Iowa State University
Department of Industrial and Manufacturing Systems Engineering

Mitigating Risk of Disruptive Events: Application to Supply Chains and Allocating Resources for Preparedness

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IMSE Grad Seminar
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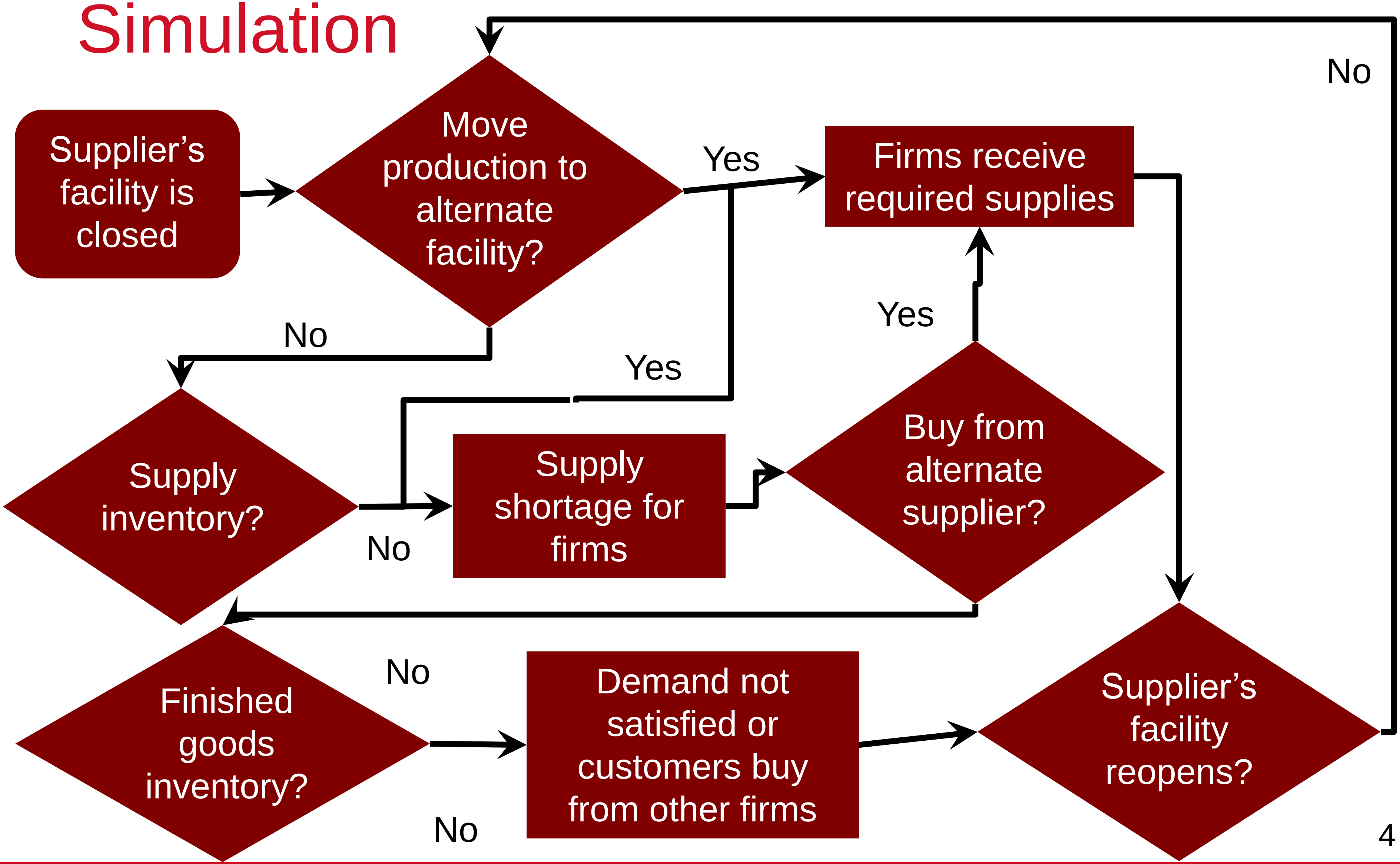
Outline

- Supply chain risk and disruptions
  - Severe supply chain disruptions (simulation)
  - Fault tree analysis
  - Contamination in food supply chains
- Resource allocation for emergency preparedness

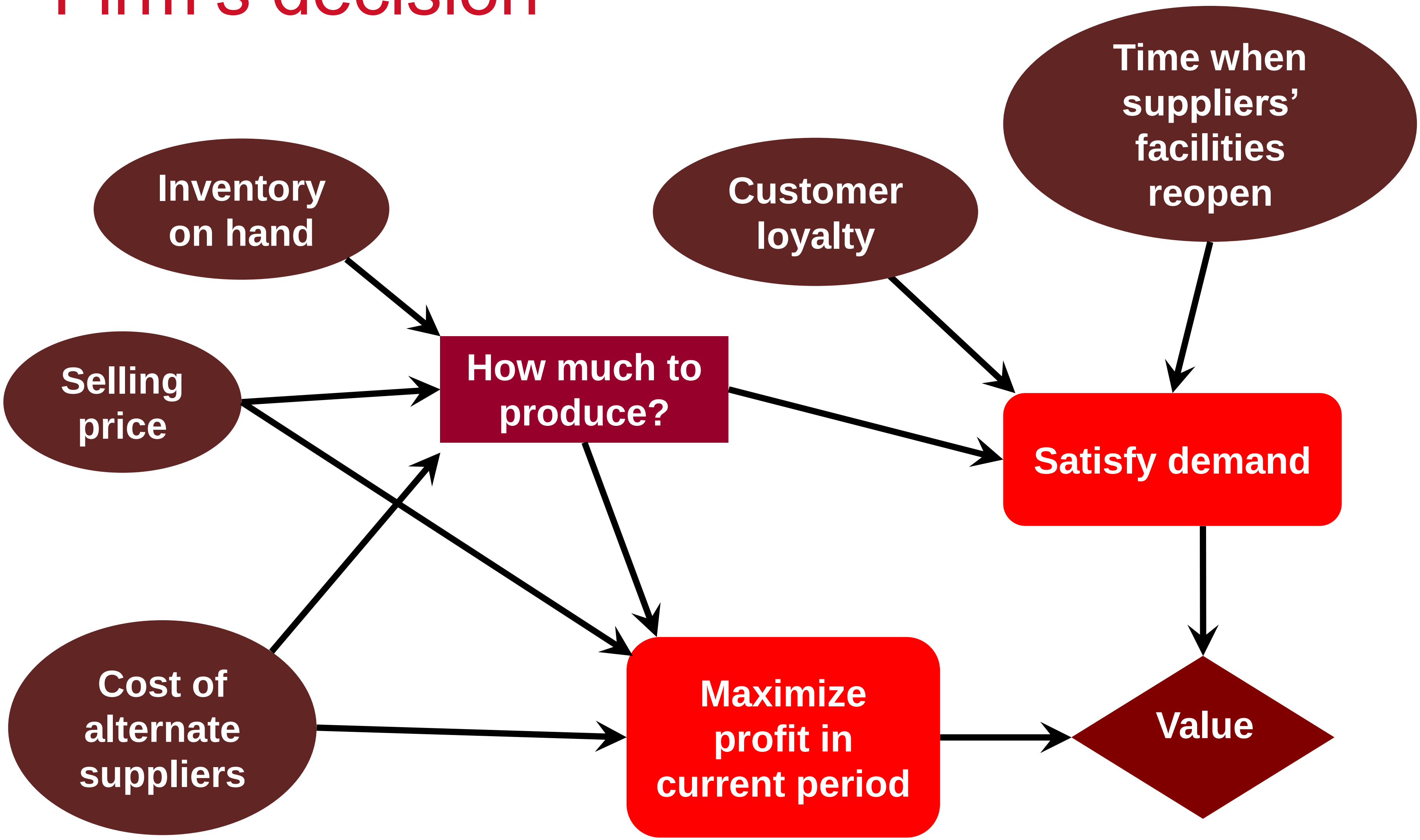
Interdependent economy

Simulation



Supplier's facility is closed
Move production to alternate facility?
Yes
Firms receive required supplies
No
No
Yes
Yes
Supply inventory?
Supply shortage for firms
Buy from alternate supplier?
No
No
Finished goods inventory?
Demand not satisfied or customers buy from other firms
Supplier's facility reopens?
No

Firm's decision



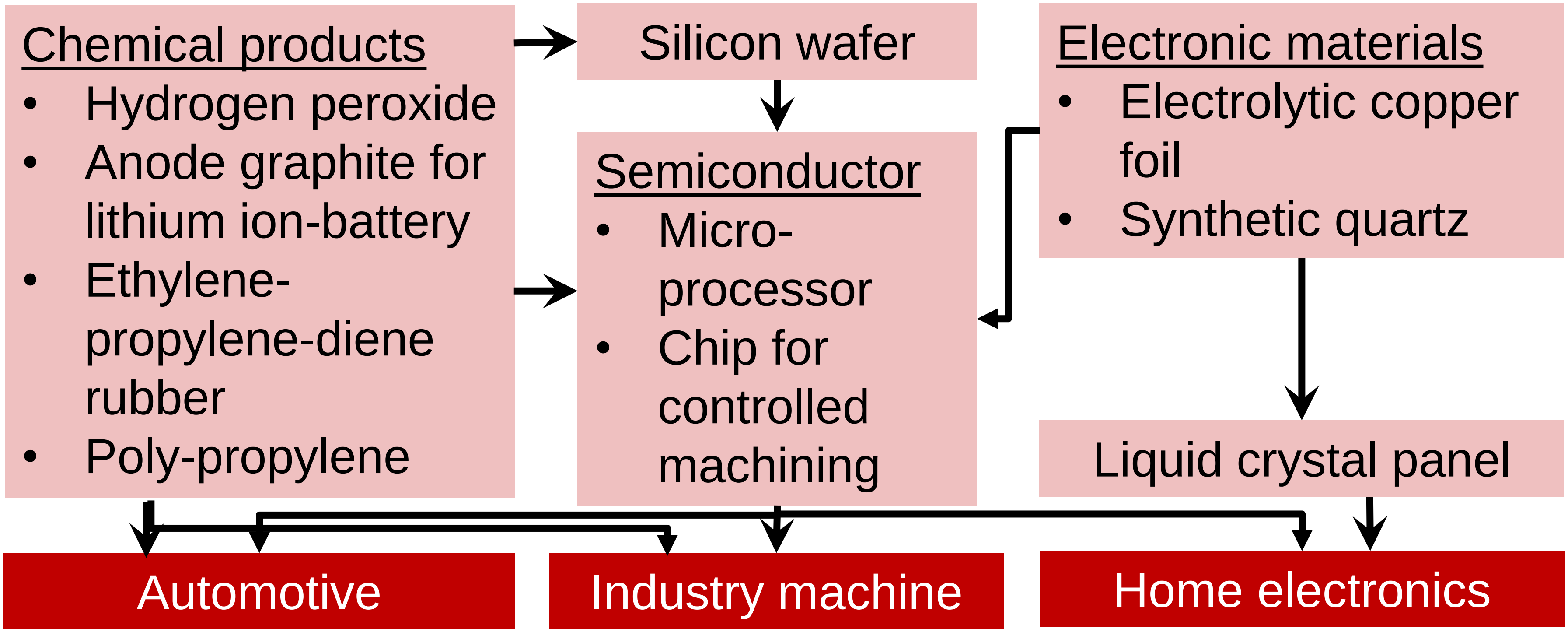
Results in automobile sector

Average percent of total demand satisfied

	Maximize profit and no alternate facility	Sacrifice profit to meet demand and no alternate facility	Sacrifice profit to meet demand and alternate facility
Ford, GM, and Chrysler	91.7	98.7	99.0
Toyota and Honda	68.7	86.7	93.4
Nissan	82.5	92.7	96.1

MacKenzie, C.A., Barker K., & Santos, J.R. (2014). Modeling a severe supply chain disruption and post-disaster decision making with application to the Japanese earthquake and tsunami. *IIE Transactions*, 46(12), 1243-1260.

Previous work



Ono, K., Akakura, Y., Kanda, M., & Ishihara (2015). Analyzing and simulating supply chain disruptions to the automobile industry based on experiences of the Great East Japan Earthquake. *Journal of Integrated Disaster Risk Management*, DOI10.5595/idrm.2015.0102

Preliminary results (concept demonstration)

Average percent of total demand satisfied

Industry	Maximize short-term profit and no alternate facility	Sacrifice profit to meet demand and no alternate facility	Sacrifice profit to meet demand and alternate facility
Automobile	57.9	87.2	95.7
Electronics	38.9	98.1	99.4
Chemical	100	100	100
Semiconductor	44.3	97.3	100

Collaborators: Xue (Snow) Bai and Andre Fristo

Fault tree analysis for supply chain risk

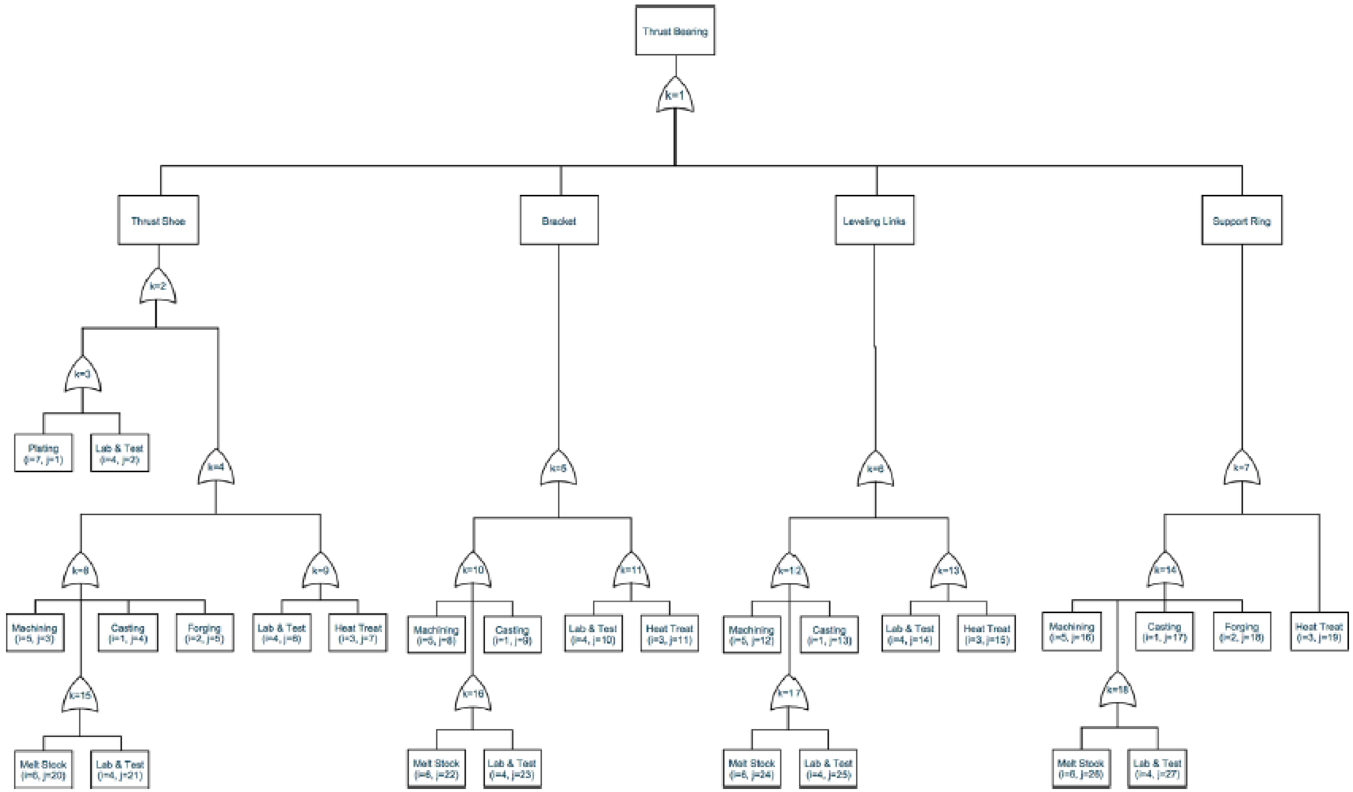


Fig. 2. Baseline fault-tree.

Sherwin, M.D., Medal, H., & Lapp, S.A. (2016). Proactive cost-identification and mitigation of supply delay risk in a low volume high value supply chain using fault tree analysis. *International Journal of Production Economics* 175, 153-163.

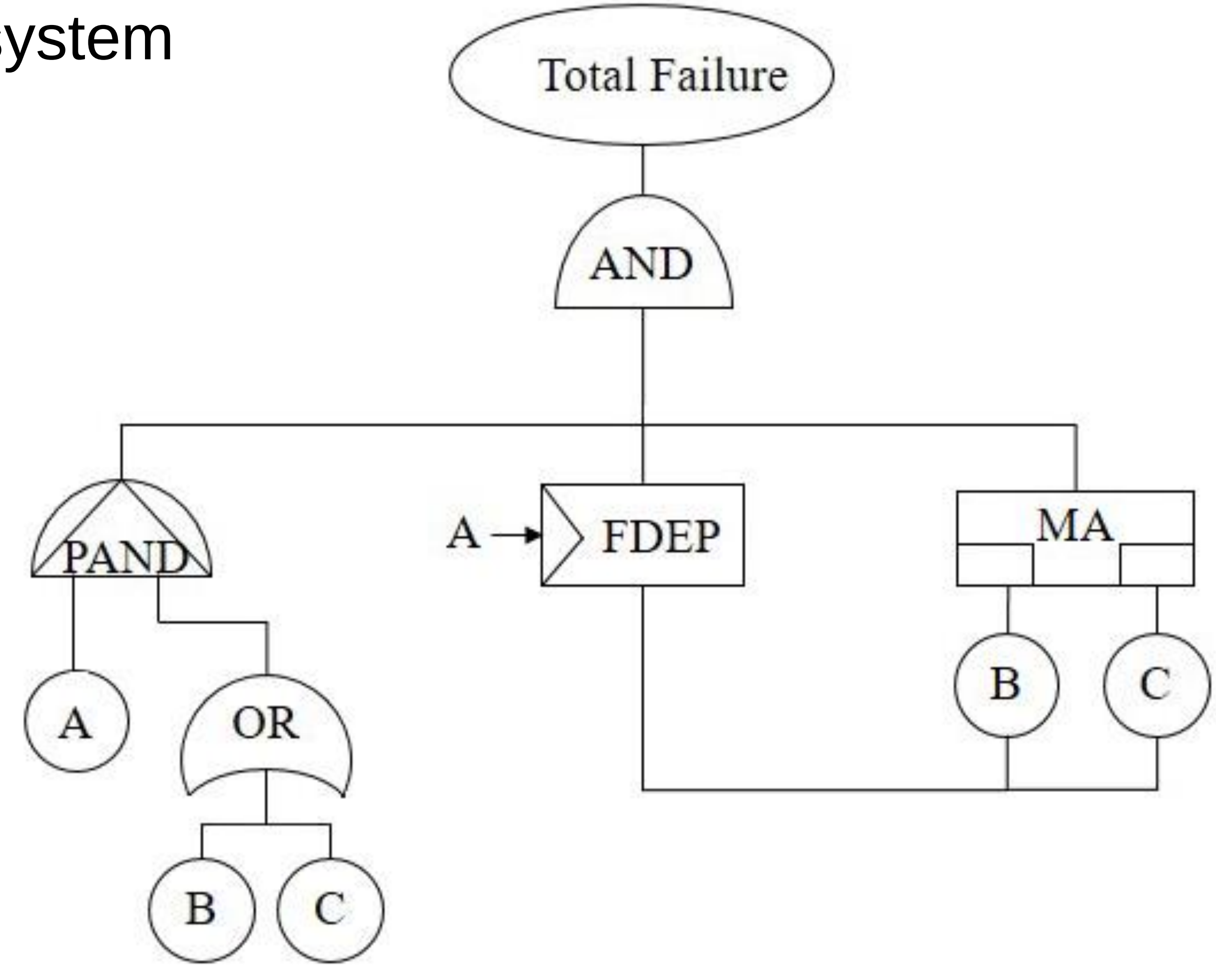
Dynamic fault tree

- Dynamic fault trees (DFT) are used to calculate reliability over time in engineered systems
- Apply DFT to supply chains
- Main-backup supply chain
  - Multiple units
  - Single unit
- Mutual-assistant supply chain
  - Multiple units
  - Single unit

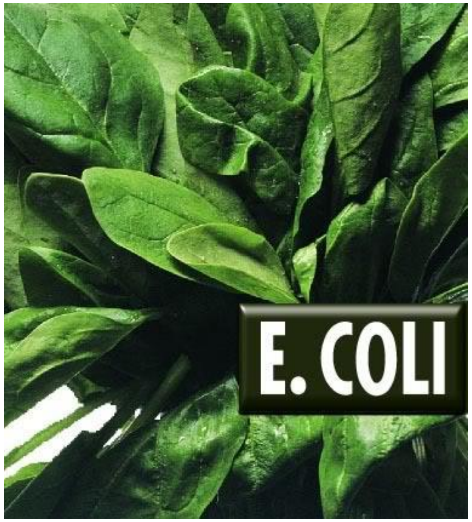
Lei, X., & MacKenzie, C.A. (2017). Supply chain risk analysis using dynamic fault trees. Working paper.

Four scenarios

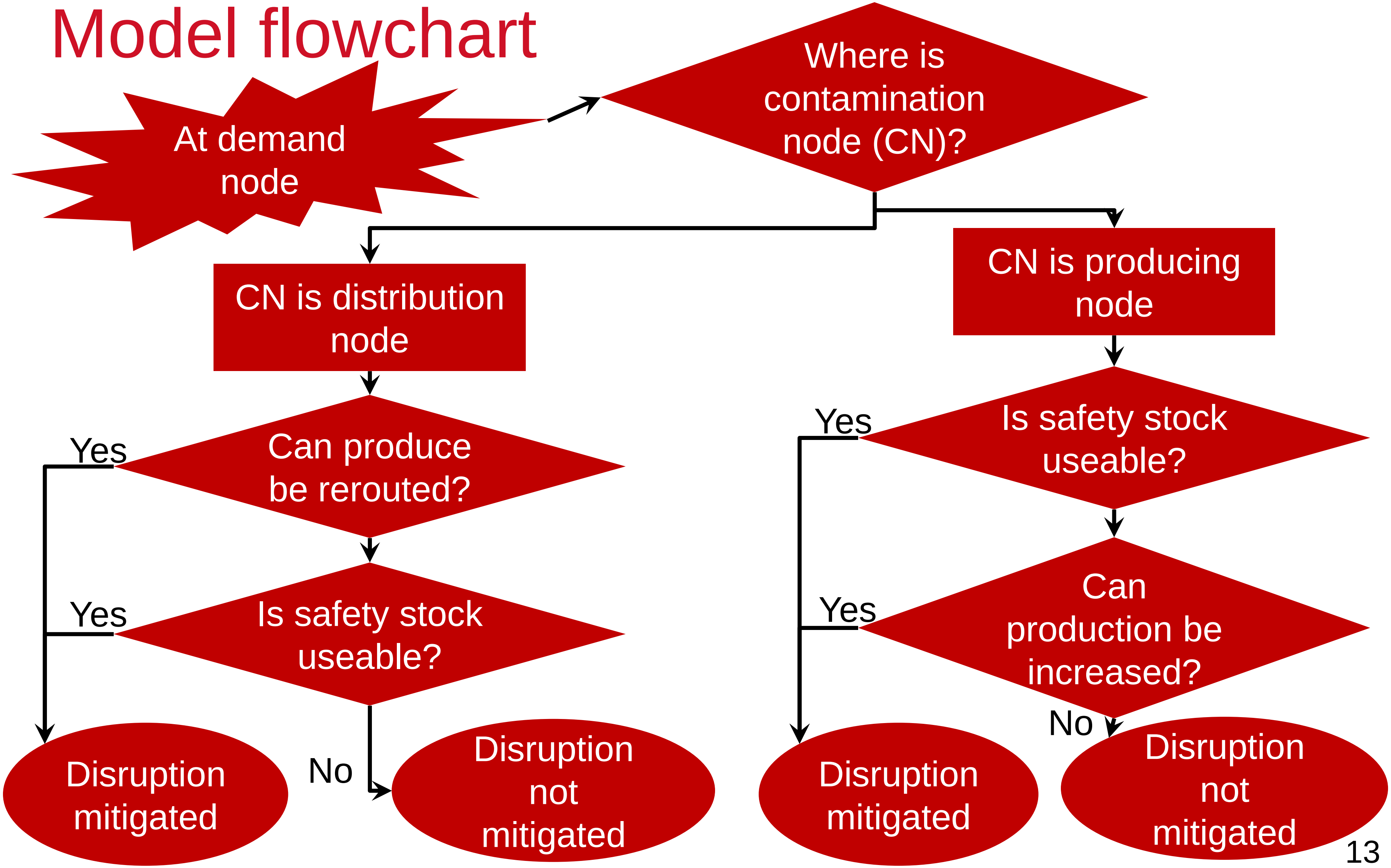
A: information system
B: supplier 1
C: supplier 2



Fresh produce contamination



Model flowchart

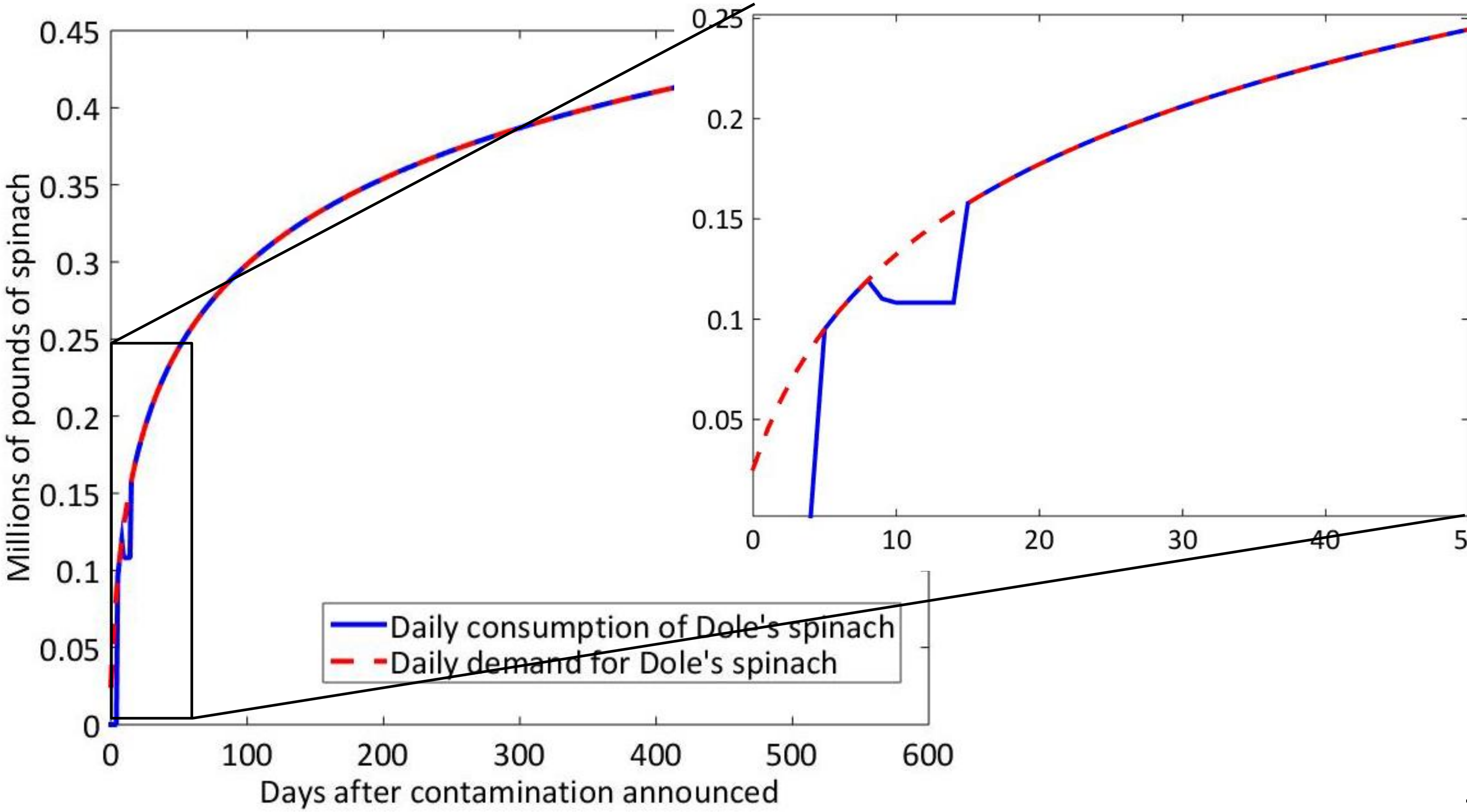


E. coli in bagged spinach

- *E. coli* discovered in bagged spinach in September 2006
- Source of contamination traced back to Natural Selection Foods, a supplier to Dole
- Fresh and bagged spinach was pulled from shelves for 5 days
- Spinach from California unavailable for an additional 10 days

MacKenzie, C.A., & Apte, A. (2017). Modeling disruption in a fresh produce supply chain. *Journal of Logistics Management*, 28(2), 656-679.

Dole's production of spinach



RESOURCE ALLOCATION FOR EMERGENCY PREPAREDNESS

U.S. spending on disasters

- $85 - $136 billion per year (Weiss and Weidman, 2013; Kostro et al., 2013)
- From 1985-2004 (Healy and Malhotra, 2009)
  - $195 million per year on disaster preparedness
  - $3.04 billion per year on disaster relief

Weiss, D.J. and J. Weidman (2013). Disastrous spending: Federal disaster-relief expenditures rise amid more extreme weather. Center for American Progress.
Kostro, S.S., A. Nichols, and A. Temoshchuk (2013). White paper on U.S. disaster preparedness and resilience: Recommendations for reform. CSIS-Pennington Family Foundation Series on Community Resilience, Center for Strategic & International Studies.
Healy, A. and N. Malhotra (2009). Myopic voters and natural disaster policy. *American Political Science Review* 103(3), 387-406.

Cost-benefit analyses

Benefit-cost ratio of FEMA mitigation grants (Rose et al., 2005)

- 1.5 for earthquake mitigation grants
- 5.1 for flood mitigation grants

Rose, A., K. Porter, N. Dash, J. Bouabid, C. Huyck, J. Whitehead, D. Shaw, R. Eguchi, C. Taylor, T. McLane, L.T. Tobin, P.T. Ganderton, D. Goldschalk, A.S. Kiremidjian, K. Tierney, and C.T. West (2005). Benefit-cost analysis of FEMA hazard mitigation grants. *Natural Hazards Review* 8(4), 97-111.

Research questions

- What is the optimal allocation of resources pre-disruption (prevention and preparedness) and post-disruption (response and recovery)?
- How should resources be allocated between different disruptions?
- How can we train decision makers to help them prepare for disruptions?

Outline

1. Resource allocation model
   - Theoretical results: 1 disruption
   - Example: 2 disruptions (oil spill, hurricane)
2. Hurricane decision simulator

Resource allocation model

Normal production

Interdependent matrix

Increased production if no disruption

$$\min\ p\mathbf{x}^{\top}\mathbf{D}\mathbf{c}$$

Probability of disruption

Vector of direct impacts (proportional)

Probability with no resources

Effectiveness of prevention

Pre-disruption allocation

subject to $p = \hat{p}\exp(-k_p z_p)$

Direct impacts with no resources

Allocation to industry

Allocation to benefit all industries

$$c_i = \hat{c}_i \exp(-k_q z_p - k_i z_i - k_0 z_0)$$

Effectiveness of preparation

Effectiveness of recovery allocation

$$z_p + \sum_{i=1}^{m} z_i + z_0 \leq Z$$

Overall budget

$$z_p \geq 0,\ z_i \geq 0,\ z_0 \geq 0$$

Optimal recovery allocation

Consequence * Effectiveness

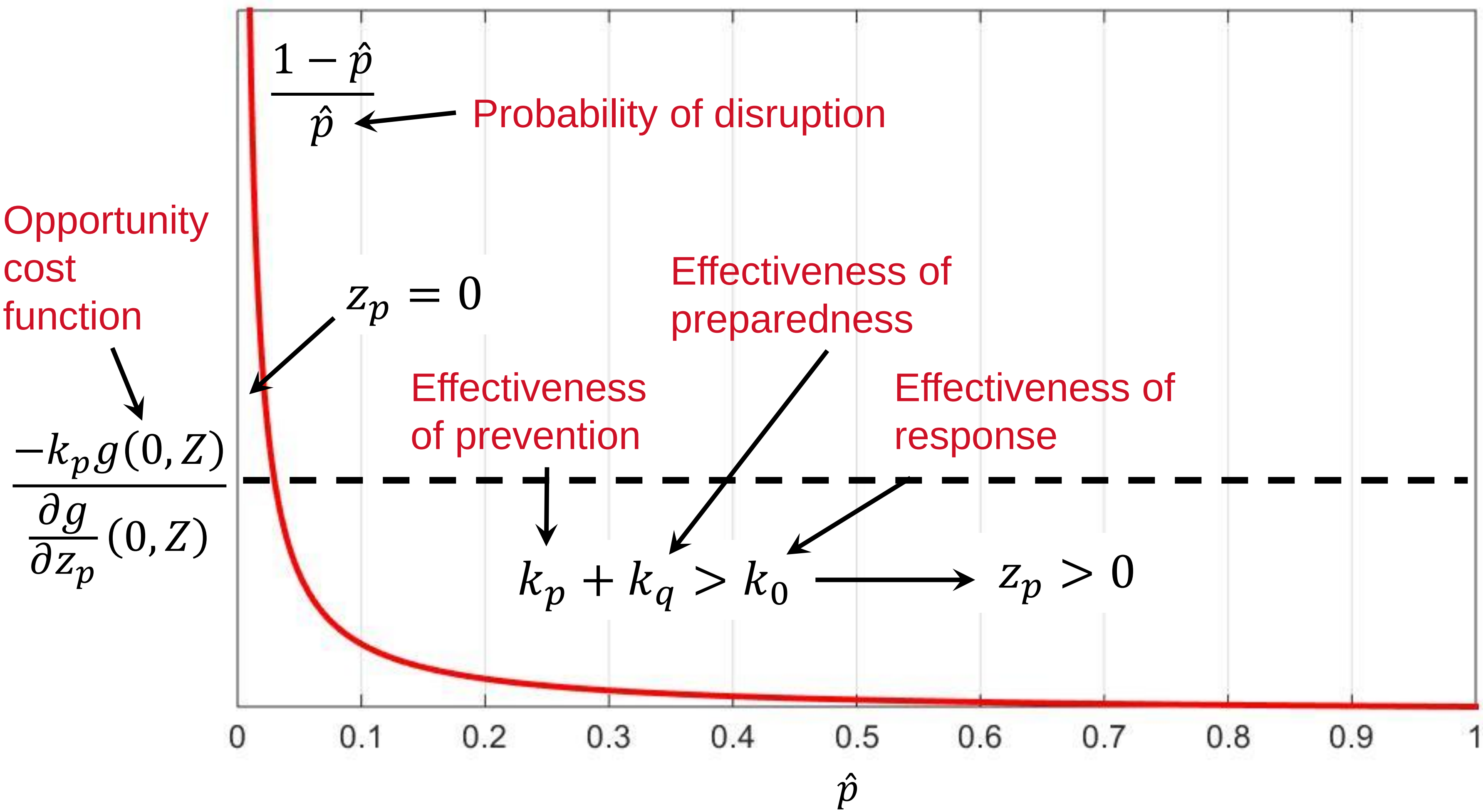
- If $\overbrace{\mathbf{x}^\intercal \mathbf{d}_{*i} \hat{c}_i k_i} \leq \mathbf{x}^\intercal \mathbf{d}_{*j} \hat{c}_j k_j$ and $z_i > 0$, then $z_j > 0$

Effectiveness to all industries

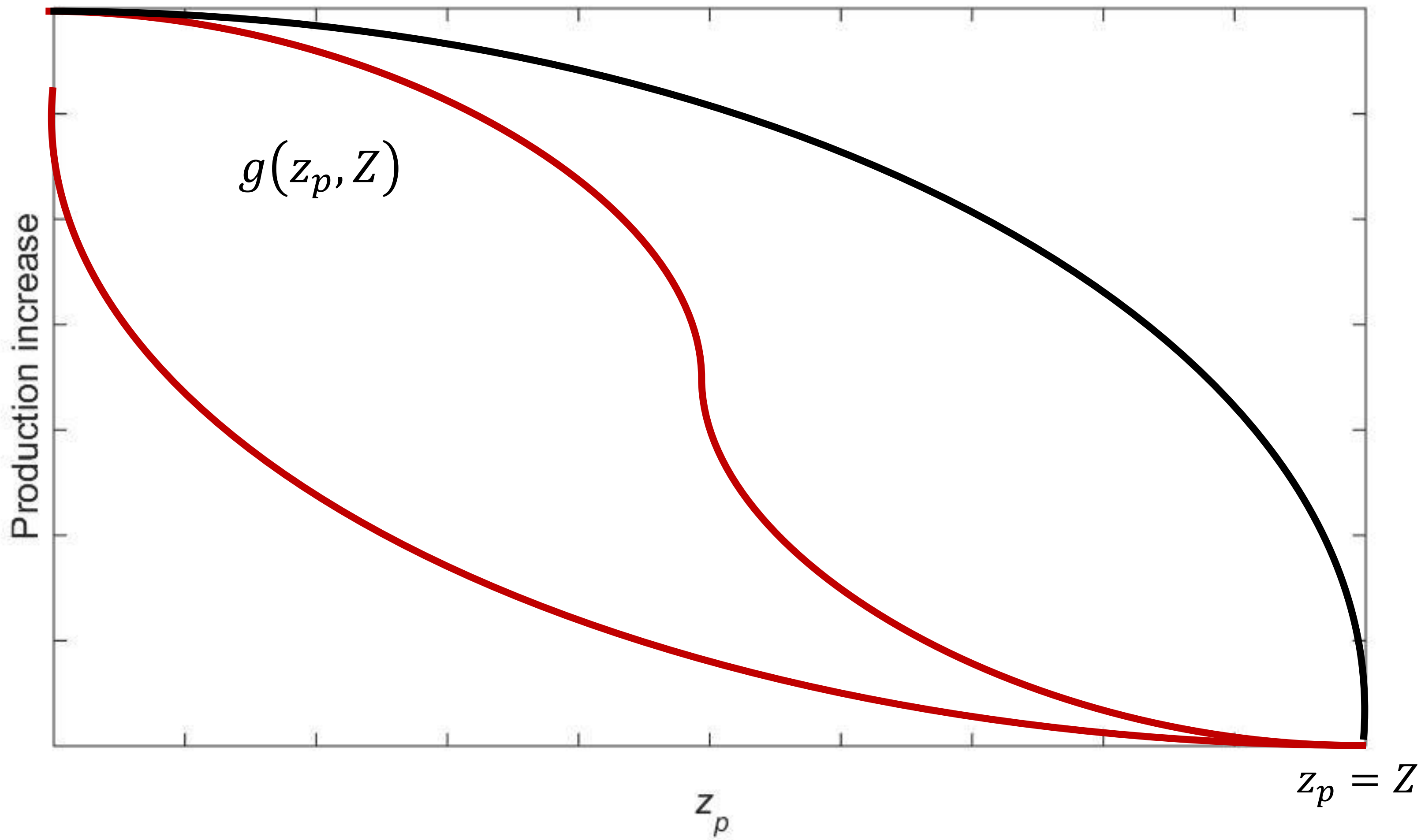
- If $k_0 > \left(\sum_{z_i > 0} {}^{1}/_{k_i}\right)^{-1}$ then some $z_i > 0$ is not optimal
- If $z_0 > 0$ then

$$z_i = \frac{1}{k_i} \log \left(\frac{\mathbf{x}^\intercal \mathbf{d}_{*i} \hat{c}_i k_i \left(1 - k_0 \sum_{z_j > 0} {}^{1}/_{k_j}\right)}{k_0 \sum_{z_j = 0} \mathbf{x}^\intercal \mathbf{d}_{*j} \hat{c}_j} \right)$$

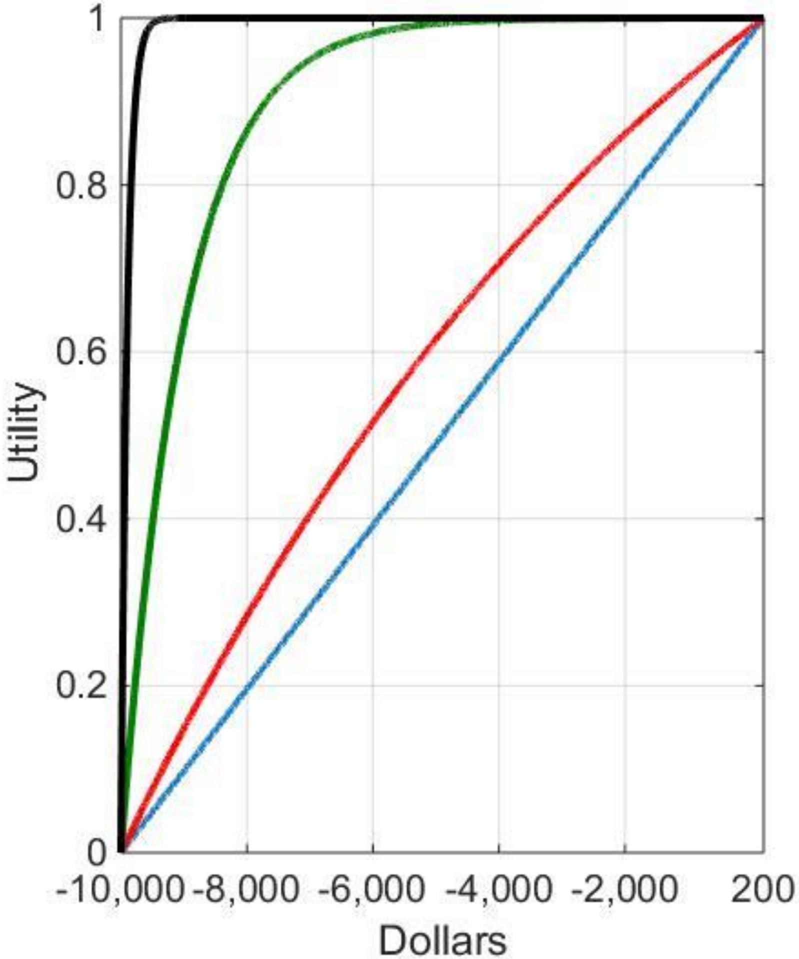
Optimal pre-disruption allocation

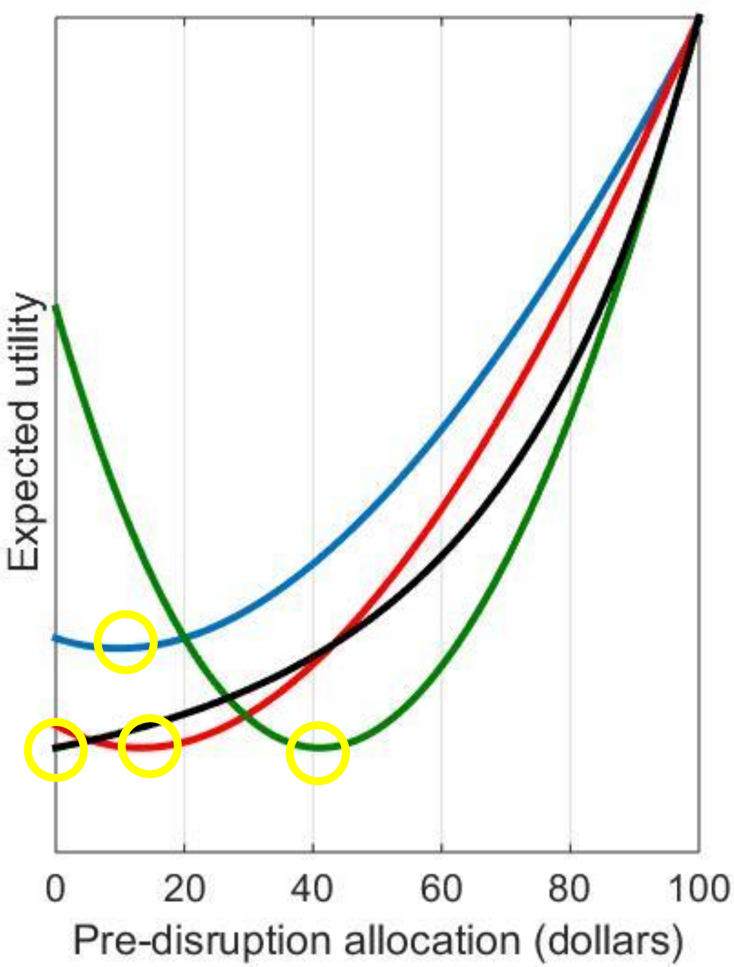


Optimal pre-disruption allocation



Risk aversion





Example: multiple disruptions

- Gulf states: Texas, Louisiana, Mississippi, Alabama, Florida
- 2 disruptions: oil spill (*Deepwater Horizon*) and hurricane (Katrina)
  - Probability of each disruption
- Economic losses
  - Demand losses
  - Production shut-down
- Hypothetical decision maker

MacKenzie, C.A., A. Al-Kazimi (2017). Optimal resource allocation model to prevent, prepare, and respond to multiple disruptions, with application to *Deepwater Horizon* oil spill and Hurricane Katrina. Under review.

Input parameters

	Oil spill	Hurricane
Probability	$\hat{p} = 0.045$	$\hat{p} = 0.56$
Prevention	$k_p = 2.8 \times 10^{-4}$	$k_p = 0$
Preparedness	$k_q = 1.6 \times 10^{-4}$	
All industries	$k_0 = 1.1 \times 10^{-5}$	
Directly impacted industries	$m = 5$	$m = 31$
	Fishing, Real estate, Amusements, Accommodations, Oil and gas	Service industries, Farms, Fishing, Construction, Manufacturing industries, Utilities, Ports, Oil and gas,

$$g(z_p, Z) = 1.6(Z - z_p)$$

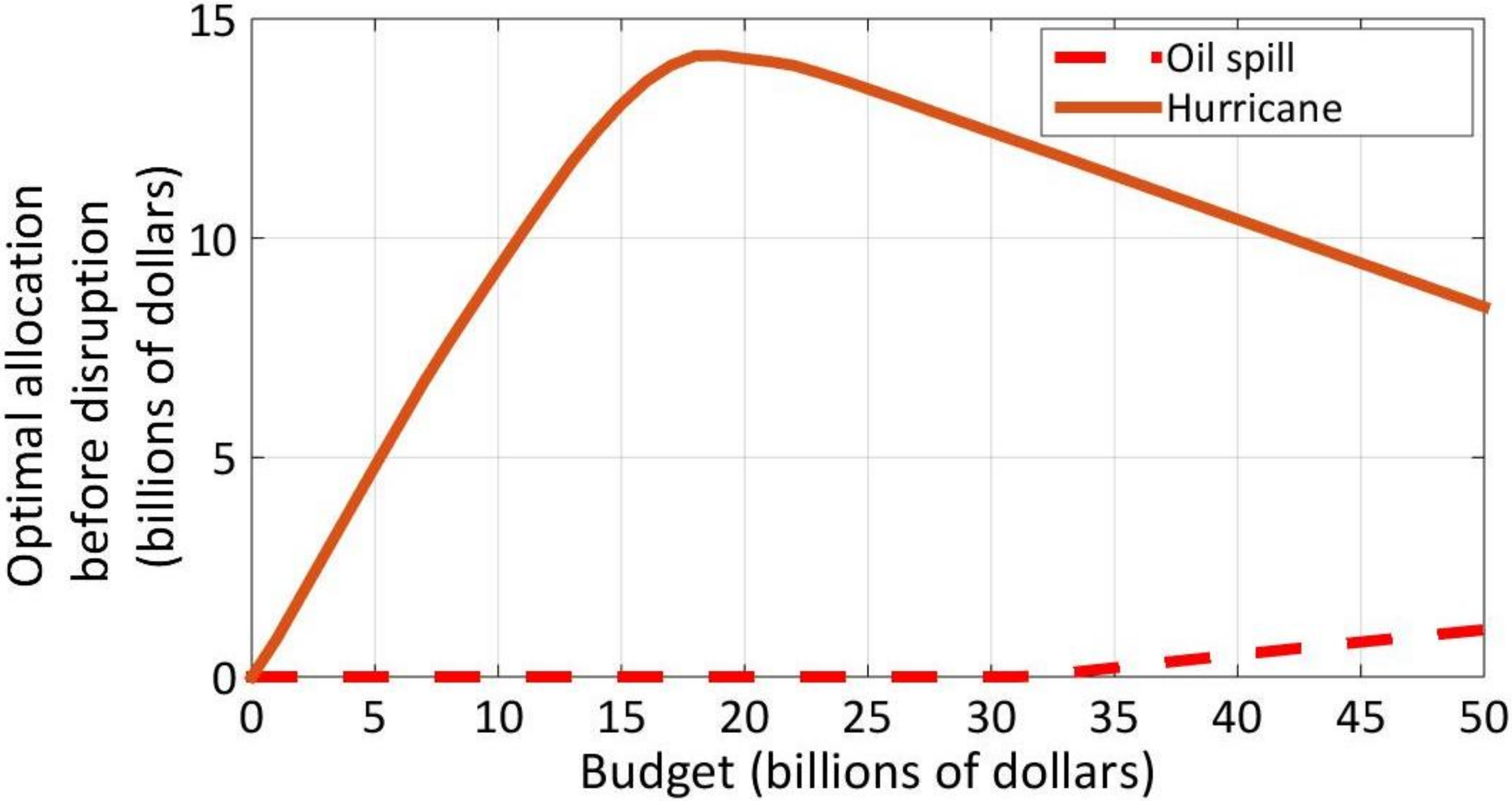
Parameter estimation for fishing

$62 million lost sales from Gulf Coast fishing
→ 0.84% of region's fishing and forestry production

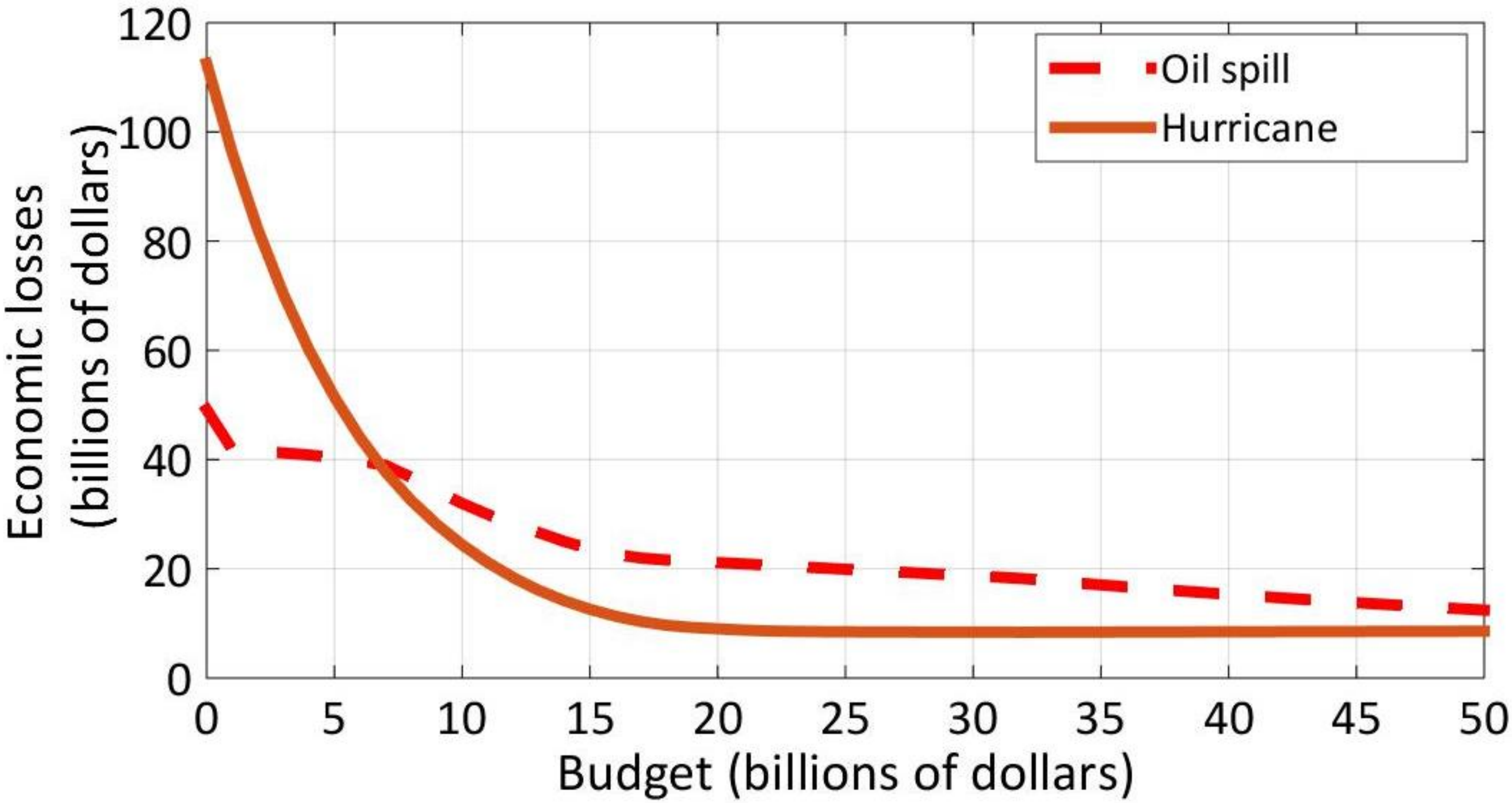
Studies on food safety and impact of positive media stories
→ $792,000 to reduce losses by $40 million

MacKenzie, C.A., H. Baroud, and K. Barker (2016). Static and dynamic resource allocation models for recovery of interdependent systems: Application to the *Deepwater Horizon* oil spill. *Annals of Operations Research*, 236, 103-129.

Optimal pre-disruption allocation

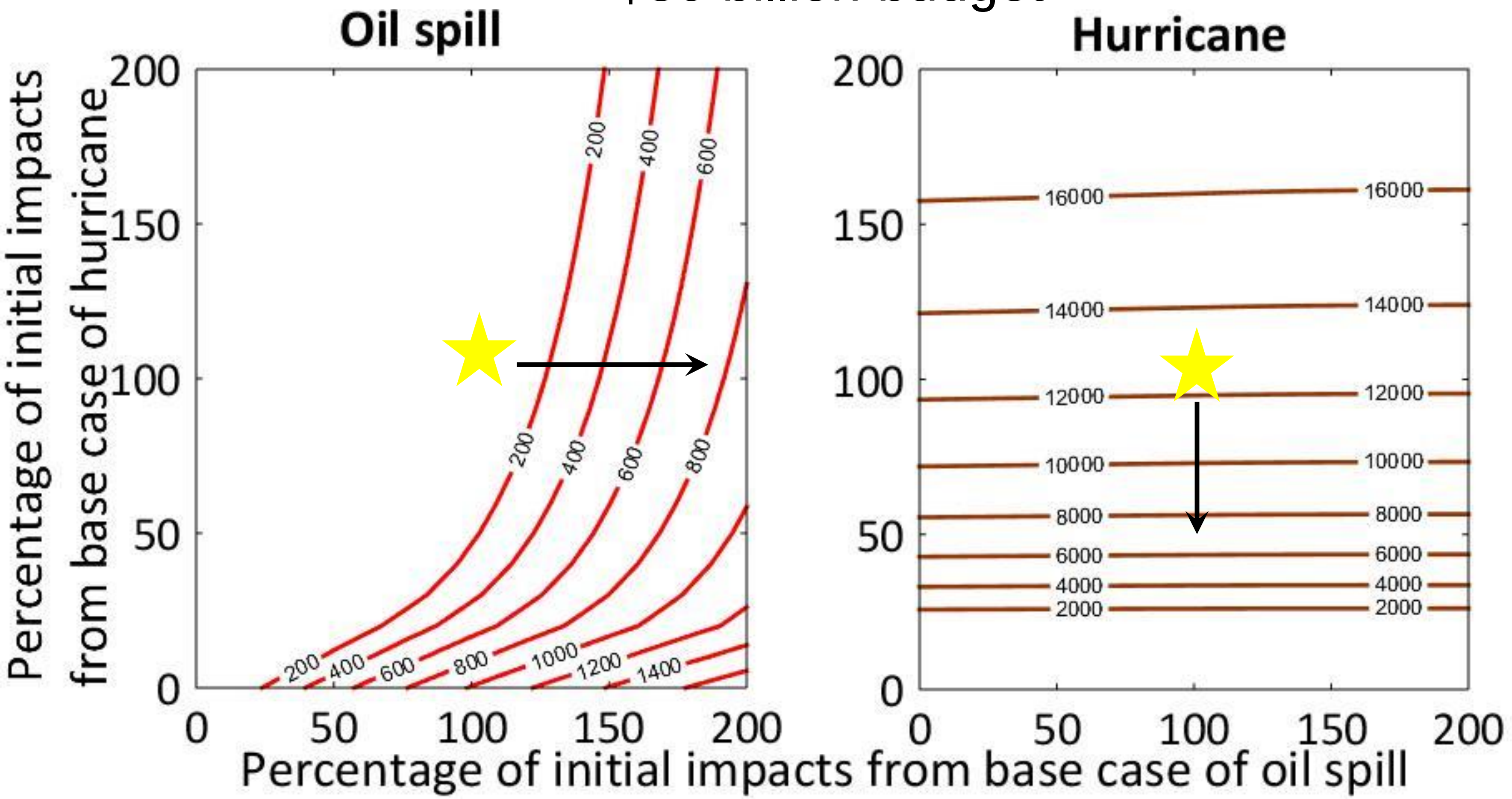


Economic losses



Sensitivity analysis (pre-disruption allocation as initial impacts vary)

$30 billion budget



Conclusions

- Model benefits
  - Consider one disruption versus another disruption
  - Pre versus post-disruption allocation
  - Consider spending on disruptions versus other priorities
- Decision maker should allocate more for hurricane than oil spill → more probable and more consequential
- Lei Yao: allocating resources under deep uncertainty

Final thoughts

- Models for disruptions provide insight into the consequences of disruptions
- Models provide insight into how to make decisions
- Getting data is difficult

If you are a new graduate student

- Find problems that interest you
- Don’t worry if data is not available: think about how you might want to solve the problem first

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