The Global Crude Oil Market
One-Level vs. Two-Level Games

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Agenda

• Motivation, Market Setups & Methodology

• The Model

• Numerical Application

• Conclusions and Future Directions
Motivation

• Market Power in the Crude Oil Market?
  Market setups usually proposed:
  - Competitive market
  - Nash-Cournot behaviour
  - OPEC cartel
  - Stackelberg leader-follower market

• Influence of liquid spot markets and price indices?
  Theory: „one great pool“ of crude oil
Caveats of this Approach

• Supply & Demand-Model
  - speculation and „paper oil“ market are not included

• One-period Model
  - Inter-temporal optimization (Hotelling) is not considered

• Profit Maximising Agents
  - Ignores political aspects of National Oil Companies

• Simplification: only one type of crude oil
  - Quality differences are neglected
Methodology – Nash Cournot Trade Models

• Numerical partial equilibrium modelling
  - Nash-Cournot markets – non-cooperative strategic behaviour
  - Formulated as Mixed Complementarity Problems (MCP)

• Extensively used in modelling...

  ...natural gas markets
  Gastale (Boots et al, 2004),
  World Gas Model (Egging et al, 2008), etc.

  ...electricity markets
  Poolco Model (Hobbs, 2001)
Integrated Global Crude Oil Markets

Specific characteristic of the crude oil market:

• Existence of spot markets with arbitrageurs (pool hubs)

Introduction of equilibrium condition in the MCP Model:

Demand node Price = Pool Price + Transport Costs
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The Model – Agents

• Profit maximizing producers
  - Production Entity (quadratic cost function)
  - Trading Entity (may exert market power vis-à-vis demand)

• Cartel vs. independent behaviour
  - either one trading entity for all OPEC suppliers (standard cartel)
  - or one trading entity per supplier

• Inverse Demand Curve for Refineries
  (Final Demand for Crude Oil)
The Model – Framework

- Pool hubs with competitive arbitrageurs
  - WTI (West Texas Intermediate), USA
  - Brent, UK
  - Dubai Basket, UAE

- Types of transport
  - Tanker ship
  - Pipeline
Profit Maximization Problem of the Supplier

- **Production Entity**

\[
\max_{Prod^p_n} Prod^p_n \cdot \phi^T_n - Cost^P_n(Prod^p_n) \\
\text{s.t. } Prod^p_n \leq \text{Cap}_n^p \quad \downarrow \quad \alpha^{'Prod}_n \geq 0
\]  

- **Trading Entity**

\[
\max \sum_{Sales_{n}^{T\rightarrow R}} \left[ Sales_{n}^{T\rightarrow R} \cdot \left[ \delta^T \cdot \Pi^R_n (\cdot) + (1 - \delta^T) \cdot \sum_{i \in I} \theta_{n,i} \cdot (\pi^Pool_i + TC_{i\rightarrow n}) \right] \\
- \sum_{m \in A(n)} \text{Flow}^T_{n\rightarrow m} \cdot \text{TC}_{n\rightarrow m}^{Pipe} - \sum_{k \in Pt} \text{Ship}^T_{n\rightarrow k} \cdot \text{TC}_{n\rightarrow k}^{Ship} - Prod^P_n \cdot \phi^T_n \right]
\]

\[
\text{s.t. } Sales_{n}^{T\rightarrow R} - \sum_{m \in A(n)} \text{Flow}^{out}_{n\rightarrow m} - \sum_{k \in Sea} \text{Ship}^{out}_{n\rightarrow k} \\
+ \sum_{l \in A(n)} \text{Flow}^{in}_{l\rightarrow n} + \sum_{h \in Pt} \text{Ship}^{in}_{h\rightarrow n} \leq 0 \quad \downarrow \quad \phi^T_n \geq 0 \quad \forall \ n \in N
\]
Final Demand and the Arbitrageur

• Arbitrageur Neutrality Constraint

\[
\sum_{n \in N} Arbit_{i,n}^{Pool} = 0 \perp \beta_i^{Pool}(\text{free}) \ \forall \ i \in I
\]  (5)

• Final Demand – Inverse Demand Function

\[
DemInt_n^R - DemSlp_n^R \cdot \left[ \sum_T Sales_n^{T \rightarrow R} + \sum_{i \in I} \vartheta_{n,i} \cdot Arbit_{i,n}^{Pool} \right] \\
\quad - \sum_{i \in I} \vartheta_{n,i} \cdot (\pi_i^{Pool} + TC_{i \rightarrow n}) = 0 \perp \beta_n^{Price}(\text{free}) \ \forall \ n \in N
\]  (6)
One-Level vs. Two Level-Games

• One-Level Game:
  - All players act simultaneously
  - Formulated as Mixed Complementarity Problem (MCP)

• Two-Level Game:
  - Stackelberg-Leader decides first, taking into account its own effects on the second level
  - Stackelberg-Followers compete simultaneously for the remaining market share
  - Formulated as Mathematical Problem with Equilibrium Constraints (MPEC)
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Countries in the Model
Model Data

Base Year: 2006

Data sources:

- Consumption and production quantities, reference prices
  IEA (2008), BP (2008)

- Production Cost

- Transport Costs
  Bundesanstalt für Geowissenschaften und Rohstoffe, Hannover (2003)

- Demand Elasticity – assumed to be -0.1

- Production Capacity
  assumption that each country operates at 95% of capacity in base year
The Model – Market Power Scenarios (I)

One-Level (simultaneous) Games:

- Perfectly competitive market – *(Perfect Competition)*

- Nash-Cournot market (all suppliers exert market power) – *(Nash-Cournot)*

- OPEC members exert market power (but do not jointly maximize profits), others: competitive fringe – *(Oligopoly)*

- OPEC forms a standard cartel and exerts market power, others: competitive fringe – *(Cartel)*
The Model – Market Power Scenarios (II)

Two-Level Games with Saudi Arabia as Stackelberg leader:

- Perfectly competitive market – *(Perfect Competition SB)*
- Nash-Cournot market – *(Nash-Cournot SB)*
- OPEC members exert market power, others: competitive fringe – *(Oligopoly SB)*
Results – Final Demand Prices

Final demand prices in $/barrel
Results – OPEC Production of Crude Oil

in mio tons/annum, selected countries
Results – Fringe Production of Crude Oil

in mio tons/annum, selected countries
Observations of Production Levels

- Competitive fringe producers (USA, China, etc.):
  ...produce below full capacity in competitive scenario, full capacity otherwise

- Russia („uncompetitive fringe“):
  ...considerably reduces production if it exerts market power (Nash-Cournot scenario)

- Saudi Arabia:
  ...produces at full capacity in competition and Stackelberg scenario, significantly below capacity in all other scenarios

- Other OPEC:
  ...produce at full capacity at all times, apart from cartel and Stackelberg scenario
Saudi and OPEC Profits (I)

in mio $
Sensitivity Analysis

Demand Elasticity Variation:

• Assumption in the Standard Model: -0.1
• Less elastic demand (-0.2, -0.3)
  - generally higher total production
  - observed prices between model output of Nash-Cournot Stackelberg and the Cartel scenarios
• More elastic demand (-0.05)
  - generally lower total production
  - observed prices closer to model output in the Oligopoly Stackelberg scenario
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Conclusions

• Pool Setup offers an improvement in modeling the crude oil market (include „one great pool“ theory)

• Both the OPEC standard cartel and a perfectly competitive market can be rejected

• Results indicate Stackelberg leadership of Saudi Arabia and a Nash-Cournot follower market

• Assumption of profit maximization ignores important aspects of the behaviour of National Oil Companies
Future Directions & Model Extensions

...regarding the specifics of the crude oil market:

• More realistic maximization problem for the supplier
  - e.g. Target Revenue Approach, Social Welfare Function
• Better data/assumptions regarding production capacity

...regarding the modelling approach:

• Multi-period model with endogenous investment
• Stochasticity in future demand levels
References


