CAOE | CENTER FOR ACCELERATING OPERATIONAL EFFICIENCY

A DEPARTMENT OF HOMELAND SECURITY CENTER OF EXCELLENCE

Modeling the Impact of Complex, Multi-Vector Disruptions to the Marine Transportation System (MCAT)

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Project Overview

- The Marine Transportation System (MTS) is a vital part of the nation's supply chain. The MTS is resilient, but complex disruptions can have unexpected impacts.

- Understanding the operational and economic consequences of these disruptions can help policy makers, businesses, and others plan for, mitigate, recover from them.

- We are **identifying plausible complex disruptions, possible countermeasures, and building a decision-support tool called** ***MCAT*** for **use by the Coast Guard and others to improve risk management.**

The Ever Given wedged in the Suez Canal, blocking traffic in both directions. Credit: Contains modified Copernicus Sentinel data 2021, CC BY 2.0, via Wikimedia Commons

Complex disruption: COVID + ship blocking Suez Canal

Project Components

1. **Scenarios:**
    - Develop plausible scenarios for complex disruptions (~40); 4 in detail
    - All with help of SMEs, Advisory Board, and stakeholders (e.g., USCG)
2. **Consequences:**
    - Direct and Indirect
    - Core of the MCAT Decision-Support Software
3. **Countermeasures** (both mitigation and resilience)
    - Develop plausible countermeasures for all of the scenarios
    - Again with help of SMEs, Advisory Board, and stakeholders

Project Components (cont'd)

4. **MCAT decision-support tool**
    - Develop and use tool to analyze economic impacts of the four detailed complex scenarios
    - Use tool to analyze reduction in impact of different countermeasures for those scenarios
    - Deliver the tool + users guide
5. **Ukraine War proof of concept**
    - Study economic impacts of the Ukraine War on the MTS
    - Analyze the economic impacts of the Ukraine War using the MCAT tool
6. **Extensive Engagement with DHS components, other Government Agencies, Private Sector**

Complex Disruption Example: NY/NJ (KVK) Scenario

- **Background Conditions:** A combination of truck driver, chassis, and warehouse shortages has significantly increased terminal dwell time of containers in the NY/NJ area.

- **Initial Disruption:** Ship fire and blockage of the KVK
- **Secondary Disruption:** Malware impacts to terminal operating systems
- Sadly, an event similar to this actually occurred in 2023.
- Discussions with RADM Mauger (D1) led to us participating in a SECNY cyber/physical exercise last year.

LIVE
NEWSCOPTER 7
BREAKING NEWS
NEWARK FIREFIGHTERS KILLED

Low Water on the Mississippi River

Background: Increasing demand worldwide for food as a result of Ukraine; already high demand for corn and fertilizer due to ethanol and other needs

Initial Disruption: Hot, dry summer disrupting Western Rivers, leaves LMR levels below their 2022 record from Memphis to New Orleans; barge trains are shorter, barge loads are lighter; affects shipments of energy, fertilizer and grain on the rivers

Secondary disruption: Lock and dam failure to Lock 27 (near St. Louis) just before Spring planting

Exacerbating Events: Exacerbated by reductions of fertilizer import at Port of New Orleans

Complex Disruption Example: West Coast Scenario

Background Scenario: Labor dispute

- Labor dispute at POLA/LB leads to cargo diversions, ocean shipping spot rates almost $9K/40ft container (vs. 5-yr average of ~$3,500), and a wait time as high as 26 days

Initial Disruption: Wildfires and power loss

- Wildfires damage transmission lines and substations servicing the port area leading to 3 days of blackouts/brownouts in the port area; 2 more days for full power to be restored.

Secondary Disruption: Sustained security requirements

- Two days after power is restored, a bomb explodes in a container at POLA/LB, damaging cranes. Threats of further explosions lead to MARSEC 2 conditions for the port area for all West Coast ports for one week. Increased screening requirements create delays, and workers are reluctant to return until safety is assured.

The MCAT Economic Consequence Analysis Tool and its Applications

- We are developing **a user-friendly, decision-support tool for use by the Coast Guard and others to improve risk management**.
- The ***MCAT Tool***
  - ***Based on an Economic Consequence Analysis Tool (E-CAT)*** developed by our partner center CREATE to identify direct ***and indirect*** economic impacts of disruptive events.
  - For the West Coast scenario, used a specialized TERM-USA CGE (computable general equilibrium) model consisting of 4 regions (LA, SF, Rest of CA, Rest of U.S.)
  - CGE models the economy as a set of interrelated supply chains
  - Helps determine economic impacts of complex disruptions and provide insight into how to minimize them.

West Coast Scenario Economic Impact Analysis

- Analysis of 3 threats:
  - Labor strike
  - Power outage (due to wildfire)
  - Terrorist attack on container (MARSEC level raised to 2)
- Simulations without Resilience:
  - Base Case
  - Avoidance Behavior (MARSEC)
  - Upper & Lower Bounds on disruption duration and port capacity
- Simulations including Resilience:
  - Port: excess capacity, ship rerouting, management effectiveness
  - Customers: use of inventories, production rescheduling (recapture)

Timing and Impact of Events on Port Closure and Capacity Reduction

	Lower Bound	Base Case	Upper Bound
Panel A. Immediate aftermath (days of 100% closure)			
Labor Strike	1	5	14
Wildfire Power Outage	1	3	5
MARSEC Incident (affected terminal)	3	5	14
MARSEC Incident (rest of port)	2	3	10
Panel B. Recovery period (days of reduced capacity)			
Labor Strike (Partial/Prolonged)	182.5	273.75	365
Wildfire Power Outage	1	2	6
MARSEC Incident (affected terminal – crane repairs)	365	547.5	730
MARSEC Incident (all terminals – MARSEC 2)	4	10	40
MARSEC Incident (all terminals – return to normal - MARSEC 1, but lingering worker avoidance)	7	14	60
Panel C. Reduction in capacity during recovery period (%)			
Labor Strike Prolonged	10	15	33
Wildfire Power Outage	50	50	50
MARSEC Incident (affected terminal – crane repairs)	8	10	15
MARSEC Incident (all terminals – MARSEC 2)	33	50	66
MARSEC Incident (all terminals – return to normal - MARSEC 1, but lingering worker avoidance)	5	10	20

West Coast Scenario Results

Macro Variable	LA Metro	SF Metro	RoCA	RoUS	National
Real GDP (millions of 2023$)	-4,084.5	41.9	- 330.1	4,073.2	-297.6
Real GDP (% change)	-0.373	0.007	-0.043	0.024	-0.002

Disruption (% change in GDP)	LA Metro	SF Metro	RoCA	RoUS	National
Strike	-0.036	-0.001	-0.008	0.001	-0.0011
Power Outage	-0.025	-0.001	-0.002	0.001	-0.0008
MARSEC Incident	-0.085	-0.001	-0.009	0.004	-0.0006
Complex Event Summation	-0.146	-0.003	-0.019	0.006	-0.0025
Complex Event Combined	-0.373	0.007	-0.043	0.024	-0.0020

West Coast Scenario Results

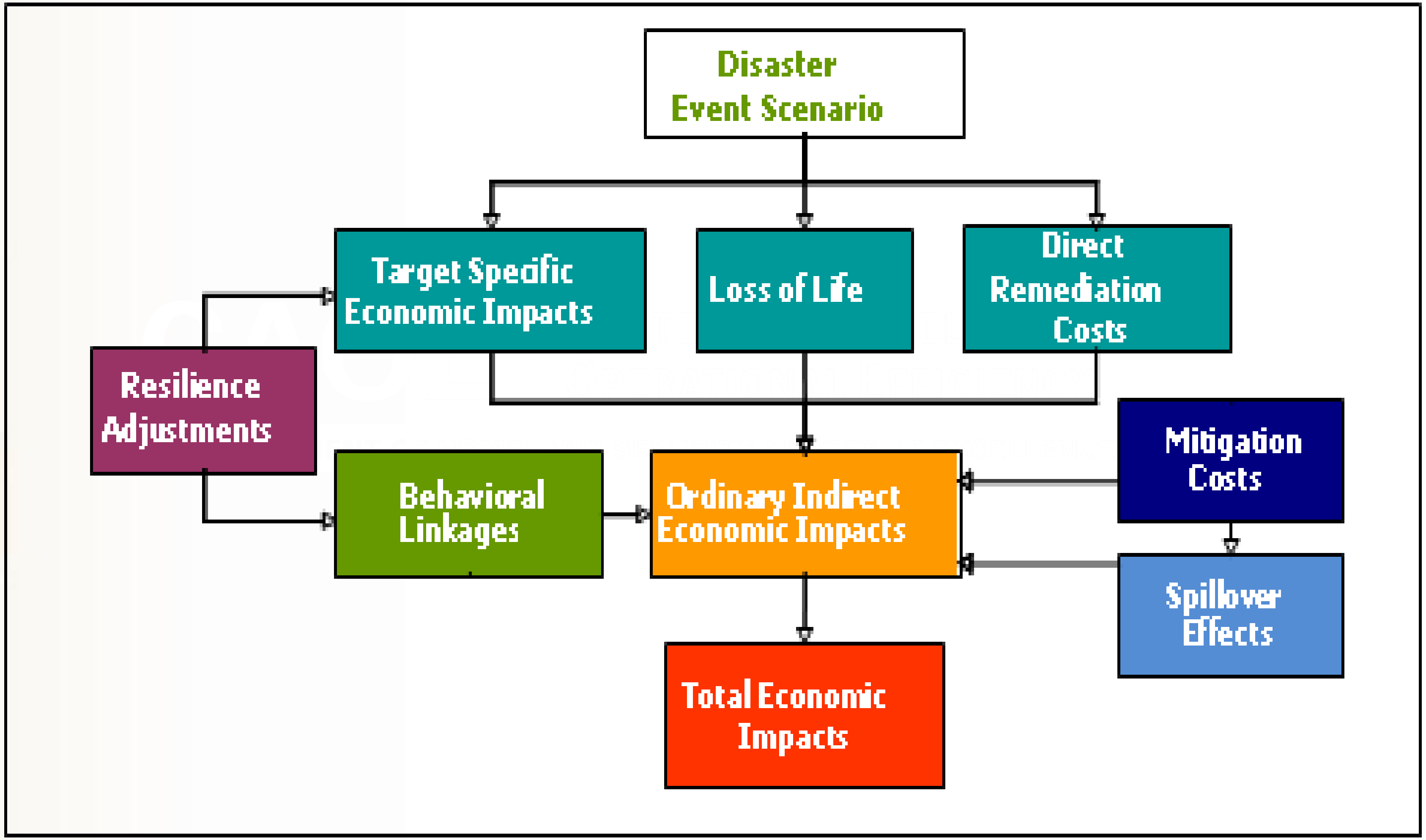
- **Base Case Impacts**:
  - LA Metro area economy: -$4.1 billion (0.373% decrease in annual GDP)
  - US economy: -$300 million (SF and Rest of US picks up much of the slack)
- **Individual Threat Impacts: Comparing Impacts of the Three Disruptions:**
  - MARSEC incident has largest effect on LA Metro economy of all three
  - Strike has largest effect on US economy of all three
  - Substantial negative synergies stemming from ship congestion
- **Sensitivity Tests:**
  - Avoidance behavior (MARSEC) leads to LA Metro impacts 13% higher
  - Results very sensitive to lower and upper bound changes in basic assumptions
- **Resilience Analysis:**
  - Five resilience tactics can reduce losses for LA Metro by 72%
  - Production recapture, inventories, and ship-rerouting have strongest effects

E-CAT Development Objectives

- Develop a standardized capability to estimate approximate economic consequences of 30+ types of HRNSC threats
    - Includes a comprehensive set of economic impact categories
    - Standardization facilitates comparisons across threat types

- Transition the research into a user-friendly, quick turn-around time, software tool for high-level decision-makers
    - Risk management: resource allocation across multiple threats
    - Rapid response: estimates for remediation/aid/recovery

CREATE Economic Consequence Analysis Framework


Disaster Event Scenario
Target Specific Economic Impacts
Loss of Life
Direct Remediation Costs
Resilience Adjustments
Behavioral Linkages
Ordinary Indirect Economic Impacts
Mitigation Costs
Spillover Effects
Total Economic Impacts

Port and Supply-Chain Resilience Tactics

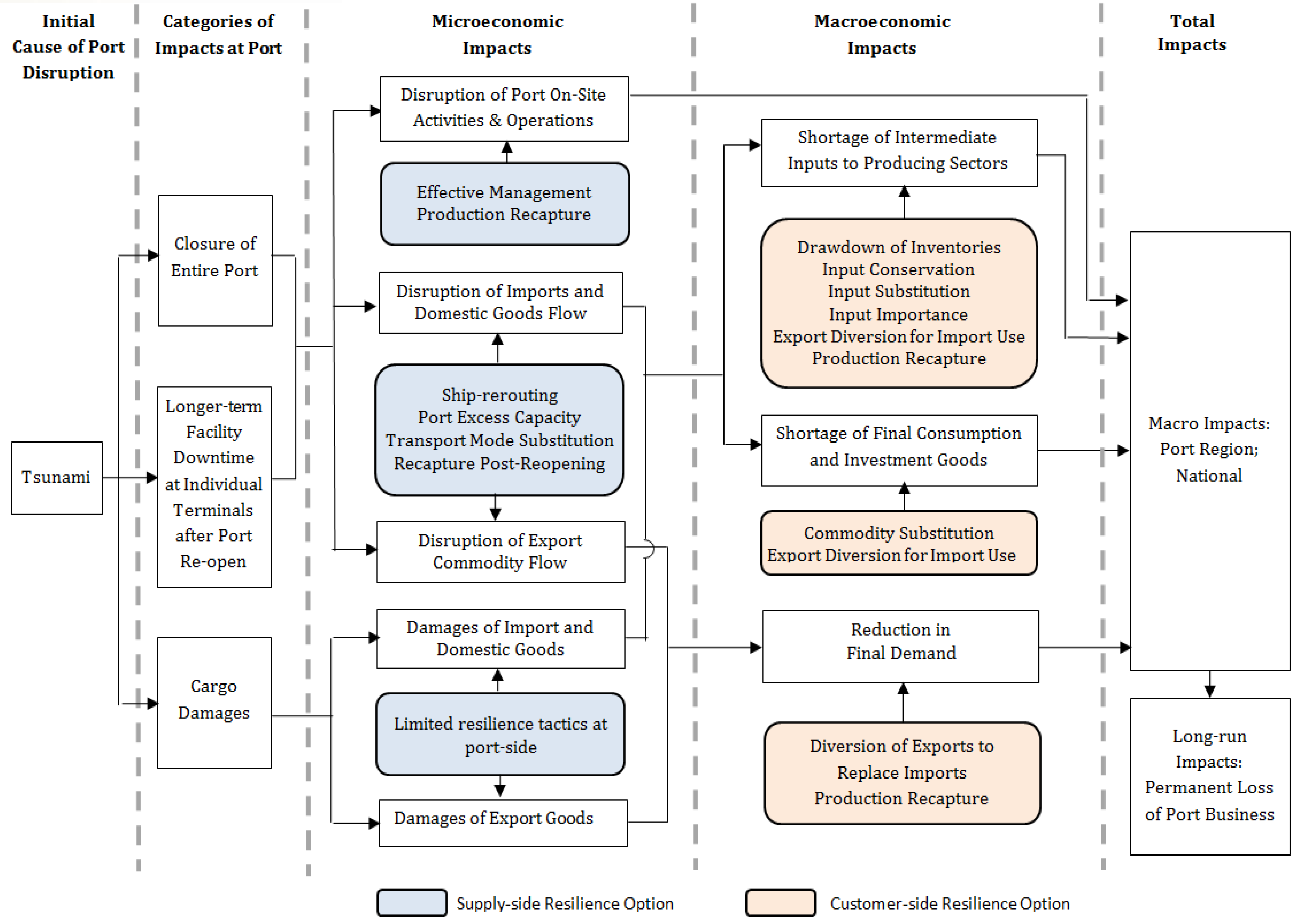
Supplier-Side Resilience Options	Customer-Side Resilience Options
Excess capacity: Utilization of unused capacity at undamaged terminals	**Use of inventories**: Stockpiling critical inputs for the production of goods and services by firms
Cargo prioritization: Altering schedules for unloading or loading based on the characteristics or value of the cargo	**Conservation**: Finding ways to utilize less of disrupted imported goods in production processes
Ship re-routing: Sending ships to other ports	**Input substitution:** Utilizing similar goods in the production process to those whose production has been disrupted
Export diversion for import use: Sequestering goods intended for export to substitute for lack of availability of imports or domestically-produced goods	**Import substitution**: Bringing in goods and services in short supply from outside the region through means other than water transportation.
Effective management: Improvements in decision-making and expertise that enhance functionality	**Production relocation**: Shifting production to branch plants or losing production opportunities to competitors in other locations.
Production recapture (Rescheduling): Working extra shifts or over-time to clear up backlog of vessels after resumption of port operation	**Production recapture (Rescheduling)**: Making up lost production by working extra shifts or over time after the supply of critical inputs resumes.

E-CAT Analytical Stages

Step 1: Enumeration Tables → **Step 2:** Direct Impact → **Step 3:** User Interface Variables → **Step 4:** CGE Analysis → **Step 5:** Reduced Form Analysis → **Step 6:** Uncertainty Analysis → **Step 7:** E-CAT Tool

1. Enumeration Tables – Qualitative Direct Impact estimates identified from historical data, literature, or expert judgment
2. Lower- and upper-bound Direct Impact values estimated for each category above the “Low Influence” threshold
3. User Interface Variables identified:
   (Magnitude, Time of Day, Duration, Economic Structure, Location, Clean Up, Behavioral Avoidance & Aversion, Resilience Relocation, Substitution, Recapture)
4. Randomized draws of 100 variable combinations converted to CGE inputs and run to estimate GDP and employment impacts
5. Reduced-form equation estimated with OLS & quantile regression
6. Uncertainty distributions generated with reduced-form results
7. Reduced-form equations and uncertainty analysis combined into the user-friendly interface

Framework for Estimating Total Economic Impacts of a Port Disruption



Initial Cause of Port Disruption

Categories of Impacts at Port

Microeconomic Impacts

Macroeconomic Impacts

Total Impacts

Tsunami

Closure of Entire Port

Longer-term Facility Downtime at Individual Terminals after Port Re-open

Cargo Damages

Disruption of Port On-Site Activities & Operations

Effective Management Production Recapture

Disruption of Imports and Domestic Goods Flow

Ship-rerouting
Port Excess Capacity
Transport Mode Substitution
Recapture Post-Reopening

Disruption of Export Commodity Flow

Damages of Import and Domestic Goods

Limited resilience tactics at port-side

Damages of Export Goods

Shortage of Intermediate Inputs to Producing Sectors

Drawdown of Inventories
Input Conservation
Input Substitution
Input Importance
Export Diversion for Import Use
Production Recapture

Shortage of Final Consumption and Investment Goods

Commodity Substitution
Export Diversion for Import Use

Reduction in Final Demand

Diversion of Exports to Replace Imports
Production Recapture

Macro Impacts: Port Region; National

Long-run Impacts: Permanent Loss of Port Business

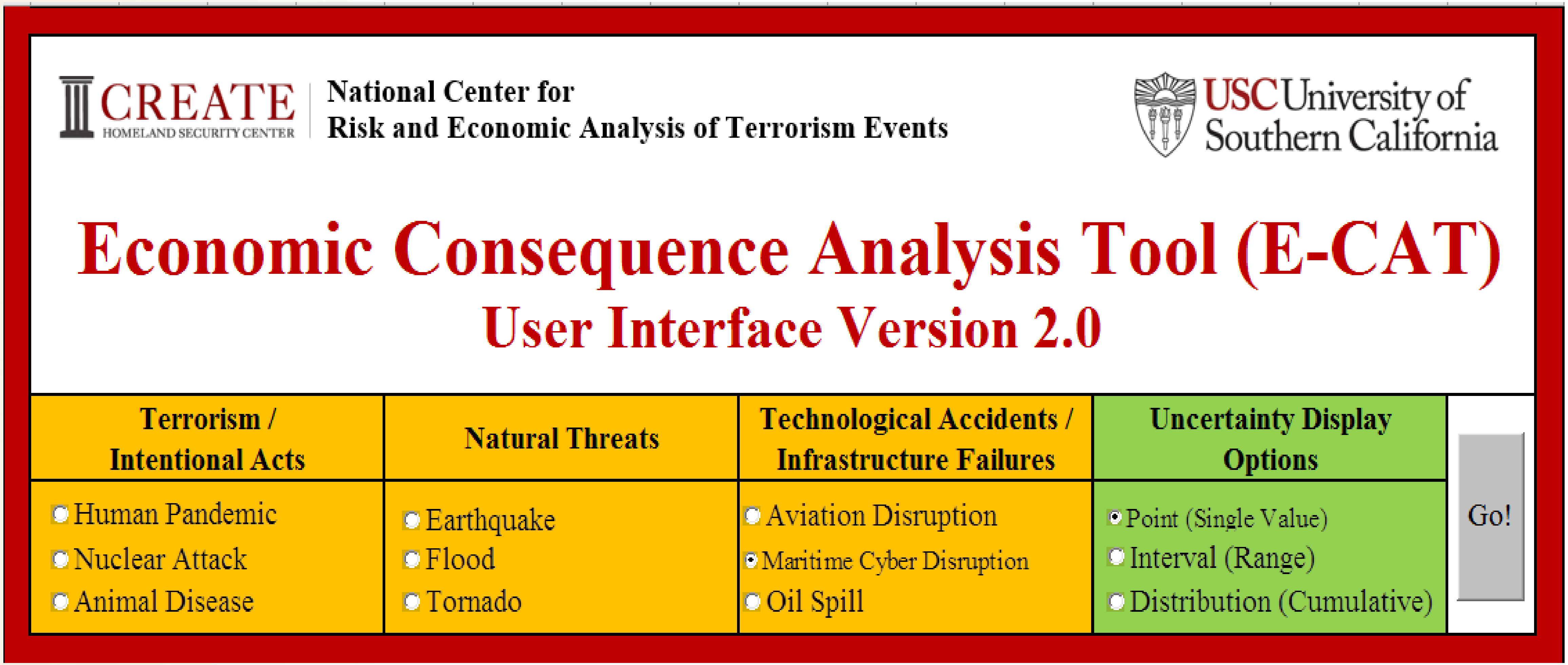
▭ Supply-side Resilience Option

▭ Customer-side Resilience Option

E-CAT Regression Results: Marine Cyber Scenario

	GDP (Value Terms)		
Model	**Ship Rerouting**	**Cargo-Diversion, Imports**	**Cargo-Diversion, Exports**
Magnitude	-0.454***	-0.454***	-0.454***
Inventory 5%	1.049***	1.049***	1.049***
Inventory 10%	1.940***	1.940***	1.940***
Conservation 2%	0.359***	0.359***	0.359***
Conservation 5%	1.084***	1.084***	1.084***
Ship-Rerouting	12.017***		
Cargo-Diversion, Imports		192.582***	
Cargo-Diversion, Exports			20.029***
Constant	-1.500***	-9.935***	-3.503***
No. of observations	498	498	498
R-squared	0.985	0.985	0.985

E-CAT User Interface



CREATE HOMELAND SECURITY CENTER

National Center for
Risk and Economic Analysis of Terrorism Events

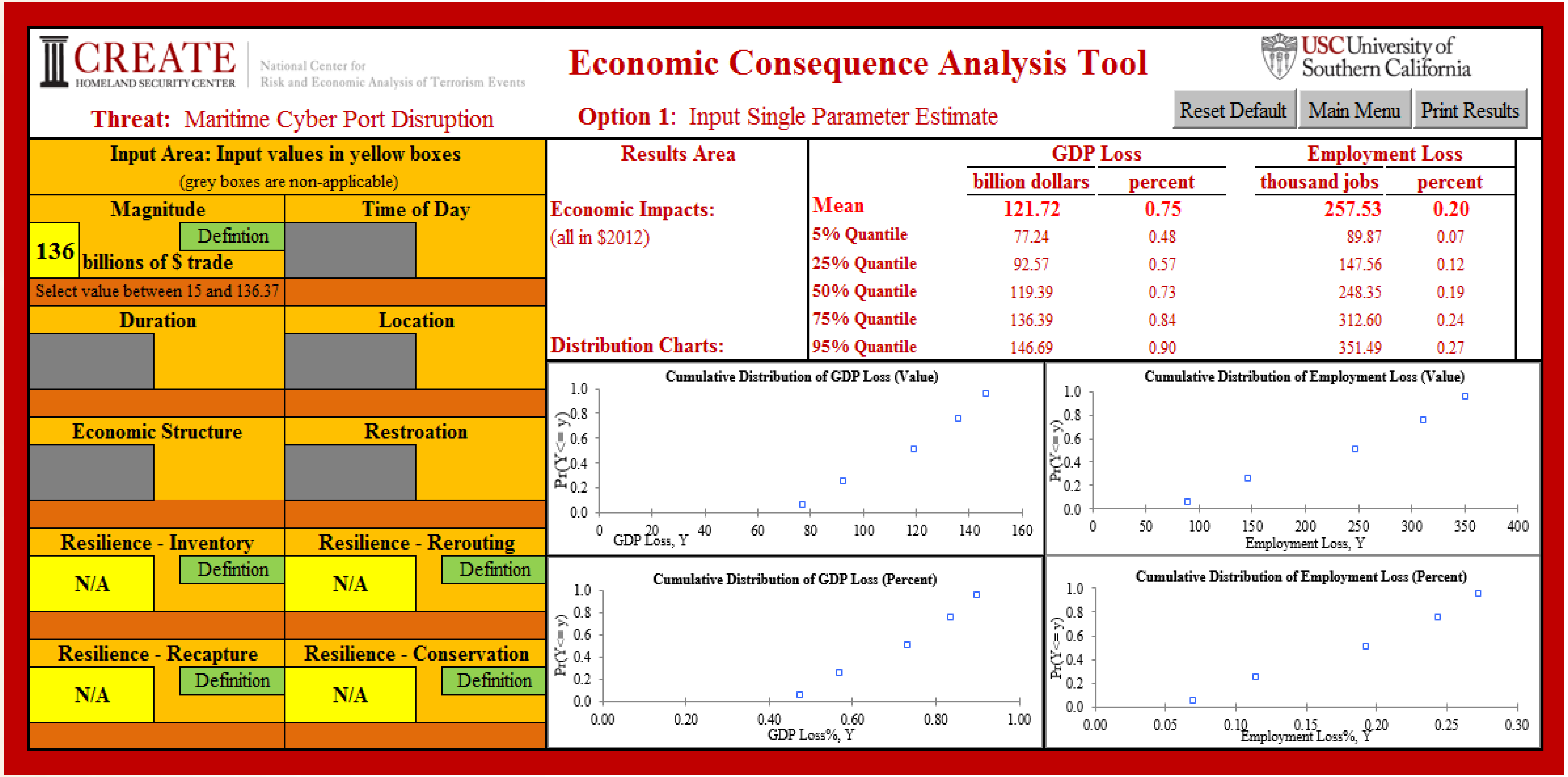
USC University of Southern California

Economic Consequence Analysis Tool (E-CAT)

User Interface Version 2.0

Terrorism / Intentional Acts	Natural Threats	Technological Accidents / Infrastructure Failures	Uncertainty Display Options
○ Human Pandemic	○ Earthquake	○ Aviation Disruption	● Point (Single Value)
○ Nuclear Attack	○ Flood	● Maritime Cyber Disruption	○ Interval (Range)
○ Animal Disease	○ Tornado	○ Oil Spill	○ Distribution (Cumulative)

Point Estimate: Default Values



CREATE HOMELAND SECURITY CENTER | National Center for Risk and Economic Analysis of Terrorism Events

Economic Consequence Analysis Tool

USC University of Southern California

Threat: Maritime Cyber Port Disruption

Option 1: Input Single Parameter Estimate

Reset Default | Main Menu | Print Results

Input Area: Input values in yellow boxes
(grey boxes are non-applicable)

Magnitude 136 **billions of $ trade** Defintion Select value between 15 and 136.37	**Time of Day**
Duration	**Location**
Economic Structure	**Restroation**
Resilience - Inventory N/A Defintion	**Resilience - Rerouting** N/A Defintion
Resilience - Recapture N/A Definition	**Resilience - Conservation** N/A Definition

Results Area

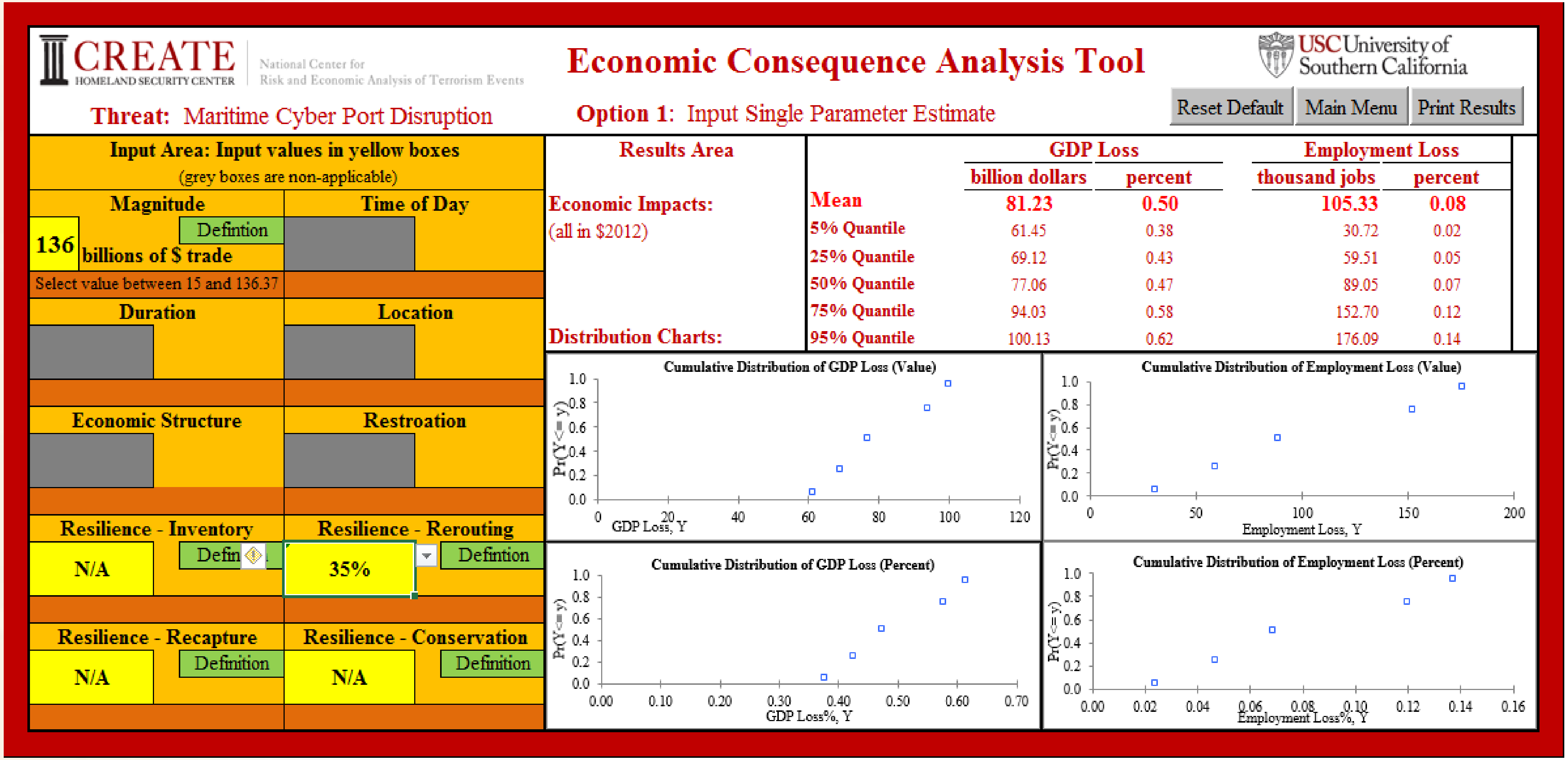
Economic Impacts:
(all in $2012)

	GDP Loss		Employment Loss	
	billion dollars	percent	thousand jobs	percent
Mean	121.72	0.75	257.53	0.20
5% Quantile	77.24	0.48	89.87	0.07
25% Quantile	92.57	0.57	147.56	0.12
50% Quantile	119.39	0.73	248.35	0.19
75% Quantile	136.39	0.84	312.60	0.24
95% Quantile	146.69	0.90	351.49	0.27

Distribution Charts:

Cumulative Distribution of GDP Loss (Value)
Pr(Y<=y)
1.0
0.8
0.6
0.4
0.2
0.0
0
20
40
60
80
100
120
140
160
GDP Loss, Y
Cumulative Distribution of Employment Loss (Value)
Pr(Y<=y)
1.0
0.8
0.6
0.4
0.2
0.0
0
50
100
150
200
250
300
350
400
Employment Loss, Y
Cumulative Distribution of GDP Loss (Percent)
Pr(Y<=y)
1.0
0.8
0.6
0.4
0.2
0.0
0.00
0.20
0.40
0.60
0.80
1.00
GDP Loss%, Y
Cumulative Distribution of Employment Loss (Percent)
Pr(Y<=y)
1.0
0.8
0.6
0.4
0.2
0.0
0.00
0.05
0.10
0.15
0.20
0.25
0.30
Employment Loss%, Y

Adjustment for Ship-Rerouting Resilience = 35%


CREATE
HOMELAND SECURITY CENTER
National Center for
Risk and Economic Analysis of Terrorism Events
USC University of Southern California
Reset Default
Main Menu
Print Results

Economic Consequence Analysis Tool

Threat: Maritime Cyber Port Disruption

Option 1: Input Single Parameter Estimate

Input Area: Input values in yellow boxes

(grey boxes are non-applicable)

Magnitude: 136 **billions of $ trade** — Defintion

Select value between 15 and 136.37

Time of Day

Duration

Location

Economic Structure

Restroation

Resilience - Inventory: N/A — Defin⚠

Resilience - Rerouting: 35% — Defintion

Resilience - Recapture: N/A — Definition

Resilience - Conservation: N/A — Definition

Results Area

Economic Impacts:
(all in $2012)

	GDP Loss		Employment Loss	
	billion dollars	**percent**	**thousand jobs**	**percent**
Mean	**81.23**	**0.50**	**105.33**	**0.08**
5% Quantile	61.45	0.38	30.72	0.02
25% Quantile	69.12	0.43	59.51	0.05
50% Quantile	77.06	0.47	89.05	0.07
75% Quantile	94.03	0.58	152.70	0.12
95% Quantile	100.13	0.62	176.09	0.14

Distribution Charts:

Cumulative Distribution of GDP Loss (Value)
Pr(Y<= y)
1.0
0.8
0.6
0.4
0.2
0.0
0
20
40
60
80
100
120
GDP Loss, Y
Cumulative Distribution of Employment Loss (Value)
Pr(Y<= y)
1.0
0.8
0.6
0.4
0.2
0.0
0
50
100
150
200
Employment Loss, Y
Cumulative Distribution of GDP Loss (Percent)
Pr(Y<= y)
1.0
0.8
0.6
0.4
0.2
0.0
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
GDP Loss%, Y
Cumulative Distribution of Employment Loss (Percent)
Pr(Y<= y)
1.0
0.8
0.6
0.4
0.2
0.0
0.00
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
Employment Loss%, Y

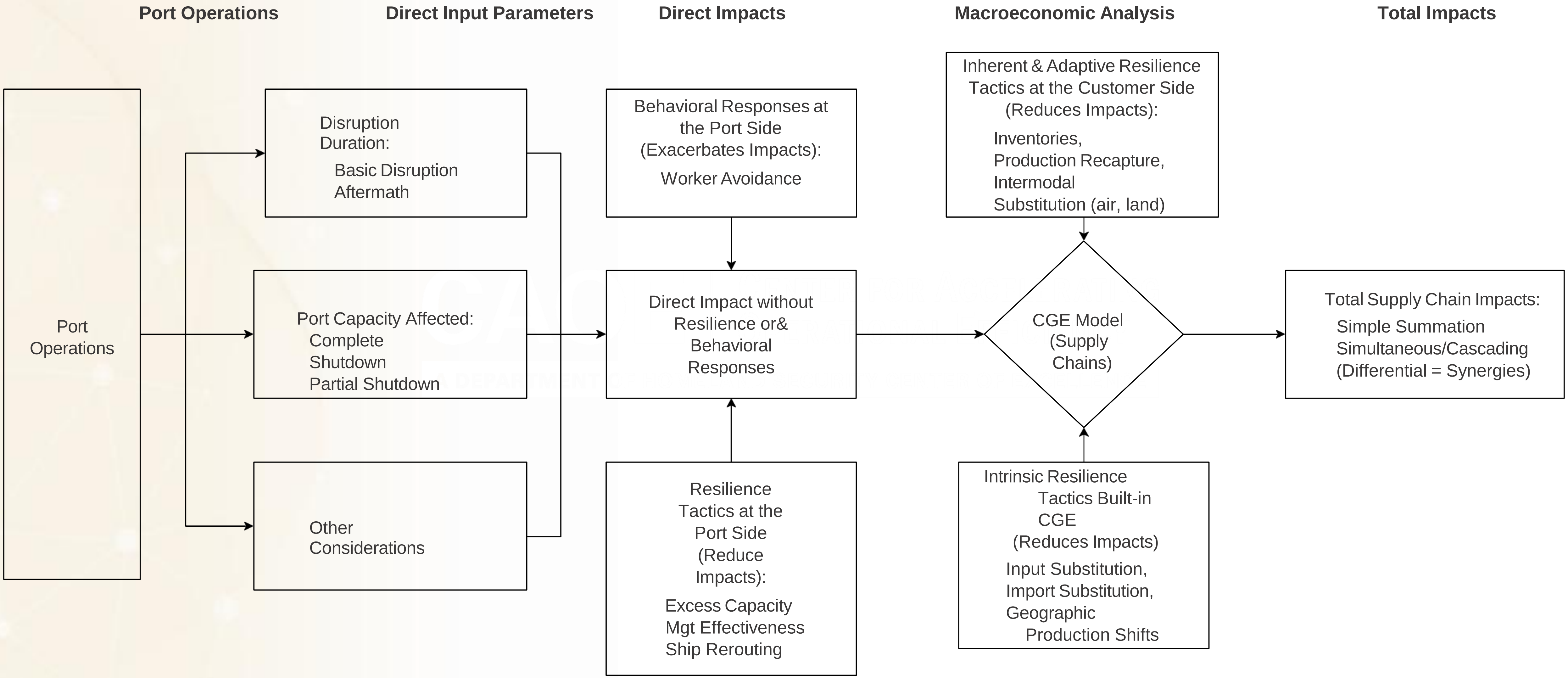
E-CAT Summary

- E-CAT can produce rapid estimates of economic consequences for several HSNRC threats(Including Marine Cyber-Attacks)
- E-CAT has a solid foundation
  - based on 10 years of research on Economic Consequence Analysis
  - uses state of the art economic model (CGE)
  - incorporates resilience & extreme behavioral responses
  - vetted in case studies & peer reviewed literature
- Incorporates major types of uncertainty
- E-CAT is user friendly programmed in Excel VBA

MCAT Comparison with E-CAT

- MCAT has same motivation: user-friendly, rapid estimation decision support tool
- MCAT maintains the best features of E-CAT
- MCAT is an advance over E-CAT in the following ways:
  - Includes complex (compound/cascading) disruptions
  - Includes a broader range of disruptions (not just catastrophic)
  - Includes more detail on port operations
  - Includes more extensive aspects of port capacity and ship-rerouting
  - Provides a more solid empirical foundation for other resilience tactics
  - Can be further enhanced by including effectiveness of mitigation in future research

MCAT Supply-Chain Disruption Model



Port Operations

Direct Input Parameters

Direct Impacts

Macroeconomic Analysis

Total Impacts

Port Operations

Disruption Duration:
- Basic Disruption
- Aftermath

Port Capacity Affected:
- Complete Shutdown
- Partial Shutdown

Other Considerations

Behavioral Responses at the Port Side (Exacerbates Impacts):
- Worker Avoidance

Direct Impact without Resilience or& Behavioral Responses

Resilience Tactics at the Port Side (Reduce Impacts):
- Excess Capacity
- Mgt Effectiveness
- Ship Rerouting

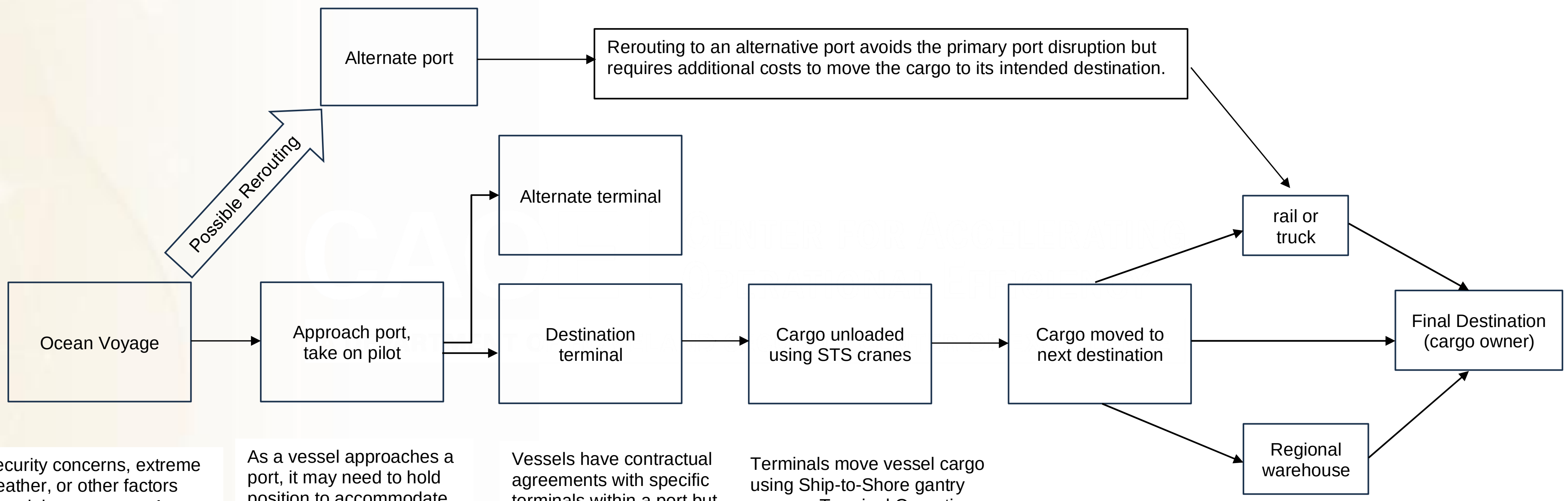
Inherent & Adaptive Resilience Tactics at the Customer Side (Reduces Impacts):
- Inventories,
- Production Recapture,
- Intermodal Substitution (air, land)

CGE Model (Supply Chains)

Intrinsic Resilience Tactics Built-in CGE (Reduces Impacts)
- Input Substitution,
- Import Substitution,
- Geographic Production Shifts

Total Supply Chain Impacts:
- Simple Summation
- Simultaneous/Cascading
- (Differential = Synergies)

Idealized Maritime Supply Chain



Ocean Carriers

Port Officials

Terminal Operators

Logistics Providers

Cargo Owners

Ocean Voyage

Possible Rerouting

Alternate port

Rerouting to an alternative port avoids the primary port disruption but requires additional costs to move the cargo to its intended destination.

Approach port, take on pilot

Alternate terminal

Destination terminal

Cargo unloaded using STS cranes

Cargo moved to next destination

rail or truck

Regional warehouse

Final Destination (cargo owner)

Security concerns, extreme weather, or other factors may delay a voyage. A vessel might elect to reroute to a different port at any time in a voyage due to known or expected disruptions.

As a vessel approaches a port, it may need to hold position to accommodate port schedules, respond to direction from port state authorities wait for improved weather and tide conditions, or consider diverting to another port if disruptions are severe. All vessels require pilotage.

Vessels have contractual agreements with specific terminals within a port but may use alternate terminals under special circumstances. In such cases, additional cargo delays would occur as the terminal serviced its primary customers first.

Terminals move vessel cargo using Ship-to-Shore gantry cranes. Terminal Operating Systems track, and in some cases control, cargo movement within a terminal. Ideally, inbound cargo only remains on the terminal for a few hours to a few days.

Bottlenecks and disruptions after the cargo leaves the terminal can push problems back to the port and ships, as there may be no remaining space to store cargo. This creates a negative feedback loop as congestion increases and backlogs grow.

Port Operations

Ships may have to wait in queue if pilot availability is restricted, or if overall port congestion or hazards require special vessel traffic procedures. Authorities may help broker vessel priorities in some cases.

Cargo operations require a suitable berth, power, ship to shore cranes or other cargo handling equipment, and a skilled workforce. Changes in the expected cargo loading/unloading plans cause delays and require more time and resources.

Port facilities store cargo for short periods before it is loaded on a vessel or is taken by truck or rail to its destination. On-dock storage space is always limited, and congestion can lead to delays, backlogs, and the need to devote more labor and equipment to managing the limited space.

After unloading and on-dock storage, cargo may be moved to a regional warehouse before conveyance to the cargo owner by truck and/or rail. Truck and rail disruptions, or regional warehouse shortages, can create backlogs, making further cargo unloading impossible

Ship Queue → Cargo Operations → Port facility cargo storage → Cargo conveyed to cargo owners

Resilience tactics:
Ship Rerouting
Vessel Traffic Services
Contingency Plans

Resilience tactics:
Terminal Operating Systems
Excess berth/crane capacity
Flexible workforce
Backkup power systems

Resilience tactics:
Integrated scheduling
Efficient intermodal connections

Resilience tactics:
Expanded warehouse availability
Expanded warehouse capacity
Inventory drawdown
Other business tactics

MCAT Preliminary Regression Estimates

	LA Real GDP	National Real GDP
Direct Shutdown	-.0327571	-.0002111
	(.007182)***	(.000155)
Partial Shutdown	-.0277776	-.0001317
	(.0017751)***	(.0000383)***
Avoidance Days	-.0067355	-.0000395
	(.002306)***	(.0000498)
Avoidance Pct	.923392	.0017195
	(.9196653)	(.0198537)
Excess Capacity	2.022707	.0207533
	(.1863623)***	(.0040232)***
Ship Rerouting	1.779280	.0145657
	(.5575121)***	(.0120356)
Inventories	.1176431	.0018281
	(.0183415)***	(.000396)***
Management Effectiveness	.1786608	.0027837
	(.2029131)	(.0043805)
Observations	99	99
Adj R^2	0.8512	0.4203

A Selection of New Directions Arising from Stakeholder Engagement

- **Panama Canal; Effects of Climate Change on MTS**
- **Offshore Wind Disruptions**, including cables cut + cyber
- **Smart ports**: AI, digital twins, modern info sharing; but: cyber attacks, power failures, and Chinese cranes
- **Great Lakes**: ice cutters break + Soo Lock damage
- **Dark Fleet (resulting from Ukraine War): Avoiding sanctions:** accidents with old & uninsured vessels + oil spills + all kinds of crime
- **Crowded Offshore MTS:** conflicting uses + increasingly crowded maritime traffic + ambiguous jurisdiction issues (***USCG Evergreen***)
  - Wind farms
  - Commercial space/rocket launches
  - Offshore ports to handle mega container ships, very large crude carriers, even offshore cargo inspection
  - Offshore subsea storage for hydrogen fuel
  - Offshore aquaculture

Great Lakes Exercise October 22

- Worked with CMTS on plans for an exercise near Cleveland
- Held October 22.
- Scenario: A vessel lost steering, apparently due to a cyber attack, and is hard aground at River Bridge #1.
- The Exercise highlighted the consequences of a disruption to maritime and rail traffic, with impacts to auto manufacturing, steel, and other industries.
- More Great Lakes exercises planned with USCG D9 including cyber exercise with international participation.

Thank you!

Please contact Fred Roberts or Adam Rose at froberts@dimacs.rutgers.edu or adamzros@usc.edu for questions or other feedback

Additional Slides

Mississippi River Scenario

- We were led to this scenario by **discussions with U.S. Maritime Administration** leaders
- Summer 2022 situation:
  - **Record low water**
  - A trip between Cairo Illinois to New Orleans that normally takes between 13 and 14 days, took almost 27 days during that time
  - Barges that normally get loaded up to 12 ft or more, were down to 9ft causing a severe shrinking of towing capacity leading to a reduction of over 50%
- **Discussions with American Waterways Operators** (tugboat, towboat and barge industry's advocate) and US Army Corps of Engineers ***led us to detailed scenario assumptions***
- Then summer of 2023 had a repeat of really low water
- **A good test of our MCAT model** - leading to a detailed economic analysis of the resulting impacts on the fertilizer and grain markets

Mississippi River Scenario

- **Project PI Adam Rose was invited to testify before the Senate Budget Committee in October on the Economic Impacts of Climate Change on Supply Chains**
  - His **testimony was built around our Mississippi River low water scenario** and economic analysis
- Now we have seen **drought in Panama leading to low water in the Panama Canal** with dramatic impact on Canal capacity and major disruptions to shipping world-wide
- New DHS Supply Chain Resilience Center making climate change impacts on supply chain a major theme

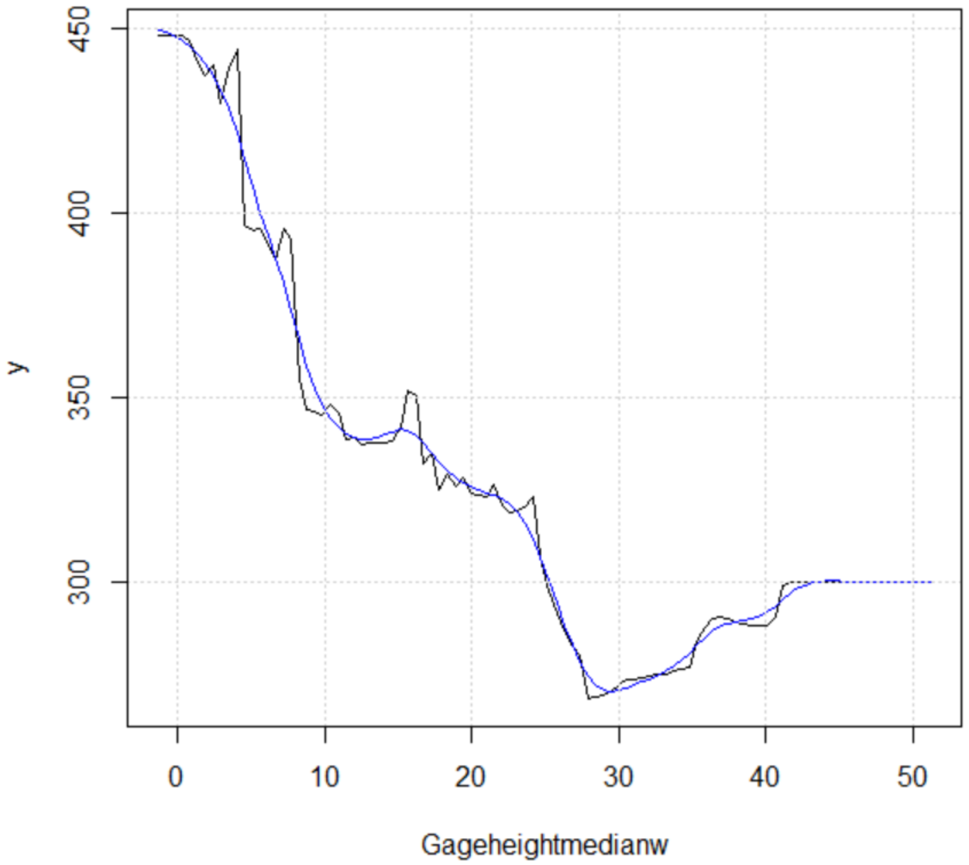
Mississippi River Scenario Economic Analysis: Barges and Fertilizer

- **Low water led to barges becoming stranded in mud and sand**
  - Necessitating **lighter barge loads, shorter barge trains** and the implementation of one-way traffic in certain river sections
  - At the low water level of October 2022, approximately 2,000 barges were backed up along the river waiting passage
  - Consequently, **barge transportation rates soared to more than 400% above average**
  - **Barge labor productivity** (the work or output achieved by a unit of labor within a specific timeframe) **dropped significantly**

credit: Wikimedia commons, Wikideas1

Three Components of the Complex Disruption

- Scenario 1: Low water on the Mississippi due to drought:
  - Our models made assumptions about water levels at Memphis
  - Then **estimated changes in barge transportation rates and barge labor productivity rates as a function of water level**



Three Components of the Complex Disruption

- **Scenario 2: Lock and Dam Failure**
  - **Locks and dams on the Mississippi are old and subject to failure**
  - We used Lock and Dam 27 at Granite City Illinois for failure – a large portion of fertilizer and grain loads use this lock
  - When a lock fails, things are held up. **We estimated effect on barge transportation rates and barge labor productivity rates of this failure, as a function of length of time of outage.**
- **Scenario 3: Disruption of fertilizer imports in New Orleans**
  - Cause not identified, but could be hurricane, labor strike, cyber attack, heat event, etc.
  - Studied **different assumptions about percentage of import reduction**

Three Components of the Complex Disruption

- **Different assumptions about water levels, duration of lock failure, and percent import reduction define different cases:**
  - Base case, lower bound case, upper bound case
- To analyze the complex disruption, we **estimate the resulting direct and indirect (supply-chain) impacts** on the regional and national economy as a whole in terms of **decreases in GDP and inflationary pressures**

Mississippi Fertilizer Scenario Results

Scenario	GDP Level Change (millions of dollars)								GDP Percent change						
	Illinois	Iowa	Minnesota	Missouri	Wisconsin	RoUSA	National		Illinois	Iowa	Minnesota	Missouri	Wisconsin	RoUSA	National
1a	-4,611	-1,609	-4,050	-2,006	-2,833	2,475	-12,634		-0.427	-0.867	-1.003	-0.701	-0.786	0.012	-0.056
1b	-167	-32	-108	-64	-60	-1,107	-1,538		-0.016	-0.017	-0.027	-0.022	-0.017	-0.006	-0.007
2a	-1,164	-417	-1,035	-167	-750	612	-2,921		-0.108	-0.225	-0.256	-0.058	-0.208	0.003	-0.013
2b	-143	-27	-92	-54	-51	-938	-1,305		-0.013	-0.015	-0.023	-0.019	-0.014	-0.005	-0.006
3	-6	-1	-2	-2	-3	-161	-176		-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001
Sum Total	-6,092	-2,087	-5,287	-2,292	-3,696	881	-18,575		-0.564	-1.124	-1.309	-0.802	-1.026	0.004	-0.083
Sim Total	-5,931	-2,001	-5,096	-2,272	-3,511	704	-18,108		-0.549	-1.078	-1.262	-0.795	-0.975	0.004	-0.081

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Results for Mississippi Fertilizer Scenario Base Case

- **The overall negative impact on US GDP is 0.083%.**
  - Seems rather minor, but percentage **impacts at the state level are several-fold higher**; e.g., Minnesota is -1.309%
- **Aggregate employment impact is only -0.025%**
  - Still, this lower percentage impact corresponds to an **employment decrease of 51,267** people throughout the U.S economy, and each of them is 100% unemployed.
- The overall effect on prices (inflation) is estimated to cause a 0.299% increase in the Producer Price Index (PPI), and a **0.257% increase in the Consumer Price Index (CPI).**
  - **At a time when we are especially sensitive to inflationary pressures, such small impacts have relatively greater meaning.**
  - **These seemingly small amounts represent a 5% increase in current inflation, so they are quite notable.**

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