With one notable exception, most of the time since the second half of 2008, oil contracts have exhibited positive comovement with equity markets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1<Go> to View Spread, 11<Go> to Save as Index, 12<Go> to View Regression
Buy SPX Index - Sell CL1 COMB Comd 96) Actions 97) Edit Spread Analysis
Data Field Last Price Data Field Last Price 10/01/200 - 08/21/201 Regression Corr. 60
Mult. 1.0 Constant 0.0 Mult. 1.0 Constant 0.0 Normalize by Facto 100.0 Calc. Percent Local CC
1D 3D 1M 6M YTD 1Y 5Y Max Daily Security/Study Event
Correlation(CL1 COMB Comdty,PR005,60,0) (SPX) 0.3479
0.80
0.60
0.3479
0.20
0.00
-0.20
-0.40
2007
2008
2009
2010
2011
2012
2013
Australia 61 2 9777 8600 Brazil 5511 3048 4500 Europe 44 20 7330 7500 Germany 49 69 9204 1210 Hong Kong 852 2977 6000
Japan 81 3 3201 8900 Singapore 65 6212 1000 U.S. 1 212 318 2000 Copyright 2013 Bloomberg Finance L.P.
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A CAPM Approach to the Commodity Market Price of Risk

Let

μ_i = Expected return on maturity i

μ_M = Expected return on the market portfolio

r = Riskfree rate of interest

Then

$$\begin{aligned}
\mu_i &= \beta_i \left(\mu_M - r\right) \\
&= \frac{\mathrm{Cov}\left(R_i,\, R_M\right)}{\mathrm{Var}\left(R_M\right)} \left(\mu_M - r\right) \\
&= \frac{\rho_i \sigma_i \sigma_M}{\sigma_M^2} \left(\mu_M - r\right) \\
&= \frac{\rho_i \sigma_i}{\sigma_M} \left(\mu_M - r\right) \\
&= \rho_i \sigma_i \, \frac{\mu_M - r}{\sigma_M} \qquad (3)
\end{aligned}$$

A Simple Model for the Equity Sharpe Ratio

Consider the Doran, Ronn and Goldberg (2009) model for an equity-market expected rate of return:[2]

$$\begin{aligned} \mu_{Mt} &= r_{St} + \left(0.46 - 0.162\,\frac{\text{S\&P } 500_t}{\text{S\&P } 500_{t-5,t-6}}\right)\text{VIX}_t \\ \Longrightarrow \quad \frac{\mu_{Mt} - r_{St}}{\text{VIX}_t} &= 0.46 - 0.162\,\frac{\text{S\&P } 500_t}{\text{S\&P } 500_{t-5,t-6}} \qquad (4) \end{aligned}$$

where

μ_{Mt} = the expected rate of return on the Market portfolio at time t

r_{St} = the one-month short-term rate of interest

S&P $500_{t-5,t-6}$ = average value of the S&P 500 Index for a one-year period centered 5.5 yrs. ago

VIX_t = contemporaneous value of the VIX implied-vol index

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[2] James S. Doran, Ehud I. Ronn and Robert S. Goldberg, "A Simple Model for Time-Varying Expected Returns on the S&P 500 Index," *Journal of Investment Management,* Second Quarter, 2009.

The model's parameters 0.46 and 0.162 were obtained from a proxy for the market's expected risk premium (*not* realized returns), inserted into a linear regression on a constant plus the ratio S&P 500_t/ S&P $500_{t-5,t-6}$.

Integrating Oil-Futures and Equity Markets: A CAPM-Based Expected Spot Price of Oil

- Combining the CAPM with the oil futures markets — i.e., eqs. (3) – (4):

$$\begin{aligned} \mu_{it} &= \rho_{it}\sigma_{it}\,\frac{\mu_M - r}{\sigma_M} \equiv \rho_{it}\sigma_{it}\lambda_t \\ &= \rho_{it}\sigma_{it}\left(0.46 - 0.162\,\frac{\text{S\&P 500}_t}{\text{S\&P 500}_{t-5,t-6}}\right) \qquad (5) \end{aligned}$$

- With respect to futures contract of maturity i,

$$\begin{aligned} E\left(F_{iT}\right) &\equiv F_{i0}\,\exp\left\{\mu_{iT}T\right\} \\ &= F_{i0}\,\exp\left\{\rho_{it}\sigma_{it}\lambda_t\,T\right\} \\ \Longrightarrow \quad \frac{1}{T}\ln\left[\frac{E\left(F_{iT}\right)}{F_{i0}}\right] &= \rho_{it}\sigma_{it}\lambda_t \qquad (6) \\ \begin{array}{c}\text{Annualized Expected}\\ \text{Futures Price Change}\end{array} &\equiv \rho_{it}\left(\begin{array}{c}\text{Current CL}_i\\ \text{Implied Vol}\end{array}\right)\left(\begin{array}{c}\text{Current Stock Market}\\ \text{Sharpe Ratio}\end{array}\right) \end{aligned}$$

- <u>Implication:</u> When $\rho_{it} < 0$ — say, because of a geopolitical crisis — the resulting $F_{i0} > E\left(F_{iT}\right)$ reflects the intuitive notion of a risk premium attributable to concerns over oil supplies reaching consumer markets

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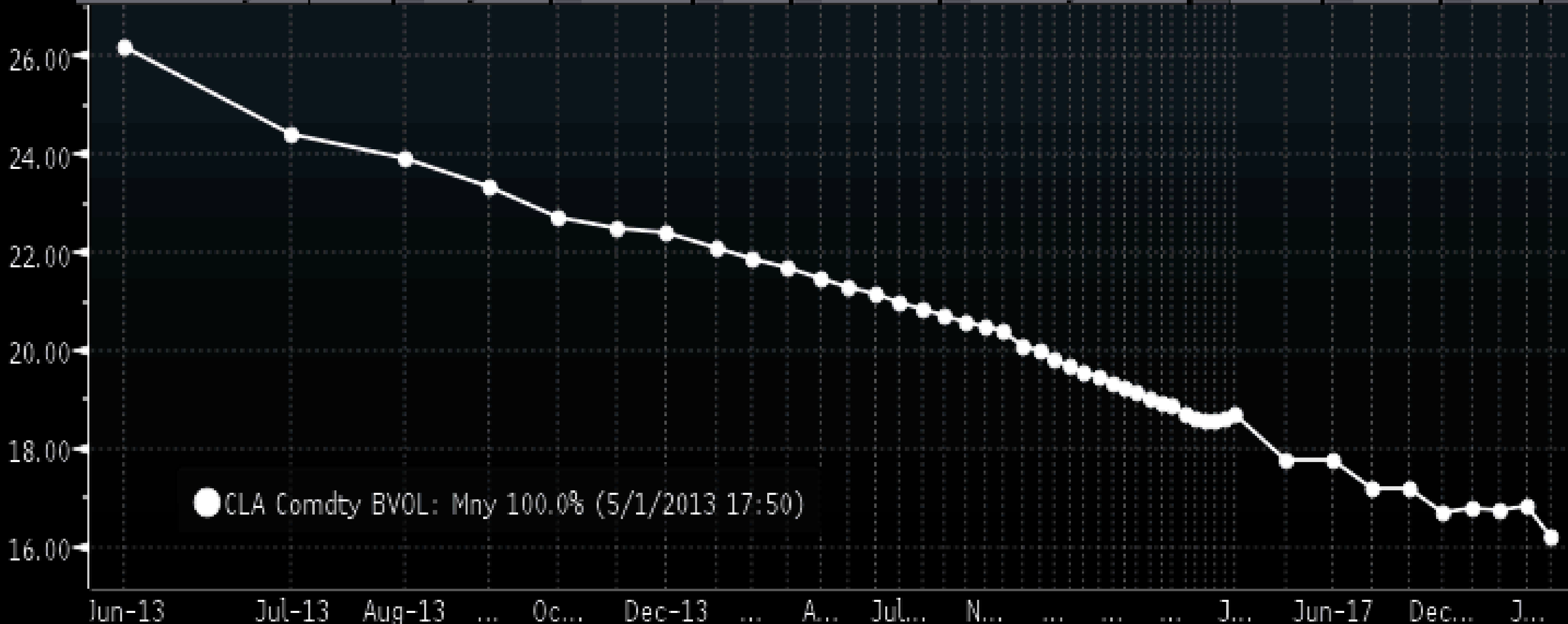
CLA Comdty | 90) Asset | 91) Actions | 92) Settings | Volatility Surface

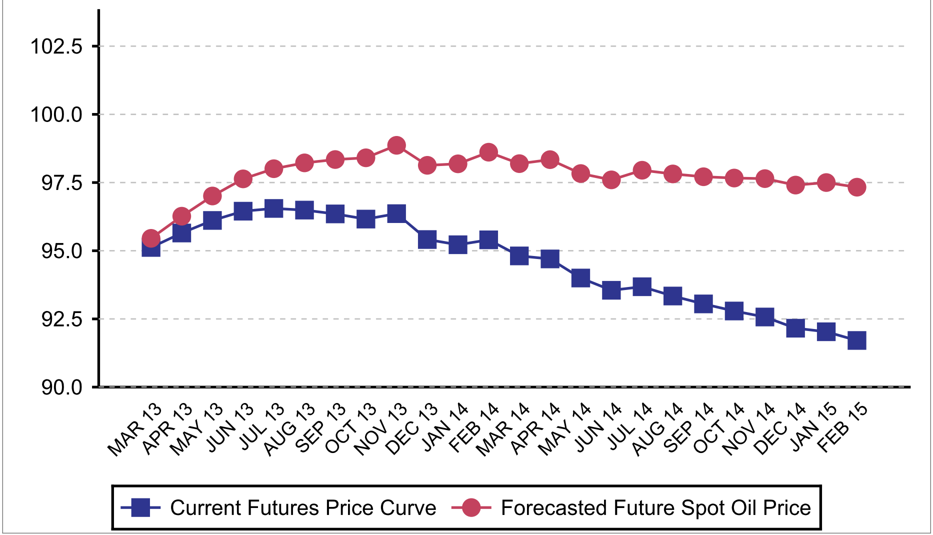
Listed Exp Tenors

1) Vol Table | 2) 3D Surface | 3) Term | 4) Skew | 6) Prices | 7) Correlation

	Security	Data Series				Surface as of			Comparison	
1.	CLA Comdty	BVOL	Mny	100.0%	Mid	TD	01-May-2013	17:50	vs 2	Abs
2.	CLA Comdty		Mny		Mid	TD	01-May-2013		None	Abs
3.	CLA Comdty		Mny		Mid	TD	01-May-2013		None	Abs
4.	CLA Comdty		Mny		Mid	TD	01-May-2013		None	Abs



Forecast WTI Prices by Maturity



Source: Bloomberg, Guzman Financial Engineers

Applying the CAPM to Historical Time-Series Tests

- Consider a simple historical time-series test of the CAPM's Implications [Ronn and Zerilli (2014), work in progress]:

$$d\ln F = -\frac{1}{2}\sigma_F^2\,dt + \beta_t\,(d\ln \mathrm{S\&P} - r\,dt) + \sigma_F\,dz, \tag{7}$$

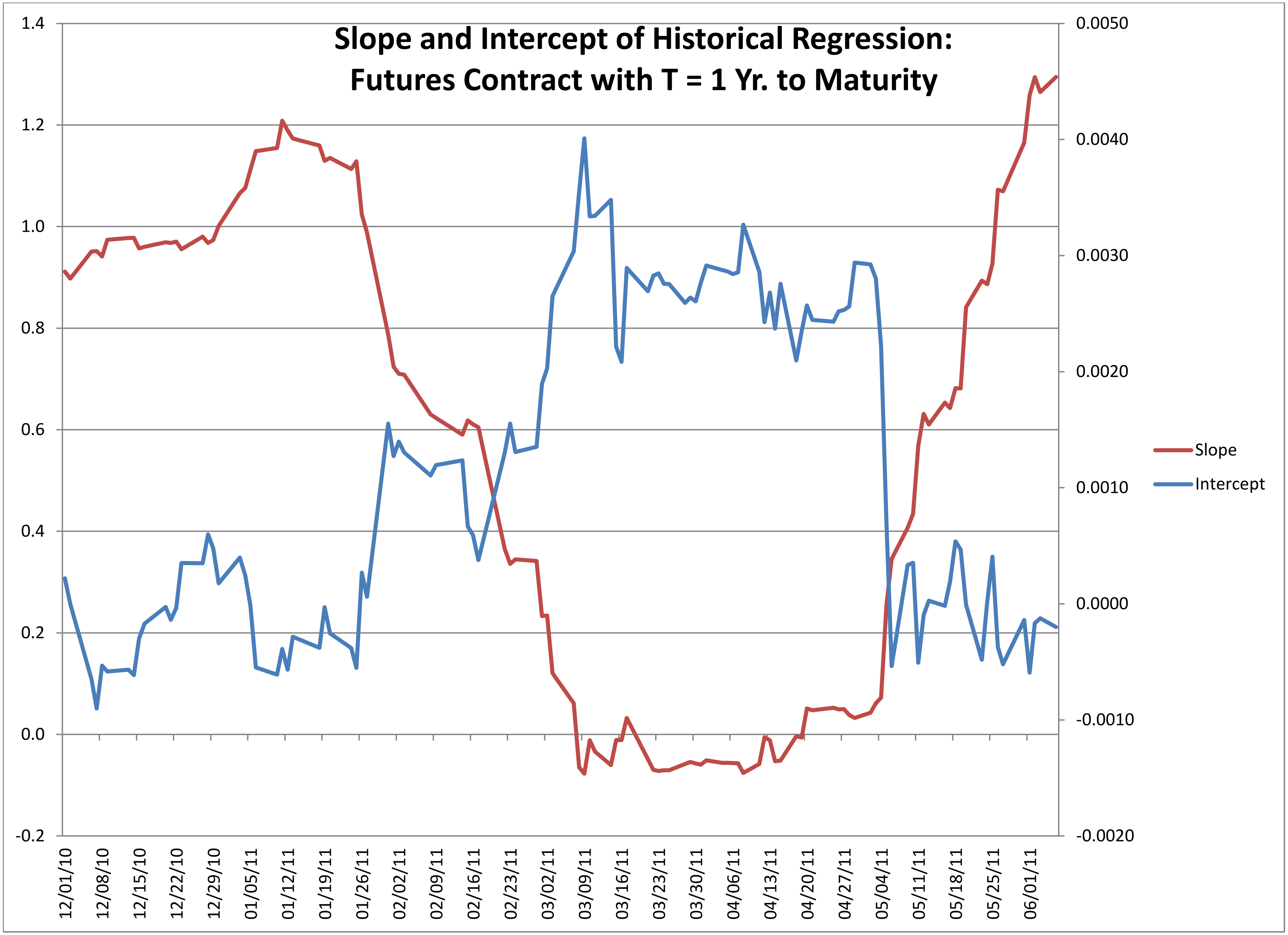
where

$$\begin{aligned} E_t\,(d\ln F) &= -\frac{1}{2}\sigma_F^2\,dt + \beta_t\,[E_t\,(\,d\ln \mathrm{S\&P}\,) - r\,]\,dt \\ &\equiv \left[-\frac{1}{2}\sigma_F^2 + \beta_t\,(\mu_{Mt} - r)\right] dt \end{aligned}$$

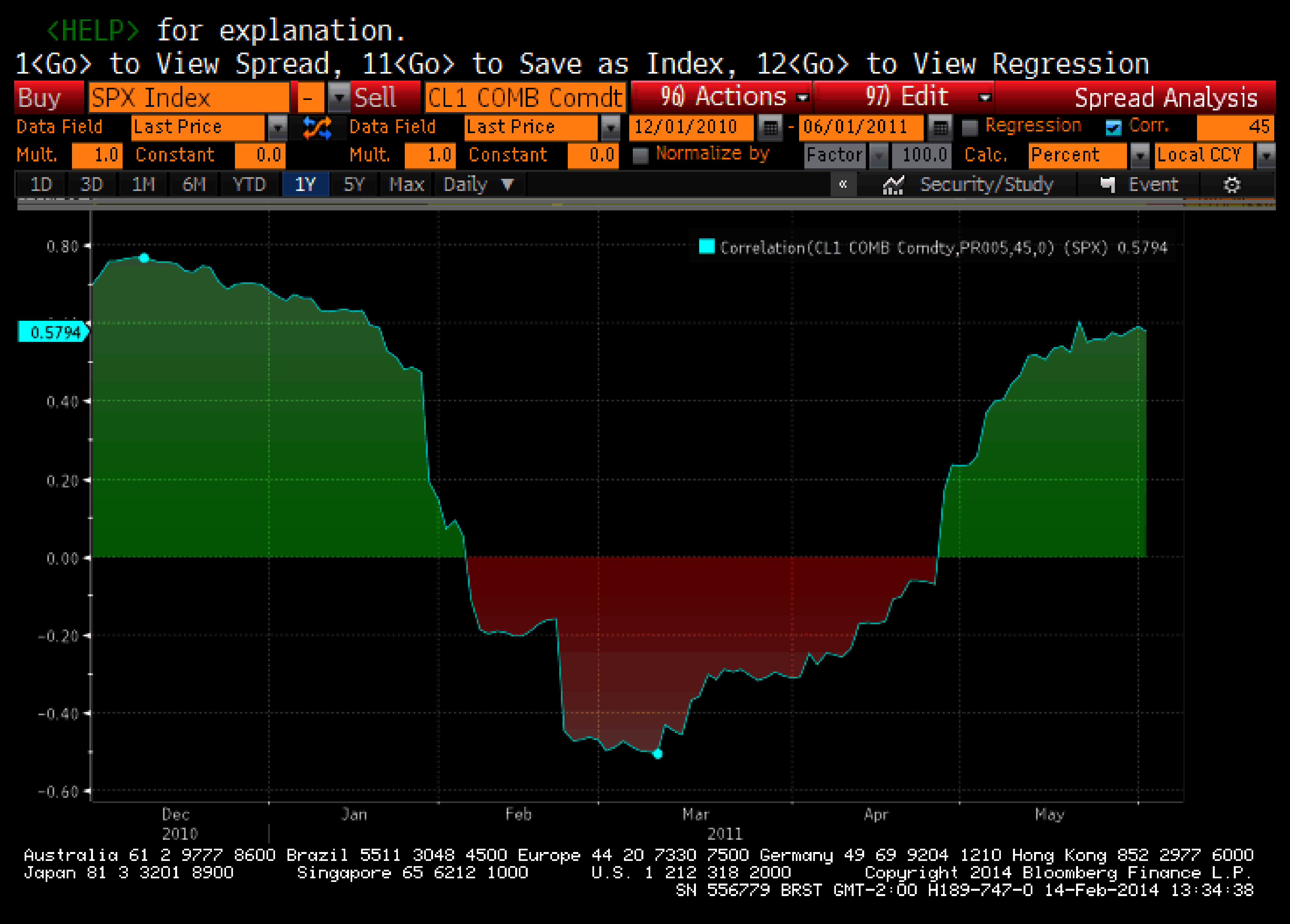
- Ignoring Ito's Lemma effects, discretizing (7) results in

$$\Delta \ln F = a_t + b_t\,\Delta \ln \mathrm{S\&P} \tag{8}$$

In (8), our interest is in the *timing* of when b_t changes signs



Slope and Intercept of Historical Regression:
Futures Contract with T = 1 Yr. to Maturity
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
0.0050
0.0040
0.0030
0.0020
0.0010
0.0000
-0.0010
-0.0020
12/01/10
12/08/10
12/15/10
12/22/10
12/29/10
01/05/11
01/12/11
01/19/11
01/26/11
02/02/11
02/09/11
02/16/11
02/23/11
03/02/11
03/09/11
03/16/11
03/23/11
03/30/11
04/06/11
04/13/11
04/20/11
04/27/11
05/04/11
05/11/11
05/18/11
05/25/11
06/01/11
Slope
Intercept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1<Go> to View Spread, 11<Go> to Save as Index, 12<Go> to View Regression
Buy
SPX Index
-
Sell
CL1 COMB Comdt
96) Actions
97) Edit
Spread Analysis
Data Field
Last Price
Data Field
Last Price
12/01/2010 - 06/01/2011
Regression
Corr.
45
Mult. 1.0
Constant 0.0
Mult. 1.0
Constant 0.0
Normalize by
Factor
100.0
Calc.
Percent
Local CCY
1D 3D 1M 6M YTD 1Y 5Y Max Daily
Security/Study
Event
Correlation(CL1 COMB Comdty,PR005,45,0) (SPX) 0.5794
0.5794
0.80
0.40
0.20
0.00
-0.20
-0.40
-0.60
Dec
2010
Jan
Feb
Mar
2011
Apr
May
Australia 61 2 9777 8600 Brazil 5511 3048 4500 Europe 44 20 7330 7500 Germany 49 69 9204 1210 Hong Kong 852 2977 6000
Japan 81 3 3201 8900 Singapore 65 6212 1000 U.S. 1 212 318 2000 Copyright 2014 Bloomberg Finance L.P.
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From Historical to Forward-Looking Estimates of Crude-Oil Correlations

- Using S&P 500 and oil-futures options for maturities $T \leq 2$, apply a market-model to returns on crude-oil futures contracts,

$$
\begin{aligned}
r_T &= a_T + \beta_T R_{\text{SPX}} + e_T && (9) \\
\Sigma_T^2 &= \beta_T^2 \sigma_{mT}^2 + \sigma_T^2 && (10)
\end{aligned}
$$

where

$\Sigma_T^2 \equiv \mathrm{Var}(r_T)$, the variance of the return on crude-oil futures contract of maturity T

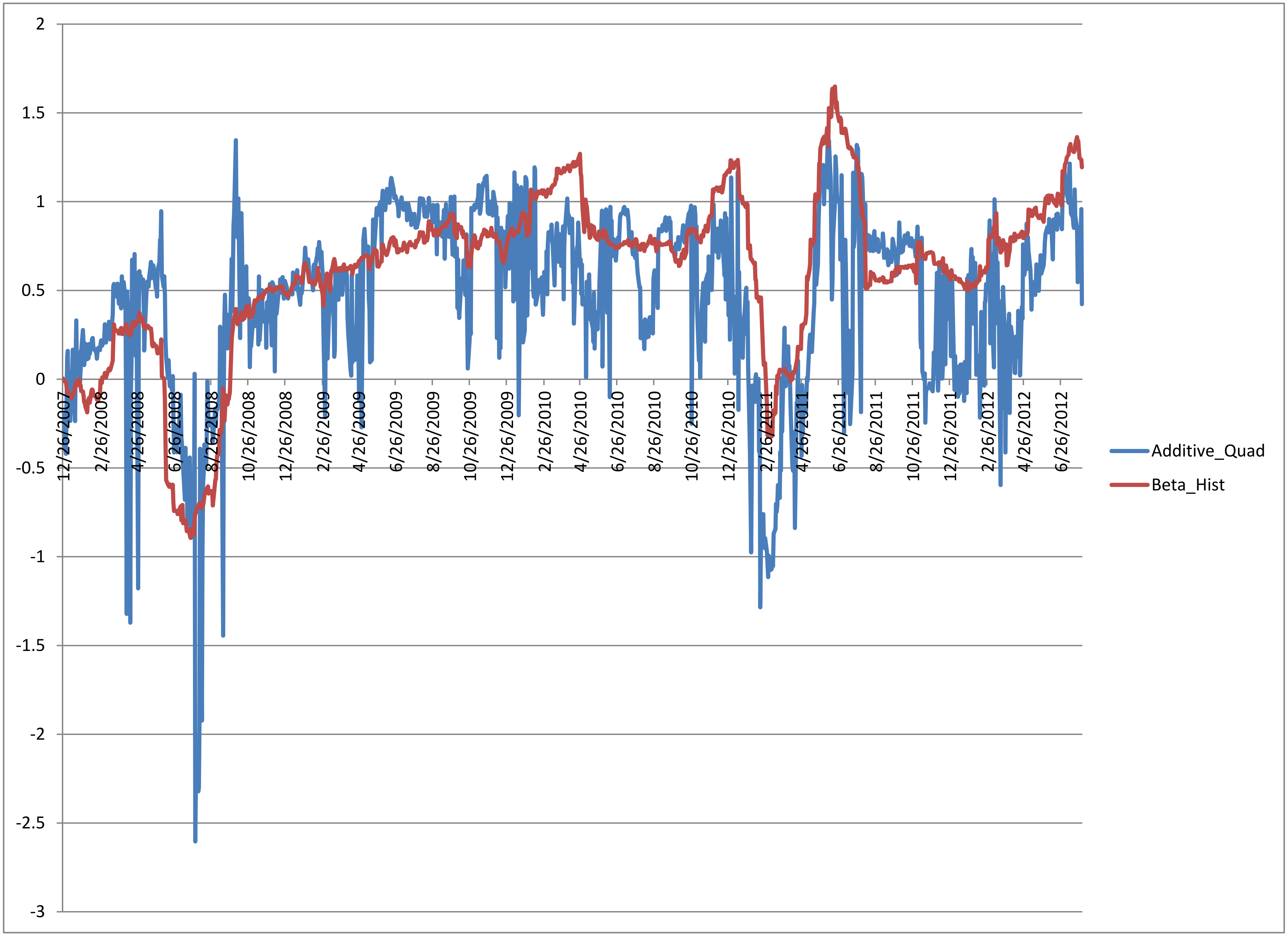
$\beta_T \equiv \rho_T \, \sigma\,(R_T) / \, \sigma_{mT}$, market beta of oil futures contract of maturity T

$\sigma_{mT}^2 \equiv \mathrm{Var}(R_{\text{SPX},\,T})$, the variance of the return on the S&P 500 market index to expiration date T

$\sigma_T^2 \equiv \mathrm{Var}(e_T)$, the idiosyncratic variance

- Empirically link the historical estimates $\{\widehat{\rho}_i,\, \widehat{\sigma}_i\}$ to their forward-looking analogues $\{\rho_i,\, \sigma_i\}$ via additive (11) (or multiplicative) *quadratic* corrections:

$$
\begin{cases}
\rho_{Tt} = \widehat{\rho}_{1t} + \alpha_{1ct} + \alpha_{1lt}\,(T-1) + \alpha_{1qt}\,(T-1)^2 \\
\\
\sigma_{Tt} = \widehat{\sigma}_{1t} + \alpha_{2ct} + \alpha_{2lt}\,(T-1) + \alpha_{2qt}\,(T-1)^2
\end{cases}
\qquad (11)
$$



2
1.5
1
0.5
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-0.5
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-1.5
-2
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-3
12/26/2007
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4/26/2008
6/26/2008
8/26/2008
10/26/2008
12/26/2008
2/26/2009
4/26/2009
6/26/2009
8/26/2009
10/26/2009
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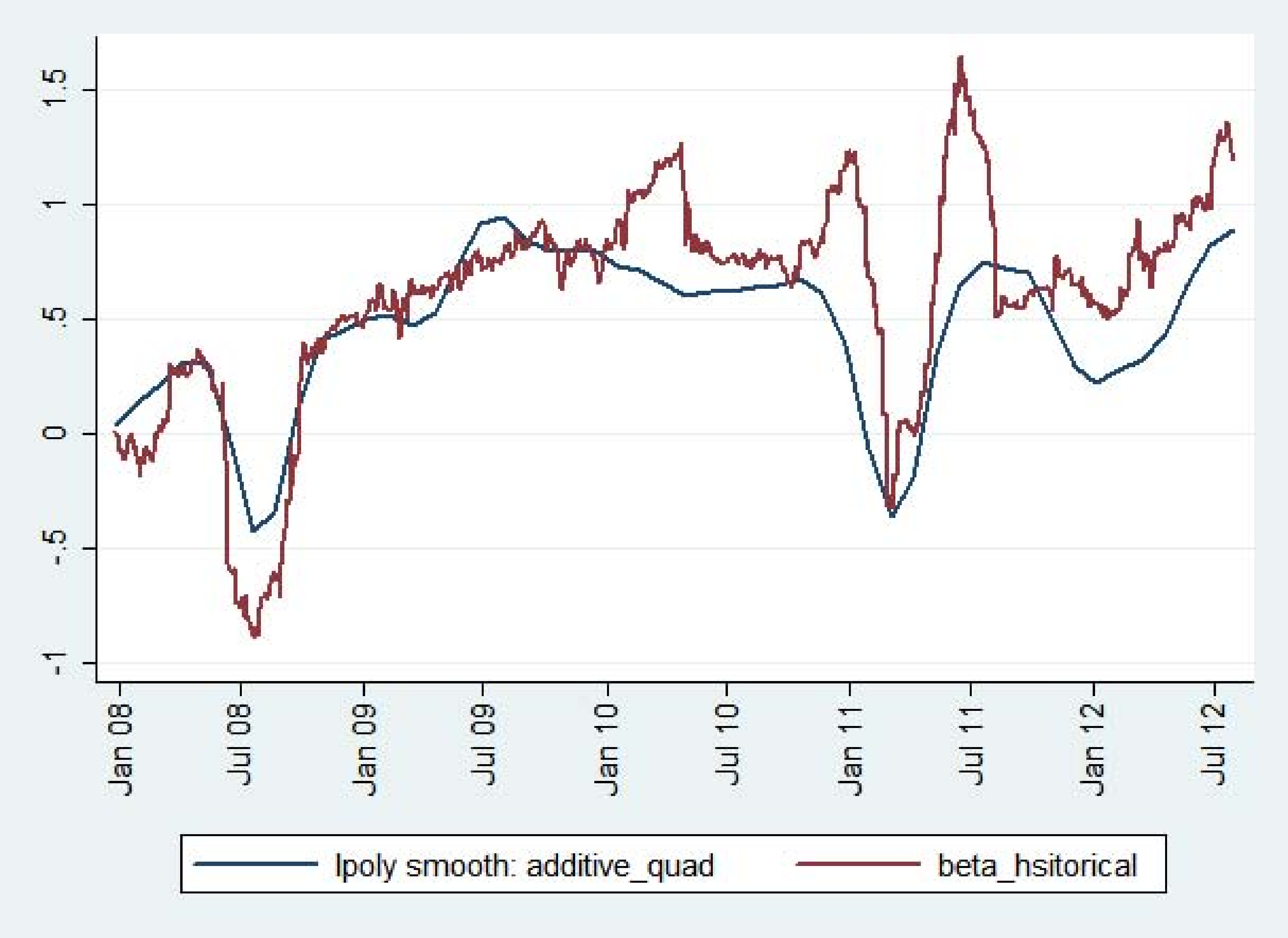

1.5
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-.5
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Jan 09
Jul 09
Jan 10
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Jan 11
Jul 11
Jan 12
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lpoly smooth: additive_quad
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SUMMARY

The Economic and Informational Role of Derivatives

- Efficient capital markets — including specifically the markets for crude-oil futures and options — can be informationally-revealing
- The Challenge, as always, is to *Interpret* them
- Using both Risk-Neutral and Physical Models, We Seek to Extract Estimates of Parameters of Interest, including *Expected Spot Prices*