

# **RISK PREMIA IN COMMODITY FUTURES MARKETS**

**Aaron Smith**

**University of California, Davis**

**<http://asmith.ucdavis.edu>**

## Average Percentage Change in Daily Futures Prices (Annualized)

|                               | <b>Mean</b> |
|-------------------------------|-------------|
| <b><i>Grains/Oilseeds</i></b> |             |
| Corn                          | -0.48       |
| Soybeans                      | -2.65       |
| <b><i>Foodstuffs</i></b>      |             |
| Cocoa                         | -9.50       |
| Coffee                        | 4.71        |
| Sugar                         | -9.74       |
| <b><i>Metals</i></b>          |             |
| Copper                        | 1.47        |
| Gold                          | -8.78       |
| <b><i>Energy</i></b>          |             |
| Crude Oil                     | 4.97        |
| Natural Gas                   | 11.78       |
| <b><i>Animal Products</i></b> |             |
| Live Cattle                   | 2.32        |
| Pork Bellies                  | 0.86        |
| <b><i>Stock Index</i></b>     |             |
| S&P 500                       | 11.68       |

**Sample period: 1981-2000**

## Average Percentage Change in Daily Futures Prices (Annualized)

|                        | Mean         | <i>t</i> -statistic | <i>n</i> | # of Days |
|------------------------|--------------|---------------------|----------|-----------|
| <i>Grains/Oilseeds</i> |              |                     |          |           |
| Corn                   | -0.48        | -0.13               | 36,814   | 5,049     |
| Soybeans               | -2.65        | -0.63               | 46,434   | 5,049     |
| <i>Foodstuffs</i>      |              |                     |          |           |
| Cocoa                  | -9.50        | -1.65               | 38,307   | 5,016     |
| Coffee                 | 4.71         | 0.70                | 34,560   | 4,943     |
| Sugar                  | -9.74        | -1.33               | 34,223   | 5,015     |
| <i>Metals</i>          |              |                     |          |           |
| Copper                 | 1.47         | 0.32                | 80,533   | 5,033     |
| Gold                   | <b>-8.78</b> | -2.45*              | 74,314   | 5,029     |
| <i>Energy</i>          |              |                     |          |           |
| Crude Oil              | 4.97         | 0.88                | 84,104   | 4,454     |
| Natural Gas            | <b>11.78</b> | 2.02*               | 56,724   | 2,693     |
| <i>Animal Products</i> |              |                     |          |           |
| Live Cattle            | 2.32         | 0.97                | 33,611   | 5,053     |
| Pork Bellies           | 0.86         | 0.13                | 28,650   | 5,053     |
| <i>Stock Index</i>     |              |                     |          |           |
| S&P 500                | <b>11.68</b> | 2.44*               | 21,464   | 4,724     |

**Sample period: 1981-2000**

## Average Percentage Change in Daily Futures Prices (Annualized)

|                               | Mean  | <i>t</i> -statistic | <i>n</i> | # of Days |
|-------------------------------|-------|---------------------|----------|-----------|
| <b><i>Grains/Oilseeds</i></b> |       |                     |          |           |
| Oats                          | -6.13 | -1.06               | 23,733   | 4,684     |
| Wheat                         | -3.80 | -0.95               | 32,062   | 5,049     |
| Soybean Meal                  | -1.03 | -0.22               | 46,252   | 5,049     |
| Soybean Oil                   | -3.27 | -0.70               | 48,244   | 5,049     |
| <b><i>Industrials</i></b>     |       |                     |          |           |
| Cotton                        | 0.61  | 0.17                | 38,884   | 5,024     |
| Lumber                        | -4.17 | -0.94               | 32,155   | 5,053     |
| <b><i>Metals</i></b>          |       |                     |          |           |
| Platinum                      | -0.10 | -0.02               | 25,849   | 5,018     |
| Silver                        | -8.55 | -1.37               | 71,191   | 5,030     |
| <b><i>Energy</i></b>          |       |                     |          |           |
| Gasoline                      | 12.46 | 1.88                | 41,821   | 4,031     |
| Heating Oil                   | 5.03  | 0.92                | 68,237   | 5,018     |
| <b><i>Animal Products</i></b> |       |                     |          |           |
| Feed Cattle                   | 2.82  | 1.16                | 37,381   | 5,053     |
| Lean Hogs                     | 4.36  | 1.32                | 43,837   | 5,053     |

**Sample period: 1981-2000**

## Futures Contracts: What Are They?

- Futures exchanges **emerged in 1870s** as steamships, railroads, and bulk storage expanded the scope of commodity markets
- A commitment to buy/sell a commodity for a particular price on a particular future date
- Traded on **exchanges** all over the world, including Chicago Board of Trade, Chicago Mercantile Exchange, New York Mercantile Exchange, and the Coffee, Sugar, and Cocoa Exchange

# What Determines Futures Prices?

## 1. Risk Management Theory

- risk-averse agents hedge
- speculators earn risk premium

## 2. Theory of Storage

- arbitrage determines futures prices
- futures price equals spot price plus cost of carry, unless supplies are short

## 3. Rational Expectations Theory

- futures price equals risk-adjusted prediction of spot price

## Arbitrage

Example: Gold futures quotes on 1/10/07 (yesterday)

| Delivery  | Price    |
|-----------|----------|
| Immediate | \$611.60 |
| Apr 07    | \$619.40 |

**Arbitrage trading strategy:**

Today: (i) borrow **\$611.60** (current 3-month T-Bill rate = 4.9%)

(ii) buy gold for **\$611.60**

(iii) short Apr 07 futures position to lock in price of **\$619.40**

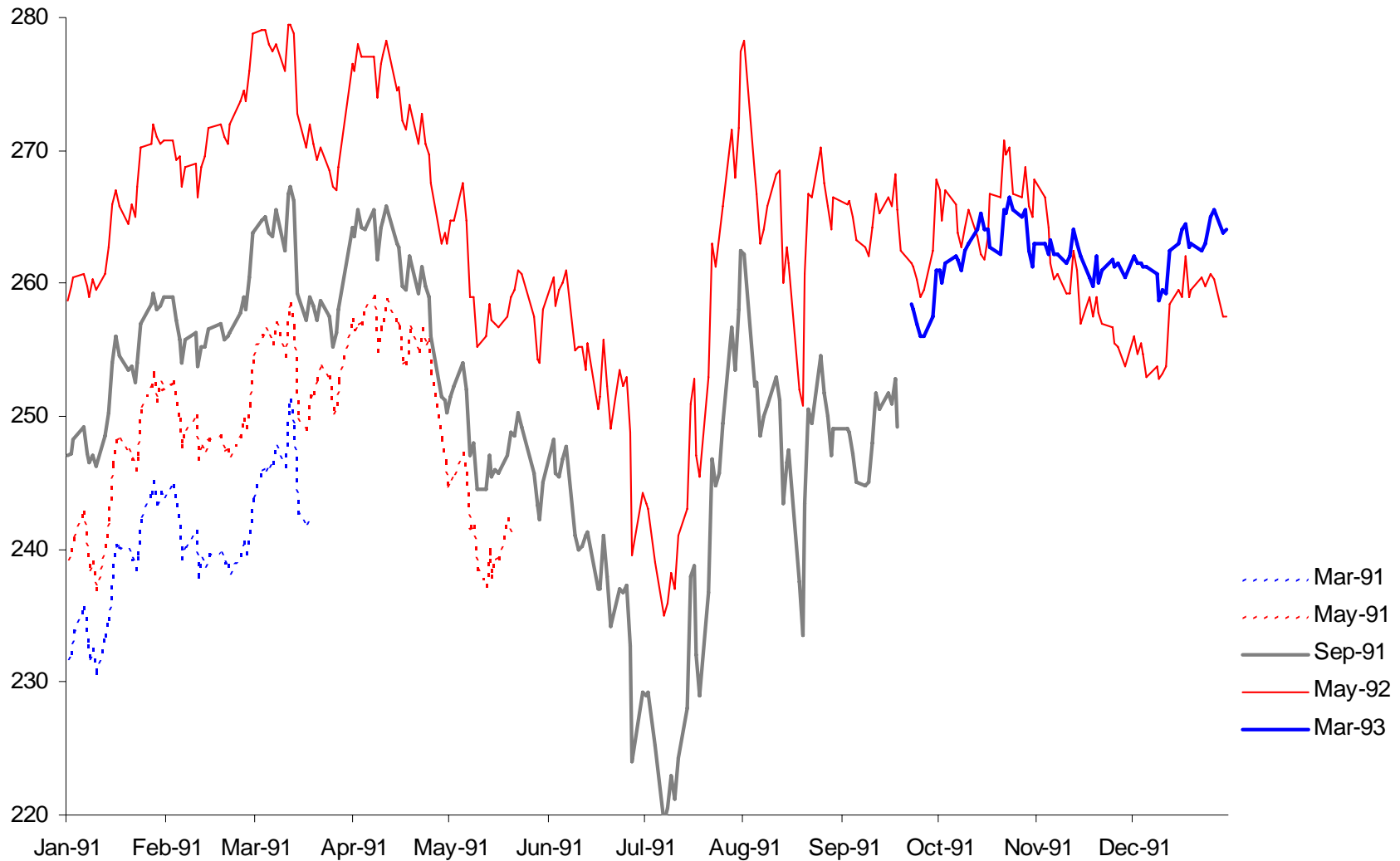
April: (i) sell gold for **\$619.40**

(ii) repay loan of (**\$611.60**) plus int (**\$7.49**), total = **\$619.09**

## Arbitrage

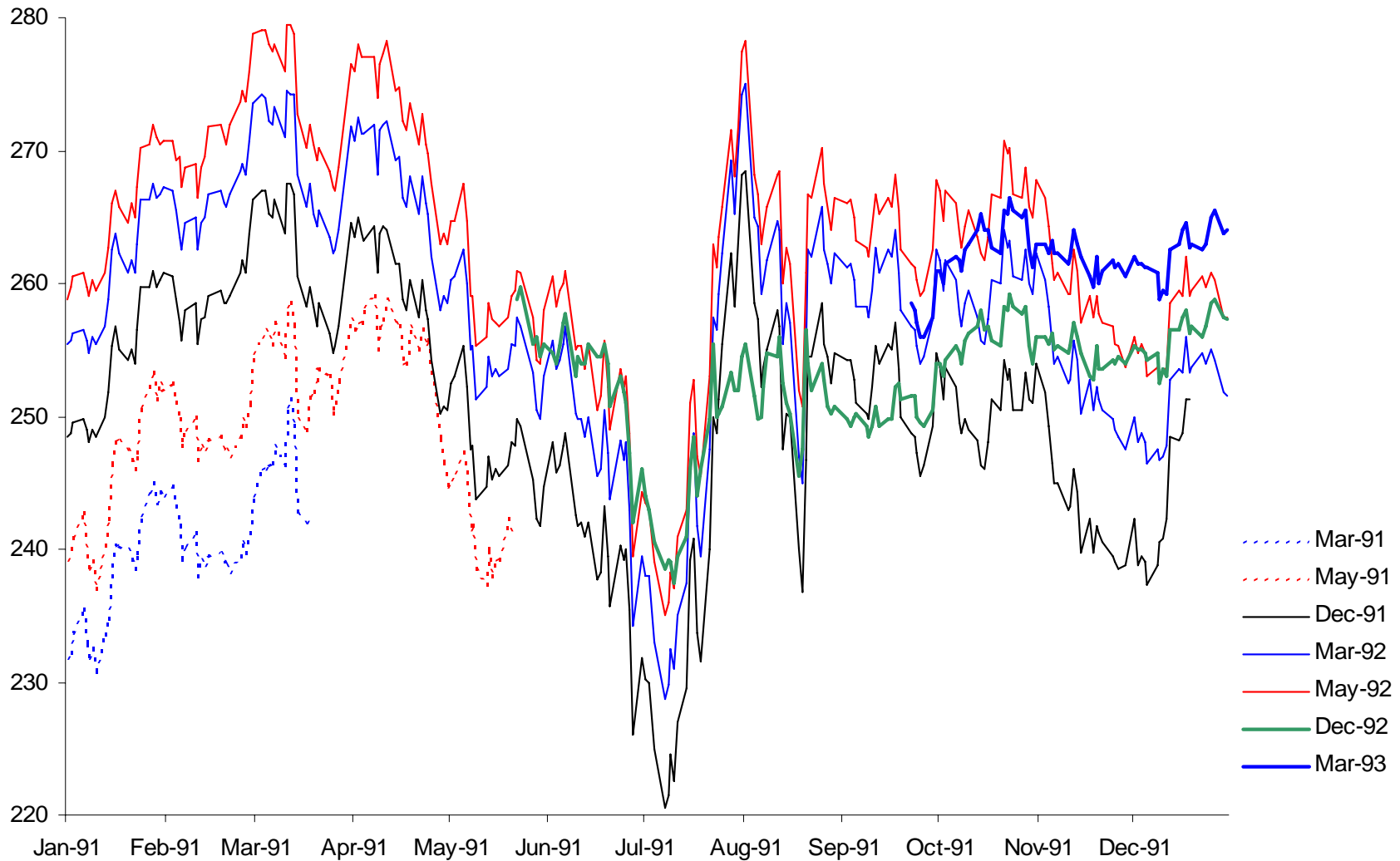
- More distant futures price equals nearby futures price plus **cost of carry**
- Cost of carry includes interest, storage fees, and “convenience yield”
- Arbitrage pricing implies that futures prices changes come from one of two sources:
  - (i) a change in the spot **price level**
  - (ii) a change in the **cost of carry**

# Futures Prices as Partially Overlapping Time Series (POTS)



Daily prices of several **corn** futures contracts that traded in 1991.

# Futures Prices as Partially Overlapping Time Series (POTS)



Daily prices of several **corn** futures contracts that traded in 1991.

## Rational Expectations

- Futures price equals risk-adjusted prediction of spot price
- Change in futures price should not be systematically different from zero, unless there is a risk premium (or irrationality).
- Mathematically,  $E(F_{t,T} - F_{t-1,T}) = \text{risk premium}$

### Example: Gold futures quotes

| Date      | Delivery | Price    |
|-----------|----------|----------|
| Yesterday | Apr 07   | \$619.40 |
| Today     | Apr 07   | \$621.00 |

## Basic POTS Model

$$\frac{F_{t,T} - F_{t-1,T}}{F_{t-1,T}} = \theta_1 \varepsilon_{1t} + \theta_2 \varepsilon_{2t} + \lambda u_{t,T}$$

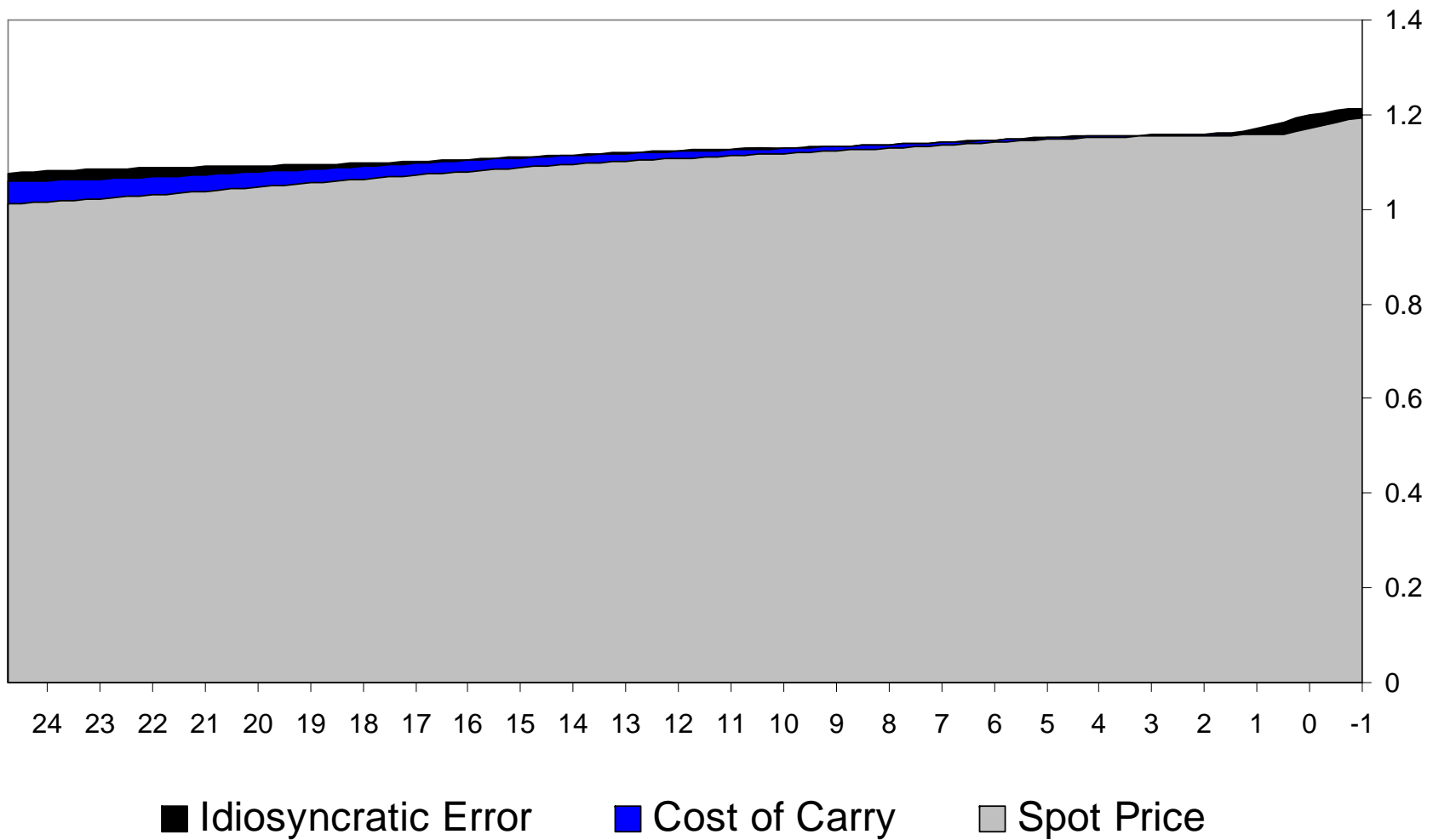
- $\varepsilon_{1t}$  denotes an unexpected change in the spot price level
- $\varepsilon_{2t}$  denotes an unexpected change in the cost of carry
- $\theta_1$  and  $\theta_2$  measure the **reaction** of  $F_{t,T}$  to  $\varepsilon_{1t}$  and  $\varepsilon_{2t}$
- $u_{t,T}$  measures an **error** component unrelated to  $\varepsilon_{1t}$  and  $\varepsilon_{2t}$

## POTS Model

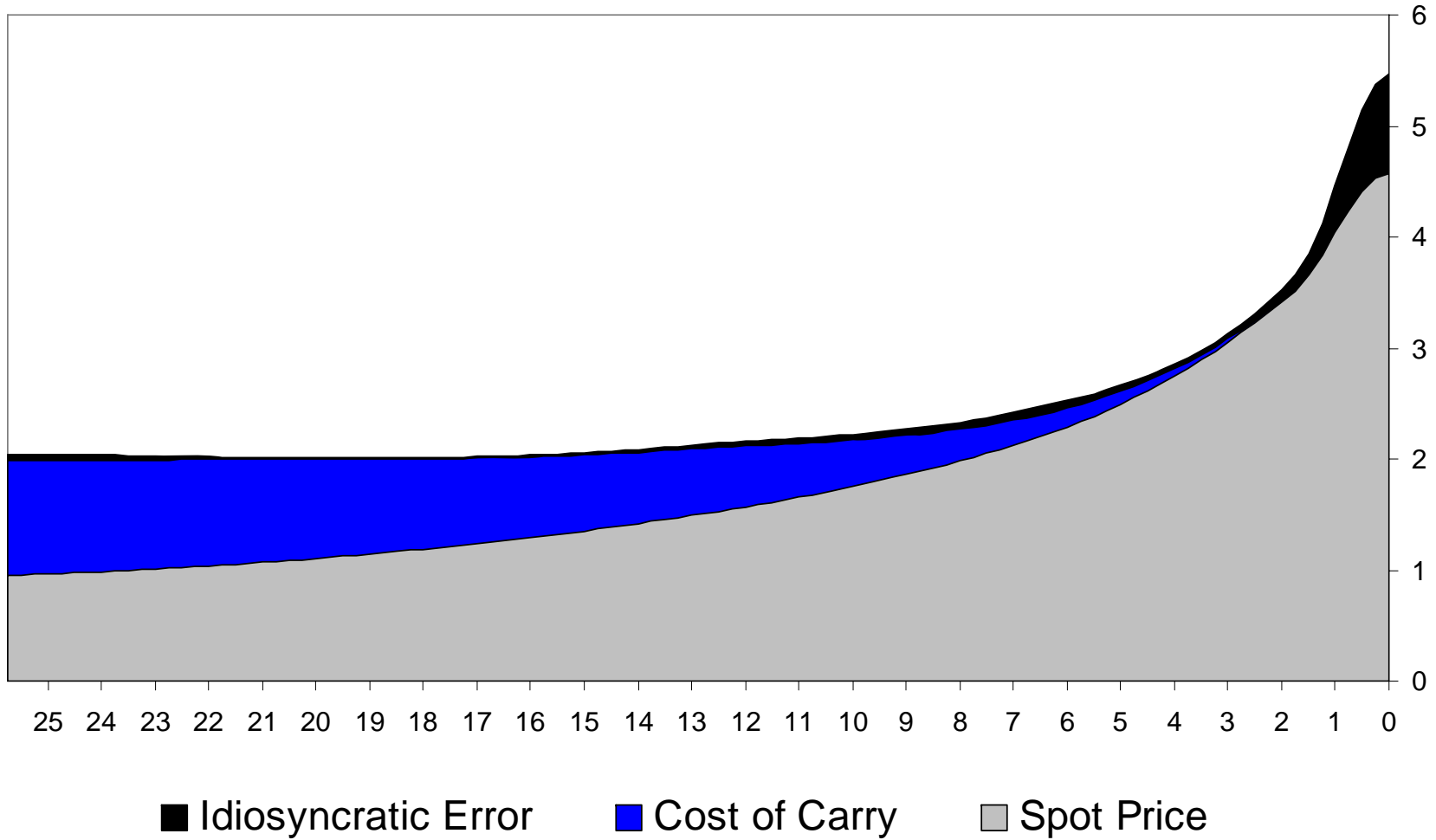
$$\frac{F_{t,T} - F_{t-1,T}}{F_{t-1,T}} = \theta_{1t,T} (\varepsilon_{1t} + \mu_1) + \theta_{2t,T} (\varepsilon_{2t} + \mu_2) + \lambda_{t,T} (u_{t,T} + \omega)$$

- $\mu_1$  is the risk premium associated with the spot price level
- $\mu_2$  is the risk premium associated with the cost of carry
- $\omega$  is the risk premium associated with the error
- $\theta_1$ ,  $\theta_2$ , and  $\lambda$  may depend on time to delivery and season

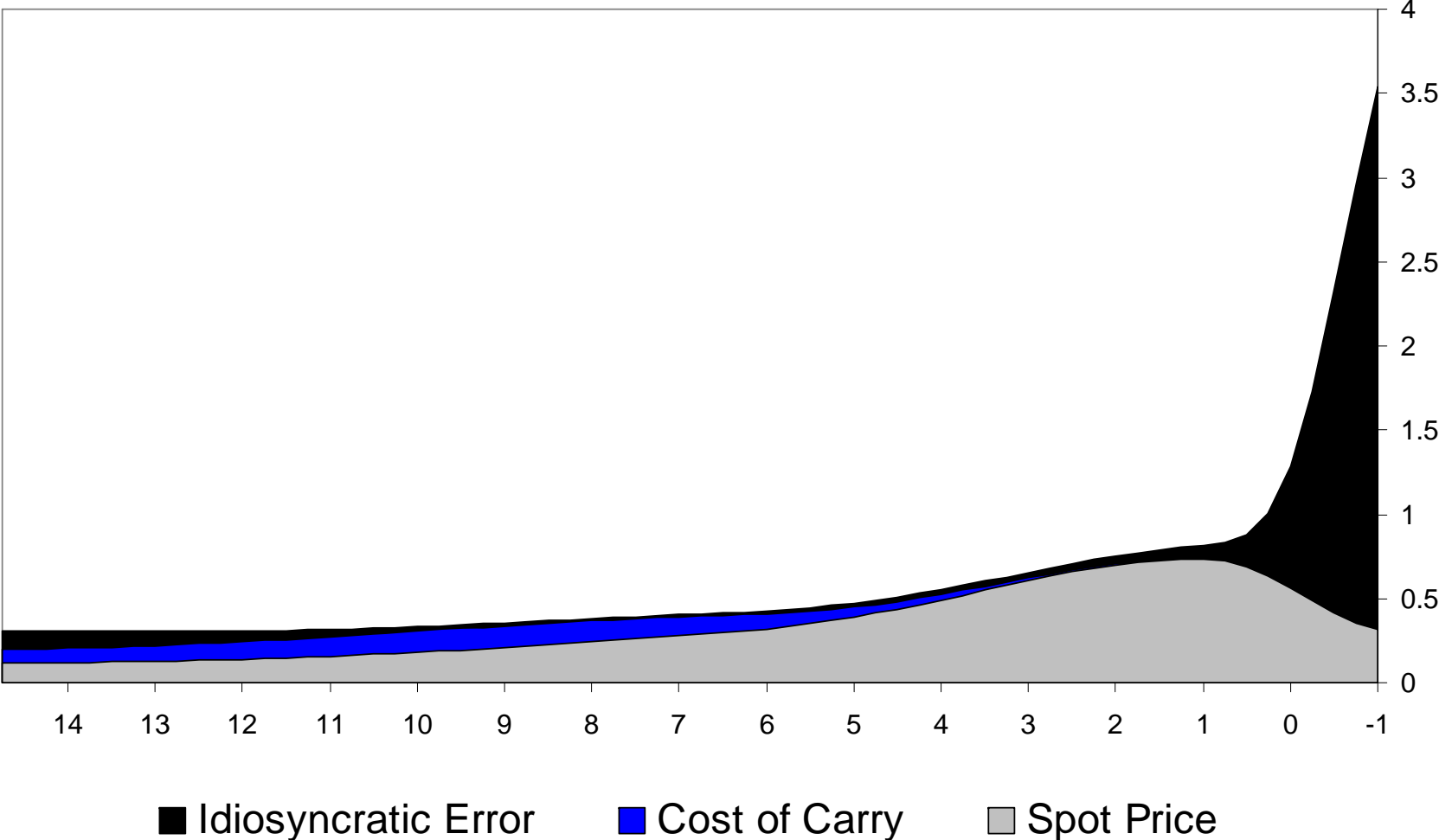
## POTS Model: Variation in Gold Futures Prices



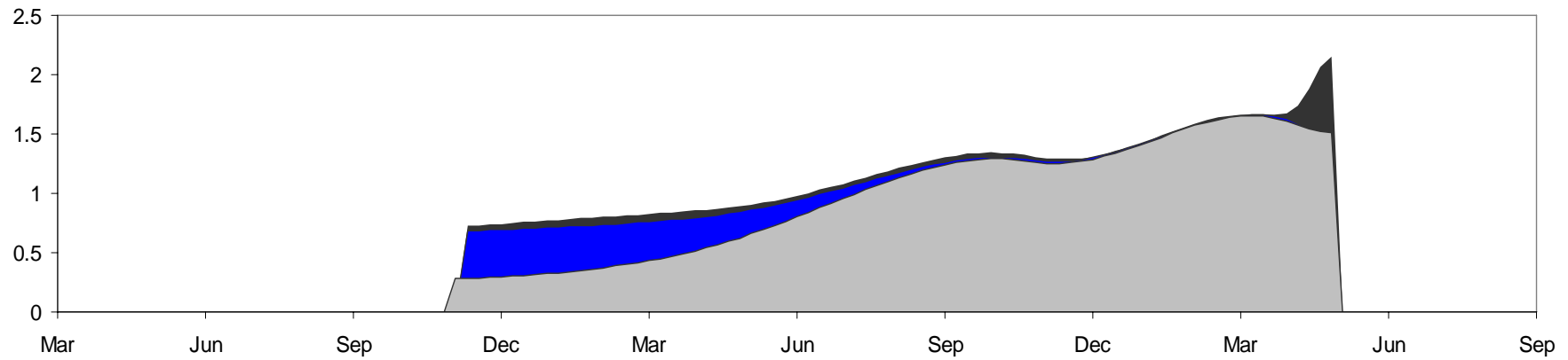
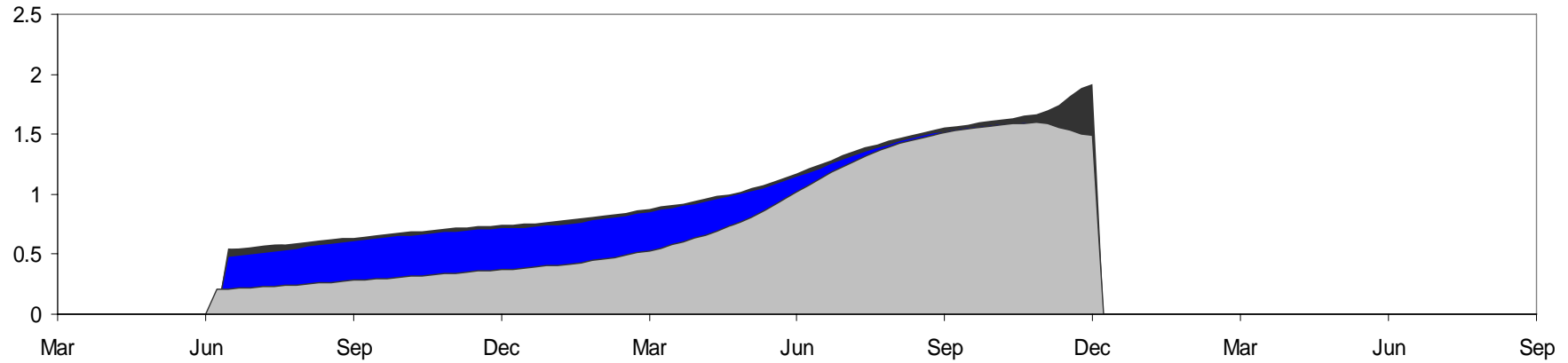
# POTS Model: Variation in Crude Oil Futures Prices



# POTS Model: Variation in Live Cattle Futures Prices



# POTS Model: Variation in Cotton Futures Prices



■ Idiosyncratic Error    ■ Cost of Carry    ■ Spot Price

## Proportion of Variation Explained by POTS Factors

|                               | Ave.      | 1 year          |                 | 6 months        |                 | delivery        |                 |
|-------------------------------|-----------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
|                               |           | $\varepsilon_1$ | $\varepsilon_2$ | $\varepsilon_1$ | $\varepsilon_2$ | $\varepsilon_1$ | $\varepsilon_2$ |
| <i><b>Grains/Oilseeds</b></i> |           |                 |                 |                 |                 |                 |                 |
| Corn                          | <b>94</b> | 61              | 37              | 88              | 9               | <b>76</b>       | 0               |
| Soybeans                      | <b>96</b> | 73              | 20              | 92              | 7               | <b>89</b>       | 0               |
| Soybean Meal                  | <b>94</b> | 49              | 32              | 83              | 14              | <b>89</b>       | 0               |
| Soybean Oil                   | <b>95</b> | 64              | 20              | 91              | 7               | <b>93</b>       | 0               |
| Oats                          | <b>94</b> | 48              | 47              | 77              | 21              | <b>78</b>       | 0               |
| Wheat                         | <b>92</b> | 66              | 24              | 90              | 8               | <b>76</b>       | 0               |
| <i><b>Foodstuffs</b></i>      |           |                 |                 |                 |                 |                 |                 |
| Cocoa                         | <b>97</b> | 95              | 3               | 98              | 1               | <b>84</b>       | 0               |
| Coffee                        | <b>93</b> | 71              | 18              | 86              | 12              | <b>86</b>       | 0               |
| Sugar                         | <b>90</b> | 80              | 16              | 96              | 2               | <b>83</b>       | 0               |
| <i><b>Metals</b></i>          |           |                 |                 |                 |                 |                 |                 |
| Copper                        | <b>97</b> | 71              | 27              | 90              | 8               | <b>92</b>       | 0               |
| Gold                          | <b>99</b> | 98              | 2               | 100             | 0               | <b>98</b>       | 0               |
| Platinum                      | <b>93</b> | 97              | 0               | 100             | 0               | <b>72</b>       | 0               |
| Silver                        | <b>99</b> | 97              | 2               | 99              | 1               | <b>98</b>       | 0               |

## Proportion of Variation Explained by POTS Factors

|                        | Ave.       | 1 year       |              | 6 months     |              | delivery     |              |
|------------------------|------------|--------------|--------------|--------------|--------------|--------------|--------------|
|                        |            | $\epsilon_1$ | $\epsilon_2$ | $\epsilon_1$ | $\epsilon_2$ | $\epsilon_1$ | $\epsilon_2$ |
| <i>Industrials</i>     |            |              |              |              |              |              |              |
| Cotton                 | <b>94</b>  | 60           | 33           | 88           | 6            | <b>65</b>    | 0            |
| Lumber                 | <b>84</b>  | 19           | 43           | 76           | 15           | <b>70</b>    | 0            |
| <i>Energy</i>          |            |              |              |              |              |              |              |
| Crude Oil              | <b>97</b>  | 71           | 27           | 90           | 7            | <b>84</b>    | 0            |
| Gasoline               | <b>95</b>  | 69           | 27           | 84           | 14           | <b>79</b>    | 0            |
| Heating Oil            | <b>96</b>  | 76           | 22           | 92           | 6            | <b>78</b>    | 0            |
| Natural Gas            | <b>86</b>  | 57           | 36           | 88           | 6            | <b>71</b>    | 0            |
| <i>Animal Products</i> |            |              |              |              |              |              |              |
| Feed Cattle            | <b>93</b>  | 47           | 28           | 83           | 13           | <b>80</b>    | 0            |
| Live Cattle            | <b>75</b>  | 42           | 32           | 73           | 23           | <b>28</b>    | 0            |
| Lean Hogs              | <b>85</b>  | 23           | 34           | 66           | 25           | <b>65</b>    | 0            |
| Pork Bellies           | <b>94</b>  | 19           | 66           | 74           | 22           | <b>86</b>    | 0            |
| <i>Stock Index</i>     |            |              |              |              |              |              |              |
| S&P 500                | <b>100</b> | 97           | 3            | 99           | 1            | <b>100</b>   | 0            |

## Hedging Example: Cotton

- Growing season runs from March to October
- Futures contract has **five delivery locations**: Galveston TX, Greenville SC, Houston TX, Memphis TN and New Orleans LA
- Spot price data from USDA for 1992-2003 in five locations: San Joaquin Valley, Desert Southwest, West Texas, Delta, Southeast
- Assess annual **hedging of price risk** over three periods:
  - (i) March-December
  - (ii) December-March
  - (iii) March-May

## Hedging Example: Dec 2000-March 2001

In December 2000, the expected March 2001 price was \$0.676 per pound.

### Standard Hedge (uses March 01 futures contract)

|        |        |
|--------|--------|
| Dec 00 | Mar 01 |
|        |        |
| 0.676  | 0.531  |

|                                |              |
|--------------------------------|--------------|
| Futures profit (0.676 – 0.531) | 0.145        |
| SJV Selling Price              | <u>0.508</u> |
| Total Revenue                  | <u>0.653</u> |
| Prediction Error               | -3.4%        |

### Fundamental Hedge (uses May 01 futures contract)

|        |        |        |
|--------|--------|--------|
| Dec 00 | Mar 01 | May 01 |
|        |        |        |
| 0.690  | 0.538  |        |

|                                |              |
|--------------------------------|--------------|
| Futures profit (0.690 – 0.538) | 0.152        |
| SJV Selling Price              | <u>0.508</u> |
| Total Revenue                  | <u>0.660</u> |
| Prediction Error               | -2.4%        |

## Relative Standard Deviation of Prediction Errors

### No Hedge / Standard Hedge

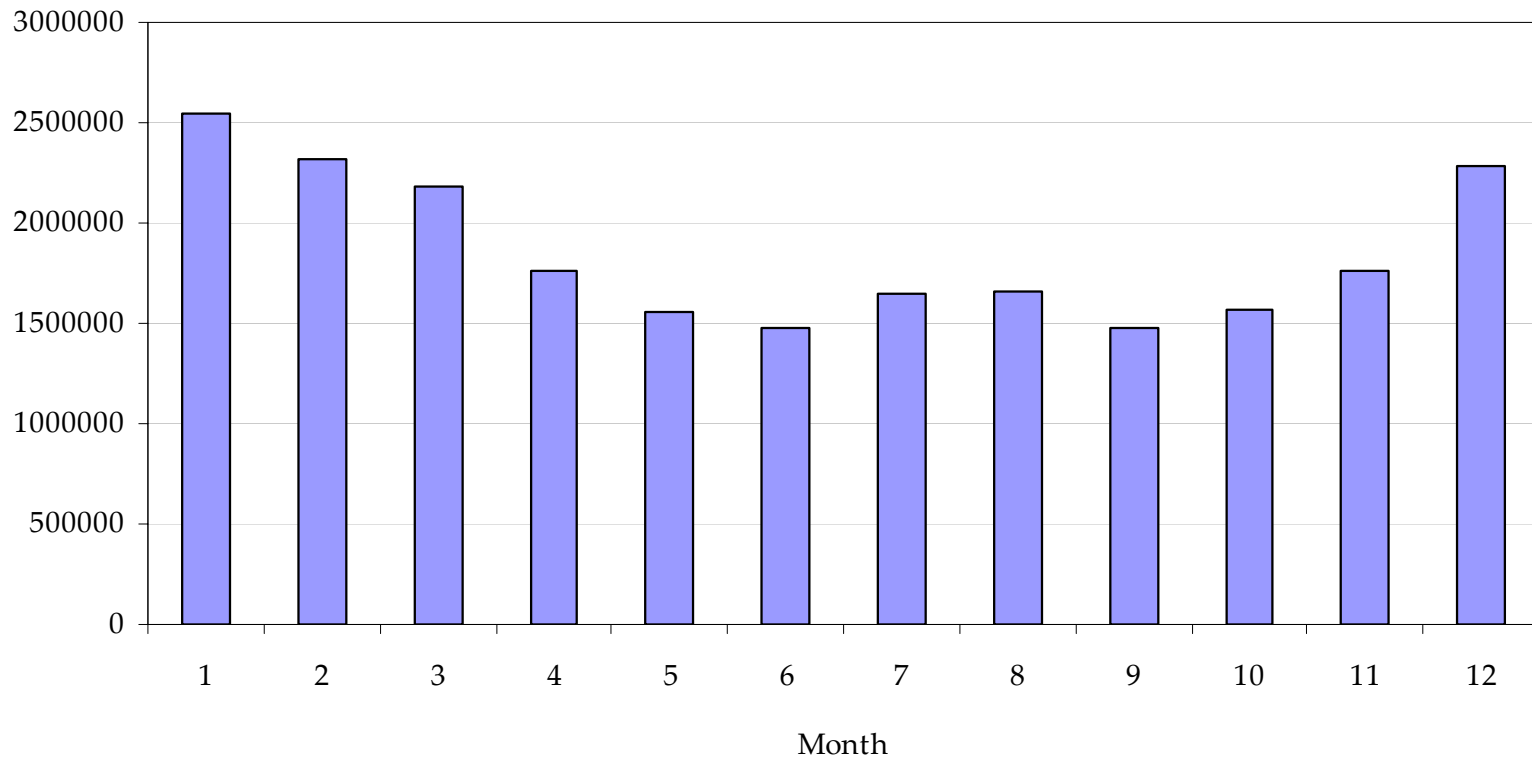
|                    | Mar-Dec | Dec-Mar | Mar-May |
|--------------------|---------|---------|---------|
| San Joaquin Valley | 2.06    | 2.55    | 1.68    |
| Desert Southwest   | 3.05    | 2.46    | 2.74    |
| West Texas         | 3.95    | 2.78    | 3.03    |
| Delta              | 3.90    | 2.45    | 1.87    |
| Southeast          | 5.14    | 2.79    | 2.14    |

### Fundamental Hedge / Standard Hedge

|                    | Mar-Dec | Dec-Mar | Mar-May |
|--------------------|---------|---------|---------|
| San Joaquin Valley | 0.92    | 0.94    | 1.01    |
| Desert Southwest   | 1.06    | 0.62    | 1.34    |
| West Texas         | 0.85    | 0.50    | 0.98    |
| Delta              | 0.74    | 0.71    | 0.86    |
| Southeast          | 0.79    | 0.70    | 0.86    |

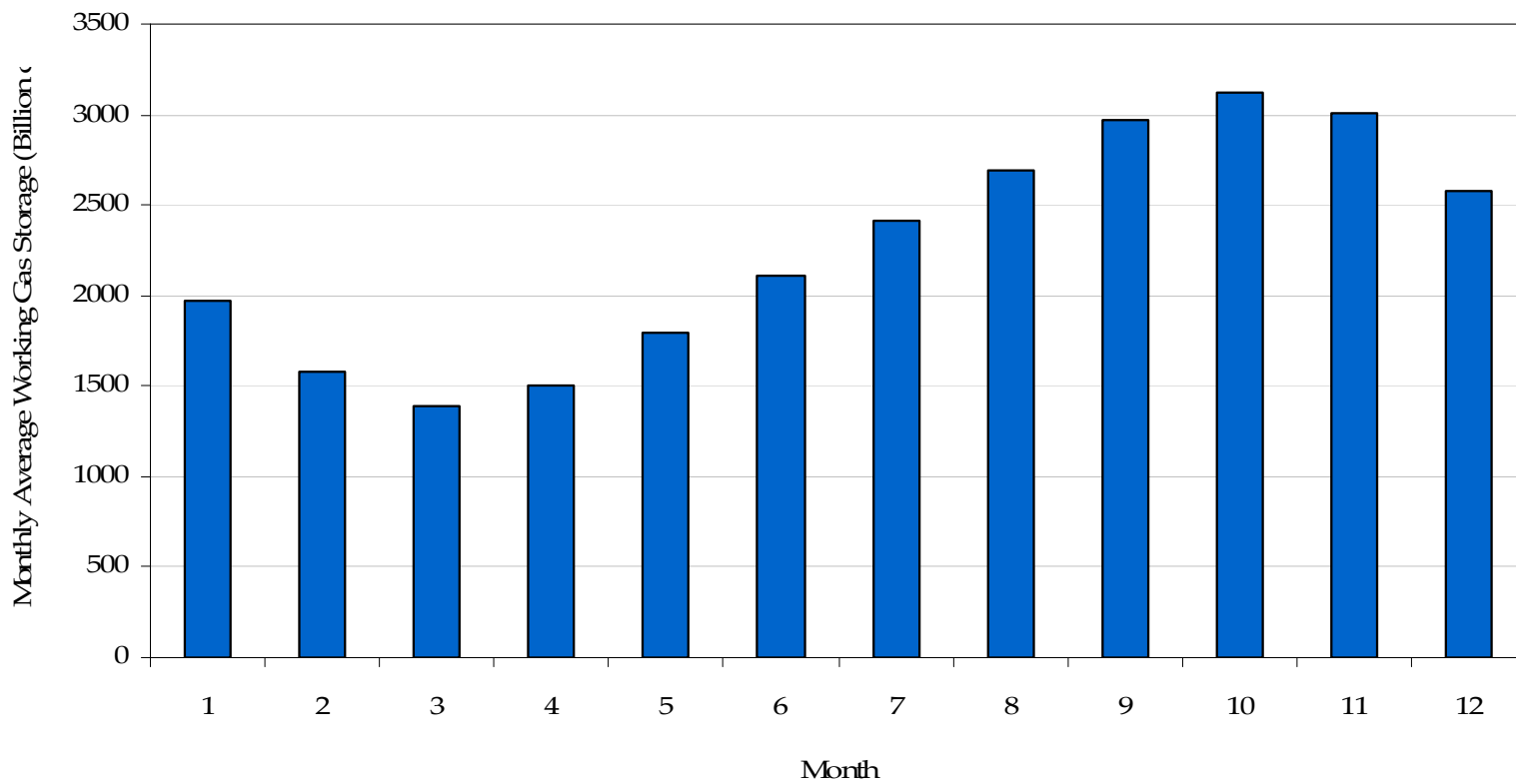
# Seasonality in U.S. Aggregate Natural Gas Demand

US Natural Gas Total Consumption (MMcf) by Month  
- Jan 2001 - May 2005

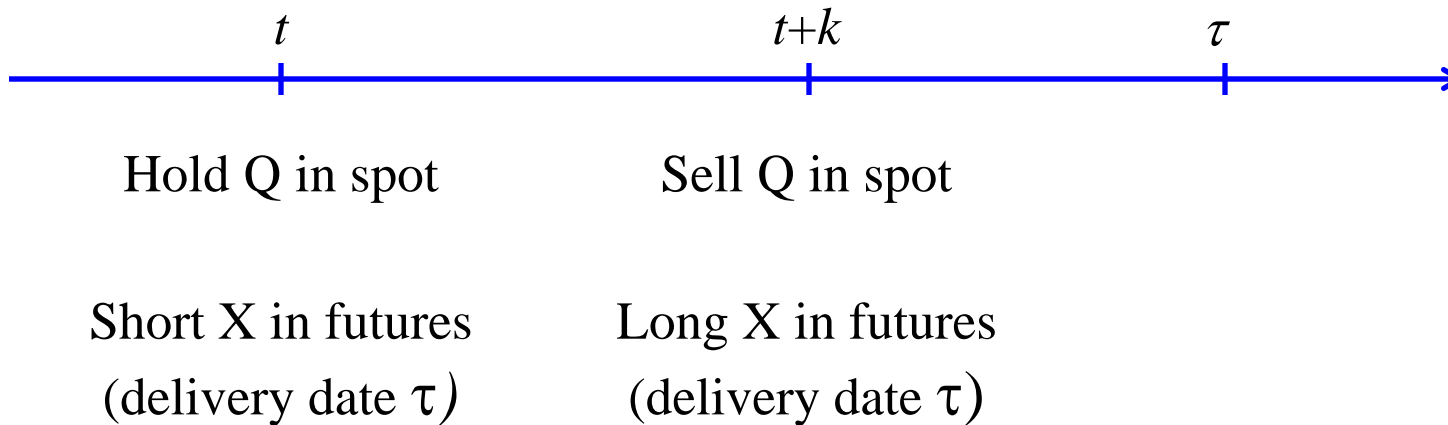


# Seasonality in U.S. Aggregate Natural Gas Storage

**Figure 3. US Natural Gas Underground Storage - Monthly Average of Working Gas for 1976 - 2005**



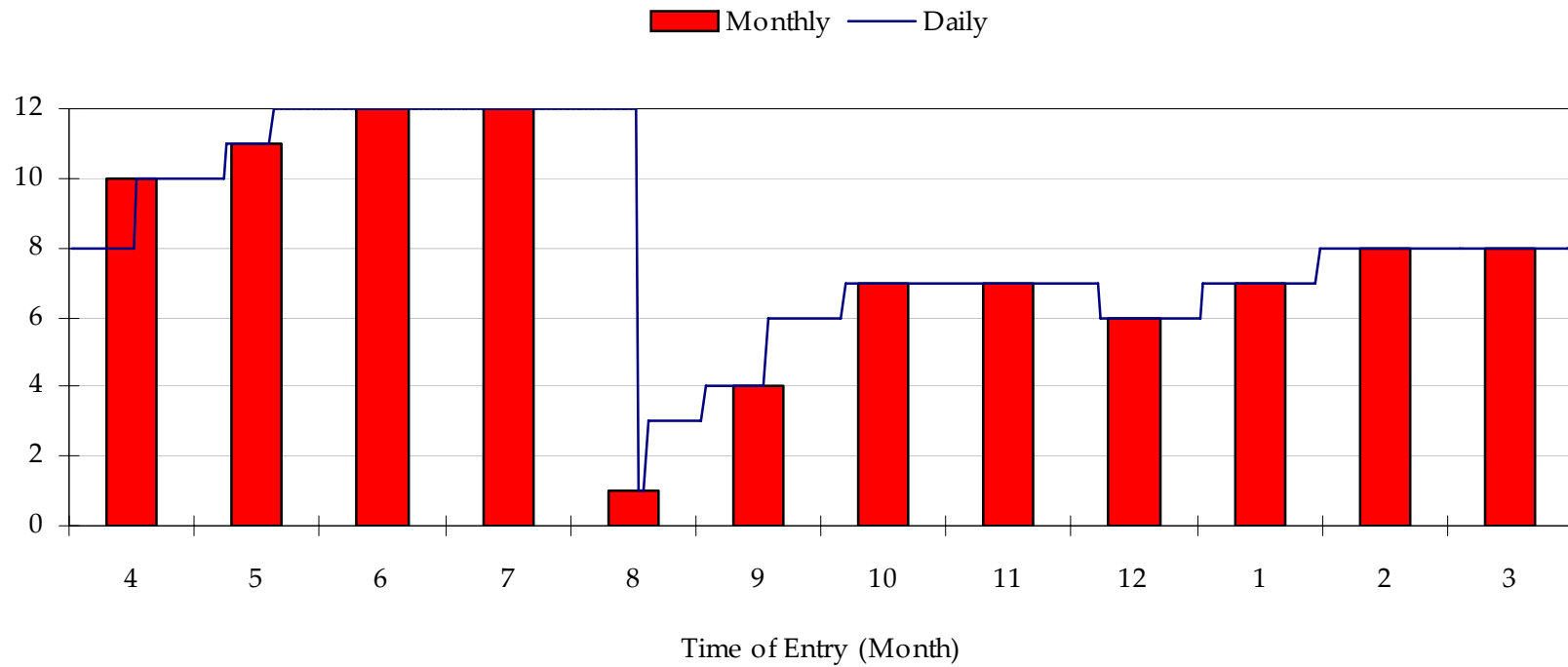
## Optimal Hedging Strategy



- **Aim:** Choose  $X$  and  $\tau$  to minimize portfolio variance
- **Result:** For  $\tau$ , choose contract with largest covariance with factor  
  
Increase  $X/Q$  when covariance is large or futures contract variance is low.

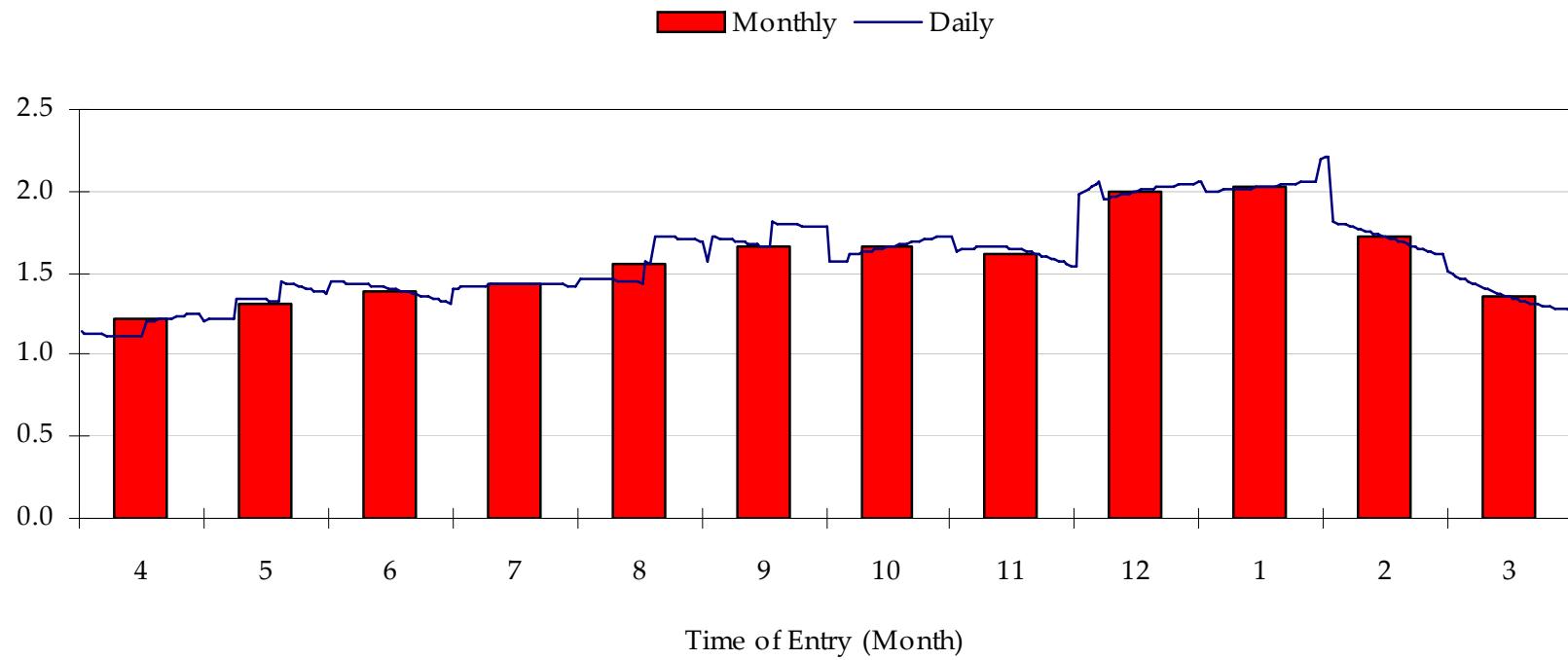
# Contract Included in Optimal Portfolio

Figure 5. Delivery Month of the Futures Contract Included in the Optimal Portfolio



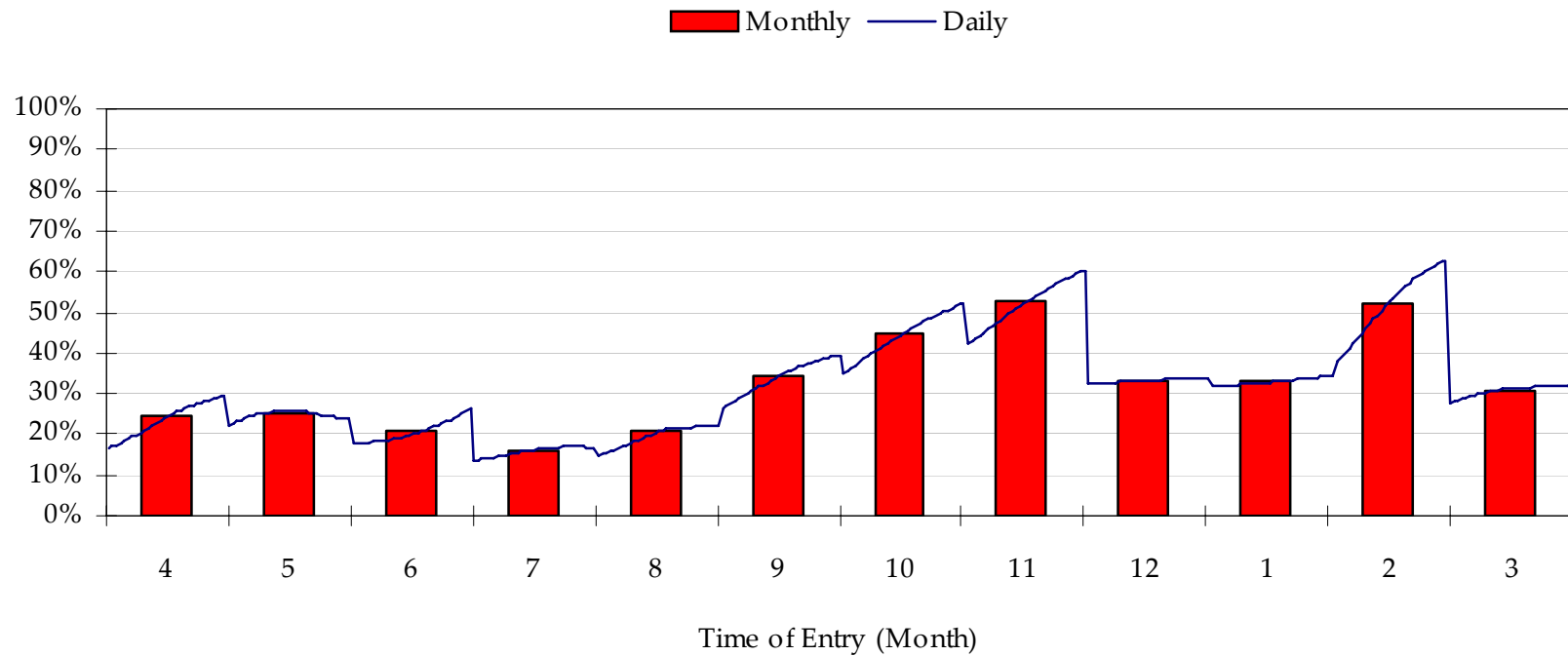
# Optimal hedge ratio

Figure 6a. Optimal Hedge Ratio



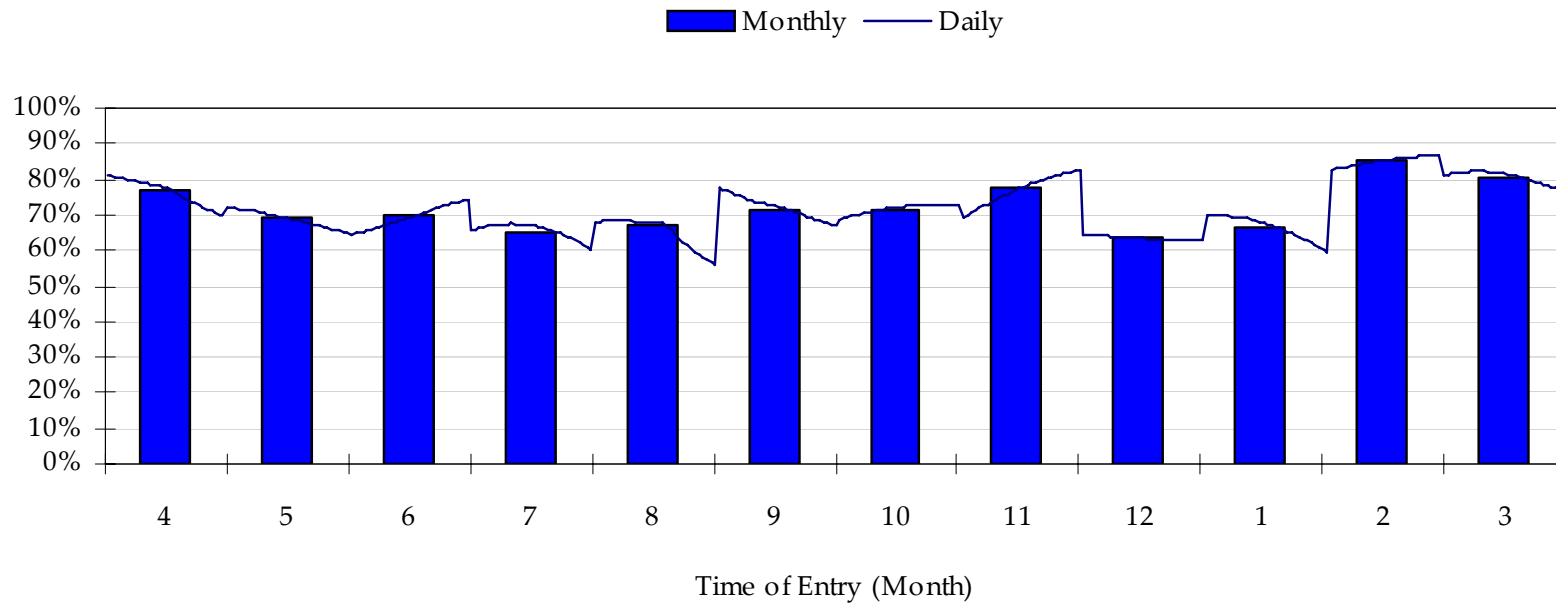
# Variance Relative to Unhedged Portfolio

Figure 7a. Minimum Variance Relative to the Variance of Unhedged Portfolio



# Variance Relative to Hedging with 2<sup>nd</sup> Position Contract

Figure 7b. Minimum Variance Relative to the Variance of Portfolio with Second Position



## Risk Premium Estimates

|                        | LR Test | Daily Premium For Each Factor (×100) |       |       |
|------------------------|---------|--------------------------------------|-------|-------|
|                        |         | Spot                                 | Carry | Error |
| <i>Grains/Oilseeds</i> |         |                                      |       |       |
| Corn                   | 0.00    | -2.6                                 | 1.1   | 4.1   |
| Soybeans               | 0.13    | -1.6                                 | -1.2  | 1.2   |
| Soybean Meal           | 0.03    | -1.1                                 | 2.1   | 2.9   |
| Soybean Oil            | 0.00    | -2.0                                 | 1.5   | 3.4   |
| Oats                   | 0.00    | -3.3                                 | -1.5  | 4.9   |
| Wheat                  | 0.08    | -2.9                                 | 1.0   | 0.9   |
| <i>Foodstuffs</i>      |         |                                      |       |       |
| Cocoa                  | 0.00    | -3.6                                 | -0.2  | 2.7   |
| Coffee                 | 0.61    | 0.6                                  | -0.6  | 1.2   |
| Sugar                  | 0.41    | 0.1                                  | -1.2  | 1.2   |
| <i>Metals</i>          |         |                                      |       |       |
| Copper                 | 0.69    | 0.9                                  | 0.3   | -0.5  |
| Gold                   | 0.00    | -3.6                                 |       |       |
| Platinum               | 0.32    | -1.7                                 | 0.1   | 0.9   |
| Silver                 | 0.01    | -3.2                                 |       |       |

= significant at 95%

= significant at 90%

## Risk Premium Estimates

|                        | LR Test     | Daily Premium For Each Factor (×100) |             |            |
|------------------------|-------------|--------------------------------------|-------------|------------|
|                        |             | Spot                                 | Carry       | Error      |
| <i>Industrials</i>     |             |                                      |             |            |
| Cotton                 | 0.86        | -0.5                                 | 0.2         | -0.8       |
| Lumber                 | 0.72        | -0.1                                 | -0.3        | -1.3       |
| <i>Energy</i>          |             |                                      |             |            |
| Crude Oil              | <b>0.07</b> | <b>1.8</b>                           | 1.6         | -0.5       |
| Gasoline               | 0.22        | 2.1                                  | -0.6        | 0.9        |
| Heating Oil            | <b>0.00</b> | 1.6                                  | <b>-3.2</b> | <b>3.0</b> |
| Natural Gas            | 0.18        | 0.0                                  | 2.5         | 0.5        |
| <i>Animal Products</i> |             |                                      |             |            |
| Feed Cattle            | <b>0.01</b> | 1.5                                  | 0.4         | <b>5.0</b> |
| Live Cattle            | <b>0.05</b> | <b>3.3</b>                           | 1.7         | -0.4       |
| Lean Hogs              | <b>0.07</b> | 1.5                                  | 0.6         | <b>2.7</b> |
| Pork Bellies           | 0.19        | -1.0                                 | -0.2        | <b>2.9</b> |
| <i>Stock Index</i>     |             |                                      |             |            |
| S&P 500                | <b>0.00</b> | <b>4.1</b>                           |             |            |

= significant at 95%

= significant at 90%

## Conclusion

- Significant negative premia in **gold**, **silver**, and **cocoa** price levels
  - some evidence of the same for *corn*, *oats*, and *wheat*
- Significant positive premia in **live cattle** and **S&P 500** price levels
  - some evidence of the same for *oil*
- Significant positive premia in idiosyncratic term for most **agricultural products** indicates non-diversifiable delivery risk.