Not on My Coast? North American Natural Gas Markets Under LNG Demand Growth and Infrastructure Restrictions

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Goal: To analyze the effects of restricting development of new LNG facilities on the West Coasts of the U.S. and Canada on North American natural gas markets and infrastructure via scenario analyses.
General Overview

- **Goal:** To analyze the effects of restricting development of new LNG facilities on the West Coasts of the U.S. and Canada on North American natural gas markets and infrastructure via scenario analyses.

- **Method and Scope:** An equilibrium model formulated as a mixed complementarity problem (MCP) representing interactions between different players in North America from 2017 to 2050.
Goal: To analyze the effects of restricting development of new LNG facilities on the West Coasts of the U.S. and Canada on North American natural gas markets and infrastructure via scenario analyses.

Method and Scope: An equilibrium model formulated as a mixed complementarity problem (MCP) representing interactions between different players in North America from 2017 to 2050.

Key Findings:
- North American markets can significantly scale up LNG exports to satisfy strong Asian demand growth.
- Even if new LNG terminals cannot be constructed on the West Coast, LNG exports mostly shift to other regions rather than an overall decline.
- Increasing external demand for LNG puts upward pressure on regional prices in North America, and directs production and pipeline flows toward the regions that export LNG.
Agenda

1. Problem Motivation and Background

2. Model
   - Regions
   - Features
   - Players

3. Scenarios

4. Results

5. Conclusions
Problem Motivation and Background

- Shale gas revolution in North America
- Emergence of the United States and Canada as LNG exporters
- Strong demand growth in Asia fueled by rapid industrialization and urbanization of China
- Geographical proximity of the North American West Coast to Asian demand and potential political opposition to LNG development on the West Coast.
Mixed complementarity problem (MCP)

9 North American regions, 2 LNG demand regions

6 types of profit maximizing players, 2 types of aggregated demand structures.

Discrete-time model with 2 seasons per year: high demand and low demand

Endogenous capacity investment decisions

Linear demand functions

Parameterization is done with publicly available data from government agencies such as EIA and NEB as well as agency and industry reports

Current pipeline and LNG export projects that are not operational yet but are to be constructed are exogenously defined in the model
An Example Optimization Problem (Producer)

**Parameters**
- $Q_{ist}^{n,\text{max}}$: Daily production capacity
- $V_{i}^{n,\text{prod},\text{max}}$: Total reservoir
- $\text{CAP}_{it}^{n,\text{prod}}$: Daily capacity expansion limit
- $Days_{s}$: Number of days in a season

**Decision Variables**
- $q_{ist}^{n,\text{prod}}$: Daily production
- $\Delta_{it}^{n,\text{prod}}$: Daily capacity expansion
- $\pi_{st}^{n,\text{wholesale}}$: Wholesale price of gas
- $\delta_{t}^{n}$: Discount factor

**Maximize**

$$\sum_{t} \delta_{t} \left[ \sum_{s} \left( Days_{s} \left\{ \pi_{st}^{n,\text{wholesale}} q_{ist}^{n,\text{prod}} - C_{ist}^{n,\text{prod}} (.) \right\} \right) - E_{it}^{n,\text{prod}} (\Delta_{it}^{n,\text{prod}}) \right]$$

**s.t.**

1. $q_{ist}^{n,\text{prod}} \leq Q_{ist}^{n,\text{max}} + \sum_{t' < t} \Delta_{it'}^{n,\text{prod}}, \forall s, t$ \hspace{1cm} ($\alpha_{1ist}^{n}$) (1)
2. $\sum_{t} \sum_{s} Days_{s} q_{ist}^{n,\text{prod}} \leq V_{i}^{n,\text{prod},\text{max}}$ \hspace{1cm} ($\alpha_{2i}^{n}$) (2)
3. $\Delta_{it}^{n,\text{prod}} \leq \text{CAP}_{it}^{n,\text{prod}}, \forall t$ \hspace{1cm} ($\alpha_{3it}^{n}$) (3)
4. $q_{ist}^{n,\text{prod}}, \Delta_{it}^{n,\text{prod}} \geq 0, \forall s, t$ \hspace{1cm} (4)
<table>
<thead>
<tr>
<th>Scenario</th>
<th>LNG Demand</th>
<th>LNG Infrastructure Restrictions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference</td>
<td>3% for Pacific and 0.3% for Atlantic</td>
<td>None</td>
</tr>
<tr>
<td>No West Coast</td>
<td>3% for Pacific and 0.3% for Atlantic</td>
<td>West Coast</td>
</tr>
<tr>
<td>High LNG Demand</td>
<td>6% for Pacific and 0.6% for Atlantic</td>
<td>None</td>
</tr>
<tr>
<td>No West Coast and High LNG Demand</td>
<td>6% for Pacific and 0.6% for Atlantic</td>
<td>West Coast</td>
</tr>
</tbody>
</table>
Results (Market)

(a) Reference

(b) No West Coast

(c) High LNG Demand

(d) No West Coast and High LNG Demand

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Results (Infrastructure)

(a) Reference

(b) No West Coast

(c) High LNG Demand

(d) No West Coast and High LNG Demand
Results (Production and Consumption)

Total natural gas production in North America

Total natural gas end use consumption in North America
Results (Price)

Average price of natural gas in North America

Year

2017 2020 2023 2026 2029 2032 2035 2038 2041 2044 2047 2050

Price ($/Mcf)

0 2 4 6 8 10 12

Reference High LNG Demand No West Coast No West Coast and High LNG Demand
Results (LNG Shipments)

Total LNG shipments to Pacific Market from North America

Total LNG shipments to Atlantic Market from North America

Year

Reference, High LNG Demand, No West Coast, No West Coast and High LNG Demand
Conclusions

Without any restrictions on new LNG export facilities, the Western Canada and Western U.S. regions are well positioned to export LNG to the Pacific market.
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- If new LNG export infrastructure cannot be built along the West Coast of the U.S. and Canada, then LNG exports to the Pacific market largely relocate to the Gulf Coast of the U.S. and (to a lesser extent) the Pacific coast of Mexico.
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The total volume of North American LNG exports is thus robust to the possibility that opposition to gas infrastructure development on the West Coast would prevent new facilities from being constructed there.
Conclusions

- Without any restrictions on new LNG export facilities, the Western Canada and Western U.S. regions are well positioned to export LNG to the Pacific market.

- If new LNG export infrastructure cannot be built along the West Coast of the U.S. and Canada, then LNG exports to the Pacific market largely relocate to the Gulf Coast of the U.S. and (to a lesser extent) the Pacific coast of Mexico.

- The total volume of North American LNG exports is thus robust to the possibility that opposition to gas infrastructure development on the West Coast would prevent new facilities from being constructed there.

- Increasing external demand for LNG puts upward pressure on regional prices within North America, an effect which is stronger if infrastructure restrictions concentrate LNG development within fewer regions.
Thank You


Wholesale Market Clearing Conditions

\[
\sum_{i \in \text{suppl}(n)} \text{Days}_s q_{ist}^{n,\text{prod}} = \sum_{k \in \text{trader}(n)} v_{kst}^{n,\text{purch,tra}} \quad \forall n, s, t
\]

where \( \pi_{st}^{n,\text{wholesale}} \) is the dual variable and \( v_{kst}^{n,\text{purch,tra}} \) denotes the amount of gas bought by the trader.
Producers’ KKT Conditions

\[ 0 \leq \delta_t Days_s \left( -\pi^{n,\text{wholesale}}_{st} \right) + \frac{\partial C^{n,\text{prod}}_{ist}(.)}{\partial q^{n,\text{prod}}_{ist}} + \alpha 1^n_{ist} + Days_s \alpha 2^n_i \]

\[ \perp q^{n,\text{prod}}_{ist} \geq 0, \forall n, i, s, t \]

\[ 0 \leq \delta_t \frac{dE^{n,\text{prod}}_{it} \left( \Delta^{n,\text{prod}}_{it} \right)}{\Delta^{n,\text{prod}}_{it}} + \sum_{t'>t} \sum_{s} \frac{\partial C^{n,\text{prod}}_{ist'}(.)}{\partial \Delta^{n,\text{prod}}_{it}} - \sum_{t'>t} \sum_{s} \alpha 1^n_{ist'} + \alpha 3^n_{it} \]

\[ \perp \Delta^{n,\text{prod}}_{it} \geq 0, \forall n, i, t \text{ and } t' < t \]

\[ 0 \leq Q^{n,\text{max}}_{ist} - q^{n,\text{prod}}_{ist} + \sum_{t'<t} \Delta^{n,\text{prod}}_{it'} \perp \alpha 1^n_{ist} \geq 0, \forall n, i, s, t \]

\[ 0 \leq V^{n,\text{prod},\text{max}}_i - \sum_{t} \sum_{s} Days_s q^{n,\text{prod}}_{ist} \perp \alpha 2^n_i \geq 0, \forall n, i \]

\[ 0 \leq CAP^{n,\text{prod}}_{it} - \Delta^{n,\text{prod}}_{it} \perp \alpha 3^n_{it} \geq 0, \forall n, i, t \]
Mixed Complementarity Problem

Nonlinear Complementarity Problem
Given a mapping $F : \mathbb{R}^n \rightarrow \mathbb{R}^n$, find a vector $x$ such that $0 \leq x \perp F(x) \geq 0$.

Mixed Complementarity Problem is the generalization of Nonlinear Complementarity Problem which can take upper and lower bounds into account.

Mixed Complementarity Problem
Given a mapping $F : \mathbb{R}^n \rightarrow \mathbb{R}^n$, lower values $l_i \in \mathbb{R} \cup \{-\infty\}$ and upper values $u_i \in \mathbb{R} \cup \{\infty\}$ find a vector $x$ such that

- $x_i = l_i, F_i(x) \geq 0$
- $l_i < x_i < u_i, F_i(x) = 0$
- $x_i = u_i, F_i(x) \leq 0$