Analyzing the Impact of Larger Ships through Panama Canal on the U.S. Container Imports

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Introduction

• The Panama Canal expansion & larger ship size
  – Substantial impact or not?
• Player interactions in container shipping market
  – Vertical integration of shipment chain
  – Long-term contracts between shipping companies and others
  – Coalitions and merges of ocean carriers
  – Intense competition between ports
Study Purpose

• Study purpose
  – to incorporate player relationships into the optimal container shipping problem;
  – to capture the Panama Canal expansion’s potential impacts on the container flow patterns and the distribution of market power among the players in the container shipping market;
  – assuming PostPanama containerships are used for the East Coast route after expansion

• Approach
  – Game theory models & Shapley value changes
Game Theory Concepts

• Stackelberg games (leader-follower)
  – Ocean carrier vs. others
  – Bi-level programming models

• Cooperative games
  – Characteristic function $\rightarrow$ coalition values $v(K)$
  – Shapley value:

$$\phi_i(v) = \sum_{K} [v(K) - v(K\{i\})] \frac{(k - 1)! (n - k)!}{n!} \ldots \ldots (1)$$
Case Study

• One origin (Hong Kong Port) & one destination (Norfolk, VA)

• Five Players
  – One ocean carrier (OC)
  – Los Angeles Port (P1)
  – Norfolk Port (P2)
  – One rail operator (R)
  – Panama Canal (PC)
Notations

Control Variables

**feu(j):** number of FEU containers through port j

**pr1:** Port 1 rate per FEU

**rr:** Railroad rate per FEU

**pr2:** Port 2 rate per FEU

**cr:** Panama Canal rate per FEU

5 Players

- **Ocean carrier**
- **Los Angeles Port**
- **Railroad**
- **Norfolk Port**
- **Panama Canal**

Objective Functions

- **R_{oc}:** OC revenue
- **C_{oc}:** OC total vessel operating cost
- **f_{p1}:** Port 1 profit
- **R_{p1}:** Port 1 revenue
- **f_{r}:** Railroad profit
- **R_{r}:** Railroad revenue
- **f_{p2}:** Port 2 profit
- **R_{p2}:** Port 2 revenue
- **f_{pc}:** Canal profit
- **R_{pc}:** Canal revenue
<table>
<thead>
<tr>
<th>Model</th>
<th>Level 1 Coalition value</th>
<th>Level 2 Coalition value</th>
<th>Level 1 Objective Function</th>
<th>Level 2 Objective Function</th>
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</thead>
<tbody>
<tr>
<td>$M_0$</td>
<td>$v({OC}) = v_0^1$</td>
<td>$v({R, P1, P2, PC}) = v_0^2$</td>
<td>$\max(R_{oc} - C_{oc} - R_{p1} - R_{p2} - R_{pc} - R_r) = v_0^1$</td>
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<td>$v({OC, P1}) = v_1^1$</td>
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<td>$\max(\emptyset) = v_{15}^2$</td>
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**Model 1 Formulation**

Max $\left(R_{oc} - C_{oc} - C_{p1} - R_{p2} - R_{pc} - R_r\right)$  
subject to:  
max$f_{p2} + f_{pc} + f_r$  
subject to:  
g_i(X) \leq 0, i = 1, \ldots, m$  
(Capacity, demand and non-negative constraints)
### Model 1 Formulation

$$\text{Max } (R_{oc} - C_{oc} - C_{p1} - R_{p2} - R_{pc} - R_r)$$

subject to:

$$\text{max}(f_{p2} + f_{pc} + f_r)$$

subject to:

$$g_i(X) \leq 0, i = 1, ..., m$$

(Capacity, demand and non-negative constraints)

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<th>Original Constraints</th>
<th>Constraints after KKT Transformation</th>
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<td>$M_0$</td>
<td>$\sum_j(fe_j) \geq DMD$&lt;br&gt;$fe_j \leq \text{Cap}(j)$&lt;br&gt;$PRL_1 \leq pr_1 \leq PRU_1$&lt;br&gt;$PRL_2 \leq pr_2 \leq PRU_2$&lt;br&gt;$RRL \leq rr \leq RRU$&lt;br&gt;$CRL \leq cr \leq CRU$&lt;br&gt;$fe_j, pr_j, rr, cr, u_i \geq 0$</td>
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Impacts of Larger Ships

• Scenario 1 (S1): —Before Canal Expansion: 4,000-TEU Vessels for East Coast & 8,000-TEU Vessels for West Coast
• Scenario 2 (S2): —After Canal Expansion: 8,000-TEU Vessels for Both Routes
• Assumptions: Both terminals 80% of total container demand
• Parameters
  – Vessel operating costs
  – shipping rates
  – lower and upper bounds of railroad rates, terminal rates, and Panama Canal rates
  – transit time
Result Analysis

- **S1**: if the grand coalition is formed, the OC prefers the WCR (80% of containers via West Coast)
- **S2**: OC chooses ECR via the Panama Canal (80% via East Coast route)
- Market power shift due to the usage of PostPanama containerships for East Coast
- Power is gained by the Canal and the East Coast ports
- Slight lessening of market power for railroads and the West Coast ports

| TABLE 3 Shapley Values and Value Ratios for Scenario 1 (S1) and Scenario 2 (S2) |
|---------------------------------|-----|-----|-----|-----|-----|-----|
|                                 | P1  | P2  | R   | PC  | OC  | Total|
| S1: Before Canal Expansion      | 80.82| 63.94| 337.22| 31.82| 1589.57| 2103.37|
| S2: After Canal Expansion       | 30.53| 122.08| 265.40| 57.71| 1645.61| 2121.34|
| S1 Ratio: Before Canal Expansion| 0.04 | 0.03 | 0.16 | 0.02 | 0.76 | 1.00 |
| S2 Ratio: After Canal Expansion | 0.01 | 0.06 | 0.13 | 0.03 | 0.78 | 1.00 |
Conclusions

• Relationships of multiple entities have direct impacts on the container shipping choices
• The expansion has positive impacts on the ECR, and negative impacts on the WC players’ market power
• The expansion has a two-sided impact on the OC
  – saves vessel operating costs for the OC
  – hurts the OC’s relative market power
Future Study

• The game theory solutions offer a measurable tool to understand the interactive relationships in the ocean shipping industry, to compare the relative powers of players, and to make predictions of market equilibrium;
• More players need to be added to include nationwide containerized-import shipments, and more factors other than ship size need to be considered;
• Main challenge: computational complexity when the number of mathematical models and the complexity of each model both rise dramatically with the number of players and variables.