Socioeconomic Dimensions of Resilience to Seaport and Highway Transportation Network Disruptions

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Introduction

• Economic impacts of seaport and highway transportation network disruptions can be extensive well beyond on-site operations through supply-chain effects.

• Research gaps: 1) resilience considerations; 2) spatial distribution and networked nature of transportation systems; 3) income distribution impacts

• Objective of this study:
  • Develop a synergetic approach linking a regional transportation model, a multi-regional computable general equilibrium (CGE) model, and a multi-sector income distribution matrix to analyze socioeconomic impacts of port and transportation network disruptions and effectiveness of resilience tactics
  • Apply the integrated transportation and socioeconomic analysis model to a simulated earthquake scenario
Comprehensive Assessment of Transportation Resilience in Metropolitan Areas

- Characterize Hazard Occurrences
  - Determine Loads
- Extract Bridge Geometry
- Model Bridges and Simulate Hazard Response
- Derive Fragility Functions
- Estimate Functionality Losses
- Component-level Resilience
  - Component (e.g., bridge, tunnel) restoration curves

- Model Network Versions
  - Initialization
  - Network Skimming
- Trip Generation
- Trip Distribution
- Time of Day
- Mode Choice
- System-level (Network) Resilience
  - Network Functionality Indicators (e.g., total travel distance/time, accessibility)

- Macroeconomic Impact Analysis
  - Run TERM Multi-Regional CGE Model + Economic Resilience Analysis Framework
  - Quantify Aggregate Impact (GDP, Employment)

- Distribution Impact Analysis
  - Multi-Sector Income Distribution Matrix (MSIDM)
  - Income Distribution (Changes in Gini Coefficient and/or Atkinson Index between Base Case and individual resilience cases)

- Regional Economic Resilience
  - GDP, Employment
  - Environmental Justice
Case Study
Bridge Closures (Day 1)
Case Study
System Level Resilience
(Delay)

147 bridges closed,
approx. 690,000 hours/day additional delay in L.A. County,
730,000 hours/day additional delay in Study Region
Economic Resilience – Basic Considerations

• Static:
  – General Definition: Ability of a system to *maintain function* when shocked.
  – Econ Definition: *Efficient use of remaining resources* at a given point in time to produce as much as possible.

• Dynamic
  – General Definition: Ability of a system to *recover*.
  – Econ Definition: *Efficient* use of resources *over time* for investment in repair and reconstruction, including expediting the process & adapting to change.

  ◦ *Metric*: *averted losses as % of potential losses*
## Economic Resilience Tactics to Port and Transportation Network Disruptions

<table>
<thead>
<tr>
<th>Supplier-Side Resilience Options</th>
<th>Customer-Side Resilience Options</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Excess capacity.</strong> Utilization of unused capacity at undamaged terminals</td>
<td><strong>Use of inventories.</strong> Stockpiling critical inputs for the production of goods and services by firms</td>
</tr>
<tr>
<td><strong>Cargo prioritization.</strong> Altering schedules for unloading or loading based on the characteristics or value of the cargo</td>
<td><strong>Conservation.</strong> Finding ways to utilize less of disrupted imported goods in production processes</td>
</tr>
<tr>
<td><strong>Ship re-routing.</strong> Sending ships to other ports</td>
<td><strong>Input substitution.</strong> Utilizing similar goods in the production process to those whose production has been disrupted</td>
</tr>
<tr>
<td><strong>Export diversion for import use.</strong> Sequestering goods intended for export to substitute for unavailability of imports or domestically-produced goods</td>
<td><strong>Import substitution.</strong> Bringing in goods and services in short supply from outside the region through land routes</td>
</tr>
<tr>
<td><strong>Effective management.</strong> Improvements in decision-making and expertise that enhance functionality</td>
<td><strong>Production relocation.</strong> Shifting production to branch plants</td>
</tr>
<tr>
<td><strong>Production recapture.</strong> Working extra shifts or over-time to clear up backlog of vessels after resumption of port operation</td>
<td><strong>Production recapture.</strong> Making up lost production by working extra shifts/overtime after port re-opens</td>
</tr>
<tr>
<td><strong>Effective road infrastructure asset management.</strong> Improvements in decision-making and expertise that enhance functionality and recovery</td>
<td><strong>Effective travel demand management.</strong> Establishing measures to decrease travel demand during recovery</td>
</tr>
</tbody>
</table>
TERM CGE Model

• Bottom-up multi-regional CGE model (Monash U.)
• Based on detailed regional & sectoral accounts
• Consists of 4 regions: 3-County LA Region, 9-County Bay Area, Rest of CA, and Rest of U.S.
• Divides the economy into 97 sectors
• CES production functions (allows for substitution)
• Explicit trade and transport margins
### Simulation Results – Combined Disruptions/Damages

(in millions 2019 dollars and percent reduction from pre-disaster levels)

<table>
<thead>
<tr>
<th></th>
<th>LA Metro</th>
<th>SF Metro</th>
<th>Rest of CA</th>
<th>Rest of US</th>
<th>US Total</th>
<th>Loss Reduction Potential (for LA)</th>
<th>Loss Reduction Potential (for US)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Base Case (no resilience)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Loss</td>
<td>-24,208</td>
<td>-828</td>
<td>-855</td>
<td>-4,296</td>
<td>-30,187</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reduction</td>
<td>-3.00%</td>
<td>-0.17%</td>
<td>-0.15%</td>
<td>-0.03%</td>
<td>-0.22%</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Combined Resilience Case</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Loss</td>
<td>-14,200</td>
<td>-12</td>
<td>-167</td>
<td>1,571</td>
<td>-12,808</td>
<td>41.34%</td>
<td>57.57%</td>
</tr>
<tr>
<td>Reduction</td>
<td>-1.76%</td>
<td>0.00%</td>
<td>-0.03%</td>
<td>0.01%</td>
<td>-0.09%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## Income Distribution Impacts

- Compare Gini coefficients between the scenario cases and baseline level

<table>
<thead>
<tr>
<th>Disruption Type</th>
<th>Baseline</th>
<th>Scenario Gini Coefficient</th>
<th>Change in Gini Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Port Disruption_Base Case</td>
<td>0.465478</td>
<td>0.465614</td>
<td>0.000136</td>
</tr>
<tr>
<td>Transportation Cost Increase_Base Case</td>
<td>0.465478</td>
<td>0.465478</td>
<td>0.000000</td>
</tr>
<tr>
<td>Building Damage_Base Case</td>
<td>0.465478</td>
<td>0.463904</td>
<td>-0.001574</td>
</tr>
<tr>
<td>Combined Disruptions_Base Case</td>
<td>0.465478</td>
<td>0.464041</td>
<td>-0.001438</td>
</tr>
<tr>
<td>Port Disruption_Resilience Case</td>
<td>0.465478</td>
<td>0.465473</td>
<td>-0.000006</td>
</tr>
<tr>
<td>Transportation Cost Increase_Resilience Case</td>
<td>0.465478</td>
<td>0.465478</td>
<td>0.000000</td>
</tr>
<tr>
<td>Building Damage_Resilience Case</td>
<td>0.465478</td>
<td>0.464243</td>
<td>-0.001235</td>
</tr>
<tr>
<td>Combined Disruptions_Resilience Case</td>
<td>0.465478</td>
<td>0.464238</td>
<td>-0.001240</td>
</tr>
</tbody>
</table>

- Income losses born disproportionately by lower-income groups in Port Disruption Base Case
- Port resilience tactics help reduce income inequality
- Income losses born disproportionately by middle- & higher-income groups in the other two cases.
Conclusion

• Develop and apply an integrated transportation-socioeconomic impact model to analyze aggregate economic and income distributional impacts of port and highway transportation disruptions.

• Resilience tactics can potentially reduce GDP losses by 41% and 58% at the regional and national levels, respectively.

• Effective port resilience tactics: ship-rerouting, inventory use, input substitution, and production recapture.

• Income losses from port disruptions are born slightly disproportionately by lower- and middle-income groups; the distributional impacts are the opposite for transportation cost increase and building stock damages.

• Port resilience tactics help reduce the inequality in income distribution.
Questions and Comments?

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