An Imperfectly Competitive Model of the World Natural Gas Market

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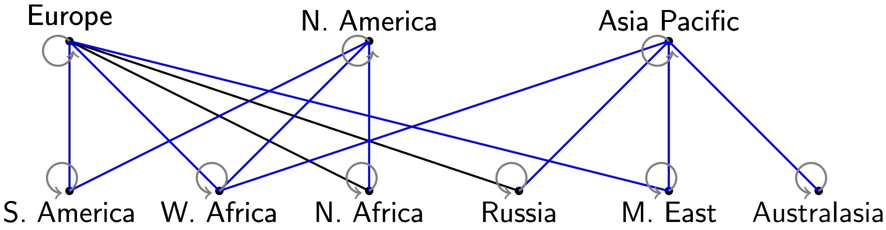
Overview

- Focus of paper: We model world natural gas trade as a network problem and solve for Cournot-Nash equilibrium
- A network structure where buyers and sellers are connected
- A buyer and a seller must have relationship, "link" to trade
- The market power of natural gas producers depends on their production capacity and their access to markets
  - At the end of 2009, Russia, Iran and Qatar held 50% of global natural gas proved reserves
  - Russia was the biggest supplier to Europe with a share of 62% where as M.East's share was 8.8%
- Motivation is to analyze how this structure of the network affect the market outcome
- Scenario analysis

We draw our graph using trade flows in *BP's Statistical Review of 2010*

- Exporters: South America, West Africa, North Africa, Russia, Middle East and Australasia
- Importers: Europe, North America and Asia Pacific



Cournot Model-I

- We assume that markets have linear inverse demand function:

$$p_i(Q_g) = \alpha_i - \beta_i c_i$$

where Q_g be the column vector of quantities supplied in graph g, α_i and β_i are positive constants and c_i is natural gas consumption in market i

$$\sum_{f_j \in N_g(d_i)} q_{ij} = c_i$$

◂ Graph

Cournot Model-II

- We assume that firms have quadratic costs of production and linear costs of transportation

$$T_j(Q_g) = \underbrace{\frac{\gamma_j}{2} s_j^2}_{\text{Cost of production}} + \underbrace{\sum_{m_i \in N_g(f_j)} \tau_{ij} q_{ij}}_{\text{Cost of transportation}}$$

where γ_j is positive constant, τ_{ij} is the marginal cost of transporting natural gas from firm j to market i and is positive if firm is supplying to abroad, is zero supplying to domestic market, s_j is quantity produced by firm j

$$\sum_{d_i \in N_g(f_j)} q_{ij} = s_j$$

Cournot Model-III

- Firm j's profit is

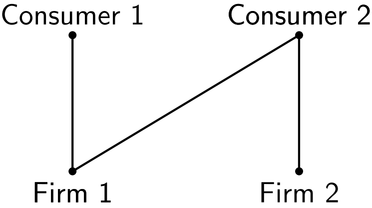
$$\pi_j(Q_g) = \sum_{d_i \in N_g(f_j)} \alpha_i q_{ij} - \sum_{d_i \in N_g(f_j)} \beta_i q_{ij} c_i - \frac{\gamma_j}{2} s_j^2 - \sum_{d_i \in N_g(f_j)} \tau_{ij} q_{ij}$$

- Profit maximizing q_{ij} is

$$q_{ij}^{\star} = \begin{cases} \frac{\alpha_i - \tau_{ij} - \gamma_j \left(\sum_{m_l \in N_g(f_j) \setminus \{m_i\}} q_{lj} \right) - \beta_i \left(\sum_{f_k \in N_g(m_i) \setminus \{f_j\}} q_{ik} \right)}{2\beta_i + \gamma_j} & \text{if } \frac{\partial \pi_j}{\partial q_{ij}}\Big|_{Q_g} \geq 0 \\ 0 & \text{if } \frac{\partial \pi_j}{\partial q_{ij}}\Big|_{Q_g} < 0 \end{cases}$$

- $q_{ij}^{\star}$ is the unique Cournot-Nash equilibrium of this game

Example



$$Q_g = \left[\begin{array}{ccc} q_{11} & q_{21} & q_{22} \end{array} \right]'$$

$$p_1(Q_g) = \alpha_1 - \beta_1 q_{11}$$

$$p_2(Q_g) = \alpha_2 - \beta_2(q_{21} + q_{22})$$

Firm 1's profit is:

$$\pi_1(Q_g) = (\alpha_1 - \beta_1 q_{11})q_{11} + (\alpha_2 - \beta_2(q_{21} + q_{22}))q_{21} - \left(\frac{\gamma_1}{2}(q_{11} + q_{21})^2 + \tau_{11} q_{11} + \tau_{21} q_{21} \right)$$

Firm 2's profit is:

$$\pi_2(Q_g) = (\alpha_2 - \beta_2(q_{21} + q_{22}))q_{22} - \left(\frac{\gamma_2}{2}(q_{22})^2 + \tau_{22} q_{22} \right)$$

Equilibrium flow in each link is

$$q_{11}^\star = \frac{\alpha_1 - \tau_{11} - \gamma_1 q_{21}}{2\beta_1 + \gamma_1} \quad q_{21}^\star = \frac{\alpha_2 - \tau_{21} - \gamma_1 q_{11} - \beta_2 q_{22}}{2\beta_2 + \gamma_1} \quad q_{22}^\star = \frac{\alpha_2 - \tau_{22} - \beta_2 q_{21}}{2\beta_2 + \gamma_2}$$

Calibration

- Symbolic solution is not feasible as we have 27 demand and supply parameters and 12 transport cost parameters
- Instead we calibrate parameters using 2009 production, consumption, trade and price data
- Our goal is to find set of parameters that minimize the square of percentage deviation from 2009 data
- Methodology: Constrained nonlinear optimization with the objective function of

$$\min_{\nu(\alpha_i,\beta_i,\gamma_j)} \sum_{i,j=1,2,3,4,5,6,7,8,9} \left(\frac{pq_{i,j}^{2009} - pq^{eqm}(\alpha_i, \beta_i, \gamma_j)_{i,j}}{pq_{i,j}^{2009}} \right)^2$$

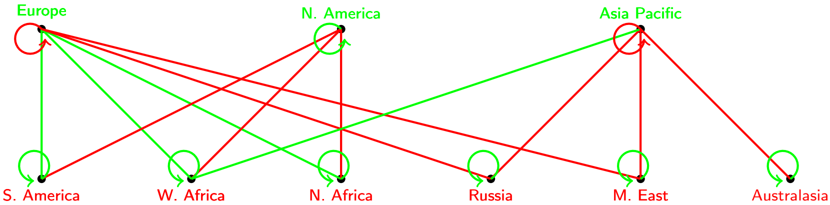
- Unique solution minimizing the objective function is yet to be achieved

Calibration-II

$$T_j(Q_g) = \underbrace{\frac{\gamma_j}{2} s_j^2}_{\text{Cost of production}} + \underbrace{\sum_{m_i \in N_g(f_j)} \tau_{ij} q_{ij}}_{\text{Cost of transportation}}$$

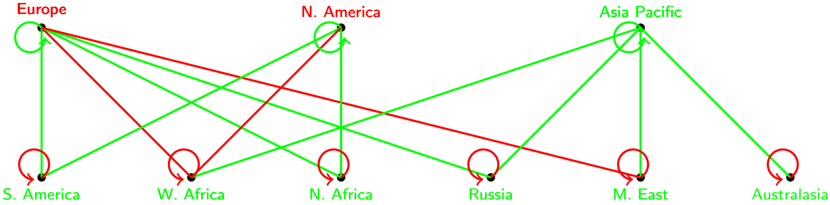
- For τ_{ij}, the marginal cost of carrying per unit of natural gas per 100 miles, we use the distance between producer and consumer
- We assume
  - all LNG shipments have the same cost per unit and per mile
  - pipeline cost per unit and per mile to be same
- The longest LNG distance in our network is from West Africa to Asia Pacific, 12300 nautical miles
- The shortest LNG distance in our network is from Russia to Asia Pacific, 1400 nautical miles

Preliminary Results-I: ⇑ in North American shale gas production



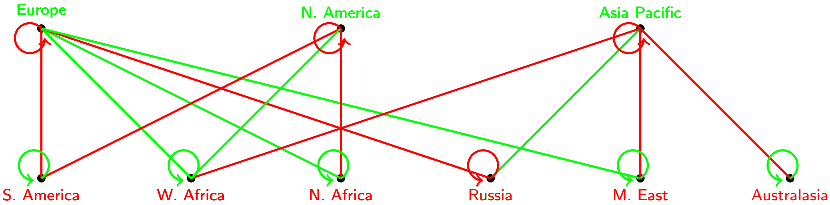
- ⇑ in N. American shale gas production ⇓ LNG exports to N. America
- All of the exporters that are connected to N. America move their resources from N. America to other regions they are connected to
- This ⇑ the competition in Europe and Asia Pacific
- Russia, Middle East and Australasia ⇑ their supply to domestic markets due to ⇑ competition in Europe and Asia Pacific
- Total consumption ⇑ in all of the exporting and importing regions
- Europe and Asia Pacific ⇓ their supply to domestic market due to ⇑ in competition from ⇓ in N. America's LNG demand
- All producers (except N. America) ⇓ their total production
- Prices ⇓ in each region due to ⇑ in competition/supply

Preliminary Results-II: ⇑ in Asia Pacific's LNG demand?



- All suppliers connected to Asia Pacific ⇑ their supply to Asia Pacific and ⇓ their supply to other markets they are connected to except Russia
- Russia benefits from decreased competition in Europe and utilizes its lower cost access advantage
- Decreased supply to Europe and N. America from W. Africa and M. East ⇑ S. America and N. Africa's supply to these two regions
- All of the exporters ⇓ their supply to domestic market but ⇑ their production to export more
- Europe and N. America ⇑ their supply to domestic market to meet the decrease in imports but overall consumption in these two regions ⇓
- Due to ⇑ in Asia Pacific's demand price ⇑ and due to ⇓ in supply in all other regions prices ⇑

Preliminary Results-III: Pipeline from Russia to Asia Pacific



- Russia $\Uparrow$ its supply to Asia Pacific and moves its resources from other markets to Asia Pacific
- $\Uparrow$ in Russian supply to Asia Pacific $\Downarrow$ marginal revenue of W. Africa, M.East and Australasia
- W. Africa, M.East and Australasia $\Uparrow$ their supply to other markets they are connected to
- N. Africa $\Uparrow$ its supply to Europe to utilize its lower cost access
- S. America $\Downarrow$ its exports to due $\Uparrow$ in competition
- All of the exporting regions $\Uparrow$ their supply to domestic market except Russia
- All of the importing regions $\Downarrow$ their supply to domestic regions because of the $\Uparrow$ in imports
- Prices $\Downarrow$ in each region (except Russia) because of the $\Uparrow$ in total supply
- Price in Russia $\Uparrow$ due to $\Downarrow$ in domestic supply

Future Research

- Stackelberg competition
  - Russia and Middle East forming "Gas-OPEC" act as leader
  - Rest of the producers are followers
- Russia and Middle East becoming more competitive