ANALYZING TERRORIST THREATS TO THE ECONOMY:

A COMPUTABLE GENERAL EQUILIBRIUM APPROACH

by

Adam Rose

The Pennsylvania State University
MODELING CHALLENGES

• Need a model that can estimate the regional & national economic impacts of a terrorist attack.

• Alternative Strategies:
  - adapt existing models from related areas
  - start from square one

• Best Strategy—Enhancing CGE:
  - recent successes in related areas
  - but more refinements are needed
WHAT IS CGE MODELING

• Economist’s definition: A multi-market simulation model based on the simultaneous optimizing behavior of individual consumers and firms, subject to economic account balances and resource constraints.

• Layman’s definition: A model of the entire economy based on decisions by individual producers and consumers in response to price signals, within limits of available capital, labor, and natural resources.
WHERE WE STAND

• CGE is the state of the art in regional economic impact analysis.

• 17-year history of related applications:
  - Brookshire & McKee (1992-overview)
  - Boisvert (1992-simple example)
  - Kokoski & Smith (1987-climate damages)
History (continued):

- Cochrane (1997-HAZUS trade adjustments)
- Rose (1998-modeling issues)
- Oladosu (2000-non-market impacts)
- Rose & Liao (2004-parameter recalibration)
- Rose et al. (2004-electricity outages)
ECONOMIC IMPACT CONSIDERATIONS

• Target-specific (micro & multi-sector)
• Stocks & flows (property & business interruption)
• Market & non-mkt (environ, iconic, infrastructure)
• Individual behavior (normal & bounded)
• Market behavior (prices as allocative signals)
• Disequilibria (economy out of sync)
• Dynamic (changing conditions & time-path)
ECON CONSIDERATIONS (cont.)

- Mitigation (reduced probability of failure)
- Resilience (reduced consequences of failure)
- Recovery (reduced time to normalcy)
- Macro repercussions (multiplier, GE)
- Financial (interest rates, insurance)
- Socioeconomic (distribution across groups)
- Interregional (geographic spread & feedback)
MODELING CONSIDERATIONS

- Operational
- Realistic about data (eng & small sample)
- Reasonable cost
- Manageable
- Not a “black box” (traceable/decomposable)
BACKGROUND ON LOSS ESTIMATION

Recent Paradigm Shift--Stock/Flow Distinction:

• prior preoccupation with property damage
  (impact at single point in time; limited decisions after event)

• realization that lost production from capital assets also counts
  (flow losses have a time dimension)

• even undamaged business may have to curtail operations if
  deprived of a critical input such as a utility lifeline service

Behavioral Considerations Become More Important for Flows:

• timing of recovery greatly affects losses (by multiples)
• human adjustment play a much greater role
GENERAL EQUILIBRIUM EFFECTS

• Loss to downstream customers of disrupted firm
  (inability to provide crucial inputs to other)

• Loss to upstream suppliers of disrupted firm
  (cancellation of orders for inputs)

• Loss to all from decreased consumer spending
  (decreased wage bill)

• Loss to all from decreased investment
  (decreased profits)

• Loss to all from cost (and price) increases
  (damaged equipment, dislocation)
RESILIENCE

General Definition:

- capacity of a system to cushion itself against damage
- ability of a system to recover from extreme shock

Economic Resilience:

- inherent--ability under normal circumstances (substitute inputs, conserve, market reallocation)
- adaptive--ability in crisis due to ingenuity (increased sub possibilities, market strengthening)

Focus on reducing the consequences of system failure (in contrast to reducing probability of failure or recovery time)
CES PRODUCTION FUNCTION

\[ Y = A_1 \left( \alpha_i A_{iw} W^{-\rho_1} + \beta_i KLEM^{-\rho_1} \right)^{-1/\rho_1} \]

1st Tier

\[ \text{KLEM} = A_2 \left( \alpha_2 M^{-\rho_2} + \beta_2 KEL^{-\rho_2} \right)^{-1/\rho_2} \]

2nd Tier

\[ \text{KEL} = A_3 \left( \alpha_3 L^{-\rho_3} + \beta_3 KE^{-\rho_3} \right)^{-1/\rho_3} \]

3rd Tier

\[ \text{KE} = A_4 \left( \alpha_4 K^{-\rho_4} + \beta_4 E^{-\rho_4} \right)^{-1/\rho_4} \]

4th Tier

Where:

- \( Y \) is output
- \( A_i \) is the factor-neutral technology parameter, \( A_i > 0 \)
- \( A_{iw} \) is the water-specific technology parameter
- \( \alpha_i, \beta_i \) are the factor shares, \( 0 \leq \alpha_i, \beta_i \leq 1 \)
- \( \rho_i \) is constant elasticity of substitution, \( \rho_i = \frac{1}{1+\rho_i} \)
- \( K, L, E, M, W \) are individual capital, labor, energy, material and water aggregates
- \( \text{KLEM} \) is the capital, labor, energy, and material combination
- \( \text{KEL} \) is the capital, energy and labor combination
- \( \text{KE} \) is the capital and energy combination
TABLE 1. ADAPTIVE RESILIENCE ADJUSTMENTS TO REDUCTION IN WATER AVAILABILITY TO BUSINESS

<table>
<thead>
<tr>
<th>Adjustment Type</th>
<th>Production Function Layer</th>
<th>Parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. conservation of water</td>
<td>1st</td>
<td>$A_{1W} \uparrow$</td>
</tr>
<tr>
<td>2. conservation of various other inputs</td>
<td>2nd, 3rd, 4th</td>
<td>$A_2, A_3, A_4 \uparrow$</td>
</tr>
<tr>
<td>3. increased substitutability of other inputs for water</td>
<td>1st</td>
<td>$\sigma_1 \uparrow$</td>
</tr>
<tr>
<td>4. back-up supplies</td>
<td>1st</td>
<td>$A_{1W} \uparrow$</td>
</tr>
<tr>
<td>5. time-of-day use</td>
<td>1st</td>
<td>ad hoc</td>
</tr>
<tr>
<td>6. change in technology</td>
<td>all</td>
<td>most to all</td>
</tr>
</tbody>
</table>
RESILIENCE OF MARKETS

- Non-interruptible service premia
- Market price changes reallocate resources
- Price signals can guide administrative decree to ration resources to highest use
- Imports and exports help relieve imbalances
EMPIRICAL ADVANCES

Major shortcoming of CGE models is empirical parameter estimation (data transfer; taken from normal conditions)

Have developed an algorithm to recalibrate production function parameters on basis of survey or simulation data

• insert direct output loss into sectoral production functions & solve for new parameters:
  —analytical solution for $A_{1W}$
  —numerical solution for $\sigma$

• then insert new functions into CGE to calculate indirect & total impacts (decompose PE & GE)
DISEQUILIBRIA

- Labor Market (Keynesian closure)
- Government Budget (surplus/deficit)
- Trade (surplus/deficit)
- Resource Constraints (capacity limits)
PORTLAND WATER SYSTEM

• Serves 840,000 people
• Sold 39 billion gallons in 1999
• 2000 kilometers of pipelines
• 29 pump stations; 69 storage tanks
• 70% of system is cast-iron pipes
• 9 service sub-areas varying significantly
EARTHQUAKE VULNERABILITY

- Portland is in a seismically active zone
- Crustal-Fault EQs: M5.5 & M5.6
- Subduction EQ: M9.0 (Year 1700)
- System operators consider it vulnerable
LOSS ESTIMATION

• Crustal fault EQ (M6.1)
• Impacts in Year 2000
• BAU & Cast-Iron Pipe Replacement
• Outages of lengths 3-9 weeks
• Resiliency of substitution & conservation
• Fixed & variable water/price
<table>
<thead>
<tr>
<th>Sector</th>
<th>Water Input Disruption</th>
<th>Output Change From Water Outage</th>
<th>Our Direct w/o Adjust</th>
<th>Chang’s Direct</th>
<th>Indirect</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Food Products</td>
<td>-49.9%</td>
<td>-48.0%</td>
<td>-33.5%</td>
<td>15.6%</td>
<td>-17.9%</td>
<td></td>
</tr>
<tr>
<td>Petroleum</td>
<td>-54.5</td>
<td>-52.5</td>
<td>-36.2</td>
<td>-15.6</td>
<td>-51.7</td>
<td></td>
</tr>
<tr>
<td>Water &amp; Sanitary</td>
<td>-48.0</td>
<td>-46.2</td>
<td>-25.0</td>
<td>-13.2</td>
<td>-38.2</td>
<td></td>
</tr>
<tr>
<td>Personal Services</td>
<td>-50.9</td>
<td>-48.9</td>
<td>-35.0</td>
<td>3.7</td>
<td>-31.3</td>
<td></td>
</tr>
<tr>
<td>Health Services</td>
<td>-52.7</td>
<td>-50.7</td>
<td>-42.5</td>
<td>25.7</td>
<td>-16.7</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>-50.5%</strong></td>
<td><strong>-49.1%</strong></td>
<td><strong>-33.7%</strong></td>
<td><strong>-7.3%</strong></td>
<td><strong>-41.0%</strong></td>
<td></td>
</tr>
</tbody>
</table>
RESILIENCE CALCULATIONS

Direct Regional Economic Resilience

\[ DRER = \frac{\%\Delta Y^m - \%\Delta Y}{\%\Delta Y^m} \]

where

\( \%\Delta Y^m \) is the maximum percent change in direct output
\( \%\Delta Y \) is the estimated percent change in direct output

Total Regional Economic Resilience

\[ TRER = \frac{\%\Delta Y^m - \%\Delta Y}{\%\Delta Y^m} = \frac{M \times \%\Delta Y^m - \%\Delta Y}{M \times \%\Delta Y^m} \]

where

\( \%\Delta Y^m \) is the maximum percent change in total output
\( \%\Delta Y \) is the estimated percent change in total output
\( M \) is the economy-wide average Type II input-output multiplier
<table>
<thead>
<tr>
<th></th>
<th>Pre-Mitigation</th>
<th>Post Mitigation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct Water Outage</td>
<td>50.5</td>
<td>31.0</td>
</tr>
<tr>
<td>Direct Output Reduction</td>
<td>33.7</td>
<td>21.3</td>
</tr>
<tr>
<td>Indirect Output Reduction</td>
<td>7.3</td>
<td>9.2</td>
</tr>
<tr>
<td>Total Output Reduction</td>
<td>41.0</td>
<td>30.5</td>
</tr>
<tr>
<td>Direct Economic Resilience</td>
<td>33.0</td>
<td>31.3</td>
</tr>
<tr>
<td>Indirect Economic Resilience</td>
<td>27.4</td>
<td>16.9</td>
</tr>
<tr>
<td>Total Economic Resilience</td>
<td>60.4</td>
<td>48.2</td>
</tr>
</tbody>
</table>
INSIGHTS FROM CASE STUDY

- Direct economic resilience in Portland > 30%
- Indirect economic resilience < direct measure
- Resilience effects on downside are much larger than GE effects on the upside
- Resilience must be measured to avoid significantly over-estimating losses
POLICIES TO ENHANCE RESILIENCE

- Disseminate information on best practices
- Reward ingenuity
- Info clearinghouse to match customers w/o suppliers to suppliers w/o customers
- Interregional pooling of lifeline services
- Solve market failure of ISC contracts
- Optimize transfer payments for recovery
MAJOR FUTURE CHALLENGE: DYNAMICS

• Longer-term economic growth
• Financial variables
• Investment disequilibrium
• Adjustment to equilibrium
• Cumulative adaptive behavior
• Technological change