
The Game That Drives the LNG Trains

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- ▶ This paper does not represent the view of Royal Dutch Shell and any of its affiliates.



What this paper is about?



- ▶ Who:
 - ▶ Major LNG downstream investors
- ▶ Where:
 - ▶ North America East Coast
- ▶ What: Location and Quantity Game
 - ▶ Choose a location for the terminal to receive their LNG cargos.
 - ▶ Deliver natural gas into different markets for end-users or trading partners through pipelines.

Explore strategic elements of decision through a theoretical model.

Model Setup

- ▶ Definition of Market Space

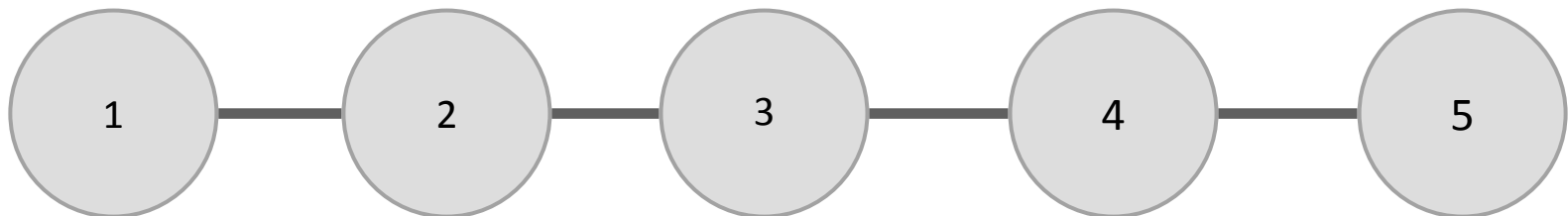
- ▶ Let $G = (V, E)$ be a market space;

- ▶ V : Market Nodes

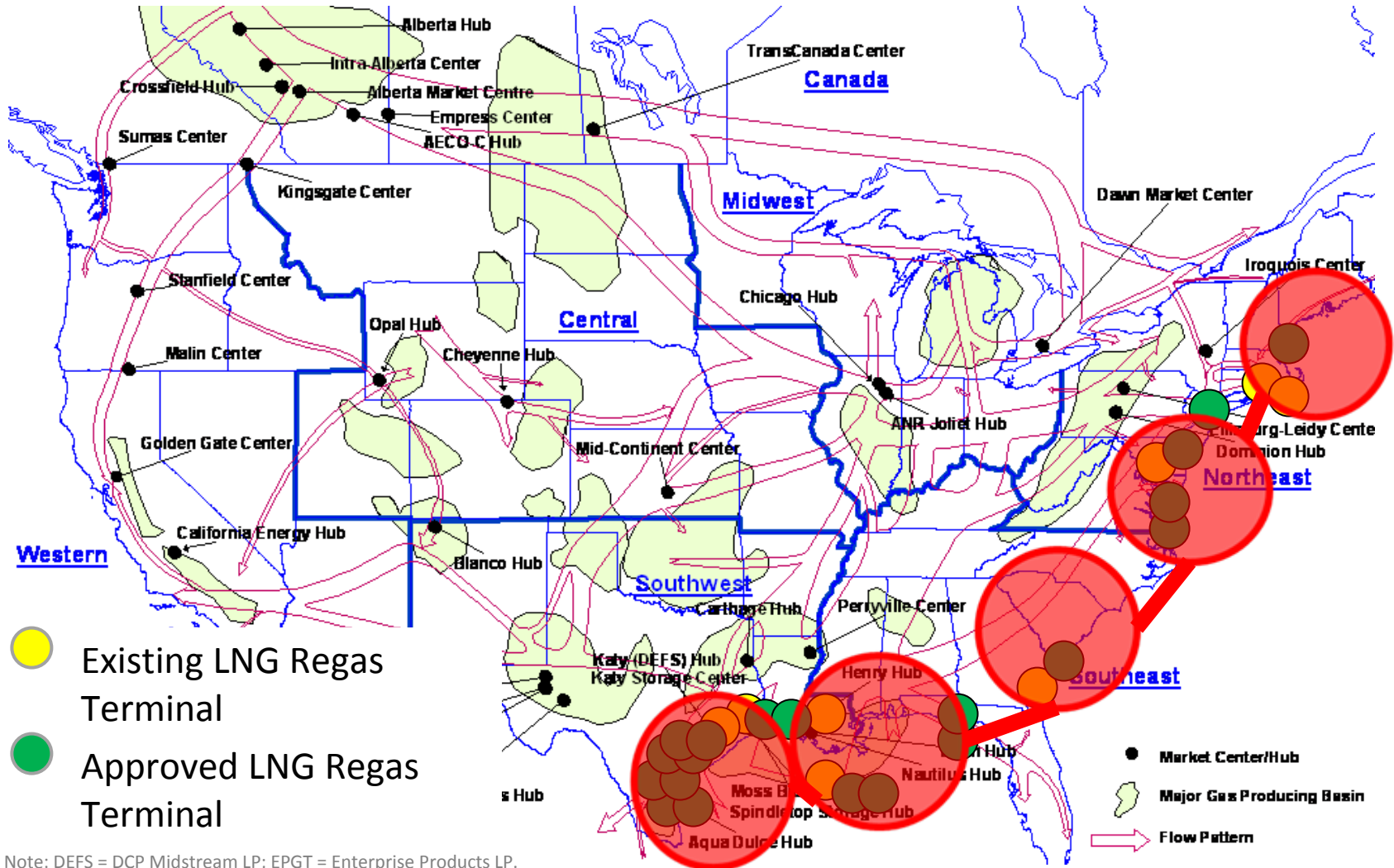
- ▶ E : Edges; i.e., Pipelines.

- ▶ $|V| = m$, where m is number of Markets

- ▶ For example, there are 5 markets that the firms can choose to serve and locate the regas terminals.



LNG Market Space in US East Coast



Note: DEFS = DCP Midstream LP; EPGT = Enterprise Products LP.

Source: Energy Information Administration, Office of Oil and Gas, Natural Gas Division, Natural Gas Market Hubs Database, as of August 2004.

Model Setup (Cont'd)

▶ Definition of Game

- ▶ Players: Firm $i \in N = \{1, \dots, n\}$
- ▶ Strategy Set: A strategy for firm i is $[x_i, Q_i]$:
 - ▶ Choice of location: $x_i = h \in M = \{1, \dots, m\}$
 - ▶ Choice of quantity supplied to each markets: $Q_i = (Q_{i1} \dots Q_{im})$
- ▶ Profit maximization:
$$\text{Max } \pi_i(x_i, Q_i)$$



Simple Example of the Game if there are only 2 firms

1st Stage: Firms simultaneously choose locations x_i

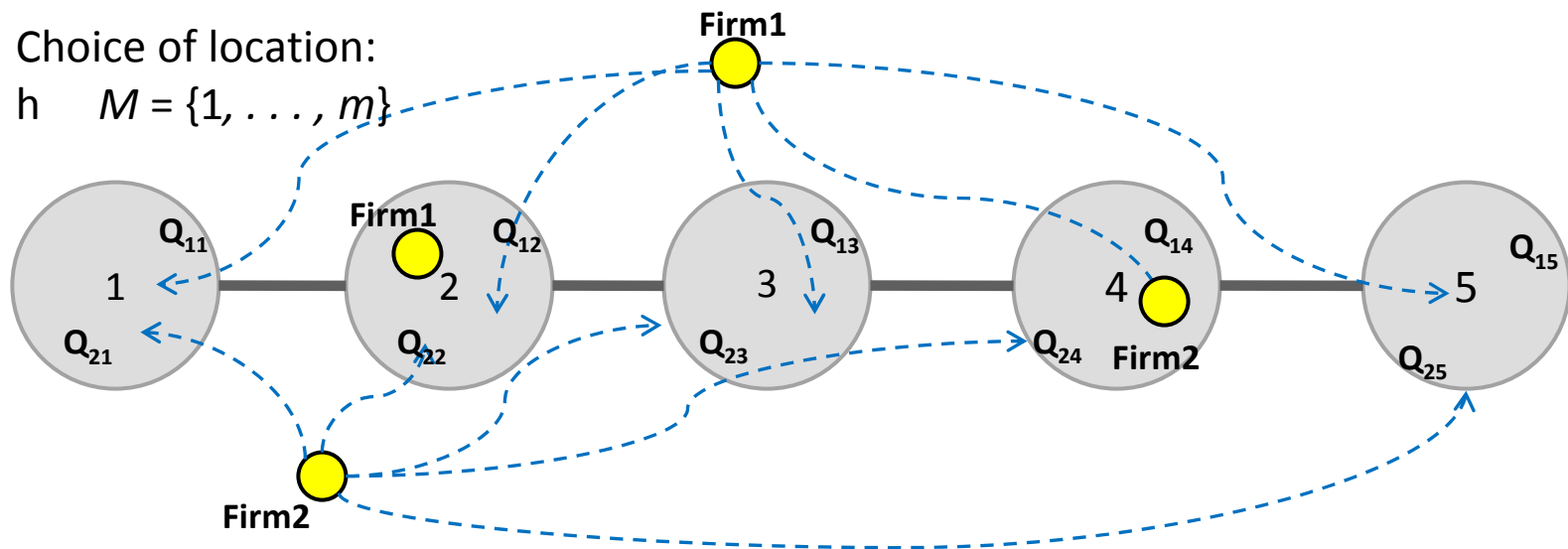
i.e. $x_1 = 2, x_2 = 4$

2nd Stage: Firms simultaneously choose quantity supplied to each markets

i.e. $Q_1 = (Q_{11}, Q_{12}, Q_{13}, Q_{14}, Q_{15}), Q_2 = (Q_{21}, Q_{22}, Q_{23}, Q_{24}, Q_{25})$

Choice of location:

$h \quad M = \{1, \dots, m\}$



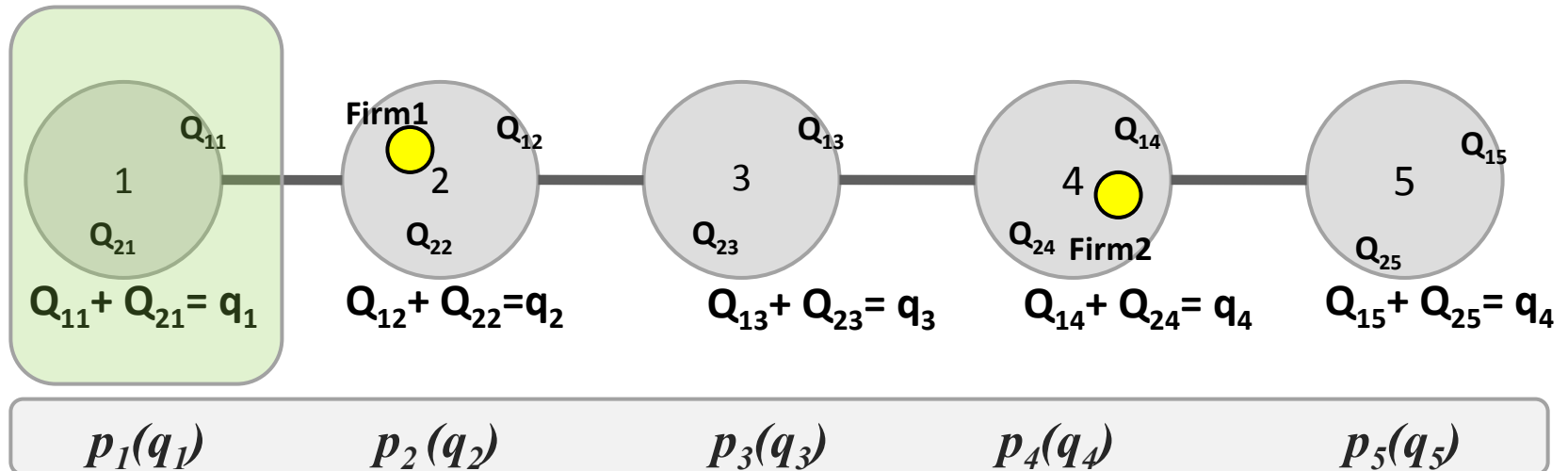
Market Clearing

- Market h 's total supply is:

$$q_h = \sum_{i=1 \dots n} Q_{ih}$$

- Inversed Demand function of market h is :

$$p_h(q_h) = \max\{\alpha_h - \beta_h \sum_{i=1 \dots n} Q_{ih}, 0\}$$



Cost Structure

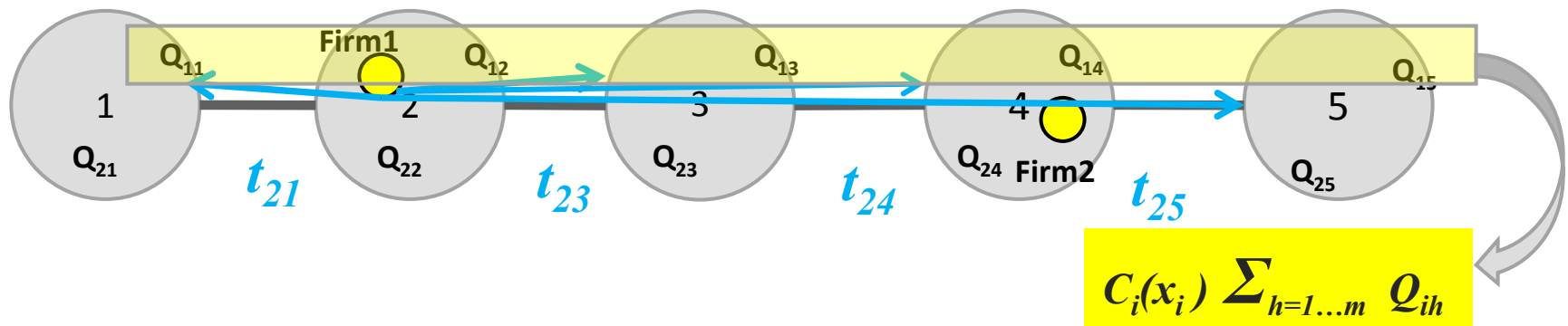
Total cost function of firm i with strategy (x_i, Q_i)

$$TC_i(x_i, Q_i) = \sum_{h=1 \dots m} t_{ih} Q_{ih} + C_i(x_i) \sum_{h=1 \dots m} Q_{ih} + w(x_i)$$

t_{ih} : Transportation cost

$C_i(x_i)$: Variable cost - Regas and shipping cost

$w(x_i)$: Fixed cost - Construction/Investment cost



Nash Equilibrium $(x_i, Q_i)^*$

$$\text{Max } \pi_i(x_i, Q_i) = \sum_{h=1 \dots m} p_h(q_h) Q_{ih} - TC_i(x_i, Q_i)$$

where

- ▶ Q_{ih} : Quantity supplied by firm i at market h
- ▶ $p_h(q_h)$: Inversed Demand function
- ▶ $TC_i(x_i, Q_i)$: Total cost function

- ▶ Nash Equilibrium is solved by backward induction
 - ▶ 2nd Stage: Given location chosen, firm i chooses optimally the vector of quantities $Q_{i\bullet} = \{Q_{i1}, \dots, Q_{im}\}$
 - ▶ 1st Stage: After determining the optimal quantity supplied for each market given location choice, firms chooses the optimal location X_i



Numerical Illustration

- ▶ Observe changes of equilibria strategies of firms if:
 - ▶ Scenario 1. – Varying Transportation Tariff
 - ▶ Scenario 2 – Varying Price Responsiveness in Markets
 - ▶ Scenario 3 – Varying Cost Structures of Firms



Findings

- ▶ Observe changes of equilibria strategies of firms if:
 - ▶ Scenario 1. – Varying Transportation Tariff

Transportation Tariff ↑
Clustering Location Choices around Biggest Demand Center.

Transportation Tariff ↓
Move to location with lowest fixed cost
Firms locate away from each other to avoid competition



Findings

- ▶ Observe changes of equilibria strategies of firms if:
 - ▶ Scenario 2. – Price responsiveness in Markets
 - ▶ Strong price responsiveness
 - > Strong price impact on changes on supply
 - > Less liquidity in the market
 - > Less demand pull , i.e., in a recession period.

Price Responsiveness \uparrow - i.e. Weak economy
Locate closer to demand center with highest liquidity.
More cautious in determining the delivered quantity



Findings

- ▶ Observe changes of equilibria strategies of firms if:
 - ▶ Scenario 3 – Varying Cost Structures of Firms
 - ▶ Firms have different cost structure
 - ▶ Location choices not only determined by shipping and regas cost, but the relative cost efficiency among competitors.

Firms with lowest operation cost located closest to the market center with highest fixed cost. Firms with higher operation cost tends to locate to markets with lower fixed cost.

Identical cost structures does NOT guarantee identical location choices.
When firms have very close cost structure, incentive to avoid competition and seek location with lower fixed cost increases.



Extensions

- ▶ Firms can choose to enter at T , or wait till next period
- ▶ Key Drivers of firms' different behaviors :
 - Shared vision vs. Different outlooks:
 - Learning by Watching: Reduced $W(x_i)$ if there is an incumbent firm



Conclusion

- ▶ Benefits of using a theoretical model to study a complicated business decision process.
 - ▶ Observe impact on key economic drivers on firms' behavior .
 - ▶ Answer what-if questions.

