Modeling Economic Resilience to Disasters

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Interpretation of Resilience

- Often refers to *any action* that reduces hazard losses
- But, there's a perfectly good word for actions taken ***before*** the event – "mitigation"
- Best use of "resilience" – actions taken ***after*** an event
  - can *build up resilience capacity beforehand* – it's a process (inventories, emergency drills, identify back-up locations)
  - but these tactics are *not implemented until after* the event
- Can only prevent property damage before the event, but can reduce *business interruption* afterwards
  - begins when the disaster strikes & continues until recovered
  - measured in terms of lost sales revenue, GDP, employment

Prominence of Business Interruption

- September 11 World Trade Center Attacks
  - property damage (PD): $25 Billion
  - business interruption (BI): $100 Billion
- Hurricane Katrina
  - PD: $75B
  - BI: >$100B
- ShakeOut San Andreas Fault Earthquake Simulation
  - PD: $100B
  - BI: $68B

Defining Economic Resilience

- 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: *Ability & speed* of a system to *recover.*
  - Economic: *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*

Loss Reduction Strategies: Reliability vs. Resilience

National Academy of Sciences Report, 2017

Enhancing the Resilience of the Nation's Electricity System

Finding: Resilience is not the same as reliability. While minimizing the likelihood of large-area, long-duration outages is important, a resilient system is one that acknowledges that such outages can occur, prepares to deal with them, minimizes their impact when they occur, is able to restore service quickly, and draws lessons from the experience to improve performance in the future.

Translates into tradeoff between mitigation and resilience

Economic Resilience Tactics

Resilience Tactic	Definition (Activities Involved)
Conservation	Maintaining production or service levels using lower amounts of an input
Resource Isolation	Modifying a portion of business operations to run without a critical input
Input Substitution	Replacing a production input in short supply with another
Inventories	Using emergency stockpiles and ordinary working supplies of inputs
Excess Capacity	Using plant or equipment that was idle
Relocation	Moving some or all of the business activity to a new location
Management Effectiveness	Improving the efficiency of business operations
Import Substitution	Obtaining needed production inputs from other regions
Technological Change	Improvising a production process
Production Recapture	Making up for lost production by working overtime or extra shifts
Resource Pooling/Sharing	Re-contracting, creating new partnerships, clearinghouses, etc.

Resilience Metric: 9/11 Relocation

- 1,100 firms in WTC; 95% survived by relocating
- If all of firms in the WTC area went out of business, direct Business Interruption loss would = $43B GDP
- If all relocation were immediate, then BI = 0
- Delays took place; still most businesses relocated within 2-4 months, so BI loss = $12B
- *Metric*: avoided loss / max potential loss

$31B/$43B = 72%

Hurricane Harvey Survey Results

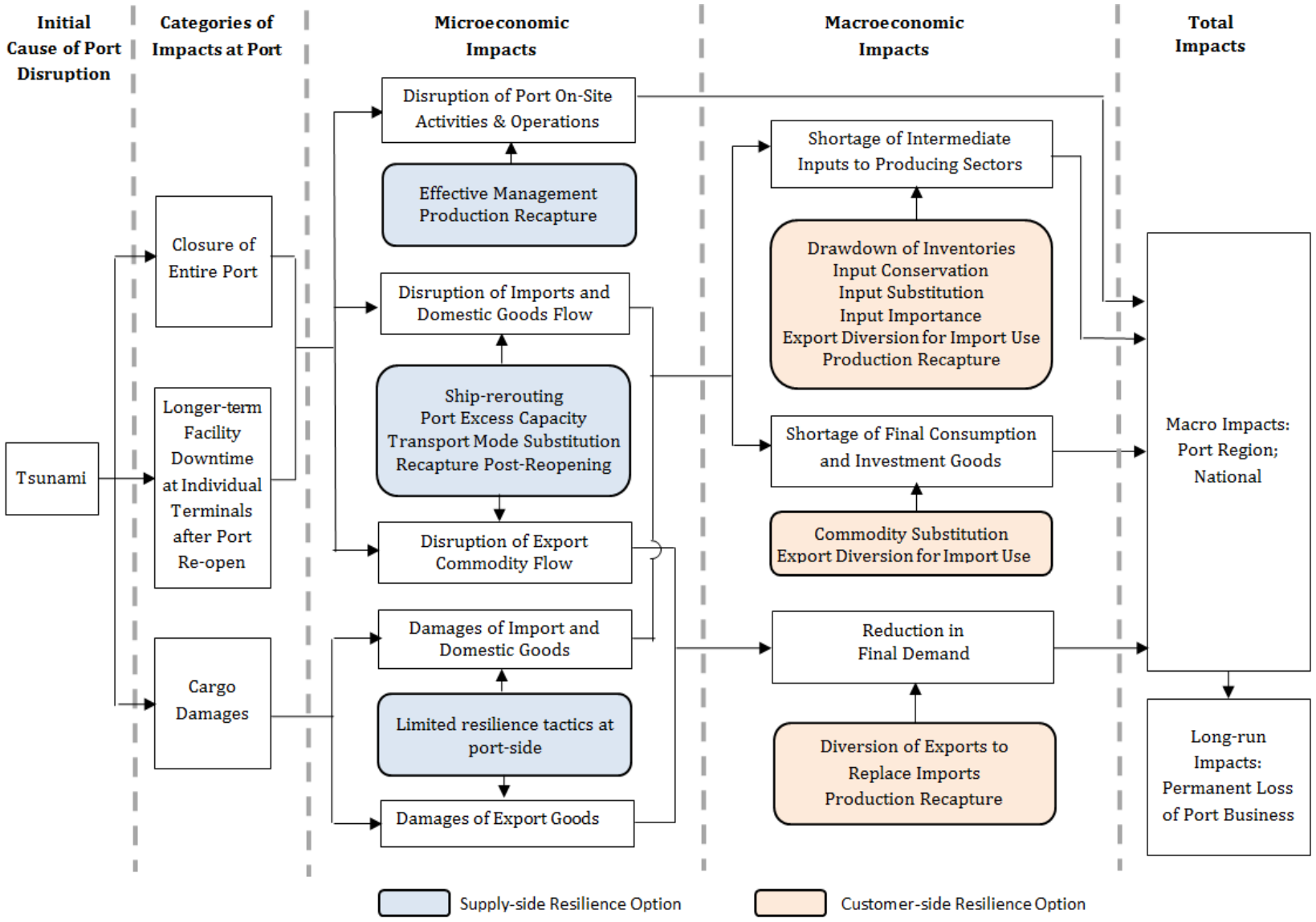
Tactic	Implementation Cost			Effectiveness (Avoided Losses)			Cost-Effectiveness
	Total Cost (Net)*	Average	Median	Total Effectiveness (Net)	Average	Median	Effectiveness/ Marginal Cost Ratio**
Conservation	-$921,120	-$25,586	-$1,000	$1,0695,663	$297,101	$27,250	-11.6
Resource Isolation	441,090	11,921	0	6,149,022	170,806	39,000	14.3
Input Substitution	1,201,875	38,770	100	9,539,292	307,719	38,750	7.9
Inventories	$3,490,610	$64,640	0	$4,119,222	$77,721	$30,000	1.2
Excess Capacity	-$2,357,800	-$157,186	$0	$2,834,450	$188,963	$67,850	-1.2
Relocation	$676,100	$18,780	$4,750	$11,706,813	$325,189	$42,618	17.3
Mgt Effectiveness	-$4,870,720	-$69,581	-$125	$12,469,063	$180,711	$29,375	-2.6
Import Substitution	-$1,016,700	-$46,213	$0	$8,457,967	$422,898	$25,000	-9.2
Technological Change	-$1,513,625	-$40,908	$2,000	$4,565,845	$130,452	$24,500	-3.2
Production Recapture	$6,543,615	$145,413	$250	$11,723,025	$266,432	$31,062	1.8
Resource Pooling	$504,855	$9,708	$0	$9,872,387	$201,477	$32,250	20.8

Resilience at 3 Levels

- Micro (individual business and household)
  - Inherent
  - Adaptive
- Meso
  - Price system
  - Non-interruptible service contracts
- Macro
  - Import substitution
  - Fiscal and monetary policy

Resilience Tactics for Port Disruptions

- Supplier-side resilience tactics:
  - *Excess capacity*
  - *Cargo prioritization*
  - *Ship re-routing*
  - *Export diversion for import use*
  - *Effective management*
  - *Production recapture (Rescheduling)*
- Customer-side resilience tactics:
  - *Inventories*
  - *Conservation*
  - *Input Substitution*
  - *Production recapture (Rescheduling)*



Framework for Estimating Total Economic Impacts of a Port Disruption

Port Disruption Example

- Scenario: 90-day disruption at POLA/POLB
- Results in both direct import & export disruptions, and multiplier effects throughout the economy
- Additional assumptions:
  - 60% CA foreign imports and 20% CA exports go through POLA/POLB
  - price differential between import goods and their domestic substitutes is roughly 7%

Linkages between Direct Impacts of a Port Disruption & REMI Inputs

Direct Impact	Policy Variable Selection in REMI
Import Disruptions	Simulate reduced quantity of imported commodities: Market Share Block → Imports from Rest of World (amount) for Manufacturing sectors → Decrease Simulate increased price of composite commodities: Compensation, Prices, and Costs → Production Costs for All Industries → Increase Compensation, Prices, and Costs → Consumer Prices of Manufactured Goods → Increase
Export Disruptions	Market Share Block → Industry Sales (International Exports) → Decrease

Modeling Approaches for Resilience Tactics in REMI

Resilience Tactic	Simulation Method in REMI	Additional Notes
Export Diversion for Import Use	Adjust import and export shocks	Using goods that were intended for export as substitutions for the lack of availability of imports.
Conservation	Assume a 2% conservation rate: - Import shocks remain the same - Reduce the increased price of composite commodities by 2% (from 0.3% to 0.294%) - Export shocks remain the same	Conservation only helps deal with import disruption
Inherent Input Substitution	Not performed for this simulation	Inherent input substitution between labor and capital is captured by the REMI model automatically through its Cobb-Douglas Production Function. However, input substitution among intermediate goods must be performed manually. All adaptive input substitution must be calculated manually.
Import Substitution	Automatic	Inherent import substitution (replacing foreign imports with domestic production) is captured by the REMI model by increasing the share of domestic demand that is supplied from within the nation when there is a shock on imports.
Ship Rerouting	Adjust import and export shocks in different regions	Steering ships to other ports in California or along the Western Coast; can be simulated in a multi-region REMI Model.
Inventory Use	Adjust import shocks by sector	Can only help deal with import disruption; can be simulated by reducing the direct import disruption for a given commodity by the amount of inventory.
Production Recapture	Application of sectoral “Recapture Factors” to sectoral output changes	A side-calculation to adjust total output losses of each sector for rescheduling of production once the disruption is over.

Simulation Results

	Employment		GDP		Gross Output		Resilience Loss Reduction Potential (in terms of GDP)
	Impact (jobs)	% change from baseline	Impact (billions 2016$)	% change from baseline	Impact (billions 2016$)	% change from baseline	
Base Case	-105,480	-0.442%	-10.9	-0.429%	-14.4	-0.306%	
w/ Export Diversion	-76,450	-0.320%	-6.9	-0.271%	-6.8	-0.144%	36.9%
w/ Conservation	-102,070	-0.428%	-10.5	-0.416%	-13.8	-0.293%	3.1%
w/ Production Recapture	-63,852	-0.268%	-6.6	-0.260%	-8.7	-0.185%	39.5%
w/ Combined Resilience*	-44,217	-0.185%	-4.0	-0.156%	-3.7	-0.079%	63.6%

*Resilience improvements are not additive because of overlaps.

Summary of Results

- A 90-day disruption at POLA/POLB would result in a decline of 105 thousand jobs and GDP losses of $10.9 billion (or about 0.43% reduction).
- Production Recapture has the highest loss reduction potential (40%), followed by Export Diversion (37%).
- Combined resilience tactics can reduce employment impacts to 44 thousand jobs and GDP losses to $4 billion (a 63.6% loss reduction potential).

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