Commodity Futures Returns:
Limits to Arbitrage and Hedging

Viral Acharya, Lars Lochstoer, and Tarun Ramadorai

NYU, Columbia University, and Oxford University

Swissquote conference 2013
Commodity futures risk premiums

- What drives level and dynamics of commodity futures risk premiums?
  - Not market beta (level) or predictors like $p-d$ ratio or term spread (dynamics)

Chen and Xiong (2012): speculators consume liquidity during financial crisis

Kang, Rouwenhorst, and Tang (2013): hedgers sell to momentum traders and profit on reversal over next days

Our paper:
- Use instrument (producer default risk) for 'true' hedging demand of producers
- Interaction with arbitrage capital/speculator risk appetite
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- Keynes: Hedging pressure, speculator risk aversion

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Limits-to-arbitrage and hedging pressure

- Measure of employed arbitrage capital versus sensitivity of the Crude Oil futures risk premium to producer hedging pressure

B-D Growth vs. Covariance (Prod. Def. Risk, Crude futures RP)

Corr = -0.50***

Covariance

B-D growth
Limits-to-arbitrage and hedging pressure

- Measure of employed arbitrage capital versus sensitivity of the Crude Oil futures risk premium to producer hedging pressure

Do limits to arbitrage cause corporate hedging activity to matter for asset price determination?

Do limits to arbitrage change producer hedging behavior?

Through this channel, do limits to arbitrage affect spot prices?

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Managers maximize firm value BUT also wants to minimize variance
- a role for futures market
- hedging has, however, *no* impact on commodity spot or futures prices
Real-world markets have frictions. An important one: Limits to Arbitrage.

- Shleifer and Vishny, 1997; Gromb and Vayanos, 2002; Brunnermeier and Pedersen, 2009.
Propose simple equilibrium model that formalizes the "limits-to-hedging"-argument
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Novel empirical analysis

- Propose measures of producers’ default risk as proxies for managers’ desire to hedge price risk:
Propose simple equilibrium model that formalizes the "limits-to-hedging"-argument

Novel empirical analysis
  - Propose measures of producers’ default risk as proxies for managers’ desire to hedge price risk:

Confirm model predictions in U.S. Crude Oil, Heating Oil, Gasoline, and Natural Gas commodity markets
  - Key result: a 1 st.dev. increase in aggregate producer fundamental hedging demand \( \rightarrow \) a 4% increase in the \textit{quarterly} futures risk premium
The model

- Two periods (empirical analysis focuses on short-term futures):
  1. Supply of commodity, $g_t$, pre-determined
  2. $r = 1/E[\Lambda] - 1; d \in [0, 1)$
The model

- Two periods (empirical analysis focuses on short-term futures):
  1. Supply of commodity, \( g_t \), pre-determined
  2. \( r = 1/E[\Lambda] - 1; \ d \in [0, 1) \)

- Consumers’ inverse demand function:

\[
S_t = \omega \left( \frac{A_t}{Q_t} \right)^{1/\varepsilon},
\]

where: \( Q_t = g_t - I_t + (1-d)I_{t-1} \)
\( \ln A_t - \ln A_{t-1} \sim N(\mu, \sigma^2) \) is demand shock
\( S_t \) is the commodity spot price
\( \omega \) and \( \varepsilon \) are positive constants.
Producers

Competitive, price-takers. Representative firm:

$$\max_{\{ I, h_p \}} S_0 (g_0 - I) + E \left[ \Lambda \left\{ S_1 \left( (1 - d) I + g_1 \right) + h_p (F - S_1) \right\} \right] \ldots$$

$$- \frac{\gamma_p}{2} \text{Var} \left[ S_1 \left( (1 - d) I + g_1 \right) + h_p (F - S_1) \right]$$

subject to

$$I \geq 0,$$

where $\gamma_p$ governs the degree of aversion to variance in future earnings.
Producers

Competitive, price-takers. Representative firm:

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subject to

$$I \geq 0,$$

where $\gamma_p$ governs the degree of aversion to variance in future earnings.

**Note:** if $E [\Lambda (S_1 - F)] > 0$, costly in terms of firm value to hedge by going short
Representative Speculator Objective Function

- Capital constraints (e.g., due to VaR constraint as in Danielsson, Shin, and Zigrand (2008)) in the form of variance penalty:

\[
\max_{h_s} h_s E [\Lambda (S_1 - F)] - \frac{\gamma_s}{2} \text{Var} [h_s (S_1 - F)]
\]

- Equilibrium: Futures and spot market clears, producer and speculator FOCs hold \((\sigma_f = \sigma_S / F)\):

\[
E \left[ \frac{S_1 - F}{F} \right] = - \underbrace{\text{Corr} (\Lambda, S_1) \text{ Std} (\Lambda) \sigma_f}_{\text{usual risk term}} + \frac{\gamma_p \gamma_s}{\gamma_p + \gamma_s} \sigma_f^2 FQ_1
\]

\{z\text{price pressure}\}
Comparative Statics and Empirical Predictions

1. Increasing producer risk aversion (fundamental hedging demand), $\gamma_p$:
   1. Increases optimal number of short futures contracts (hedging)
   2. Increases futures risk premium
   3. Decreases inventory
   4. Decreases current spot price and increases expected future spot price

Increasing speculator risk tolerance, $\gamma_s$:

1. Decreases futures risk premium
2. Increases inventory
3. Increases current spot price

Interaction between speculator risk tolerance and effect of hedging demand on risk premium, spot price, and inventory.
Comparative Statics and Empirical Predictions

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3. Interaction between speculator risk tolerance and effect of hedging demand on risk premium, spot price, and inventory.
Overview of Empirical Approach

1. Producer default risk as proxy for time-varying fundamental hedging demand ($\gamma_p$)
   - Sample: Crude Oil, Heating Oil, Gasoline, and Natural Gas (US: 1980-2011)

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4. Control for other possible omitted determinants of futures risk premium
   1. Controls: Standard predictive variables, covariances with equity pricing factors
   2. Volatility interaction (implied by model)
   3. Arbitrage capital interaction (implied by model)
   4. Hedgers versus non-hedgers
   5. Managerial risk aversion
Firm-level evidence

Firm-level (SIC code 1310, 1311; gas, oil producers) default risk proxies

1 Zmijewski-score (Zmijewski, 1984):

\[
\text{Zmijewski-score} = -4.3 - 4.5 \times \frac{\text{NetInc}}{\text{TotAssets}} + 5.7 \times \frac{\text{TotDebt}}{\text{TotAssets}} - 0.004 \times \frac{\text{CurrentAssets}}{\text{CurrentLiabilities}}.
\]
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1. Zmijewski-score (Zmijewski, 1984):

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-0.004 \times \frac{\text{CurrentAssets}}{\text{CurrentLiabilities}}. \]

2. KMV’s Expected Default Frequency (EDF)

\[ EDF \approx \Phi \left( -\left( \frac{\ln(V/F) + (\mu - 0.5\sigma_V^2)T}{\sigma_V\sqrt{T}} \right) \right) \]
Firm-level evidence (cont’d)

From EDGAR quarterly and annual reports 2000 – 2010

*Panel A: Summary statistics on micro-hedging*

<table>
<thead>
<tr>
<th>For each quarter and firm:</th>
<th># Firm-quarter obs.</th>
<th>Fraction &quot;yes&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Use derivatives?</td>
<td>2,400</td>
<td>88.0%</td>
</tr>
<tr>
<td>Futures or forwards?</td>
<td>547</td>
<td>47.7%</td>
</tr>
<tr>
<td>Swaps?</td>
<td>1,781</td>
<td>80.6%</td>
</tr>
<tr>
<td>Options?</td>
<td>1,800</td>
<td>81.8%</td>
</tr>
<tr>
<td>Significant short crude?</td>
<td>1,738</td>
<td>69.8%</td>
</tr>
<tr>
<td>Significant long crude?</td>
<td>964</td>
<td>1.0%</td>
</tr>
</tbody>
</table>
Firm-level evidence (cont’d)

From EDGAR quarterly and annual reports 2000 – 2010

• Is hedging positively related to default risk? Yes!

Panel B: Crude oil hedging vs. firm-level default risk measures

<table>
<thead>
<tr>
<th>Independent variable: Firm-quarter Zm-score</th>
<th>Independent variable: Firm-quarter log EDF-score</th>
</tr>
</thead>
<tbody>
<tr>
<td>β  (S.E.) Fixed effect  $R^2_{adj}$  N</td>
<td>β  (S.E.) Fixed effect  $R^2_{adj}$  N</td>
</tr>
<tr>
<td>dprobit 0.053*** (0.014) Time f.e. 6.1% 926</td>
<td>dprobit 0.057*** (0.009) Time f.e. 7.3% 1,100</td>
</tr>
<tr>
<td>0.055*** (0.019) Firm f.e. 18.6% 548</td>
<td>0.022*** (0.008) Firm f.e. 20.6% 660</td>
</tr>
<tr>
<td>0.058*** (0.020) Time &amp; firm f.e. 25.2% 548</td>
<td>0.058*** (0.016) Time &amp; firm f.e. 26.8% 660</td>
</tr>
<tr>
<td>OLS 0.055*** (0.014) Time f.e. 5.0% 926</td>
<td>OLS 0.057*** (0.009) Time f.e. 6.0% 1,100</td>
</tr>
<tr>
<td>0.034*** (0.011) Firm f.e. 29.8% 926</td>
<td>0.011** (0.004) Firm f.e. 31.6% 1,100</td>
</tr>
<tr>
<td>0.041*** (0.011) Time &amp; firm f.e. 32.7% 926</td>
<td>0.036*** (0.009) Time &amp; firm f.e. 34.7% 1,100</td>
</tr>
</tbody>
</table>
Aggregate producer default risk
Equal weight default risk measures each quarter for SIC code 1310, 1311
Aggregate producer default risk
Correlation average Edgar-based short crude exposure of producers vs Aggregate Default Measures

Time-series of EDGAR aggregate Zm-score versus aggregate hedging (correlation = 0.34**)
Futures Forecasting Regressions

From the model:

\[ E \left[ \frac{S - F}{F} \right] = -R_f \text{Cov} (\Lambda, S/F) + R_f \frac{\gamma_p \gamma_s}{\gamma_p + \gamma_s} \sigma^2_{S/F} FQ \]
Futures Forecasting Regressions

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- Forecasting regressions:
  \[ FuturesReturns_{t+1} = \beta \text{DefRisk}_t + \text{ControlVariables}_t + \epsilon_{t+1} \]
Futures Forecasting Regressions

- From the model:

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E \left[ \frac{S - F}{F} \right] = -R_f \text{Cov} (\Lambda, S/F) + R_f \gamma_p \gamma_s \sigma^2_{S/F} FQ
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- Forecasting regressions:

\[
FuturesReturns_{t+1} = \beta \text{DefRisk}_t + \text{ControlVariables}_t + \epsilon_{t+1}
\]

<table>
<thead>
<tr>
<th></th>
<th>Crude Oil</th>
<th>Heating Oil</th>
<th>Gasoline</th>
<th>Natural Gas</th>
<th>All</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>EDF</td>
<td>Zm</td>
<td>EDF</td>
<td>Zm</td>
<td>EDF</td>
</tr>
<tr>
<td>Dependent variable: next-quarter futures return ((r^i_{t,t+1}))</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DefRisk(_t)</td>
<td>0.058**</td>
<td>0.045***</td>
<td>0.047**</td>
<td>0.035**</td>
<td>0.040*</td>
</tr>
<tr>
<td></td>
<td>(0.023)</td>
<td>(0.017)</td>
<td>(0.021)</td>
<td>(0.017)</td>
<td>(0.026)</td>
</tr>
<tr>
<td>Controls?</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>(R^2)</td>
<td>10.6%</td>
<td>9.7%</td>
<td>9.6%</td>
<td>8.5%</td>
<td>15.2%</td>
</tr>
<tr>
<td>(N)</td>
<td>107</td>
<td>110</td>
<td>122</td>
<td>125</td>
<td>100</td>
</tr>
</tbody>
</table>

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Identification: Hedger vs Non-Hedger

Classification based on EDGAR quarterly reports on hedging activity (crude oil returns 2000-2011)

<table>
<thead>
<tr>
<th>Hedgers vs. non-hedgers</th>
<th>Zm-score</th>
<th>EDF-score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hedger default risk ($\beta_H$)</td>
<td>0.052** (0.022)</td>
<td>0.096*** (0.028)</td>
</tr>
<tr>
<td>Non-hedger default risk ($\beta_{NH}$)</td>
<td>$-0.017$ (0.013)</td>
<td>$-0.004$ (0.020)</td>
</tr>
<tr>
<td>Controls?</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>$R^2$</td>
<td>5.6%</td>
<td>11.9%</td>
</tr>
<tr>
<td>$N$</td>
<td>172</td>
<td>172</td>
</tr>
</tbody>
</table>
Identification: Volatility interaction

Hedging pressure should have larger price impact when futures return volatility is high:

<table>
<thead>
<tr>
<th>Dependent variable: next quarter futures return ( r_{t,t+1} )</th>
<th>Joint regression across commodities</th>
</tr>
</thead>
<tbody>
<tr>
<td>( RV_t )</td>
<td>EDF</td>
</tr>
<tr>
<td>( DefRisk_t )</td>
<td>Zm</td>
</tr>
<tr>
<td>( RV \times DefRisk )</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>EDF</th>
<th>Zm</th>
</tr>
</thead>
<tbody>
<tr>
<td>( RV_t )</td>
<td>-0.002</td>
<td>-0.007</td>
</tr>
<tr>
<td></td>
<td>(0.013)</td>
<td>(0.012)</td>
</tr>
<tr>
<td>( DefRisk_t )</td>
<td>0.036**</td>
<td>0.033*</td>
</tr>
<tr>
<td></td>
<td>(0.016)</td>
<td>(0.018)</td>
</tr>
<tr>
<td>( RV \times DefRisk )</td>
<td>0.022**</td>
<td>0.015**</td>
</tr>
<tr>
<td></td>
<td>(0.010)</td>
<td>(0.007)</td>
</tr>
<tr>
<td>controls?</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>( R^2 )</td>
<td>8.6%</td>
<td>7.7%</td>
</tr>
<tr>
<td>( N )</td>
<td>404</td>
<td>416</td>
</tr>
</tbody>
</table>

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Identification: Managerial risk aversion

ExecuComp (2000-2011): risk averse mgrs have high company stock holding, low option holdings

**Panel A: Crude oil hedging vs. managerial risk-aversion**

Indep.var: Indicator for top half firm equity and bottom half options / salary

<table>
<thead>
<tr>
<th>Specification</th>
<th>$\beta_{execu}$</th>
<th>(S.E.)</th>
<th>$\beta_{size}$</th>
<th>(S.E.)</th>
<th>Time fixed effect?</th>
<th>$R^2_{adj}$</th>
<th>$N$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.187**</td>
<td>(0.092)</td>
<td>-0.086**</td>
<td>(0.038)</td>
<td>No</td>
<td>23.1%</td>
<td>291</td>
</tr>
<tr>
<td>2</td>
<td>0.206**</td>
<td>(0.104)</td>
<td>-0.084**</td>
<td>(0.042)</td>
<td>Yes</td>
<td>29.2%</td>
<td>291</td>
</tr>
</tbody>
</table>

**Panel B: Managerial risk aversion and default risk**

<table>
<thead>
<tr>
<th></th>
<th>Zm-score</th>
<th>EDF-score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Risk-averse managers’ default risk ($\beta_{RA}$)</td>
<td>0.048* (0.026)</td>
<td>0.044* (0.026)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.016 (0.022)</td>
</tr>
<tr>
<td>Risk-tolerant managers’ default risk ($\beta_{RT}$)</td>
<td>-0.007 (0.038)</td>
<td>0.009 (0.040)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.004 (0.039)</td>
</tr>
</tbody>
</table>

Controls? | No | Yes | No | Yes
$R^2$ | 7.7% | 11.0% | 6.0% | 11.6%
$N$ | 272 | 272 | 272 | 272
Spot Forecasting Regressions

\[
\text{SpotReturns}_{t+1} = \beta \text{DefRisk}_t + \text{ControlVariables}_t + \epsilon_{t+1}
\]

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<td>Zm</td>
<td>EDF</td>
<td>Zm</td>
<td>EDF</td>
</tr>
<tr>
<td>(\text{DefRisk}_t)</td>
<td>0.056**</td>
<td>0.043**</td>
<td>0.038**</td>
<td>0.033**</td>
<td>0.051**</td>
</tr>
<tr>
<td></td>
<td>(0.023)</td>
<td>(0.018)</td>
<td>(0.019)</td>
<td>(0.016)</td>
<td>(0.023)</td>
</tr>
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<td>Controls?</td>
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<td>Yes</td>
<td>Yes</td>
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<td>Yes</td>
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<tr>
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<td>18.0%</td>
<td>16.9%</td>
<td>19.2%</td>
<td>19.1%</td>
<td>17.7%</td>
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<td>110</td>
<td>122</td>
<td>125</td>
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- Common component in futures risk premium and expected spot price change
  - Due to inventory arbitrage
  - I.e., basis not good predictor of time-series of futures returns
Speculator capital

Measure of Speculator Risk Tolerance:

- Adrian and Shin (2008), Etula (2009): growth in Broker-Dealer assets relative to Household Assets
  - Scaled by ratio of Broker-Dealer assets to Household assets (Flow of Funds data)
Speculator capital

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<td>(joint test across commodities)</td>
</tr>
<tr>
<td>EDF</td>
</tr>
<tr>
<td>Zm</td>
</tr>
<tr>
<td>(BD_t)</td>
</tr>
<tr>
<td>((0.011))</td>
</tr>
<tr>
<td>(DefRisk_t)</td>
</tr>
<tr>
<td>((0.015))</td>
</tr>
<tr>
<td>(BD \times DefRisk)</td>
</tr>
<tr>
<td>((0.007))</td>
</tr>
</tbody>
</table>

controls? yes yes
\(R^2\) 13.7% 10.9%
\(N\) 408 420
Hedging Pressure vs. Arbitrage Activity

- Already showed interaction effect in quarterly regressions

- Lower frequency relation striking:
  - Arb capital as source of covariation between futures risk premium and hedging demand:
    - Annual overlapping quarterly: \( \sum_{j=0}^{3} r_{t+1+j} \times DefRisk_{t+j} \) vs. \( \sum_{j=0}^{3} BD_{t+j} \)

- Arb capital predicted to be inversely related to effect of hedging pressure on the risk premium.
Hedging Pressure vs. Arbitrage Activity (cont’d)

- Producers EDF and Crude oil returns

![Graph 1: B-D growth vs. Covariance(Producer EDF, Crude futures risk premium)]

- Corr = -0.50***

![Graph 2: B-D growth vs. Covariance(Producer Zm, Crude futures risk premium)]

- Corr = -0.35**
Hedging Pressure vs. Arbitrage Activity (cont’d)

- Refiners EDF and Gasoline crack spread returns
Summary

- We show that a refinement of the 'old' hedging pressure story is important for understanding commodity futures risk premiums and spot price dynamics
  - Default risk as instrument for commercial positions that are in fact hedges
  - Interaction with speculator risk appetite

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- Support for limits-to-arbitrage / market segmentation
  - interaction with producer hedging demand
  - speculator capital supply in the futures market has real effects
  - recent debate: increased risk appetite of speculators decreases cost of hedging, which increases inventory, which increases spot prices. However, risk-sharing arguments unlikely to explain magnitude of historical price gyrations