REGIONAL ECONOMIC IMPACTS OF TERRORIST ATTACKS ON THE ELECTRIC POWER SYSTEM OF LA

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OBJECTIVES

- Proof of concept of CGE modeling to estimate regional economic impacts of electricity system outages caused by terrorism

- Focus on business interruption impacts

  - factor in resilience of utility customers
  - factor in resilience of markets

- Grounded in the realities of LA electric power system

COMPUTABLE GENERAL EQUILIBRIUM

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 & natural resources.

GENERAL EQUILIBRIUM EFFECTS

- Loss to downstream customers of disrupted firm (inability to provide crucial inputs to others)
- 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

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

Economic Resilience:

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

Focus on reducing the consequences of system failure by customers (in contrast to reducing probability of failure or recovery time).

RESILIENCE OF MARKETS

- Market price changes reallocate resources to highest value use
- Non-interruptible service premia can be built into system in advance
- Price signals can guide administrative decree to ration resources to highest use
- Imports and exports help relieve imbalances

ESTIMATES OF PE EFFECTS

Will a 30% loss of electricity result in a 30% direct loss in economic activity?

Resilience adjustments of electricity:

- back-up generation
- conservation
- input substitution
- production rescheduling
- relocation/outsourcing

ESTIMATES OF GE EFFECTS

Will an x% loss in direct output yield much larger general equilibrium output losses?

Resilience adjustments for other inputs:

- inventories
- conservation
- input substitution
- import substitution
- production rescheduling

CES PRODUCTION FUNCTION

$$Y_j = A_1 \cdot (\alpha_1 \cdot M^{-\rho_1} + \beta_1 \cdot KLE^{-\rho_1})^{-1/\rho_1} \qquad 1^{st} \text{ Tier}$$

$$KLE = A_2 \cdot (\alpha_2 \cdot L^{-\rho_2} + \beta_2 \cdot KE^{-\rho_2})^{-1/\rho_2} \qquad 2^{nd} \text{ Tier}$$

$$KE = A_3 \cdot (\alpha_3 \cdot K^{-\rho_3} + \beta_3 \cdot E^{-\rho_3})^{-1/\rho_3} \qquad 3^{rd} \text{ Tier}$$

$$E = A_4 \cdot (\alpha_4 \cdot (A_{4EL} \cdot EL)^{-\rho_4} + \beta_4 \cdot F^{-\rho_4})^{-1/\rho_4} \qquad 4^{th} \text{ Tier}$$

$$F = A_5 \cdot (\alpha_5 \cdot OG^{-\rho_5} + \beta_5 \cdot GU^{-\rho_5} + \gamma_5 \cdot RP^{-\rho_5})^{-1/\rho_5} \qquad 5^{th} \text{ Tier}$$

where:

Y_j	is output of sector *j*
A_i	is the technology parameter of tier *i*, $A_i > 0$
$\alpha_i, \beta_i, \gamma_i$	is the factor distribution parameters of tier *i*, $0 \leq \alpha_i, \beta_i, \gamma_i \leq 1$
σ_i	is the constant elasticity of substitution of tier *i*, $\sigma_i = 1/(1+\rho)$
K, L, E, M	are capital, labor, energy, material aggregates
KLE	is the capital, labor, and energy combination
KE	is the capital and energy combination
F	is the aggregate of oil/gas, gas utilities, and refined petroleum
OG	is the oil and natural gas aggregate
GU	is gas utilities
RP	is refined petroleum
EL	is electricity

APPENDIX TABLE A. RESILIENCE PARAMETER CHANGES

Type	Parameter	Data	Modification
Inherent Electricity Substitution	σ	see text	none
Adaptive Electricity Substitution	$\sigma\uparrow$	assumption	increase A_{4EL} by 10% for all sectors
Electricity Conservation	$A_{4EL}\downarrow$	assumption	decrease A_{4EL} by 5% for all sectors
Electricity Importance	A_{4EL}	ATC (1991)	loosen electricity constraints for each sector
Distributed Generation	σ_{EK} or A_{4EL}	see text	loosen electricity constraints for each sector
Production Rescheduling	Z	FEMA (1997); Rose & Lim (2002)	multiplicative factor for each sector

APPENDIX TABLE B. RESILIENCE ADJUSTMENT FACTORS

Sector	Electricity Importance (%)	Production Rescheduling (%)	Distributed Generation (%)
1. Agriculture	50	75	10
3. Construction	40	95	10
5. Petroleum Refining	100	99	50
6. Other Non-Durable Mfg	98	95	20
7. Primary Metals	100	99	50
8. Semiconductors	100	99	50
9. Other Durable Mfg	100	99	20
10. Local Private Transportation	30	30	10
12. Communications	90	40	50
13. Private Electric Utilities	80	75	0
15. Water Utilities	80	90	20
18. Retail Trade	90	80	10
20. Banking & Credit	90	90	50
21. Security Brokers	90	90	50
23. Hotels & Restaurants	80	60	20
25. Business Services	90	70	10
26. Computer Services	90	40	50
27. Entertainment	80	30	10
29. Health & Social Services	80	50	20
31. Local Public Transportation	30	30	10

LA ELECTRICITY SYSTEM

- 2002 -- $6.3B
  - Southern California Edison 56%
  - LA Dept of Water & Power 35%
  - Small Municipalities 9%
- Minimal centralized generation in County
- LADWP 21 Electric Power Service Areas

LA County Economy

- Total gross output -- $652B
- Total value added -- $372B
- Highly developed
- Highly diversified
- Highly involved in trade

LA CGE Model Refinements

- Rebalanced with utility & EIA data
- GIS overlay of economic activity for each EPSA
- Disequilibrium closure rules for electricity, labor, and trade
- Substitution elasticities reduced to exhibit very short run (2 weeks)

TOTAL BLACKOUT SIMULATION

- 100% loss of delivered electricity (99%)
- Incorporate resilience adjustments
- Simulate impact on each sector separately for PE analysis
- Combine all PE results into model to calculate GE effects
- Phase-in restoration of service in 5 increments over 2 weeks

OVERVIEW OF RESULTS

- Losses with no resilience -- $20.5B (93.6%)
- Losses with resilience -- $13.0B (59.3%)
  (excluding rescheduling)
- Losses with resilience -- $2.8B (13.0%)
  (all types)
- Indirect Losses (net GE) -- $3.1B (23.8%)
  (as percent of direct PE losses)

TABLE 6. ECONOMIC IMPACTS OF A TOTAL ELECTRICITY BLACKOUT IN LA COUNTY
(without any resilience adjustments)

Sector	Output Change during 2-week Electricity Outage			
	Recalibrated Direct (%) (Partial Equilibrium, PE)	Indirect (%) (GE-PE)	Total (%) (General Equilibrium, GE)	Total Loss (million $)
Food Processing	-98.6	-0.1	-98.7	-560
Primary Metals	-98.7	-0.3	-99.0	-122
Other Durable Mfg.	-98.8	-0.3	-99.0	-2414
Retail Trade	-98.4	-0.2	-98.6	-1053
Hotels & Restaurants	-98.6	-0.9	-99.4	-550
Health & Social Services	-98.5	-1.5	-99.5	-1159
•				
•				
•				
Total	-93.0	-0.6	-93.6	-20505

TABLE 7. ECONOMIC IMPACTS OF A TOTAL ELECTRICITY BLACKOUT IN LA COUNTY
(includes all resilience adjustments)

Sector	Output Change during 2-week Electricity Outage				
	Recalibrated Direct (%) (Partial Equilibrium, PE)	Indirect (%) (GE-PE)	Total (%) (General Equilibrium, GE)	Total Loss (million $)	Total Adj for Rescheduling
Food Processing	-56.5	-8.6	-65.1	-369	-18
Primary Metals	-30.1	-17.8	-48.0	-59	-1
Other Durable Mfg	-73.1	-4.6	-77.7	-1894	-19
Retail Trade	-66.1	-8.5	-74.6	-797	-159
Hotels & Restaurants	-43.3	-21.9	-65.2	-361	-144
Health & Social Services	-42.7	-32.2	-74.9	-869	-434
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•					
•					
Total	-47.9	-11.4	-59.3	-13010	-2839

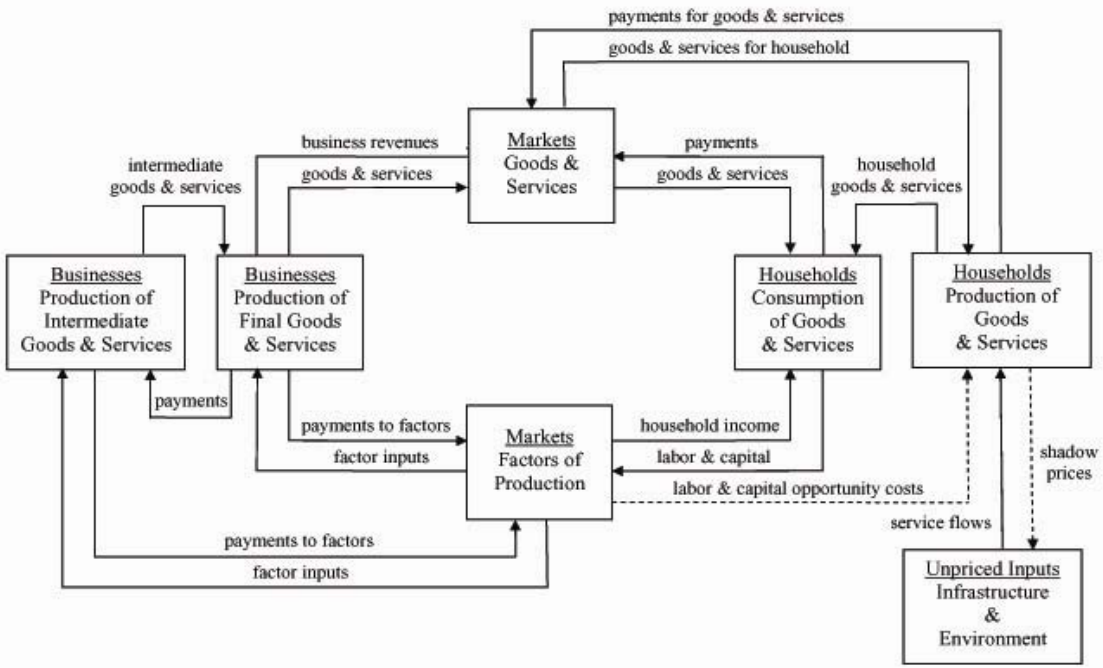
TABLE 8. RELATIVE PROMINENCE OF RESILIENCE ADJUSTMENTS

Resilience Factor	PE Effect	GE Effect
Adaptive Elec. Substitution	-92.1	-93.5
Electricity Conservation	-92.9	-93.5
Electricity Importance	-70.3	-83.9
Alternative Generation	-70.9	-78.6
Production Rescheduling	-19.6	-21.9
Total	-9.4	-13.0

TABLE 2. RESILIENCE TO UTILITY SERVICE DISRUPTIONS

Study	Location/ Event	Utility/ Duration	Method or Model	Individual Business Resilience	Market Resilience
Tierney (1995)	Los Angeles/ Northridge	Electricity/ 36 hrs	Survey	77.1%	—
Rose-Lim (2002)	Los Angeles/ Northridge	Electricity/ 36 hrs	I-O	95.0%	79.3%
Rose-Guha (2004)	Memphis/ Hypothetical	Electricity/ First week	CGE	94.9%	—
Rose-Liao (2005)	Portland/ Hypothetical	Water/ First week	CGE	88.7%	75.6%
Rose-Liao (2005)	Portland/ Hypothetical	Water/ First week	CGE	88.6%	52.2%

Expanded Circular Flow



CAVEATS

- Underestimation
  - omitted property damage
  - omitted health & safety
  - omitted cross-boundary shopping
  - omitted business failures

- Overestimation
  - omitted business relocation/outsourcing
  - omitted indirect inventories

FUTURE RESEARCH

- Incorporate more factors
- Improve empirical base
- Examine optimal recovery strategies
- Incorporate households (production)
- Apply model to other terrorist targets

Bottom Line

- Have been able to incorporate many novel & important features of blackouts within an operational & state of the art impact model

- If gov't & utilities can't protect us from blackouts, have shown how individuals can protect themselves & fellow citizens within the integrated regional economy