The Role of Time-Varying Price Elasticities in Accounting for Volatility Changes in the Crude Oil Market

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The views expressed in this presentation, or in my remarks, are my own, and do not necessarily represent those of the Bank of Canada.
Oil price volatility

• Dramatic rise in oil price volatility after 1986 price collapse
Oil production volatility

- Gradual fall in oil production volatility
Changes in volatility

- Important structural transformations in crude oil market
- Causes of inverse evolution of oil price and oil production volatility
A stylized model of the crude oil market

- Oil demand: \( Q^D_t = -d_t P_t^* + \varepsilon^d_t \)
- Oil supply: \( Q^S_t = s_t P_t^* + \varepsilon^s_t \)
- Price adjustment: \( P_t = \lambda_t P_t^* + (1 - \lambda_t) P_{t-1} \)
- Equilibrium:
  \[
  P_t = \frac{\lambda_t \varepsilon^d_t}{s_t + d_t} - \frac{\lambda_t \varepsilon^s_t}{s_t + d_t} \\
  Q_t = \frac{[s_t + (1 - \lambda_t) d_t] \varepsilon^d_t}{s_t + d_t} + \frac{\lambda_t d_t \varepsilon^s_t}{s_t + d_t}
  \]
- Oil demand and supply shocks:
  \[
  E[\varepsilon^d_t] = E[\varepsilon^s_t] = 0 \\
  E[\varepsilon^d_t]^2 = \sigma_{d,t}^2 \\
  E[\varepsilon^s_t]^2 = \sigma_{s,t}^2 \\
  E[\varepsilon^d_t, \varepsilon^s_t] = 0
  \]
Hypotheses

• Variability of crude oil prices and oil production

\[ E[P_t]^2 = \frac{\lambda_t^2 (\sigma_{d,t}^2 + \sigma_{s,t}^2)}{(s_t + d_t)^2} \quad E[Q_t]^2 = \frac{[s_t + (1 - \lambda_t)d_t]^2 \sigma_{d,t}^2 + \lambda_t^2 d_t^2 \sigma_{s,t}^2}{(s_t + d_t)^2} \]

1. Changes in the variance of oil market shocks

\[ \frac{\partial E[P_t]^2}{\partial \sigma_{s,t}^2} > 0 \quad \frac{\partial E[Q_t]^2}{\partial \sigma_{s,t}^2} > 0 \]

• 1970s: major production disruptions (Hamilton 2009)

\[ \frac{\partial E[P_t]^2}{\partial \sigma_{d,t}^2} > 0 \quad \frac{\partial E[Q_t]^2}{\partial \sigma_{d,t}^2} > 0 \]

• 1980s: shift in pricing regime (Hubbard 1986, Mabro 2005)

• mid-1980s: Great Moderation (Herrera and Pesavento 2009)
Hypotheses

2. Changes in price elasticities of oil demand and oil supply

\[ \frac{\partial E[P_t]}{\partial d_t} < 0 \quad \frac{\partial E[Q_t]}{\partial d_t} > 0 \]

- 1980s: changes in demand behavior
  (Baumeister and Peersman 2008)

\[ \frac{\partial E[P_t]}{\partial s_t} < 0 \quad \frac{\partial E[Q_t]}{\partial s_t} > 0 \]

- mid-1980s: little spare capacity
  Kilian (2008)

3. Changes in the speed of oil price adjustment to shocks

\[ \frac{\partial E[P_t]}{\partial \lambda_t} > 0 \quad \frac{\partial E[Q_t]}{\partial \lambda_t} = \frac{2d_t}{(s_t + d_t)^2} \left\{-[s_t + (1 - \lambda_t)d_t]\sigma_{d,t}^2 + \lambda_t d_t \sigma_{s,t}^2 \right\} \leq 0 \]

- mid-1980s: collapse of OPEC cartel and increased spot trading
Empirical model

- VAR with global oil production, real price of crude oil and world industrial production
- Time-varying parameters
- Stochastic volatilities in the innovation process


\[ y_t = c_t + B_{1,t} y_{t-1} + \ldots + B_{p,t} y_{t-p} + u_t \equiv X_t' \theta_t + u_t \]

- First differences, 4 lags
- 1947Q1-2010Q4 (first 25 years as a training sample)
Empirical model

- Drifting coefficients capture time variation in propagation

\[
\theta_t = \theta_{t-1} + \nu_t \quad \nu_t \sim N(0, Q)
\]

- Time-varying covariance matrix
  - Heteroscedasticity of the shocks: changes in magnitude of shocks
  - Time variation in simultaneous relationships between variables

\[
u_t \sim N(0, \Omega_t) \quad \Omega_t = A_t^{-1} H_t (A_t^{-1})'
\]

\[
A_t = \begin{bmatrix} 1 & 0 & 0 \\ \alpha_{21,t} & 1 & 0 \\ \alpha_{31,t} & \alpha_{32,t} & 1 \end{bmatrix} \quad H_t = \begin{bmatrix} h_{1,t} & 0 & 0 \\ 0 & h_{2,t} & 0 \\ 0 & 0 & h_{3,t} \end{bmatrix}
\]

- Error terms of transition equations are independent of each other and of the innovations of the observation equation
Identification

- Sign restrictions implied by stylized supply and demand model of the crude oil market

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- Oil supply shocks move oil prices and oil production in **opposite** direction
Identification

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## Identification

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- Oil supply shocks move oil prices and oil production in opposite direction
- Oil demand shocks move oil prices and oil production in the same direction
  - **Other oil** demand shocks: non-positive effect on global economic activity
  - **Aggregate** demand shocks: positive effect on global economic activity
Identification

• Sign restrictions imposed only on impact
• Kilian and Murphy (2011): sign restrictions alone are too weak

Augment identification strategy by boundary restrictions on impact price elasticities:
  – **Oil demand elasticity**: lower bound of -0.8 which corresponds to long-run oil demand elasticity (Hausmann and Newey 1995)
  – **Oil supply elasticity**: upper bound of 0.6
Results

• Impulse responses after typical (one standard deviation) oil market shocks

Oil supply shock

Other oil demand shock

Aggregate demand shock
Results

• Declining effect of oil market shocks on oil production implies: *smaller* quantity movements
Results

- Declining effect of oil market shocks on oil production
  ➞ implies: *smaller* quantity movements
- Stronger effect of oil market shocks on oil prices
  ➞ implies: *larger* price movements
Results

- Declining effect of oil supply shocks on oil production
  - implies: *smaller* quantity movements
- Stronger effect of oil supply shocks on oil prices
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![Graph showing supply and demand for oil with 1970s label](image-url)
Results

- Declining effect of oil supply shocks on oil production
  implies: *smaller* quantity movements
- Stronger effect of oil supply shocks on oil prices
  implies: *larger* price movements
Results

- Combination of *larger* price response and *smaller* quantity reaction
- Oil demand curve must have become steeper (less elastic) over time
Results

- Combination of greater price response and smaller quantity reaction
- Oil demand curve must have become steeper (less elastic) over time. The same reasoning applies for the oil supply curve.

![Graph showing changes in demand and supply curves](image-url)
Evaluation of hypotheses

• Evolution of short-run price elasticities of oil supply and oil demand: considerable decrease in responsiveness of oil supply and oil demand to price changes over time

![Oil demand elasticity graph]

Graph showing the evolution of oil demand elasticity from 1975 to 2010, indicating a decrease in responsiveness over time.
Evaluation of hypotheses

Oil supply elasticity with aggregate demand shock

Oil supply elasticity with other oil demand shock
Evaluation of hypotheses

- Evolution of variances of shocks: smooth decline over time

**Aggregate demand shock**
- Great Moderation
- Oil intensity of production

**Other oil demand shock**
- Fears about future oil supplies
- Changes in inventory behavior
- Speculation

**Oil supply shock**
Reasons for decline in elasticities

• Oil futures markets
  – Hedging possibilities reduce exposure to price changes for oil consumers and producers: less sensitive to price fluctuations
  – Volume of trading on NYMEX expanded after 1985

• Demand side
  – High oil prices of 1970s caused industries to switch away from oil to other sources of energy
  – Higher share of developing countries in global oil demand

• Supply side
  – Decline in global spare oil production capacity
  – Lack of investment in oil sector
Reasons for decline in elasticities

- Demand-supply feedback loop
  - Tightness in the market affects demand behavior
  - Operation close to full capacity can lead to relative higher share of (less elastic) precautionary oil demand

Worldwide oil rig counts

Global capacity utilization rates
Conclusions

• Important volatility changes in crude oil market
• Potential sources
  – Changes in speed of adjustment of oil prices to shocks
  – Changes in volatility of structural shocks
  – Changes in short-run price elasticities of oil demand and supply
• Time-varying framework to assess hypotheses empirically
• Key findings
  – Steepening of oil supply and oil demand curves over time
  – Decrease in variances of structural shocks
• Driving forces behind decrease in elasticities
  – Development of oil futures markets
  – Lack of investment and spare capacity in oil sector