17TH ANNUAL GLOBAL DERIVATIVES TRADING & RISK MANAGEMENT 2011

ICBI

Strategies for Overcoming Challenges in Energy Risk Management

Ehud I. Ronn
Professor of Finance
University of Texas at Austin[1]

Paris, April 13, 2011

[1] eronn@mail.utexas.edu

OVERVIEW

- The Relationship between

  Risk Premia in Energy
  (aka Commodity Market Price of Risk)

  and

  – Risk-Management from a *Corporate* Perspective
  – Using the Richness of Energy Markets' Derivative Structures

- Pricing Derivatives in Incomplete/Low-Liquidity Markets: E.g., Interruptible Contracts, Load-Following Services

- The Challenge of *Extrapolation:* Asset Valuation beyond the Liquidity Tenor of Traded Futures and Options Contracts

We Are More than Replicators — "The Analysis of Ketchup Economists"

- Financial economists "have shown that two quart bottles of ketchup invariably sell for twice as much as one quart bottles of ketchup"

  — Lawrence H. Summers, "On Economics and Finance," *Journal of Finance,* Vol. 40, No. 3, July 1985, pp. 633 – 635

- There are different ways of refuting/addressing Summers' critique:
  1. Quantifying the risk premium, in commodity markets as well as the traditional equity markets
  2. Provide guidance to firms regarding their *hedging* policies

Forward Prices and Forecast Prices in Energy — The Risk Premium in Energy Markets

- Notation:

  F_T = Futures contract price for maturity T
  $E(S_T)$ = Expected spot price at maturity T
  μ = Expected rate of return on the futures contract
  σ = Volatility of return on the futures contract
  $\lambda = \dfrac{\mu}{\sigma}$ = Commodity Market Price of Risk, the expected return compensation per unit standard deviation

- Finance theory relates forecast and forward prices: $E(S_T) = F_T \exp\{\mu T\}$

- Motivation (Why do we care?)

  1. Understanding the relationship between energy markets and other physical and financial markets
  2. Making informed informed hedging decisions based on the trade-off between risk and return
  3. Many firms' economic/structural desks produce estimates of long-term *expected,* or *forecast,* prices. Properly splicing short-term futures contracts with long-dated forecast prices requires recognizing that forward prices are not unbiased predictors of future expected prices.

- Questions:

  1. What is the magnitude, and indeed the sign, of λ?
  2. Does it differ for a domestically produced electricity/natgas from an international commodity such as oil?
  3. For power/natgas, does it vary by season?
  4. Does it depend on the asset's covariability with the stock market (à la financial economists' Capital Asset Pricing Model, CAPM), or by the participants in the futures markets?

- With respect to energy-markets' *volatility,*

  1. What is the Commodity Market Price of Volatility Risk?
  2. Equivalently, what is the relationship between (options') *implied* and *realized* volatilities?

Estimates of the Market Price of Risk using Energy Futures Contracts

Table 1 — Description of Data

Market	Contracts	Trading Dates
PJM	5/99 – 5/03	3/99 – 10/01
Cinergy	5/99 – 5/03	1/99 – 10/01
EEX monthly	8/02 – 4/04	7/02 – 10/03
EEX quarterly	IV/02 – III/05	7/02 – 10/03
EEX yearly	2003 – 2006	7/02 – 10/03
Gas	6/90 – 9/07	4/90 – 12/02
Oil	4/99 – 12/2009	3/99 – 1/05

- For futures contracts, estimation of Market Price of Risk requires modeling of the "Term Structure of Volatility" (TSOV):

$$dF = \mu_t \, F \, dt + \sigma_t \, F \, dz = \lambda \sigma_t \, F \, dt + \sigma_t \, F \, dz \tag{1}$$

- Using maximum likelihood estimation, the estimator for the Market Price of Risk λ is given by:

$$\widehat{\lambda} = \frac{\overline{\Delta \ln F_\gamma}}{\Delta t} \frac{1}{\widehat{\sigma}} + \frac{\widehat{\sigma} \overline{\gamma}}{2} \tag{2}$$

where

$$\begin{aligned}
\overline{\Delta \ln F_\gamma} &= \frac{1}{n} \sum_i \frac{\Delta \ln F_i}{\gamma_i} \\
\sigma_\tau &= \sigma \, \gamma_\tau \\
\gamma_\tau &= \begin{cases} 1 \\ e^{-\kappa \tau} \\ \sqrt{e^{-2\kappa\tau} + \xi^2} \end{cases} \\
\widehat{\sigma} &= \sqrt{2 \frac{\sqrt{1 + \mathrm{Var}\,(\gamma) \; \mathrm{Var}\,(\Delta \ln F_\gamma)} - 1}{\Delta t \, \mathrm{Var}\,(\gamma)}}
\end{aligned}$$

- Note interpretation of (2): The Market Price of Risk $\widehat{\lambda}$ is given by the ratio of the TSOV-adjusted average returns $\bar{p}_\gamma \equiv \Delta \ln F_\gamma$ to the estimator of volatility $\widehat{\sigma}$, adjusted for the annualized time interval Δt and the Ito's Lemma-induced correction $\sigma \overline{\gamma}/2$.

Empirical Estimates of the Market Price of Risk using Energy Futures Contracts

Market	**Model**	Winter	Spring	Summer	Fall	**All**
Oil	Const vol	**0.88** $(0.11, 0.26)$	**0.93** $(0.13, 0.35)$	**0.96** $(0.13, 0.33)$	**1.05** $(0.13, 0.34)$	**0.95** $(0.06, 0.30)$
	1 Factor	**0.91** $(0.11, 0.26)$	**0.97** $(0.13, 0.35)$	**0.99** $(0.13, 0.33)$	**1.06** $(0.13, 0.34)$	**0.98** $(0.06, 0.30)$
	Long Term	**0.71** $(0.15, 0.36)$	**0.83** $(0.24, 0.63)$	**0.87** $(0.32, 0.74)$	**0.60** $(0.34, 0.75)$	**0.75** $(0.11, 0.54)$
	Short Term	**0.59** $(0.56, 1.37)$	**0.44** $(0.32, 0.50)$	**0.33** $(0.63, 1.47)$	**0.95** $(0.65, 1.44)$	**0.56** $(0.29, 1.34)$
Gas	Const vol	**0.34** $(0.11, 0.24)$	**0.26** $(0.11, 0.24)$	**0.44** $(0.11, 0.24)$	**0.34** $(0.11, 0.24)$	**0.35** $(0.06, 0.23)$
	1 Factor	**0.39** $(0.11, 0.24)$	**0.35** $(0.11, 0.24)$	**0.47** $(0.11, 0.24)$	**0.39** $(0.11, 0.24)$	**0.40** $(0.06, 0.23)$
	Long Term	**0.60** $(0.23, 0.47)$	**0.19** $(0.22, 0.46)$	**0.51** $(0.24, 0.47)$	**0.30** $(0.26, 0.54)$	**0.40** $(0.12, 0.45)$
	Short Term	**0.08** $(0.30, 0.60)$	**0.70** $(0.34, 0.71)$	**0.53** $(0.38, 0.75)$	**0.59** $(0.32, 0.67)$	**0.46** $(0.17, 0.64)$
EEX	Const vol	**3.11** $(0.23, 0.93)$	**2.51** $(0.23, 0.93)$	**3.01** $(0.36, 1.00)$	**3.08** $(0.30, 1.18)$	**2.97** $(0.15, 0.97)$
	1 Factor	**2.76** $(0.23, 0.93)$	**2.07** $(0.23, 0.93)$	**2.54** $(0.36, 1.00)$	**2.71** $(0.31, 1.19)$	**2.58** $(0.15, 0.97)$
	Long Term	**1.25** $(1.22, 2.23)$	**0.81** $(1.17, 2.32)$	**1.33** $(0.74, 1.69)$	**1.55** $(1.28, 2.25)$	**1.31** $(0.56, 1.59)$
	Short Term	**2.99** $(0.76, 1.39)$	**2.83** $(0.92, 1.81)$	**5.41** $(0.94, 2.16)$	**4.09** $(0.98, 1.72)$	**3.46** $(0.43, 1.23)$
Cinergy	Const vol	**−0.01** $(0.28, 0.49)$	**0.58** $(0.32, 0.51)$	**0.08** $(0.29, 0.51)$	**−0.26** $(0.28, 0.51)$	**0.07** $(0.15, 0.45)$
	1 Factor	**0.09** $(0.28, 0.49)$	**0.53** $(0.32, 0.52)$	**0.15** $(0.30, 0.51)$	**−0.12** $(0.28, 0.51)$	**0.14** $(0.15, 0.45)$
	Long Term	**1.04** $(1.67, 2.26)$	**0.72** $(0.54, 0.79)$	**0.45** $(0.40, 0.67)$	**1.09** $(0.82, 1.36)$	**0.70** $(0.32, 0.89)$
	Short Term	**−2.28** $(2.48, 3.36)$	**1.17** $(1.89, 2.76)$	**−2.18** $(1.26, 2.12)$	**−1.69** $(1.17, 1.96)$	**−1.45** $(0.75, 2.12)$
PJM	Const vol	**0.16** $(0.30, 0.51)$	**0.22** $(0.31, 0.53)$	**0.49** $(0.31, 0.52)$	**0.44** $(0.31, 0.55)$	**0.33** $(0.15, 0.48)$
	1 Factor	**0.23** $(0.31, 0.51)$	**0.20** $(0.31, 0.54)$	**0.49** $(0.31, 0.52)$	**0.58** $(0.31, 0.55)$	**0.38** $(0.15, 0.48)$
	Long Term	**1.03** $(0.66, 1.16)$	**0.84** $(0.46, 0.77)$	**0.20** $(0.44, 0.74)$	**0.78** $(0.59, 0.95)$	**0.65** $(0.26, 0.81)$
	Short Term	**−1.81** $(1.40, 2.43)$	**1.02** $(2.29, 3.84)$	**−0.30** $(1.01, 1.69)$	**−1.19** $(1.07, 1.72)$	**−0.70** $(0.65, 2.00)$
Day-Ahead	MLE	**−6.13** (0.56)	**0.54** (0.56)	**−1.64** (0.63)	**−1.51** (0.57)	**−1.82** (0.57)
PJM	MM	**−6.13** (1.40)	**0.55** (1.15)	**−1.63** (1.07)	**−1.50** (1.21)	**−1.82** (0.59)

Note: Numbers in brackets denote low and high estimates of standard errors

TABLE 3 Estimates of the intra-day MPR for electricity forward prices.

(a) Market price of risk: EEX forward prices from August 2002 to September 2007

	r_{Mean}	r_{SD}	MPR_{A}	MPR_{B}	MPR_{C}	MPR_{D}
Working days						
EEX (continuous – auction) base	−0.009***	0.065	−9.457	−12.490***	−17.168***	−12.505***
Monday	−0.016***	0.038	−38.016***	−39.797***	−38.901***	−40.415***
Tuesday–Friday	−0.007***	0.069	−6.648	−9.859**	−13.230***	−9.873***
EEX (continuous – auction) peak	−0.015***	0.078	−14.475**	−18.110***	−29.848***	−18.125***
Monday	−0.020***	0.045	−39.282***	−41.407***	−40.639***	−42.795***
Tuesday–Friday	−0.014***	0.082	−12.110	−15.967***	−27.250***	−15.991***
Non-working days						
EEX (continuous – auction) base	−0.006	0.075	−3.814	−7.344	6.935	−10.284
Saturday	0.000	0.053	2.896	0.430	17.921	0.481
Sunday	0.003	0.054	8.078	5.552	4.771	6.664

Motivation for Corporate Risk-Management

- Smith and Stulz (1985), Froot, Scharfstein and Stein (1993) and Grinblatt and Titman (2001) have identified several reasons for corporate risk-management:
  - Reducing the costs of financial distress
  - Allowing firms to better plan for their future capital needs
  - Improving the quality of managerial decisions
  - Improving the design of management compensation contracts
  - Decreasing the firm's expected tax payments
- In particular, Froot, Scharfstein and Stein find:
  1. The firm's value function is concave in internal wealth, which is equivalent to risk aversion
  2. They also find "Options effectively create the possibility for hedge ratios to be 'customized' on a state-by-state basis"
- In applying theory,
  1. Using mean-variance efficiency for hedging with *futures contracts*
  2. Using downside risk-aversion to motivate optimal hedging strategies involving *options*

A Mean-Variance Hedging Optimization using Futures Contracts

- Letting V be firm value from cash flows at time 1/2 and 1,

$$\Delta V = \sum_{t=1/2}^{1} \frac{(Q_t - n_t)\, \Delta \widetilde{F}_t}{(1+r)^t} \tag{3}$$

where n_t is the quantity of (short) futures contracts for date t

- The relevant two first moments, $E\,(\Delta V)$ and $\text{Var}(\Delta V)$, are:

$$\begin{aligned} E\,(\Delta V) &= \sum_{t=1/2}^{1} \frac{(Q_t - n_t)\, F_{0t}}{(1+r)^t}\, E\left(\frac{\Delta \widetilde{F}_t}{F_{0t}}\right) \\ &= \lambda \left[\frac{(Q_{0.5} - n_{0.5})\, F_{0,\,0.5}}{(1+r)^{0.5}}\, 0.5\, \sigma_{0.5} + \frac{(Q_1 - n_1)\, F_{01}}{1+r}\, \sigma_1\right] \end{aligned} \tag{4}$$

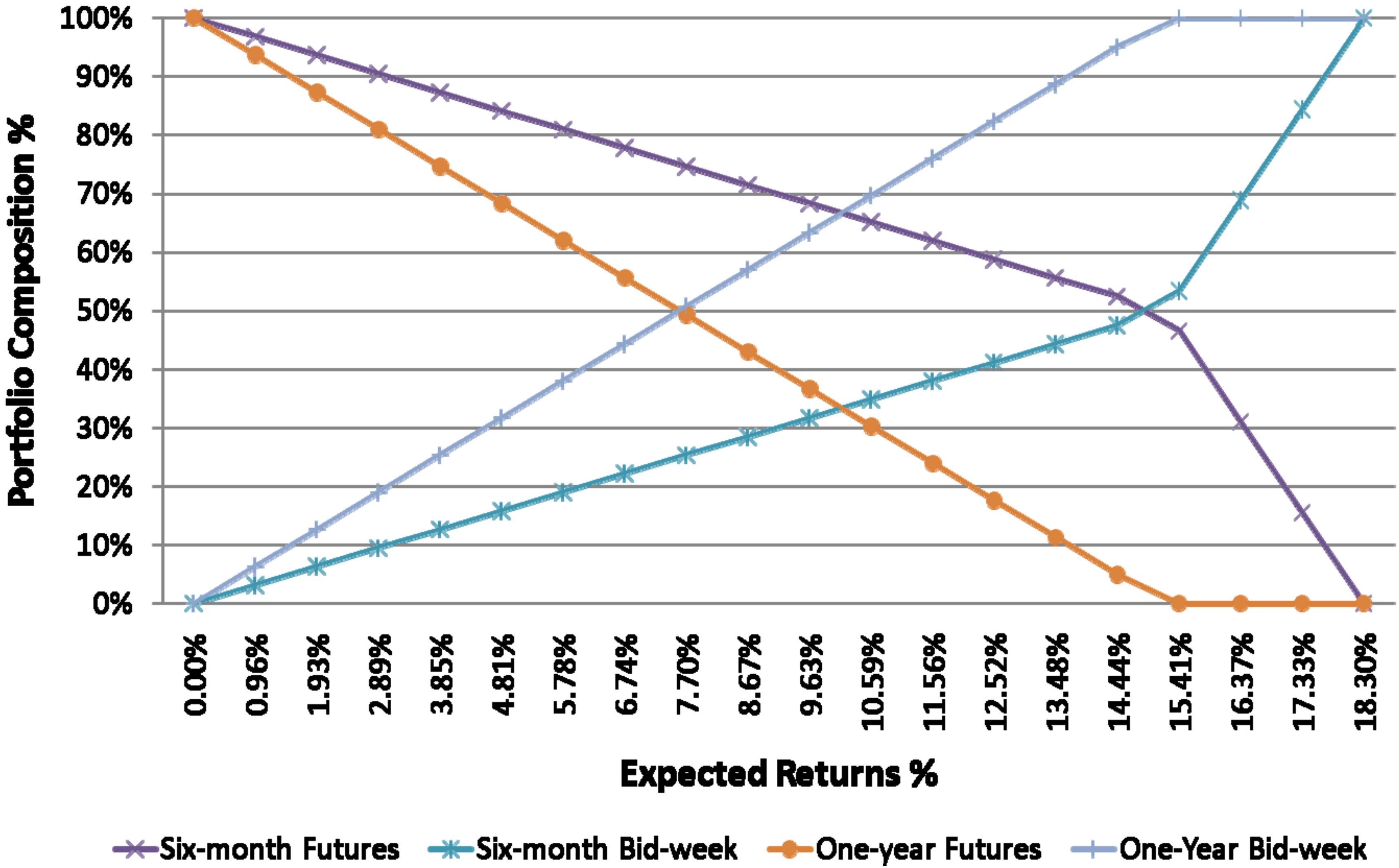
where

$\mu_{Ft} =$ Expected return on futures contract with maturity t

$\lambda =$ Market Price of Risk for this commodity

$\sigma_t =$ Annualized volatility for date t

$$\begin{aligned} \text{Var}\ (\Delta V) = {} & \left[\frac{(Q_{0.5} - n_{0.5})\, F_{0,\,0.5}}{(1+r)^{0.5}}\right]^2 0.5\, \sigma_{0.5}^2 + \left[\frac{(Q_1 - n_1)\, F_{0,\,1}}{(1+r)}\right]^2 \sigma_1^2 \\ & + 2\left[\frac{(Q_{0.5} - n_{0.5})\, F_{0,\,0.5}}{(1+r)^{0.5}}\, \frac{(Q_1 - n_1)\, F_{0,\,1}}{(1+r)}\right] \rho_{0.5,\,1}\, \sqrt{0.5}\, \sigma_{0.5}\sigma_1 \end{aligned} \tag{5}$$



100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Portfolio Composition %
0.00%
0.96%
1.93%
2.89%
3.85%
4.81%
5.78%
6.74%
7.70%
8.67%
9.63%
10.59%
11.56%
12.52%
13.48%
14.44%
15.41%
16.37%
17.33%
18.30%
Expected Returns %
Six-month Futures
Six-month Bid-week
One-year Futures
One-Year Bid-week

Definition of Earnings for Corporations Short or Long Price Exposure

- Definition of Earnings (for a Corporation *Short* Prices):

$$\widetilde{E} = -\widetilde{P}\widetilde{Q} + n_F\left(\widetilde{P} - F\right) + n_C \max\left\{0,\ \widetilde{P} - K\right\} - n_C\,(1+r)^T\, C\,(K) \tag{3}$$

where

Notation	Definition
$E\left(\widetilde{P}\right)$	Current expectation of average price for month T
$E\left(\widetilde{Q}\right)$	Current expectation of total quantity consumed in month T
$\sigma_Q,\ \sigma_P$	Proportional volatility for $\widetilde{Q}$ and $\widetilde{P}$
$\rho_{P,Q}$	Correlation coefficient between $\ln P$ and $\ln Q$
F	Forward price for month T
$C\,(K)$	Call option with given strike price K
T	Time to expiration
r	Riskfree rate of interest

- For a corporation *long* prices, the analogous earnings statement is

$$\widetilde{E} = \widetilde{P}\widetilde{Q} - n_F\left(\widetilde{P} - F\right) + n_{\mathrm{Put}} \max\left\{0,\ K - \widetilde{P}\right\} - n_{\mathrm{Put}}\,(1+r)^T\, \mathrm{Put}\,(K) \tag{4}$$

Implementing *Corporate*-Level Price Risk Management Policy Using Futures or Options

- For a Corporation short or long price exposure, define the objective function as:[2]

$$E\left(\widetilde{E}\right) + \alpha\, E_{\text{Lower Percentile}} \tag{5}$$

- Properties of optimal solution:
  - The greater is α, the more concerned is the decision-maker with the *lower* side of the earnings distribution $\Longrightarrow$ the more hedging he/she will undertake.
  - Varying α from 0 (risk-neutrality) to ∞ (in practice, α of 1 or 2 will suffice) will provide the entire range of earnings-distribution alternatives

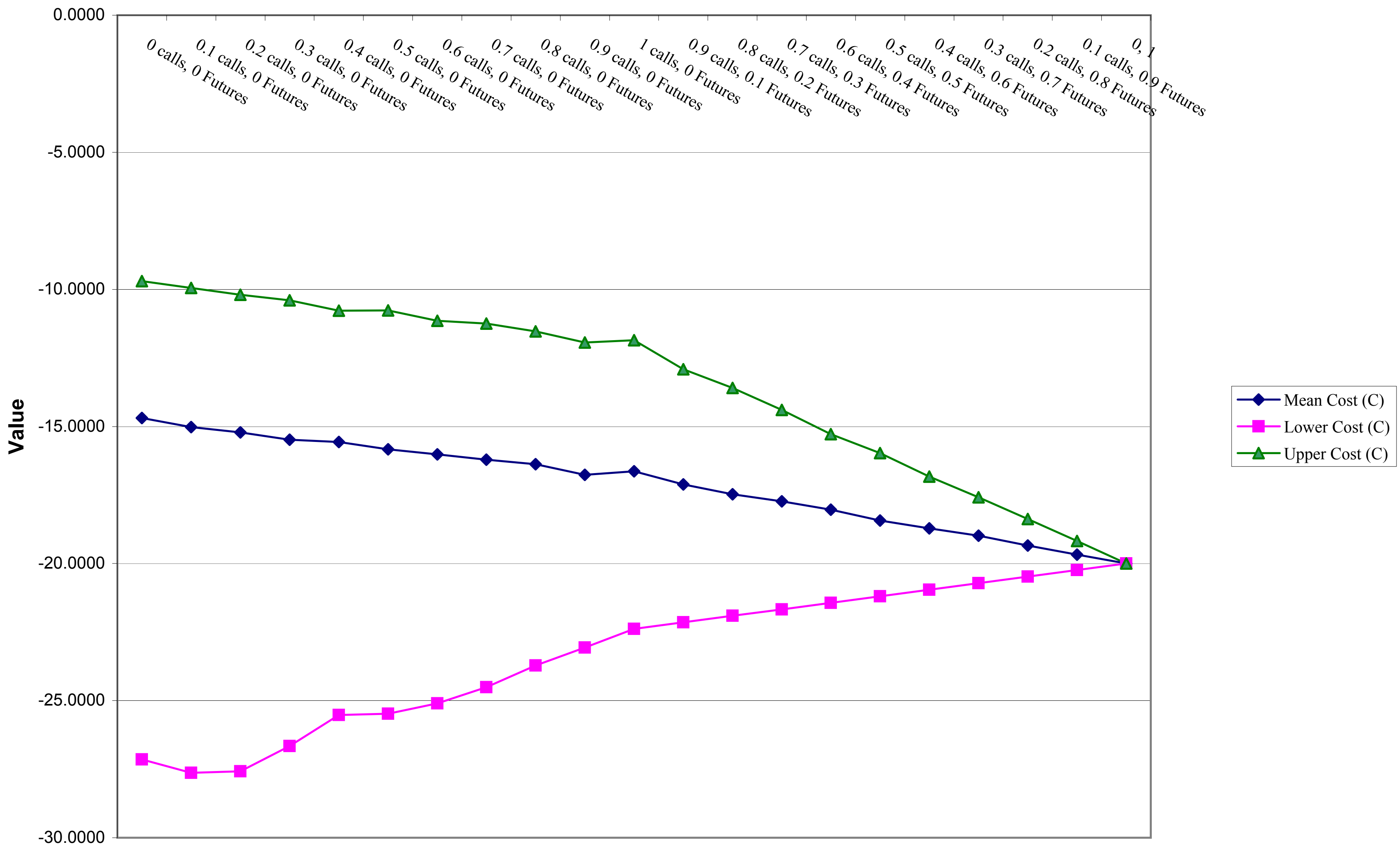
- Main Result. There exits a *systematic pattern to optimal hedging:* As α, the degree of risk aversion, increases from zero to positive values, the company's optimal hedge proceeds from
  - *No-hedging,* to
  - *Acquiring call options* (up to 100% of expected quantity), to
  - *Replacing call options with futures contracts*

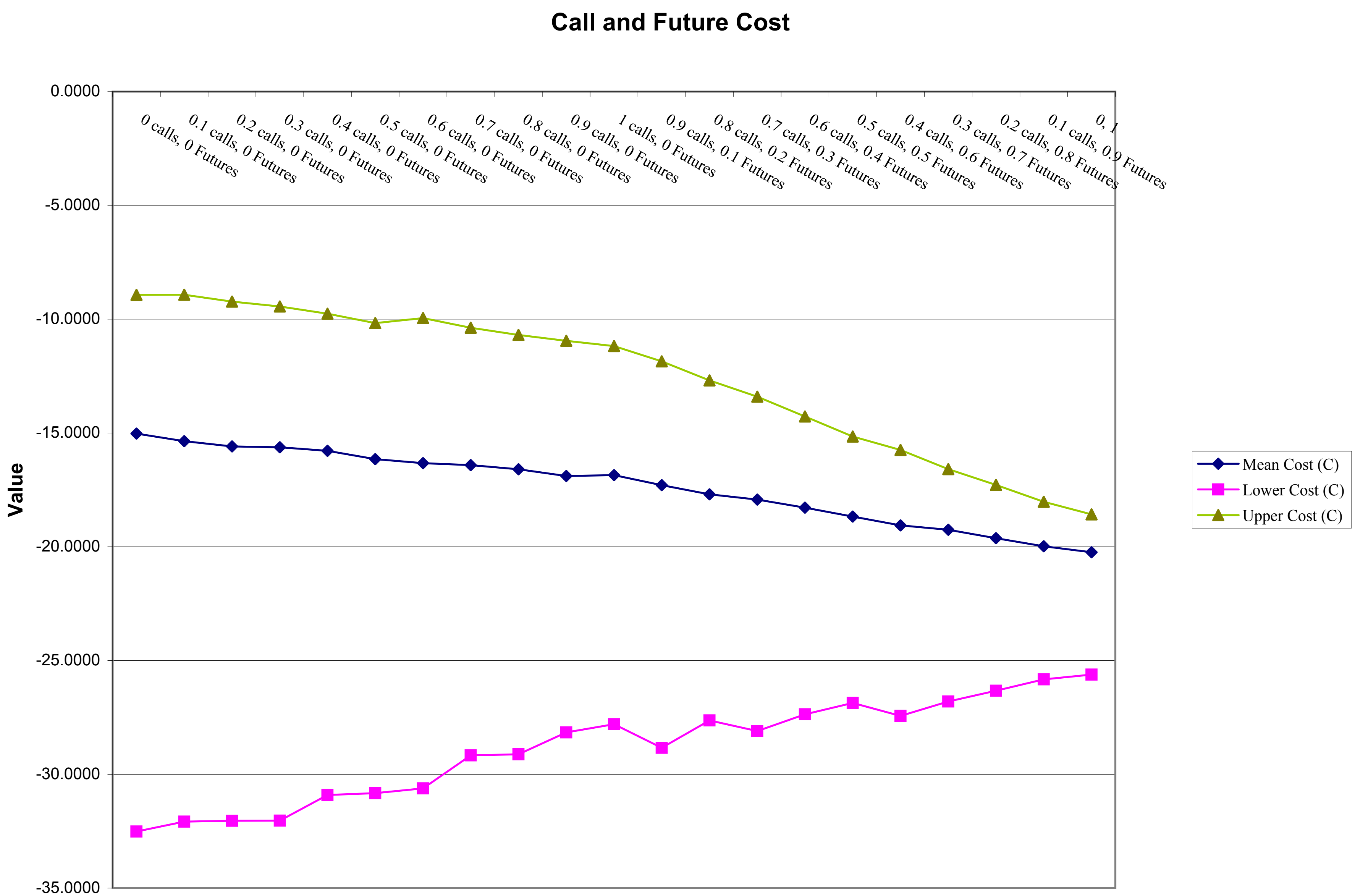
- Managerial Decision is taken upon consideration of the Expected Earnings $E\left(\widetilde{E}\right)$ and the lower percentile $E_{\text{Lower Percentile}}$

---

[2] An alternative intuitive objective function, which gives rise to the same optimal solution, is *Downside-Risk Minimization,* based on the semi-variance criterion $E\left(\widetilde{E}\right) - \alpha\sqrt{E\left(\max\left\{\left[E\left(\widetilde{E}\right) - \widetilde{E}\right], 0\right\}\right)^2}$.

Call and Future Cost





Call and Future Cost
Value
0.0000
-5.0000
-10.0000
-15.0000
-20.0000
-25.0000
-30.0000
-35.0000
0 calls, 0 Futures
0.1 calls, 0 Futures
0.2 calls, 0 Futures
0.3 calls, 0 Futures
0.4 calls, 0 Futures
0.5 calls, 0 Futures
0.6 calls, 0 Futures
0.7 calls, 0 Futures
0.8 calls, 0 Futures
0.9 calls, 0 Futures
1 calls, 0 Futures
0.9 calls, 0.1 Futures
0.8 calls, 0.2 Futures
0.7 calls, 0.3 Futures
0.6 calls, 0.4 Futures
0.5 calls, 0.5 Futures
0.4 calls, 0.6 Futures
0.3 calls, 0.7 Futures
0.2 calls, 0.8 Futures
0.1 calls, 0.9 Futures
0, 1
Mean Cost (C)
Lower Cost (C)
Upper Cost (C)

Structured Energy Derivative Products

- Linear Instruments

Traditional	Exotic
1. Forward/Futures contracts	1. Load-Following Services
2. Exchange of futures for physicals ("EFP")	2. Cross-Currency Swaps (e.g., Yen WTI Swap)
3. Swaps: Fixed for floating; floating for floating	3. Proxy Swaps on Illiquid Indices (e.g., Japan Crude-Oil Cocktail)

- Non-Linear Structures

Traditional	Exotic
1. Conventional American and European call and put options	1. Strip of *Daily* options
2. Option Collars	2. Cross-currency Exposure
3. Average options	3. Three Types of Average Options: Average Value of a Futures Contract; Average Value of Spot Prices; Swaption
4. Capped swaps; Extendible swaps; Cancellable swaps; Contingent-premium structures	4. Packaged Products: Three-Ways, Participating
	5. Spread options: Transportation; Basis; Spark (Natural gas – Electricity); Crack (Crude oil – Crude products); Frac (Natural gas – Natural gas liquids); Storage
	6. "Swing" options, with/without "ruthless" exercise
	7. Weather derivatives

Pricing Derivatives in Incomplete/Low-Liquidity Markets

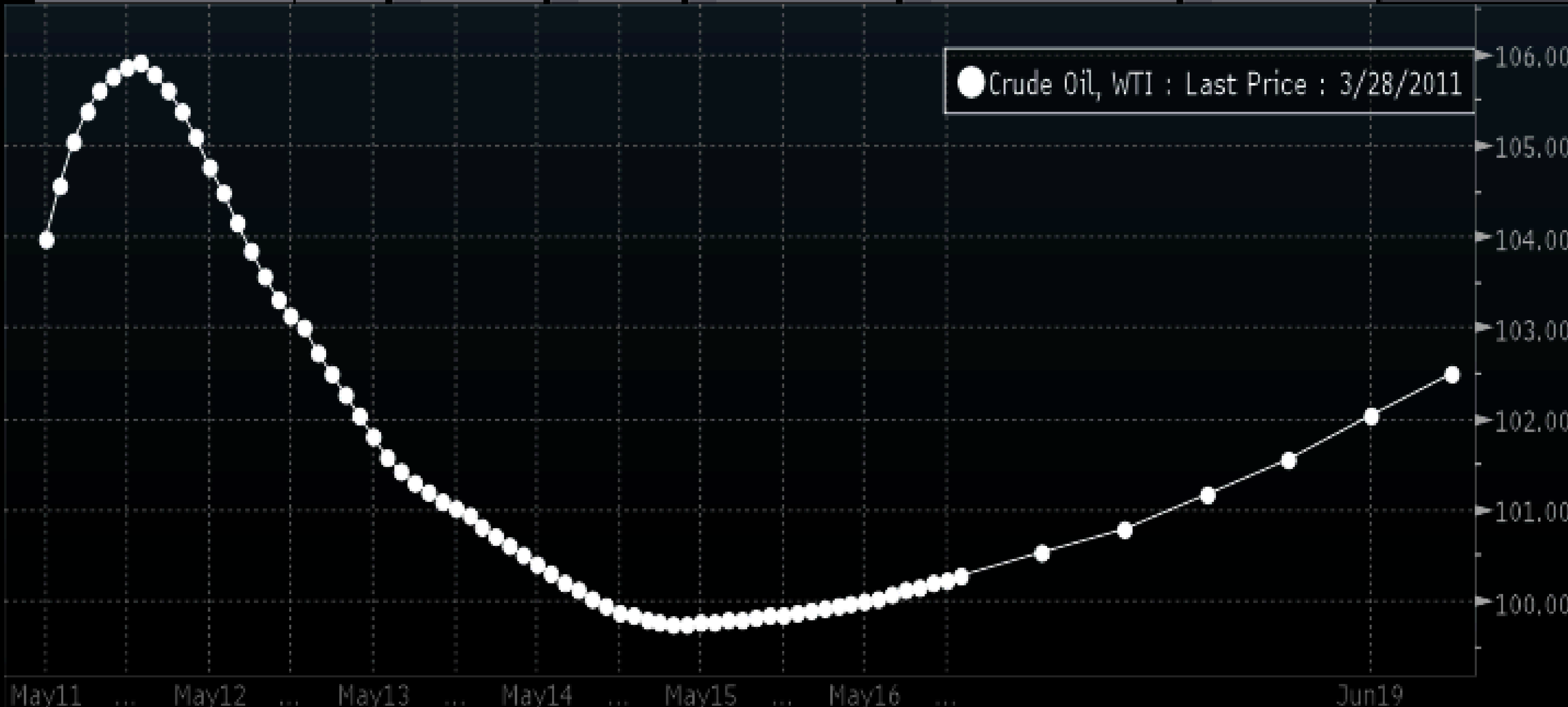
- Problems:
  1. Price-spiking behavior gives rise to so-called "incomplete markets," where no-arbitrage pricing no longer feasible
  2. Quantity (volumetric) uncertainty not hedgable.

     (Are/will weather derivatives provide an answer? Note that due to the impact of a non-zero market price of risk, weather derivatives should *not* be actuarially fair.)
  3. Other unceraintties: Credit risk, operational risk (outages), regulatory risk
- Example — Electricity Full Requirement/Load-Following:
  1. At the retail level, does *not* entail optionality
  2. In the absence of credit/operational risk, and if markets were complete, value is the riskfree rate-discounted present value of $E^*(P_T \cdot Q_T)$, where $E^*(\cdot)$ is the risk-neutral expectation
  3. Questions:
     (a) Would we accept joint LogNormality's
     $$E^*(P \cdot Q) = F \cdot E^*(Q) \exp\{\rho \sigma_F \sigma_Q T\}?$$
     (b) What do we do about the market price of risk for volumetric uncertainty — $E^*(Q) \neq E(Q)$?
     (c) How do we handle the non-rectangular block intra-day load?
     (d) What if long-dated futures prices F are illiquid?
- Other Examples: Interruptible contracts, swing options

<HELP> for explanation, <MENU> for similar functions. Comdty **CCRV**

90) Manage Chart | 91) Edit Chart | 92) Hide Entries | 93) View Table | CCRV - My Template

	Curve	Field	Source	CUR	Units	Relative Date	Date	Add Like
1)	CLA Comdty	Last P	Default	USD	barrel	1 Bus Day Ago	03/28/11	9) Select
2)		Last P	Default	USD		1 Bus Day Ago	__/__/__	10) Select
		Last P	Default	USD		1 Bus Day Ago	__/__/__	11) Select
		Last P	Default	USD		1 Bus Day Ago	__/__/__	12) Select



<HELP> for explanation. P233 Comdty OVDV

96) Settings 97) Refresh 98) Asset Commodity Volatility Surface

CLA Comdty 11/01/10 Bloomberg Surface Show Moneyness

WTI CRUDE FUTURE As of 08:00 (GMT-4:00) Strikes Spread

Contract	80.0%	90.0%	95.0%	97.5%	100.0%	102.5%	105.0%	110.0%	120.0%	150.0%	200.0%
Mar-13	28.85	27.58	27.00	26.72	26.45	26.20	25.98	25.62	25.20	25.65	28.19
Apr-13	28.58	27.36	26.82	26.57	26.32	26.10	25.90	25.57	25.19	25.62	28.13
May-13	28.31	27.14	26.64	26.41	26.19	25.99	25.82	25.53	25.19	25.60	28.07
Jun-13	28.07	26.95	26.49	26.28	26.08	25.90	25.75	25.49	25.19	25.58	28.01
Jul-13	27.81	26.75	26.32	26.13	25.96	25.81	25.67	25.45	25.19	25.56	27.94
Aug-13	27.58	26.56	26.17	26.00	25.85	25.72	25.60	25.41	25.18	25.54	27.86
Sep-13	27.36	26.39	26.03	25.88	25.75	25.63	25.53	25.36	25.16	25.51	27.77
Oct-13	27.11	26.20	25.87	25.73	25.62	25.53	25.44	25.30	25.13	25.46	27.66
Nov-13	26.88	26.02	25.72	25.60	25.51	25.42	25.35	25.23	25.08	25.41	27.53
Dec-13	26.68	25.87	25.59	25.48	25.39	25.32	25.26	25.15	25.02	25.35	27.40
Jun-14	25.41	24.88	24.72	24.67	24.63	24.60	24.57	24.54	24.50	24.83	26.36
Dec-14	24.33	24.07	24.00	23.98	23.96	23.96	23.95	23.95	23.99	24.33	25.46
Jun-15	23.48	23.48	23.48	23.48	23.47	23.47	23.48	23.49	23.56	23.97	25.05
Dec-15	22.85	23.04	23.08	23.09	23.10	23.10	23.10	23.12	23.20	23.64	24.58
Dec-16	22.80	22.73	22.72	22.73	22.74	22.75	22.76	22.79	22.83	22.96	23.12
Dec-17	21.03	21.38	21.60	21.73	21.86	22.00	22.12	22.33	22.62	22.41	21.04

90) Launch OVML Extrapolated 100%

1) Vol Table 2) 3D Surface 3) Term Analysis 4) Skew Analysis 6) Prices

<HELP> for explanation, <MENU> for similar functions. ComdtyCCRV

90) Manage Chart 91) Edit Chart 92) Hide Entries 93) View Table CCRV - My Template

	Curve	Field	Source	CUR	Units	Relative Date	Date	Add Like
1)	NGA Comdty	Last P	Default	USD	MMBtu	1 Bus Day Ago	03/28/11	9) Select
2)		Last P	Default	USD		1 Bus Day Ago	__/__/__	10) Select
		Last P	Default	USD		1 Bus Day Ago	__/__/__	11) Select
		Last P	Default	USD		1 Bus Day Ago	__/__/__	12) Select

<HELP> for explanation. P233 ComdtyOVDV

96) Settings | 97) Refresh | 98) Asset | Commodity Volatility Surface

NGA Comdty | 11/01/10 | Bloomberg Surface | Show Moneyness

NATURAL GAS FUTR As of 08:00 (GMT-4:00) Strikes Spread

Contract	80.0%	90.0%	95.0%	97.5%	100.0%	102.5%	105.0%	110.0%	120.0%	150.0%	200.0%
Aug-13	20.51	20.53	20.55	20.56	20.57	20.58	20.59	20.62	20.68	21.02	21.57
Sep-13	21.00	21.06	21.08	21.10	21.11	21.13	21.14	21.17	21.24	21.49	21.57
Dec-13	19.32	19.48	19.58	19.64	19.70	19.77	19.83	19.97	20.28	21.32	23.19
Mar-14	18.57	18.72	18.82	18.88	18.94	19.00	19.07	19.20	19.50	20.50	23.25
Jun-14	17.94	18.09	18.19	18.25	18.30	18.36	18.43	18.56	18.85	19.82	23.12
Jan-15	17.00	17.18	17.28	17.34	17.40	17.46	17.53	17.66	17.94	18.85	22.39
Feb-15	16.93	17.11	17.22	17.28	17.34	17.40	17.47	17.60	17.88	18.79	22.24
Mar-15	16.88	17.07	17.18	17.24	17.31	17.37	17.44	17.57	17.85	18.76	22.11
Apr-15	16.85	17.04	17.16	17.22	17.29	17.35	17.42	17.56	17.84	18.74	21.96
May-15	16.83	17.04	17.16	17.22	17.29	17.36	17.43	17.56	17.85	18.75	21.80
Jun-15	16.83	17.05	17.18	17.24	17.31	17.38	17.45	17.59	17.88	18.77	21.64
Jul-15	16.85	17.08	17.21	17.28	17.35	17.42	17.49	17.64	17.93	18.82	21.49
Aug-15	16.89	17.13	17.27	17.34	17.42	17.49	17.56	17.71	18.01	18.90	21.31
Oct-15	17.01	17.29	17.44	17.52	17.59	17.67	17.75	17.91	18.21	19.10	20.99
Nov-15	17.10	17.40	17.56	17.64	17.72	17.80	17.88	18.04	18.35	19.24	20.81
Dec-15	17.19	17.51	17.67	17.76	17.84	17.93	18.01	18.17	18.49	19.38	20.66

90) Launch OVML Extrapolated 100%

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

Calibrating the Two-Factor Schwartz-Smith Model

1. Under the two-factor Schwartz-Smith model, each futures contract price F_T satisfies[3]

$$\begin{aligned} d\ln F_T &= \exp\{-\kappa T\}\, dz_\chi + dz_\xi \\ \ln F_T &= \xi_0 + e^{-\kappa T}\chi_0 + \left(1 - e^{-\kappa T}\right)\chi_1 + \mu_\xi T + \tfrac{1}{2}\sigma_T^2 T \qquad (6) \\ \sigma_T^2 T &= \left(1 - e^{-2\kappa T}\right)\frac{\sigma_\chi^2}{2\kappa} + \sigma_\xi^2 T + 2\left(1 - e^{-\kappa T}\right)\frac{\rho_{\chi\xi}\sigma_\chi\sigma_\xi}{\kappa} \qquad (7) \end{aligned}$$

2. Letting c_T be prices of ATM-Forward (call or put) options, the eight parameters we would like to calibrate are

$$\mathbf{x} \equiv \{\, \kappa,\ \xi_0,\ \chi_0,\ \chi_1,\ \mu_\xi,\ \sigma_\chi,\ \sigma_\xi,\ \rho_{\chi\xi}\,\}\,.$$

On any given day use Solver (say) to perform the minimization:

$$\min_{\{\mathbf{x}\}} \left[\sum_{T=1/12}^{60/12}\left(\ln F_T - \ln \widehat{F}_T\right)^2 + \sum_{T=1/12}^{16/12}\left(\ln c_T - \ln \hat{c}_T\right)^2\right]$$

where $\widehat{F}_T$ and $\hat{c}_T$ are the *data* on any given day

[3] The expression $\frac{1}{2}\sigma_T^2 T$ in eq. (6) follows from the property of the LogNormal distribution: If $\ln x \sim N\left(\mu,\, \sigma^2\right)$, then the log expectations of x is given by $\ln E(x) = \mu + \frac{1}{2}\sigma^2$.

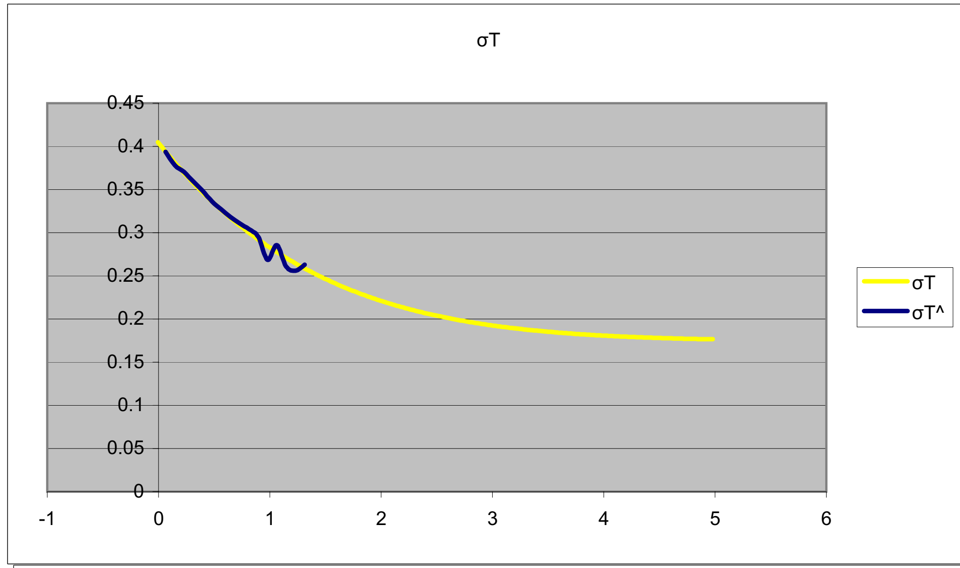
Current Date 1/31/2007

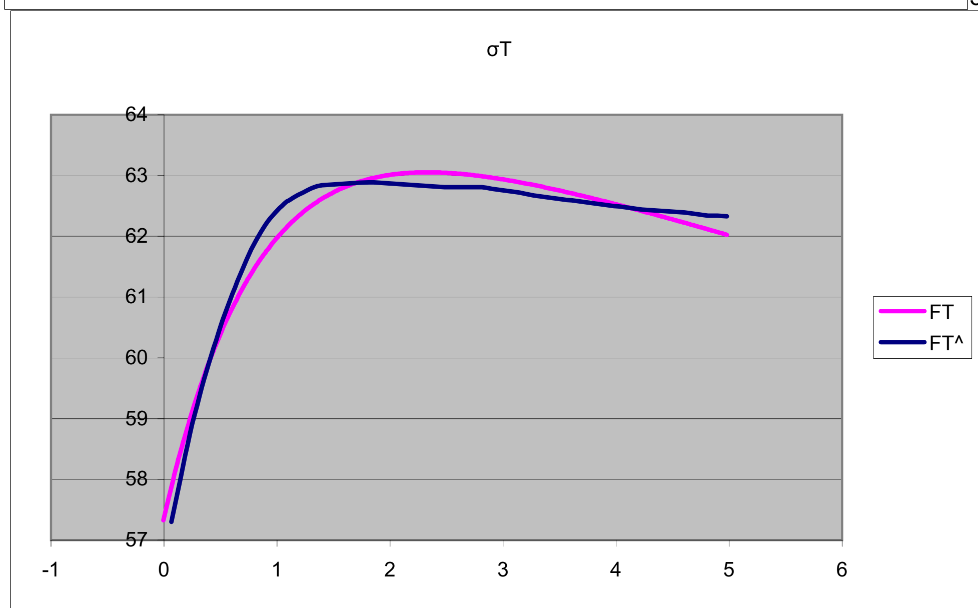
	Free Parameters	Adjustment
κ	0.630876762	0
X_0	1.776136537	0
X_1	1.910689368	0
μ_ξ	-0.025761377	0
σ_X	0.534684723	0
σ_ξ	0.182279128	0
$\rho_{X\xi}$	-0.8	0
q	0	0
ξ_0	2.273408843	0

Time Period - Yrs	5

Abs or **Squared**	**Squared**
β	**1**
quadratic (y/n)	**y**

T ln (F_T) $\sigma_T^2 T$ σ_T F_T C_T F_T^ σ_T^





I/A
I/A
I/A
I/A
I/A
3937
3937
3937
3937
3937
3937
3781
3781
3781
3781
3781
3781
3704
704
704
704
704
704
591
591
591
591
591
591
487
487
487
487
487
487
362
362
362
6/12 4.1623 0.037331 0.331267 60.49329 3.778439 60.41 0.3362

SUMMARY: Challenges in Risk Management

- Risk-Management from a Corporate Perspective:
  - How to Model, How to Estimate, and When to Use *Risk Premia*
  - Implementing a Corporate-Level Risk-Management Policy
  - Motivation for Structured Products in Energy
- Pricing Derivatives in Incomplete/Low-Liquidity Markets
- Valuation of Long-Dated Assets: The Challenge of *Extrapolation*