MIT Energy and Environmental Policy Workshop
6-7 December 2007

Dynamics of the Heavy-Light Spread in the N. American Oil Market

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The Issue

- North American crude oil markets
  - Light sweet crude: global light market
  - Heavy sour crude: Mexican and Venezuelan oil
  - New entrant: heavy products from Canadian oil sands
- Question: how do heavy and light crude prices relate?
  - Is there a reliable long run equilibrium?
    - Fixed percent spreads?
    - Fixed differentials?
    - Other?
  - What about the dynamics of the market?
    - Short-run responses to shocks?
    - Long-run shifts?

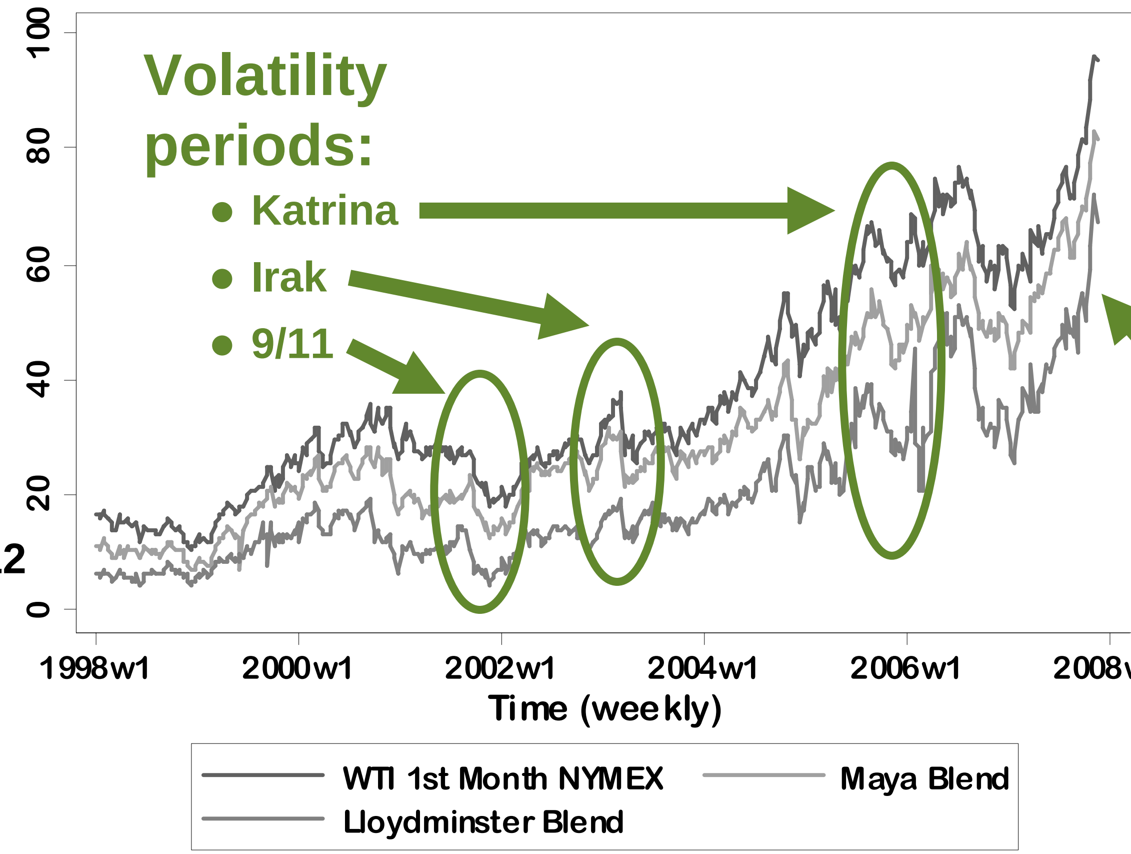
The Data

- **Focus on three key marker crudes: WTI, LLB and Maya**
  - **West Texas Intermediate Blend → global light crude market**
  - **Lloydminster Blend → Canadian heavy crude market (benchmark for Diluted Bitumen from the Athabasca oil sands)**
  - **Maya Blend → Central and South Am. heavy crude market**

- **Data: weekly prices for the 1998 - 2007**
  - **WTI: NYMEX front month contract for delivery at Cushing, OK**
  - **LLB: spot contract for delivery at Hardisty, Alb.**
  - **Maya: sold CIF to USGC based on Pemex marked price**

Historical Evolution of Prices

- **1998/01:**
  - **WTI: 16.63**
  - **Maya: 11.12**
  - **LLB: 6.70**

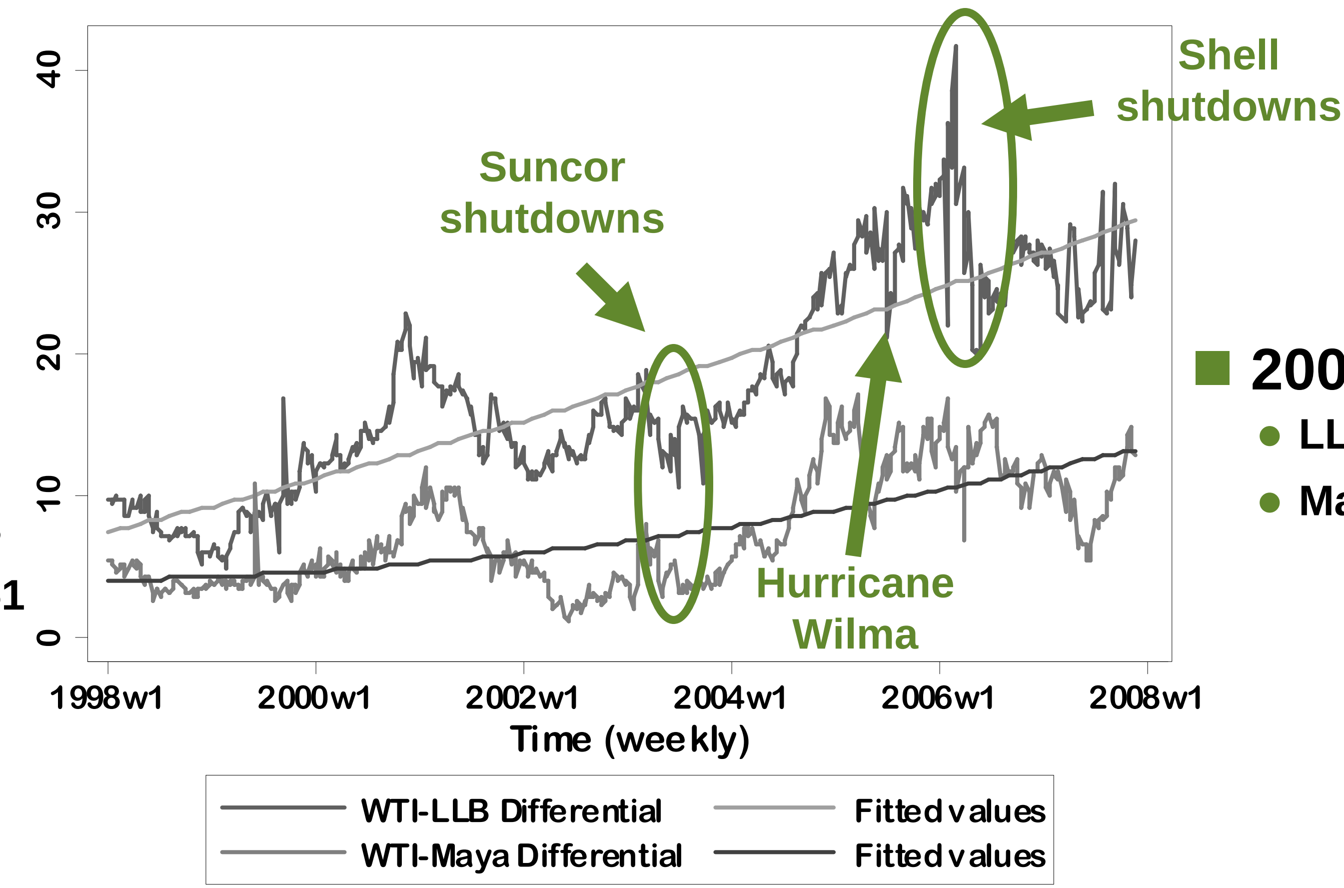


- **2007/11:**
  - **WTI: 95.10**
  - **Maya: 81.98**
  - **LLB: 67.02**

Global rise in prices

Absolute Spreads: WTI-Maya and WTI-LLB

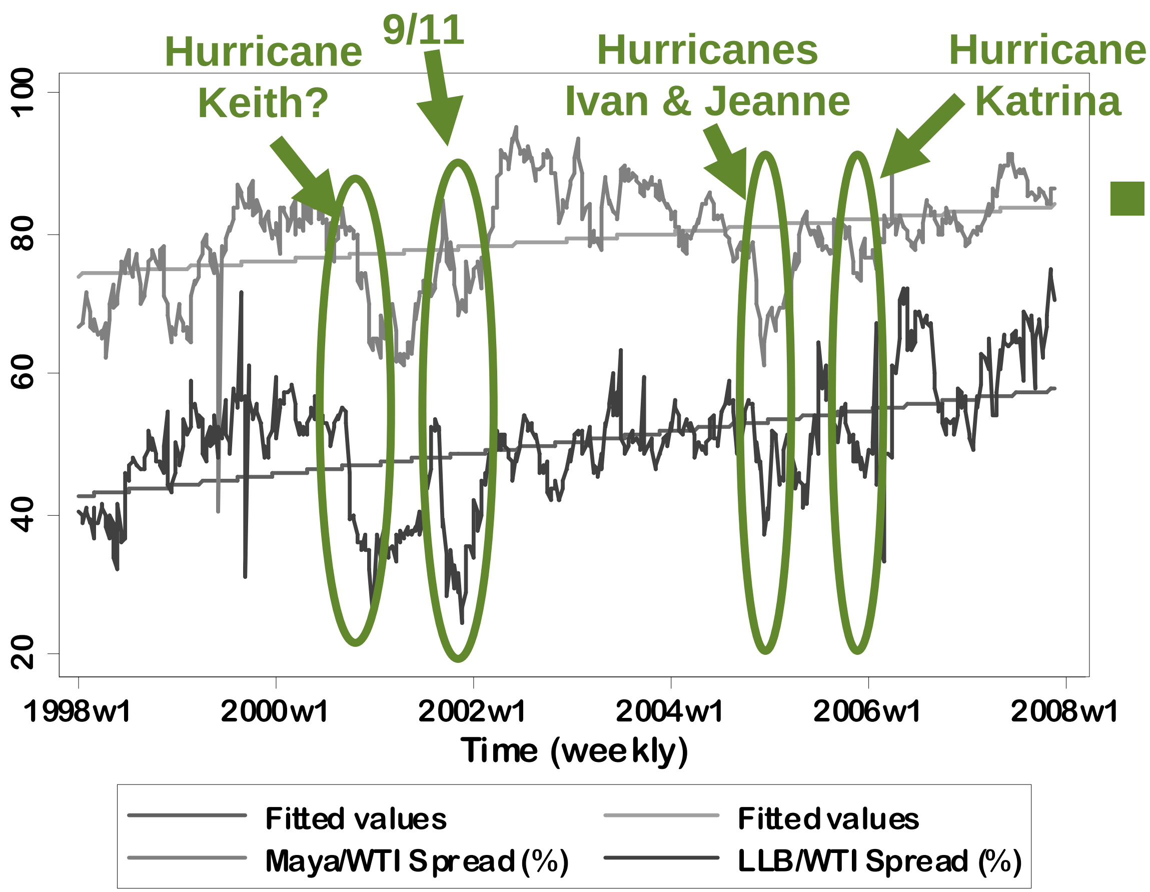
- **1998/01:**
  - LLB: -9.93
  - Maya: -5.51



- **2007/11:**
  - LLB: -28.08
  - Maya: -13.12

Percent Spreads: Maya/WTI and LLB/WTI

- **1998/01:**
  - **LLB: 40.9%**
  - **Maya: 64.6%**



- **2007/11:**
  - **LLB: 63.5%**
  - **Maya: 82.8%**

Early Conclusions

- No simple long run equilibrium relationship
  - Fixed price differentials exhibit heteroskedasticity
  - Fixed percent spreads are shifting with time
- Differential shocks impact all markets
  - Global shocks have differentiated local effects
  - Local shocks have repercussions on other markets

Need for thorough time series analysis

Time Series Analysis

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Estimating a Model of Price Dynamics

- **Problem in inference on time trended time series…**
  - **very easy to *erroneously* find a relationship between 2 series if they are not stationary**
  - **E.g. oil prices went up while steel price went up too: Causality? Correlation?**

Estimating a Model of Price Dynamics

- **Problem in inference on time trended time series…**
  - **very easy to *erroneously* find a relationship between 2 series**
- **One solution is to first detrend the series, e.g., by taking first differences**
  - **this works sometimes, but the underlying problem is sometimes more subtle and undermines the validity of this simple solution**
  - **E.g. for oil and steel -- if energy prices impact steel price, the following structure may prevail:**

$$P_{Steel} = \alpha P_{Energy} + \varepsilon_{Steel}$$
$$P_{Oil} = \beta P_{Energy} + \varepsilon_{Oil}$$

  - **In that case, differencing ignores long run equilibrium between the variables due to the shared stochastic trend**

Estimating a Model of Price Dynamics

- **Problem in inference on time trended time series…**
  - **Very easy to *<u>erroneously</u>* find a relationship between 2 series**
- **One solution is to first detrend the series, e.g., by taking first differences**
  - **This works sometimes, but the underlying problem is sometimes more subtle and undermines the validity of this simple solution**
- **Resolution: cointegration analysis**
  - **Search for the cointegration vector… a more robust search through a broader universe of possible stationary linear combinations of the non-stationary variables**
  - **If variables cointegrated…**

$$P_{Steel} - \frac{\alpha}{\beta} P_{Oil}$$ **stationary → reversal to a long run equilibrium**

Traditional Diagnostics

- **Standard estimation method: VAR(p) model**
  - **Works for stationary variables**
  - **Standard form assumes no contemporaneous effect of variables on each other**
  - **Structural form (informed by standard form) can allow contemporaneous effects**

Test lag order p

↓

Standard VAR(p) model:

$$P_t = \sum_{i=1}^{p} A_i P_{t-i} + \varepsilon_t$$

↓

Structural VAR(p) model:

$$P_t = BP_t + \sum_{i=1}^{p} A_i P_{t-i} + \varepsilon_t$$

Structural assumptions

Traditional Diagnostics

- **Estimation method for non-stationary variables: VECM model**
  - **First differences of VAR(p) model in standard form**
  - **Implies linear combination of lagged price levels is stationary**
  - **Hence need to choose a constraint on rank → Johansen test**

Test lag order p

↓

Johansen test for rank r

↓

VECM(p,r) model:

$$\Delta P_t = \sum_{i=1}^{p-1} \Pi_i \Delta P_{t-i} + \Pi P_{t-1} + \varepsilon_t$$

Stationary linear combination

↓

CECM(p,r) model:

$$\Delta P_t = \sum_{i=0}^{p-1} \Pi_i \Delta P_{t-i} + \Pi P_{t-1} + \varepsilon_t$$

Structural assumptions

Overview of the Path for Estimation

Unit root test

- **Stationary →VAR**

Test lag order p

Standard VAR(p) model:

$$P_t = \sum_{i=1}^{p} A_i P_{t-i} + \varepsilon_t$$

Structural VAR(p) model:

$$P_t = BP_t + \sum_{i=1}^{p} A_i P_{t-i} + \varepsilon_t$$

- **Integrated →VECM**

Test lag order p

Johansen test for rank r

VECM(p,r) model:

$$\Delta P_t = \sum_{i=1}^{p-1} \Pi_i \Delta P_{t-i} + \Pi P_{t-1} + \varepsilon_t$$

CECM(p,r) model:

$$\Delta P_t = \sum_{i=0}^{p-1} \Pi_i \Delta P_{t-i} + \Pi P_{t-1} + \varepsilon_t$$

Traditional Diagnostics: Unit Root Tests

- **Philipps-Perron unit root test**
  - **Null hypothesis: price variables exhibit a unit root**

Variable	P-value for null hypothesis
log WTI	90.25%
log LLB	67.94%
log Maya	79.29%

Variables exhibit unit roots

  - **First differences are found stationary by the same test**

- **Conclusion: price variables are integrated of order 1 → they behave like random walks**

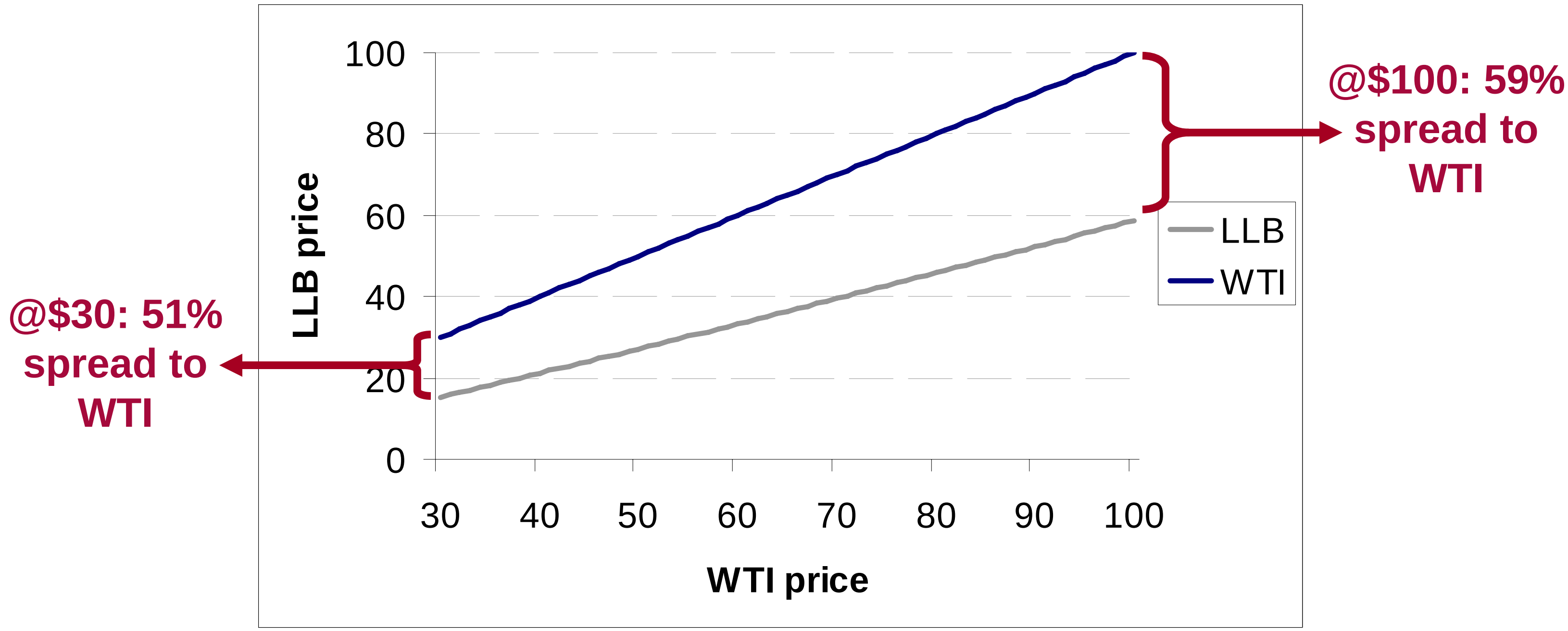
- **Therefore… need for co-integration analysis!**
  - **VECM to reveal long run equilibrium and link with short run dynamics**
  - **CECM if specific structure is found**

Bottom-line: Cointegration of Crude Prices

- **Part #1. Long-run equilibrium relationship: co-integration framework between WTI, Maya and LLB**
  - Diagnostics: lag order 4, rank 2
  - Reveals long run equilibrium
- **Part #2. Linking short-run to long-run dynamics: Vector Error Correction Model (VECM)**
  - Highlights relationship between long run equilibrium and short rum dynamics
  - Reveals underlying asymmetry between WTI and the other variables
- **Part #3. Imposing structure on short run dynamics: Conditional Error Correction Model (CECM)**
  - WTI is assumed exogenous
  - We study its contemporaneous and long-run effect on heavy crudes prices

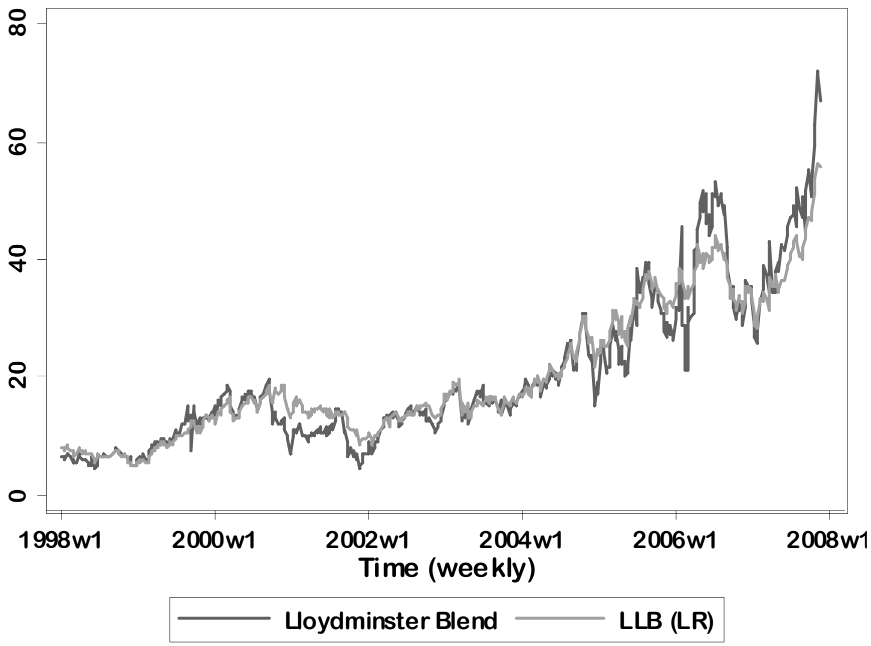
Part #1
Bottom Line: Long-run Equilibrium

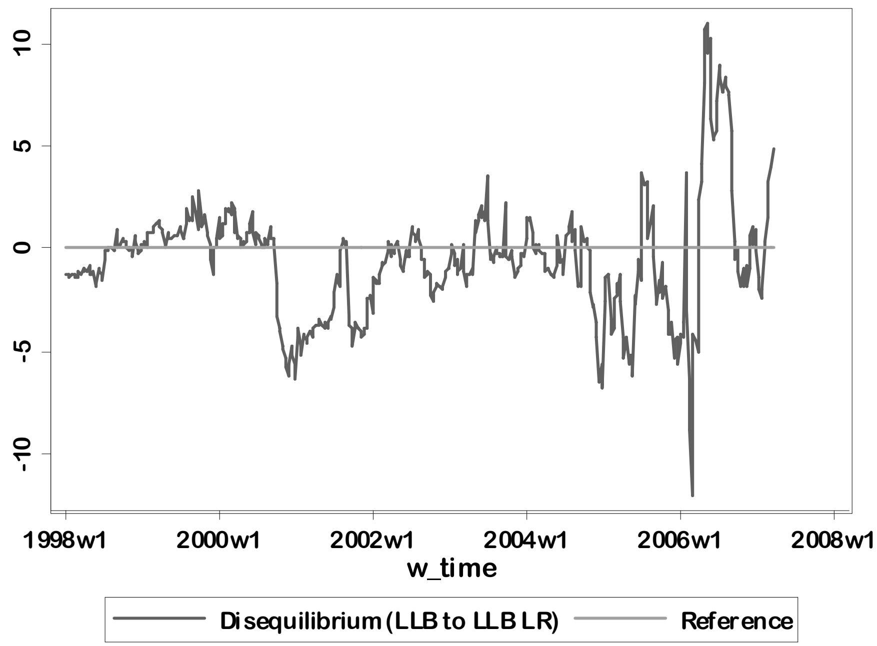
- **Long run equilibrium between LLB and WTI:**
  - **log LLB = (- 1.0613) + (1.115015) log WTI**
- **Predicted 'equilibrium' in price levels:**



Part #1
Bottom Line: Long-run Equilibrium (cont.)

- **Historical prices**
  - **Actual and predicted prices**
  - **Departure from equilibrium**





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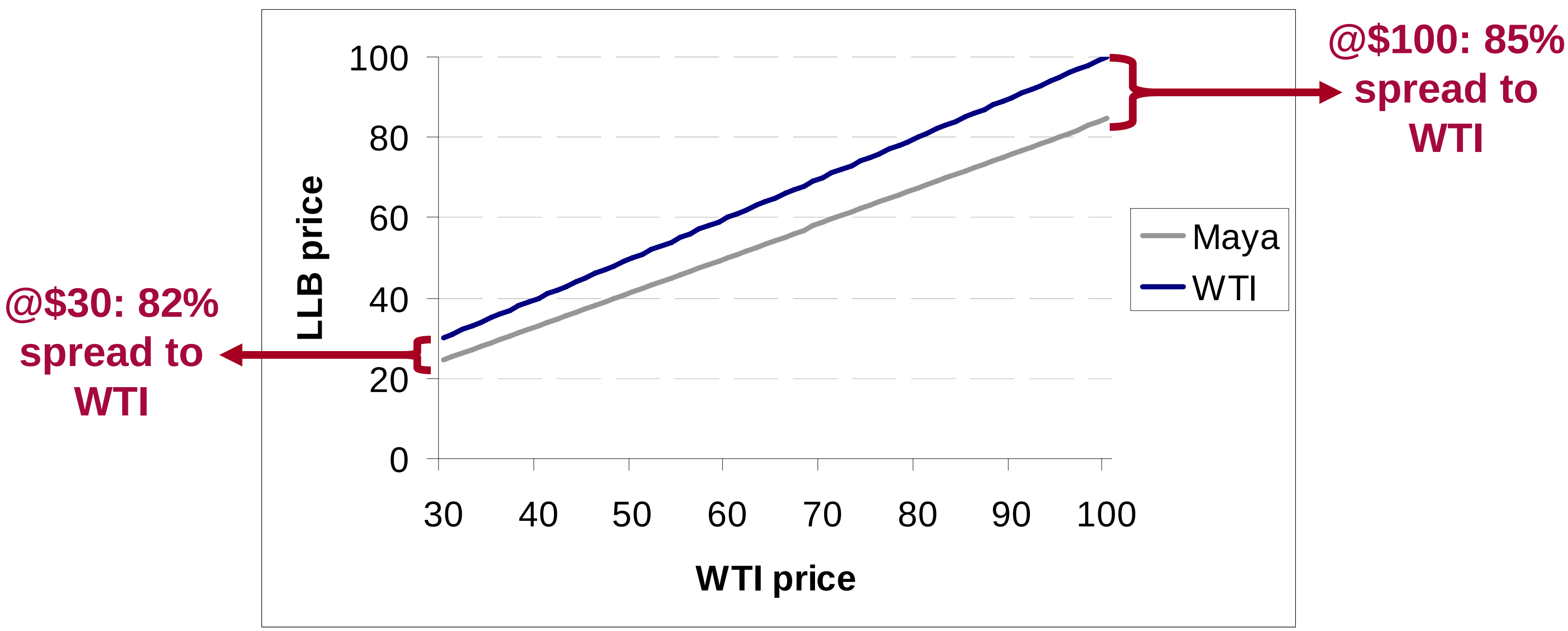
Part #1
Bottom Line: Long-run Equilibrium (cont.)

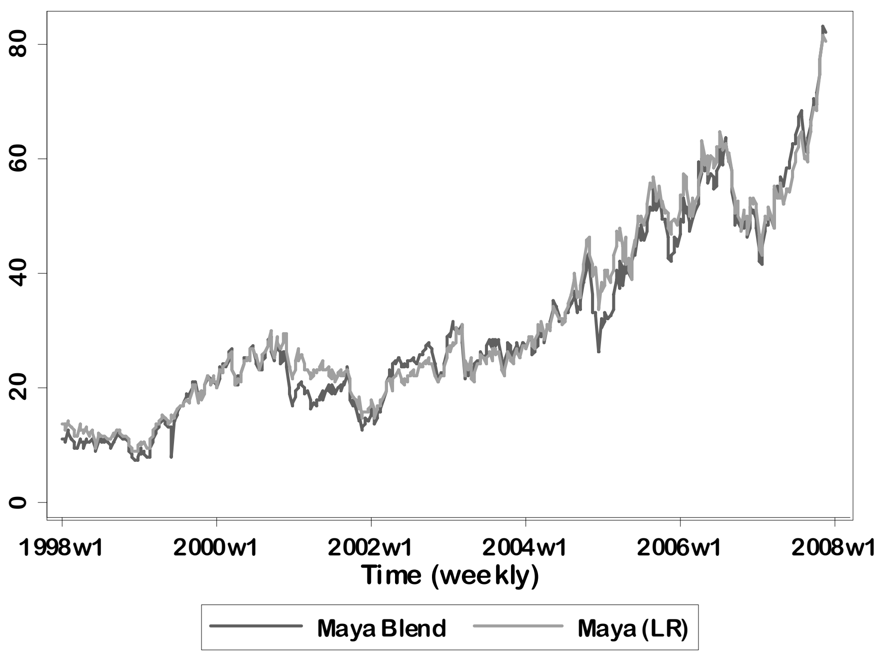
- **Long run equilibrium between Maya and WTI:**
  - **log Maya = (- .2773277) + (1.02387) log WTI**

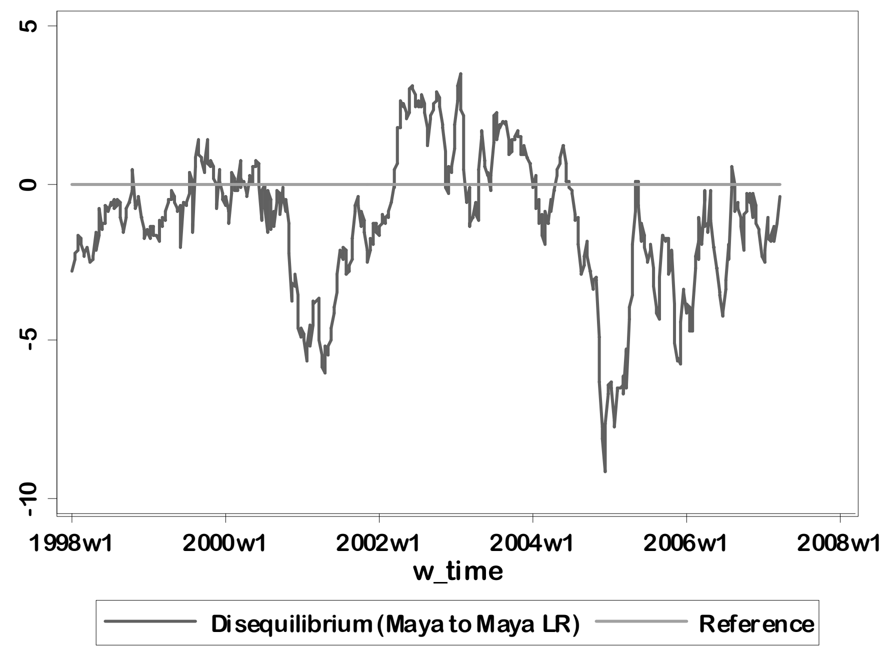
- **Predicted 'equilibrium' in price levels:**



Part #1
Bottom Line: Long-run Equilibrium (cont.)

- **Historical Maya prices**
  - **Actual and predicted prices**
  - **Departure from equilibrium**





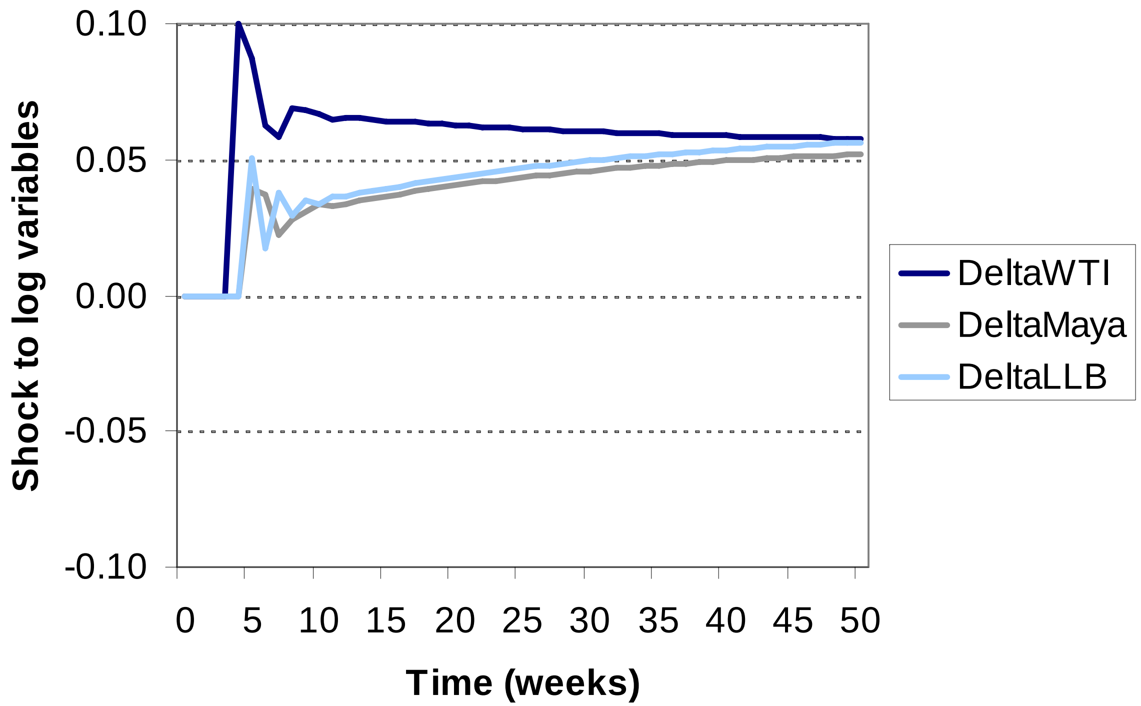
Part #2

Bottom Line: Short-run Dynamics

- **Shocks to WTI**
  - **Affect LLB and Maya in the short run**
  - **Impose a strong drag to equilibrium on both heavy crudes**
- **Shocks to LLB and Maya**
  - **Affect WTI in the short run**
  - **But drag to equilibrium is not significant: WTI is weakly exogenous**
- **Shocks to LLB**
  - **Affect Maya in the short run**
  - **Imbalance between LLB and WTI affects Maya in the long run**
- **Shocks to Maya**
  - **Affect LLB in the short run**
  - **Imbalance between Maya and WTI does not affect LLB**

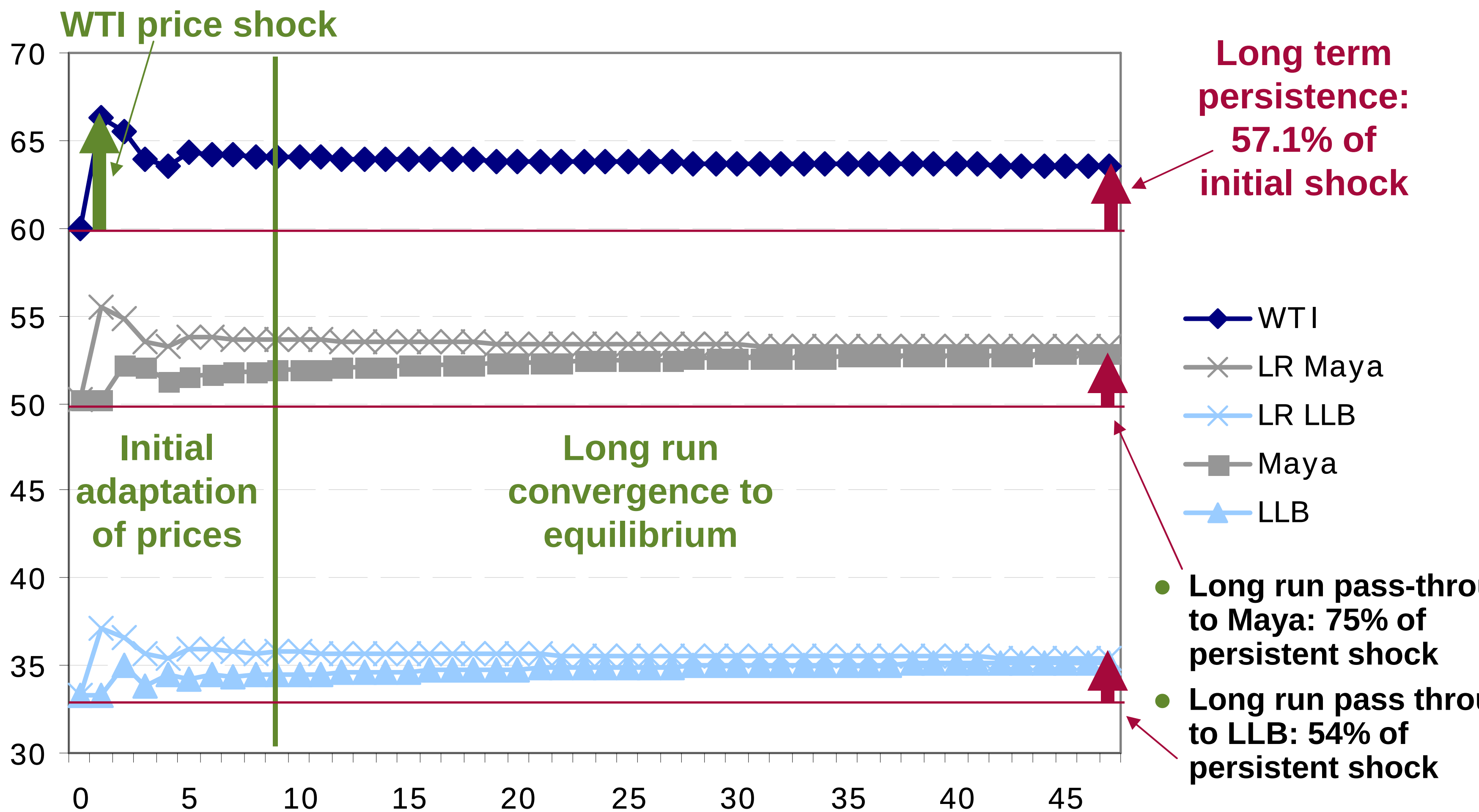
Part #2
Bottom Line: Short-run Dynamics (cont.)

- **Shocks to WTI cause short run shocks to Maya and LLB**
- **Once WTI is stabilized, shocks are persistent and impact long run prices of Maya & LLB**
  - **Convergence to long-run equilibrium takes over after 9 weeks**



Part #2

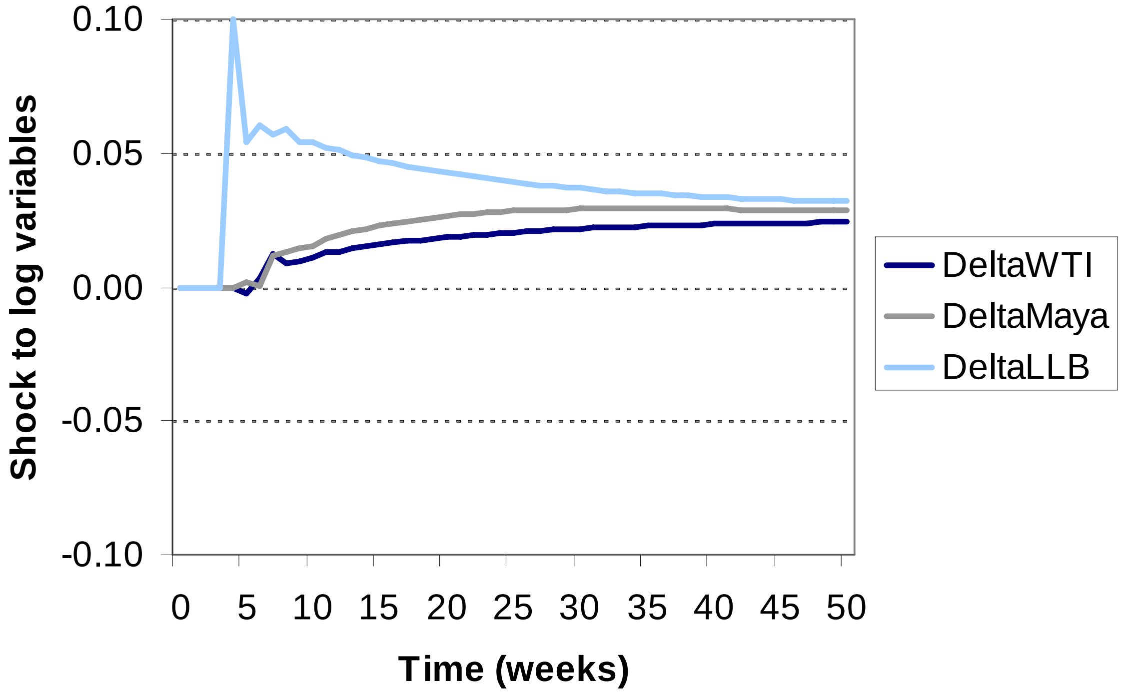
Bottom Line: Short-run Dynamics (cont.)



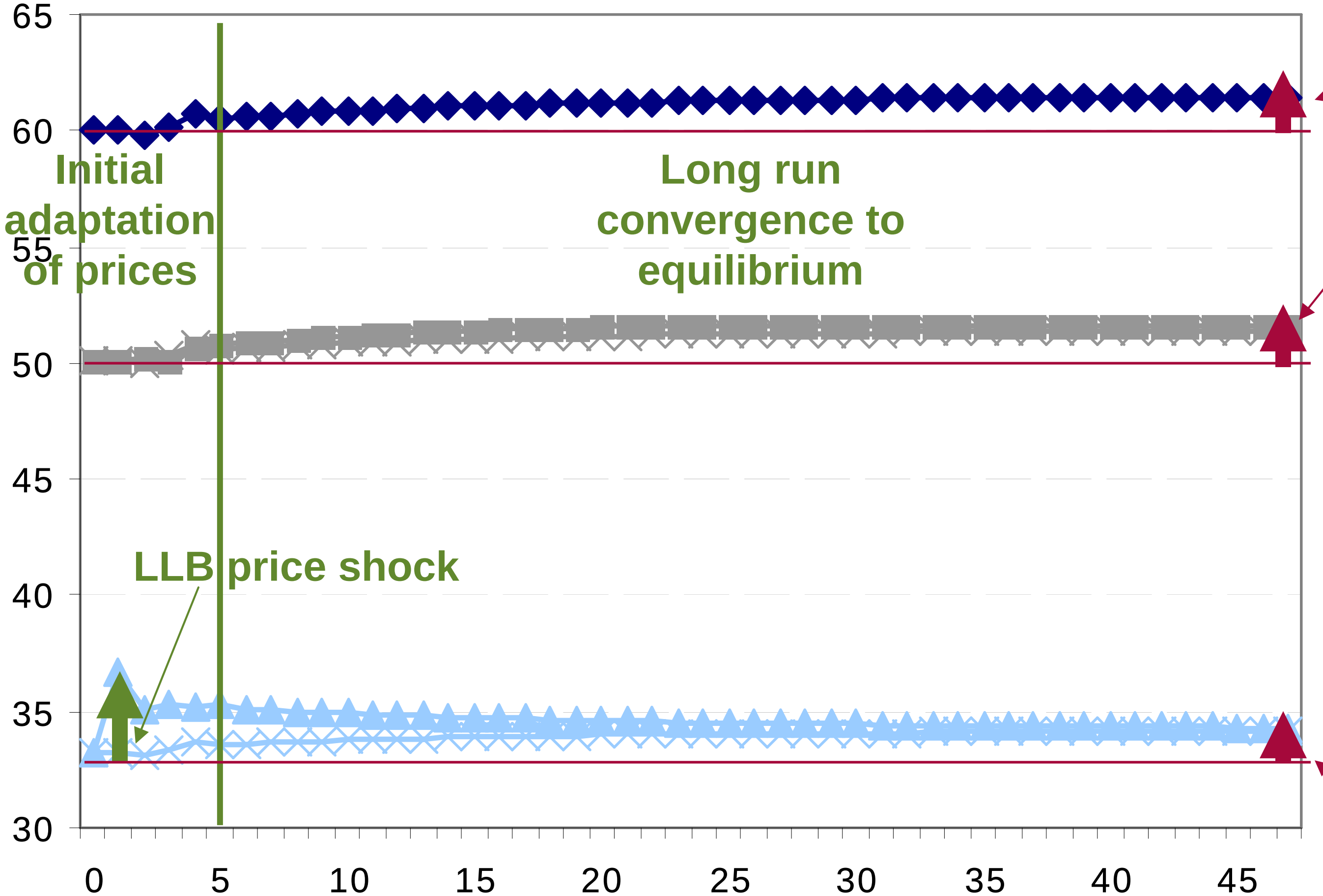
- **Long run pass-through to Maya: 75% of persistent shock**
- **Long run pass through to LLB: 54% of persistent shock**

Part #2
Bottom Line: Short-run Dynamics (cont.)

- **Shocks to LLB cause short term shocks to other variables**
- **Once other variables have stabilized, LLB has limited further impact on long-run prices**
  - **Convergence to long-run equilibrium takes over after 5 weeks**



Part #2
Bottom Line: Short-run Dynamics (cont.)

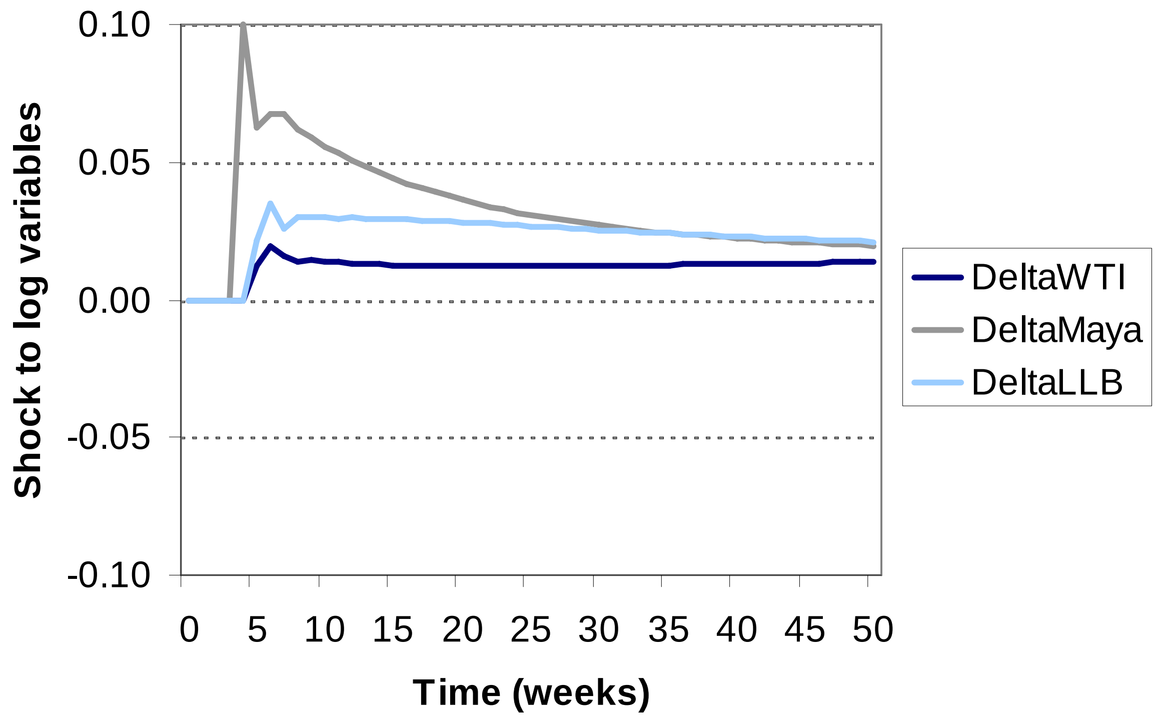


- Long run pass-through to WTI: 43% of initial shock
- Long run pass through to Maya: 42% of initial shock

Long term persistence: 31.2% of initial shock

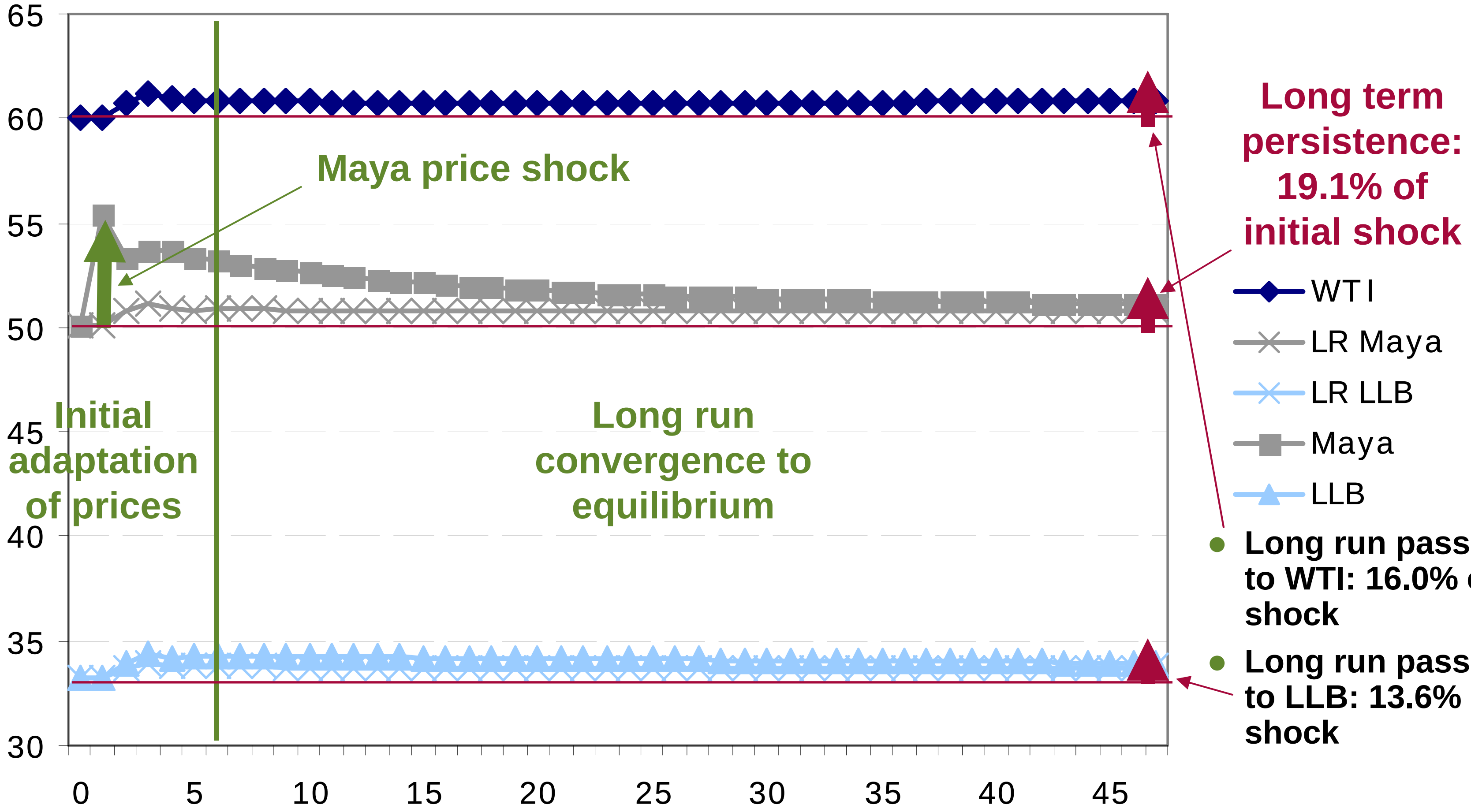
Part #2
Bottom Line: Short-run Dynamics (cont.)

- **Shocks to Maya cause short term shocks to other variables**
- **Once other variables have stabilized, Maya has no further impact on long-run prices**
  - **Convergence to long-run equilibrium takes over after 6 weeks**



Part #2

Bottom Line: Short-run Dynamics (cont.)



- **Long run pass-through to WTI: 16.0% of initial shock**
- **Long run pass through to LLB: 13.6% of initial shock**

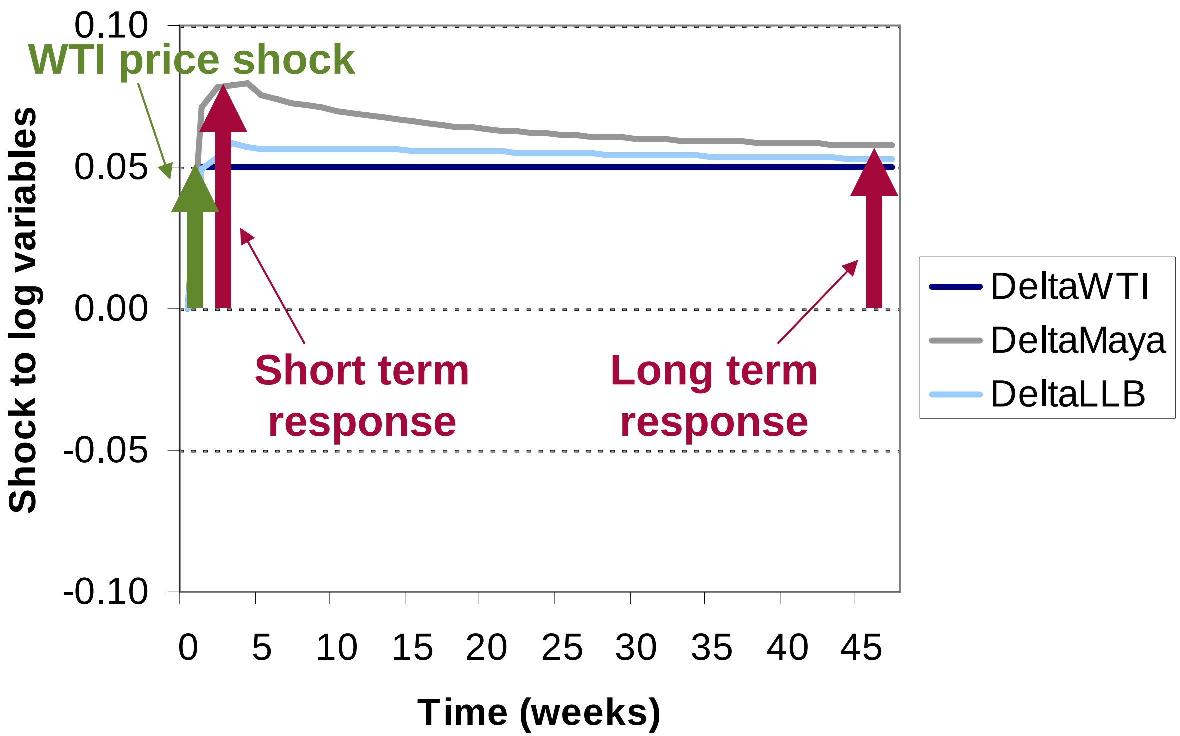
Part #3
Bottom-line: Exogenous impact of WTI

- **Implications of the VECM:**
  - **Short run and long run movements of heavy oil prices are linked to WTI price through different channels**
  - **However, the model misses the contemporaneous effect of WTI on other variables**

- **New model: Conditional Error Correction Model (CECM)**
  - **WTI is assumed *exogenous* with a *contemporaneous effect on heavy crudes***
  - **Result: fit is much better! (R^2 = 12% → 52% for LLB, 8% → 59% for Maya)**
  - **But we loose information on the feedback from heavy crudes to WTI**

Part #3
Bottom-line: Exogenous impact of WTI (Cont.)

- **CECM estimates the following short run dynamics:**



- **Differential hedging ration between long run and short run**
- **Hedging ratios are dependent on the level of prices**

Implications

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Optimal Hedging Strategy

- For a natural long with heavy oil to sell:
  - There is no futures contract on heavy oil
  - Can one hedge with the NYMEX WTI front month contract? → CECM
- Naïve hedging strategy
  - Single, unconditional hedge ratio with NYMEX WTI 1st month to 1 year swap
  - BMO (formerly Bank of Montreal): 78.1%

Optimal Hedging Strategy

BMO Commodity Products Group

BMO Capital Markets

Member of BMO Financial Group

Managing Heavy Oil Price Risk

February 2006

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Introduction

Many energy producers have two types of price risk inherent in their crude oil sales. First, global supply/demand fundamentals affect the general price of crude oil, which is best exemplified by price changes in NYMEX Light Sweet Crude Oil. Secondly, physical crude oil sale prices can be affected by the supply/demand variables as they relate to the quality or location of the physical production. Recently, a number of producers have expressed interest in ideas for hedging their heavy oil production. This report summarizes heavy oil historical pricing and back-tests some different risk management strategies.

Executive Summary

- Since 2001, the Bow River Blend differential has averaged \$11.24/bbl and the Lloyd Blend differential has averaged \$12.05/bbl.
- There is a significant relationship between outright crude prices and heavy oil differentials. Heavy oil differentials tend to widen as general price levels increase. Using data back to January 2001, on average a \$1.00 increase in NYMEX WTI prices results in a \$0.59 increase in Bow River prices.
- Historical data analysis suggests the best proxy hedge for 1,000 barrels of heavy oil is a fixed-for-floating swap on approximately 750 barrels of NYMEX WTI.

Optimal Hedging Strategy

- **For a natural long with heavy oil to sell:**
  - There is no futures contract on heavy oil
  - Can one hedge with the NYMEX WTI front month contract? → CECM
- **Naïve hedging strategy**
  - Single, unconditional hedge ratio with NYMEX WTI 1st month to 1 year swap
  - BMO (formerly Bank of Montreal): 78.1%
- **Conditional long run strategy**
  - Conditional hedge ratio for NYMEX WTI 1st month contract
  - WTI @ $30/bbl → ratio 51%, vs. WTI @ $100/bbl → 59%
- **Short-run strategy**
  - Single hedge ratio for NYMEX WTI 1st month contract: 84.5%
  - Position informed by reversal to long run equilibrium

The End

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