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# Optimal Resource Allocation for Preparedness and Recovery of Interdependent Systems


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# Prevention, preparedness, response

# 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 among different industries to help those industries recover?

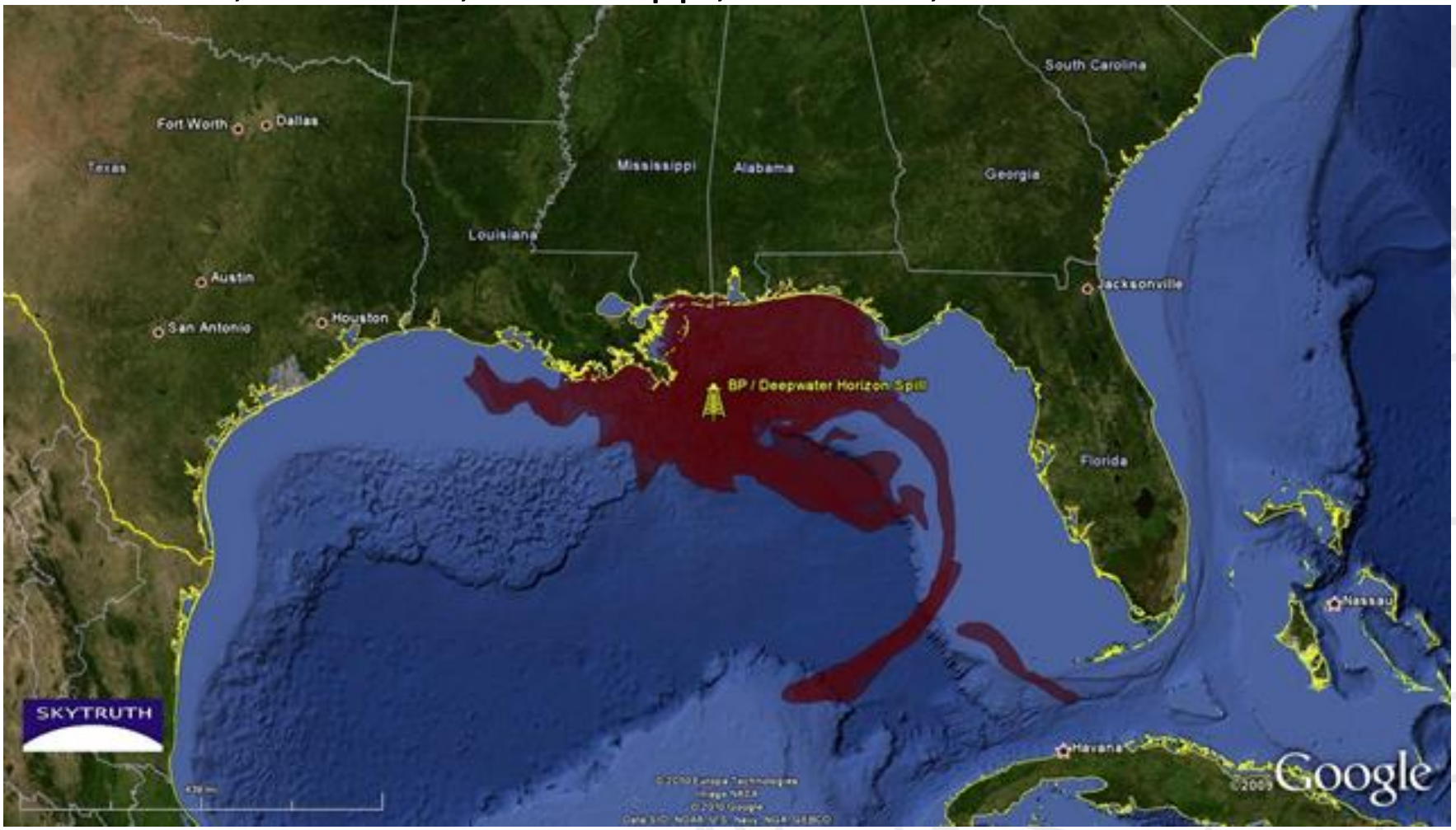
# *Deepwater Horizon* oil spill

# Key assumptions

- Objective function minimizes expected economic impact of a disruption
- Preparedness resources reduce chances of disruption
- Response resources reduce economic impact of disruption
  - Allocation to individual industries
  - Allocation to all industries

# Impacted area

Texas, Louisiana, Mississippi, Alabama, and Florida



# Directly impacted industries

Fishing

Real estate

Amusements

Accommodations

Oil and gas

# Resource allocation model

Normal production

Interdependent matrix

Increased production if no disruption

$$\min\ p\mathbf{x}^{\mathsf{T}}\mathbf{D}\mathbf{c} - (1-p)g(Z - z_p)$$

Probability of disruption

Vector of direct impacts (proportional)

Effectiveness of preparedness allocation

Probability with no resources

Allocation to prepare

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

Allocation to benefit all industries

Direct impacts with no resources

Allocation to industry

$$c_i = \hat{c}_i \exp(-k_i z_i - k_{General} z_{General})$$

Effectiveness of recovery allocation

*i* = {*Fish, Real Estate, Amusements, Accommodations, Oil*}

$$z_p + z_{Fish} + z_{RealEstate} + z_{Amuse} + z_{Accom} + z_{oil} + z_{General} \leq Z$$

$$z_p \geq 0,\ z_i \geq 0,\ z_{General} \geq 0$$

Overall budget

# Input parameters for oil spill

| | | |
|---|---|---|
| Preparedness | $k_p = 0.0031$ | $\hat{p} = 0.045$ |
| All industries | $k_{General} = 8.6*10^{-5}$ | |

| Industry | $k_i$ (per $1 mil) | $\hat{c}_i$ |
|---|---|---|
| Fishing | 0.074 | 0.0084 |
| Real estate | 0 | 0.047 |
| Amusements | 0.0038 | 0.21 |
| Accommodations | 0.0027 | 0.16 |
| Oil and gas | 0.0057 | 0.079 |

# Parameter estimation for fishing

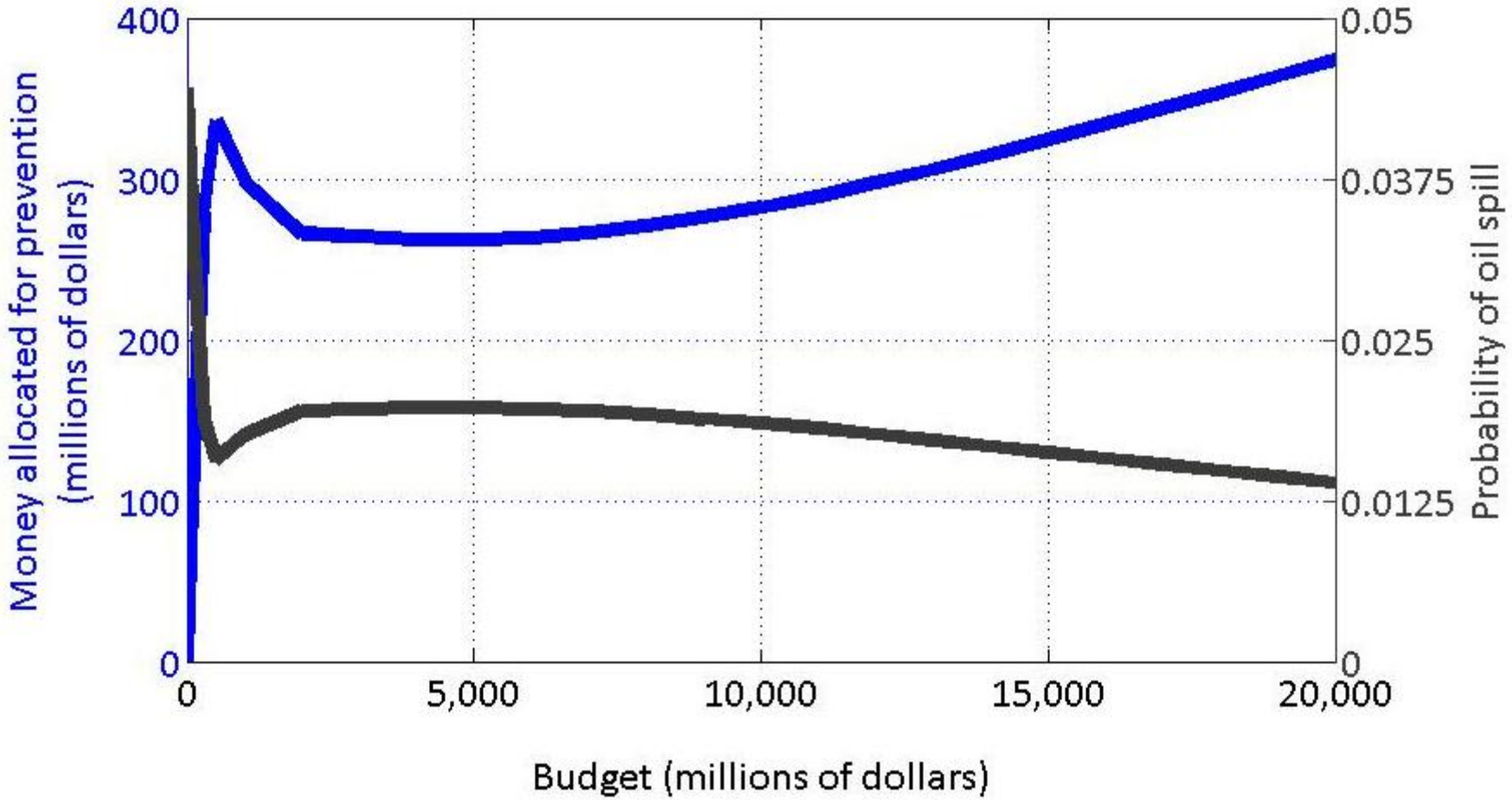
BEA
BUREAU OF ECONOMIC ANALYSIS
U.S. DEPARTMENT OF COMMERCE

NRDC
THE EARTH'S BEST DEFENSE

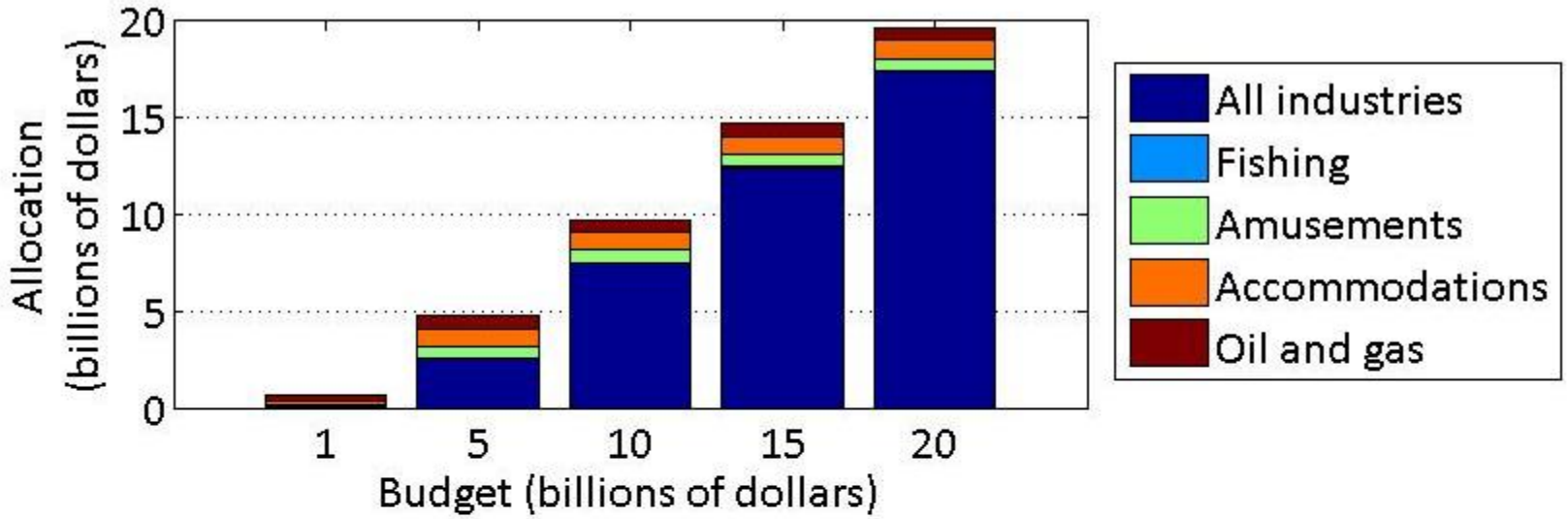
$62 million lost sales from Gulf Coast fishing
→ 0.84% of region's fishing and forestry production

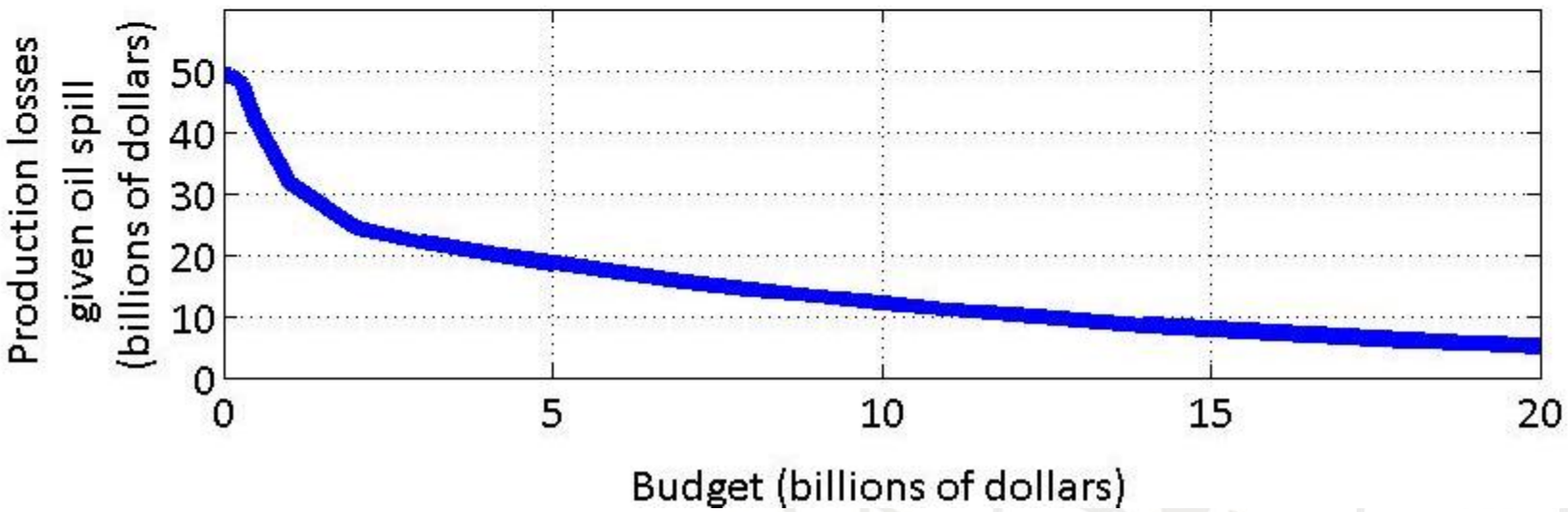
Studies on food safety and impact of positive media stories
→ $792,000 to reduce losses by $40 million

# Allocation for prevention



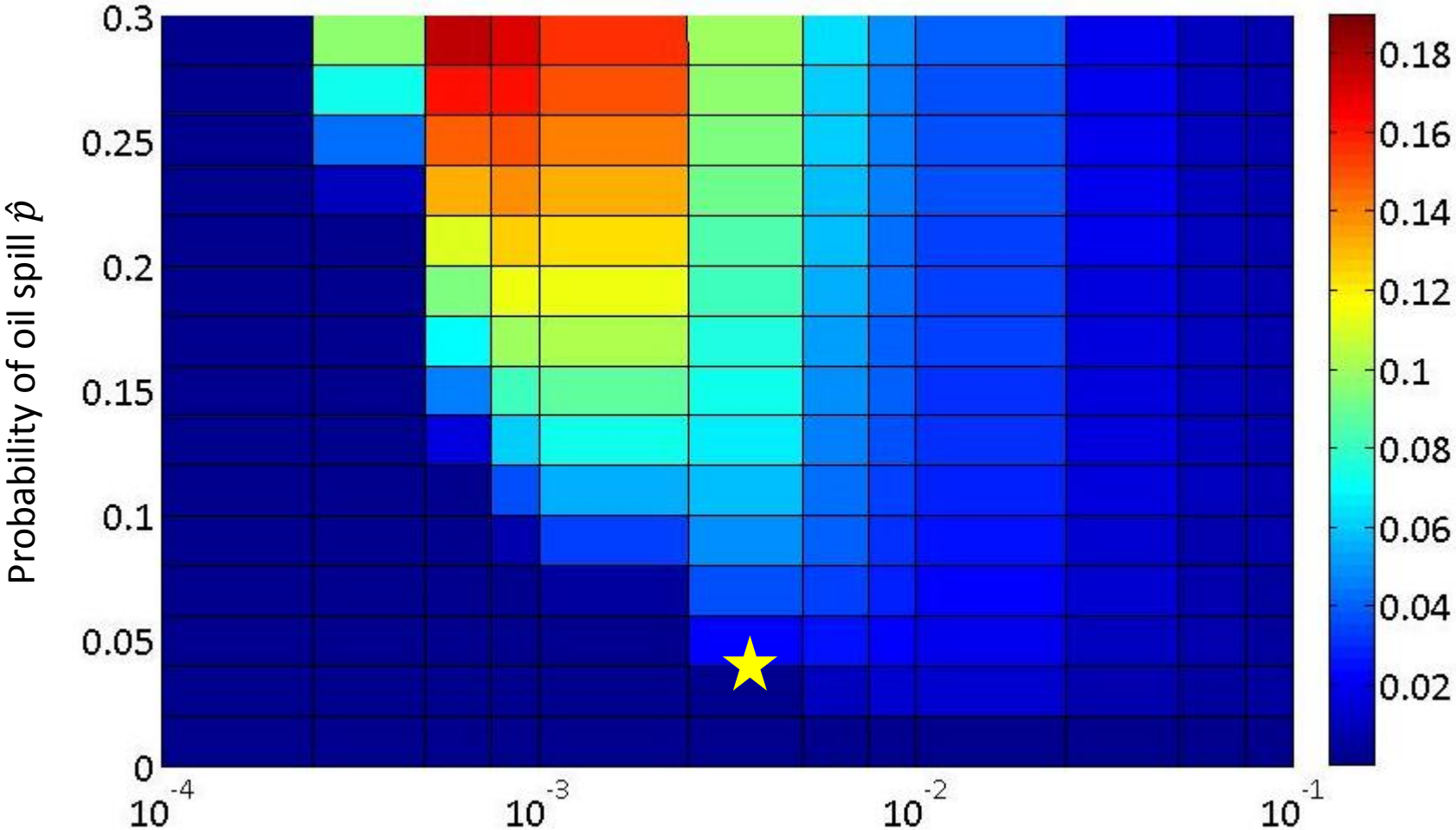
# Allocation for response



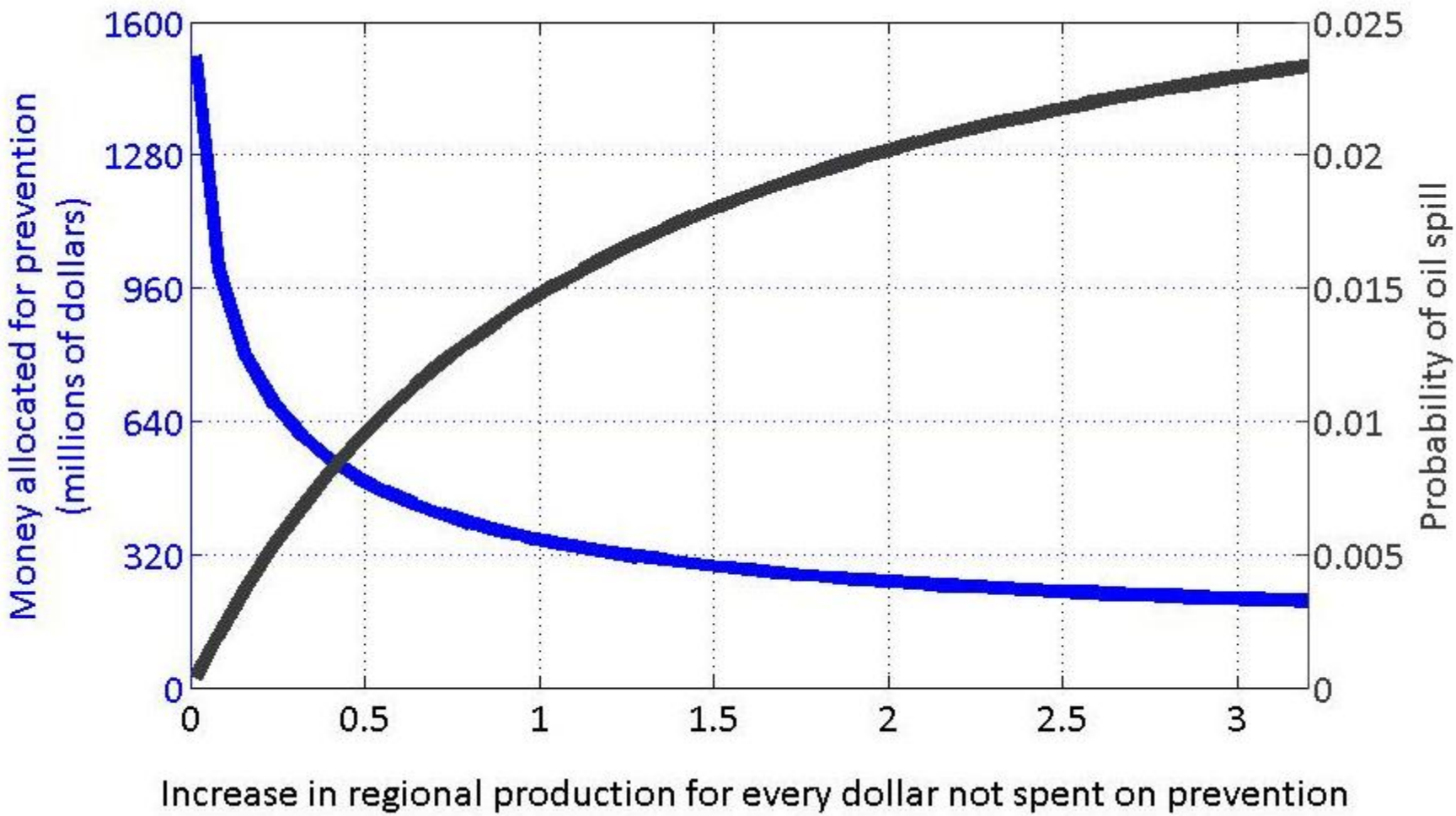
# Sensitivity analysis for prevention

Proportion of $10B budget allocated for preparedness

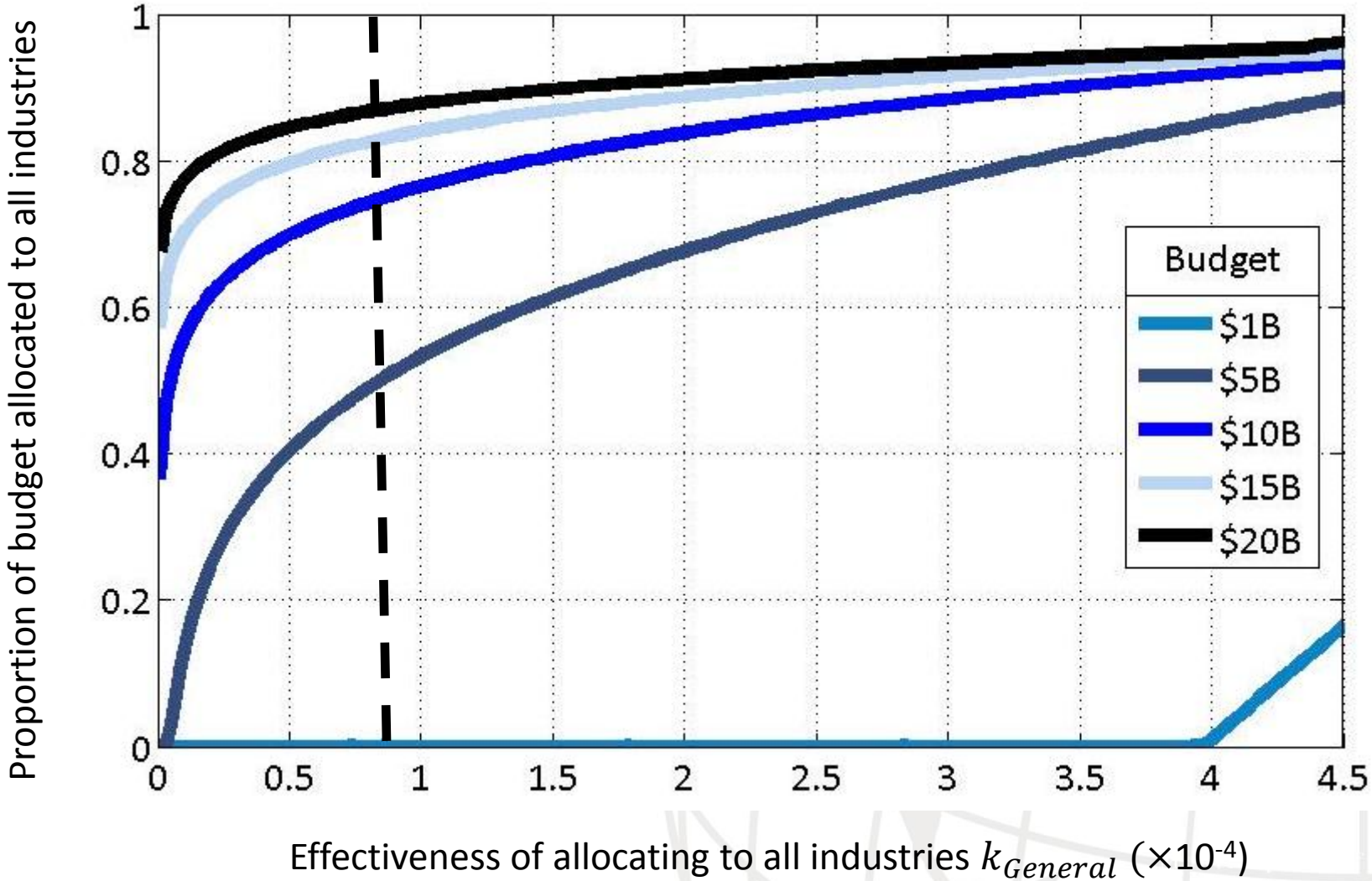



Effectiveness of allocating for preparedness $k_p$

# Sensitivity analysis for $g(Z - z_p)$



# Sensitivity analysis for response



# Allocation to all industries

$$z_{General} > 0 \text{ if } k_{General} > k^*$$

Overall budget

Allocation to prepare

Column of interdependent matrix

$$\frac{1}{k^*} = \sum_{z_i>0} \frac{1}{k_i} + \left[\frac{\exp(Z - z_p)}{\prod_{z_i>0}(\mathbf{x}^\intercal \mathbf{d}_{*i}\hat{c}_i k_i)^{1/k_i}}\right]^{\left(\sum_{z_i>0} 1/k_i\right)^{-1}} \sum_{z_i=0} \mathbf{x}^\intercal \mathbf{d}_{*i}\hat{c}_i$$

Effectiveness of recovery allocation

Normal production

Direct impacts with no resources

# Preliminary conclusions

- Allocating to prevent a disruption may be small compared to allocation to respond
  - Assumptions that prevention reduces chances of disruption
  - Assumption that money not allocated to prevention can increase regional production if no disruption
- Pre-disruption allocation should increase if
  - Preparedness reduces impacts
  - Decision maker is risk averse

# Preliminary conclusions

- As budget increases, greater incentive for response allocation to be allocate to benefit all industries versus targeting individual industries
- Future research can include multiple scenarios

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