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How much should we spend on preparing for disruptions?

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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 among different industries to help those industries recover?
- How does the optimal allocation change based on risk preferences?

Resource allocation model

Normal production — Interdependent matrix — Increased production if no disruption

$$\min \; p\mathbf{x}^{\mathsf{T}}\mathbf{D}\mathbf{c}$$

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

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

$$z_p \ge 0,\; z_i \ge 0,\; z_{General} \ge 0$$

Overall budget

Optimal recovery allocation

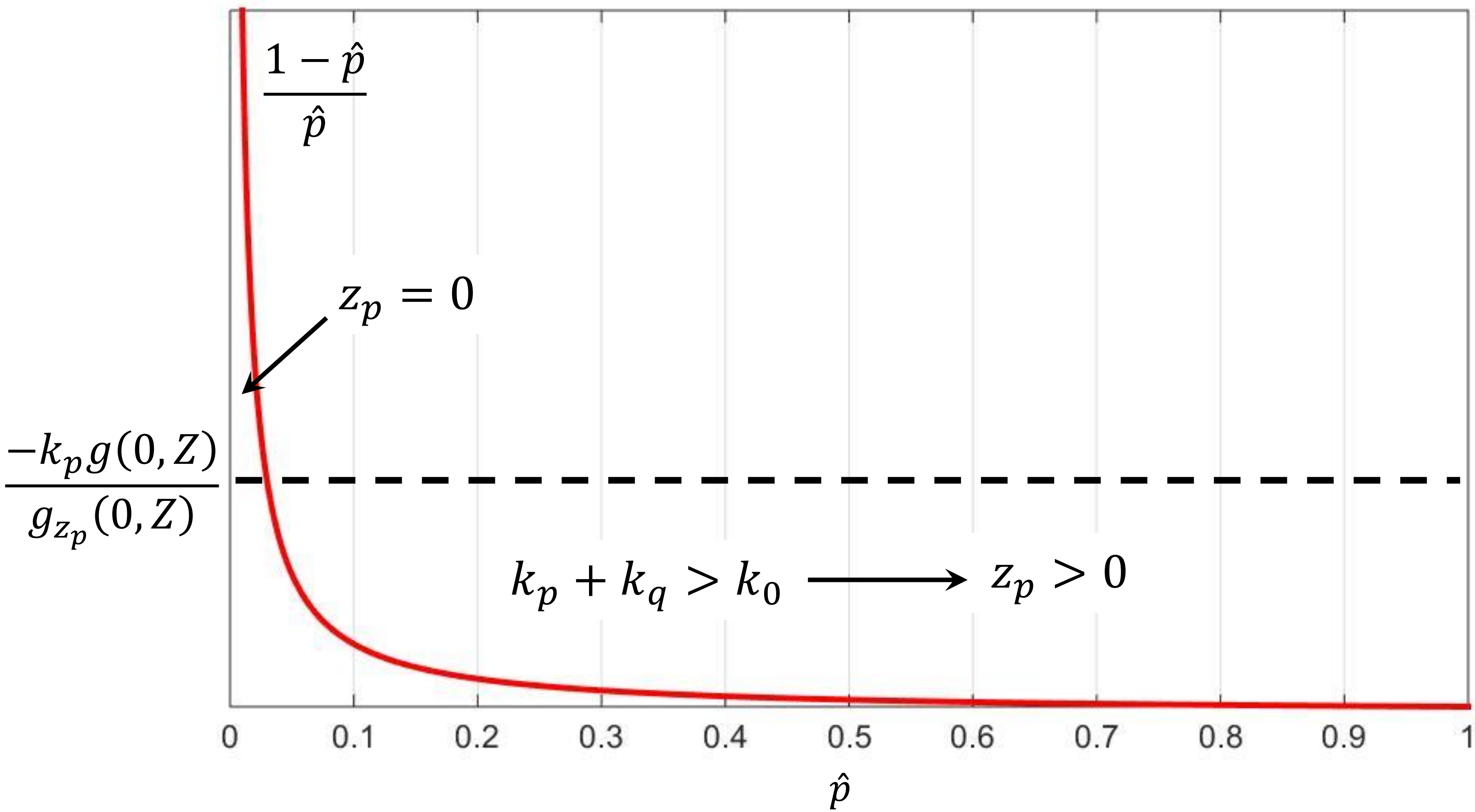
Consequence * Effectiveness

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

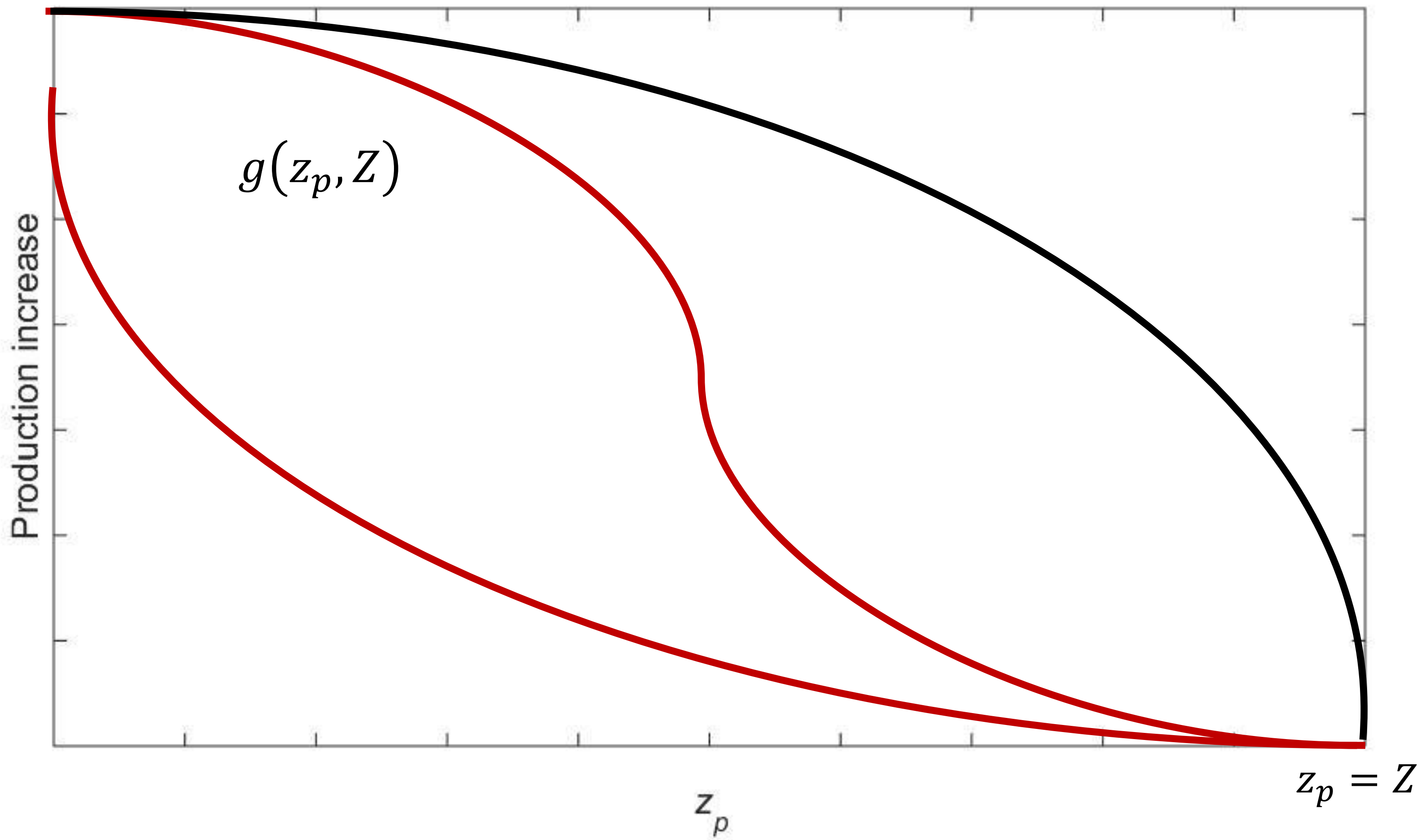
- If ${}^{1}/_{k_0} < \sum_{z_{i>0}} {}^{1}/_{k_i}$ then all $z_i > 0$ is not optimal
- If $z_0 > 0$ then

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

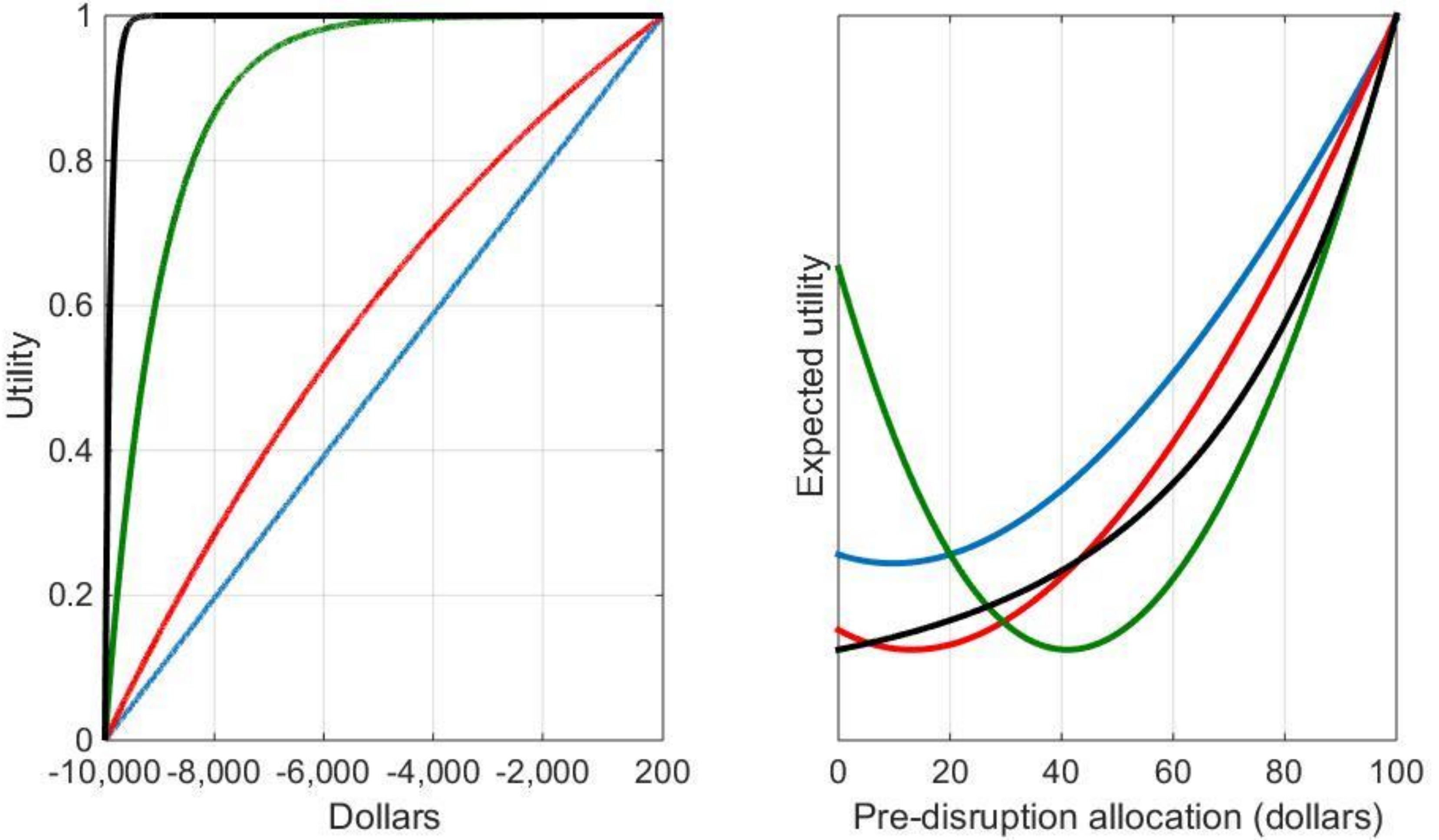
Optimal pre-disruption allocation



Optimal pre-disruption allocation



Risk aversion



Deepwater Horizon oil spill

Input parameters for oil spill

Prevention	$k_p = 2.8 \times 10^{-4}$	$\hat{p} = 0.045$
Preparedness	$k_q = 1.6 \times 10^{-4}$	
All industries	$k_0 = 1.1 \times 10^{-5}$	

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

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

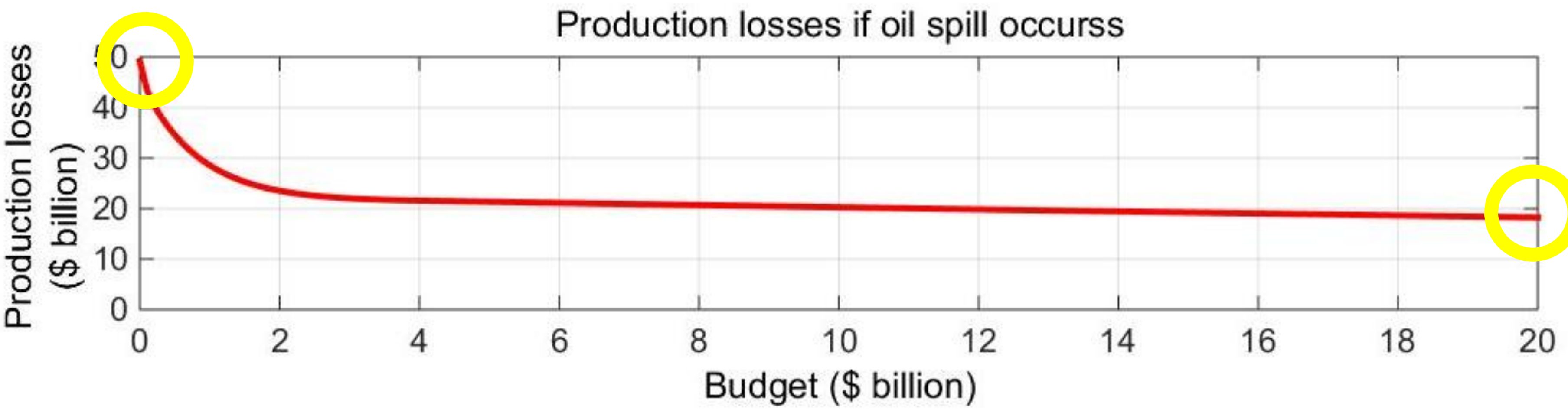
Parameter estimation for fishing

$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 (2014). Static and dynamic resource allocation models for recovery of interdependent systems: Application to the *Deepwater Horizon* oil spill. *Annals of Operations Research*. In press.

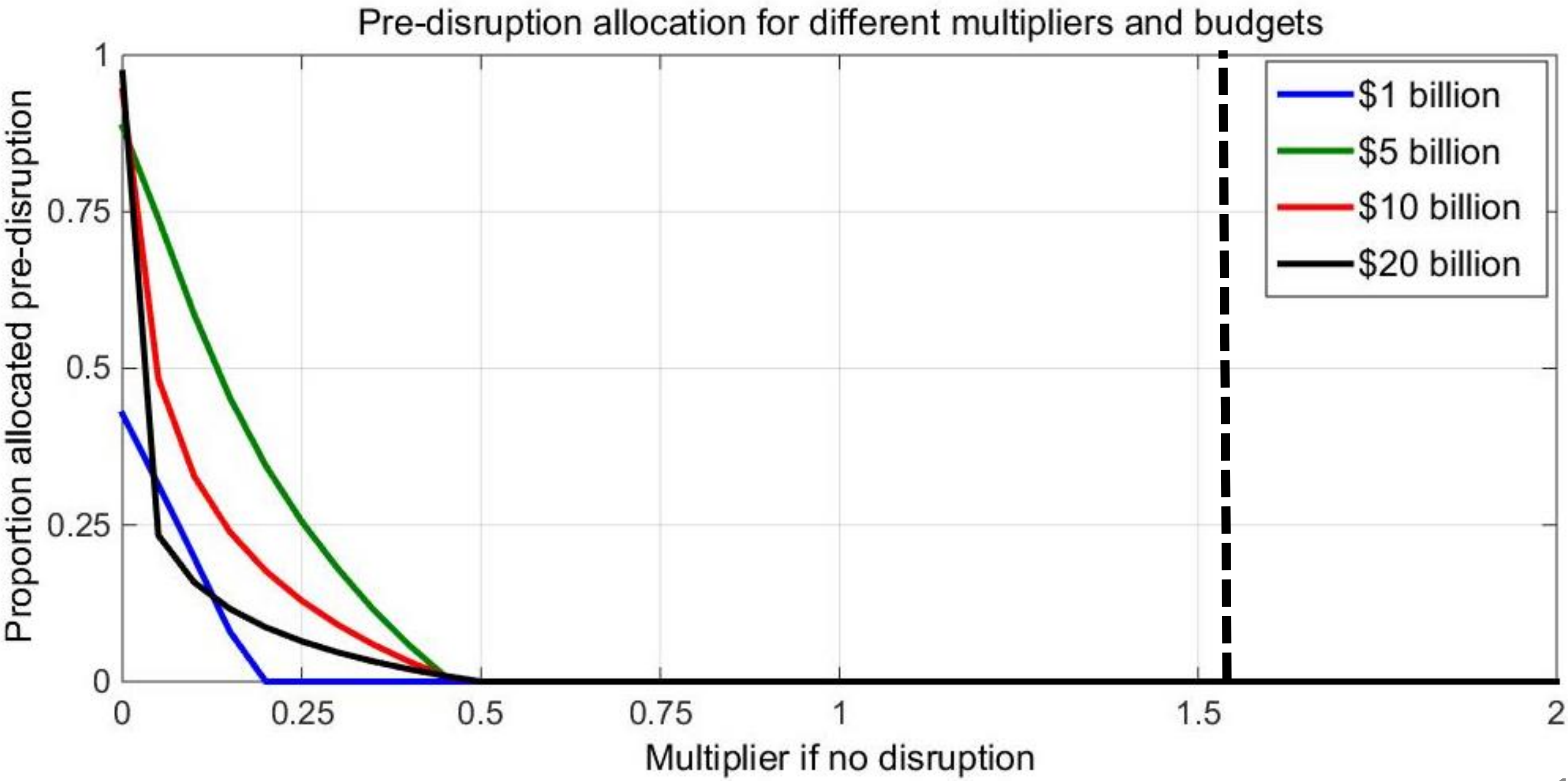
Model results



Industry	Millions of dollars allocated to each industry			
Fishing	0	46	46	46
Real estate	0	0	0	0
Amusements	250	1,209	1,209	1,209
Accommodations	379	1,752	1,752	1,752
Oil and gas	372	1,011	1,011	1,011
All industries	0	981	5,981	15,981
Total budget	**1,000**	**5,000**	**10,000**	**20,000**

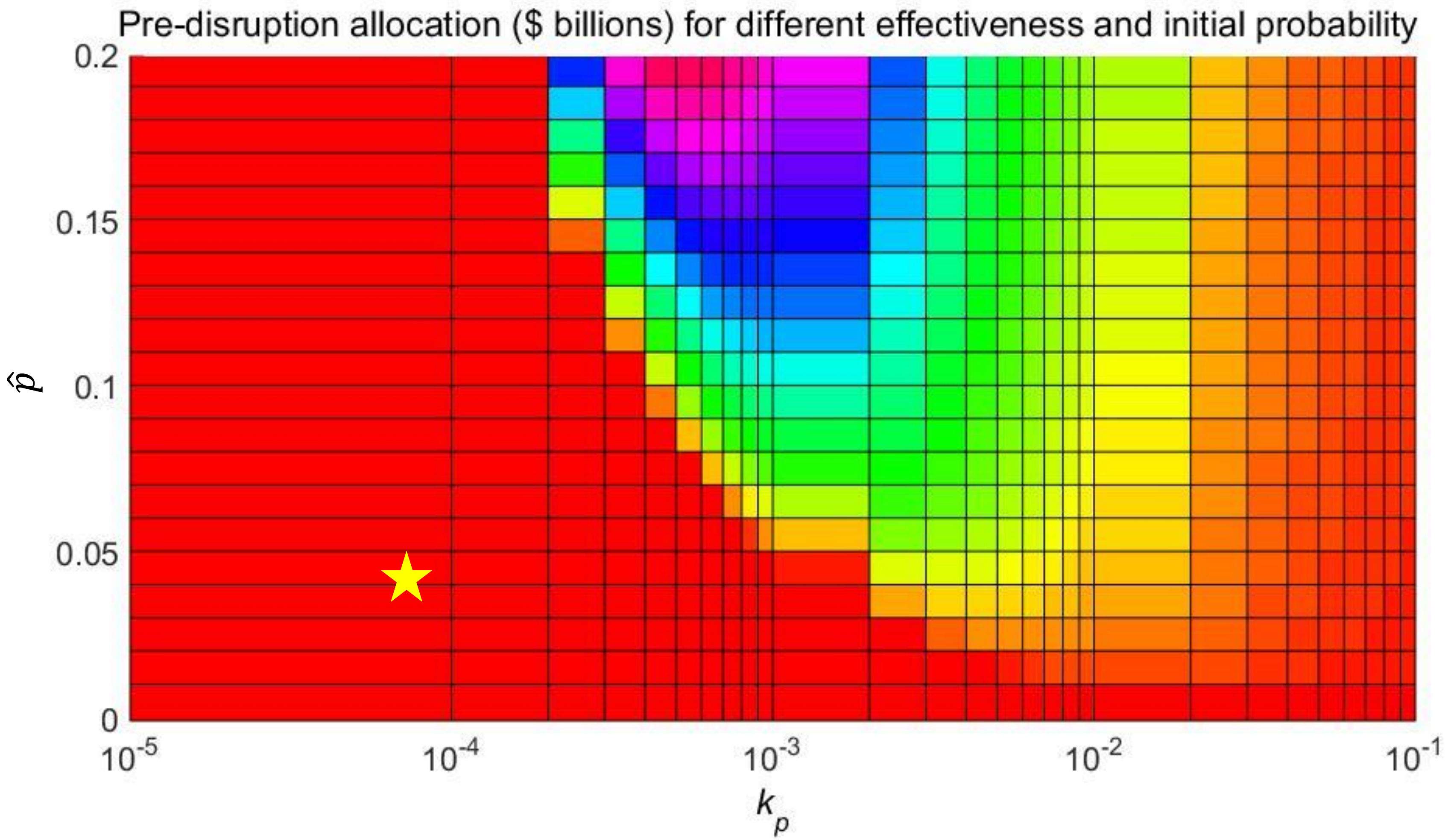
Sensitivity analysis

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

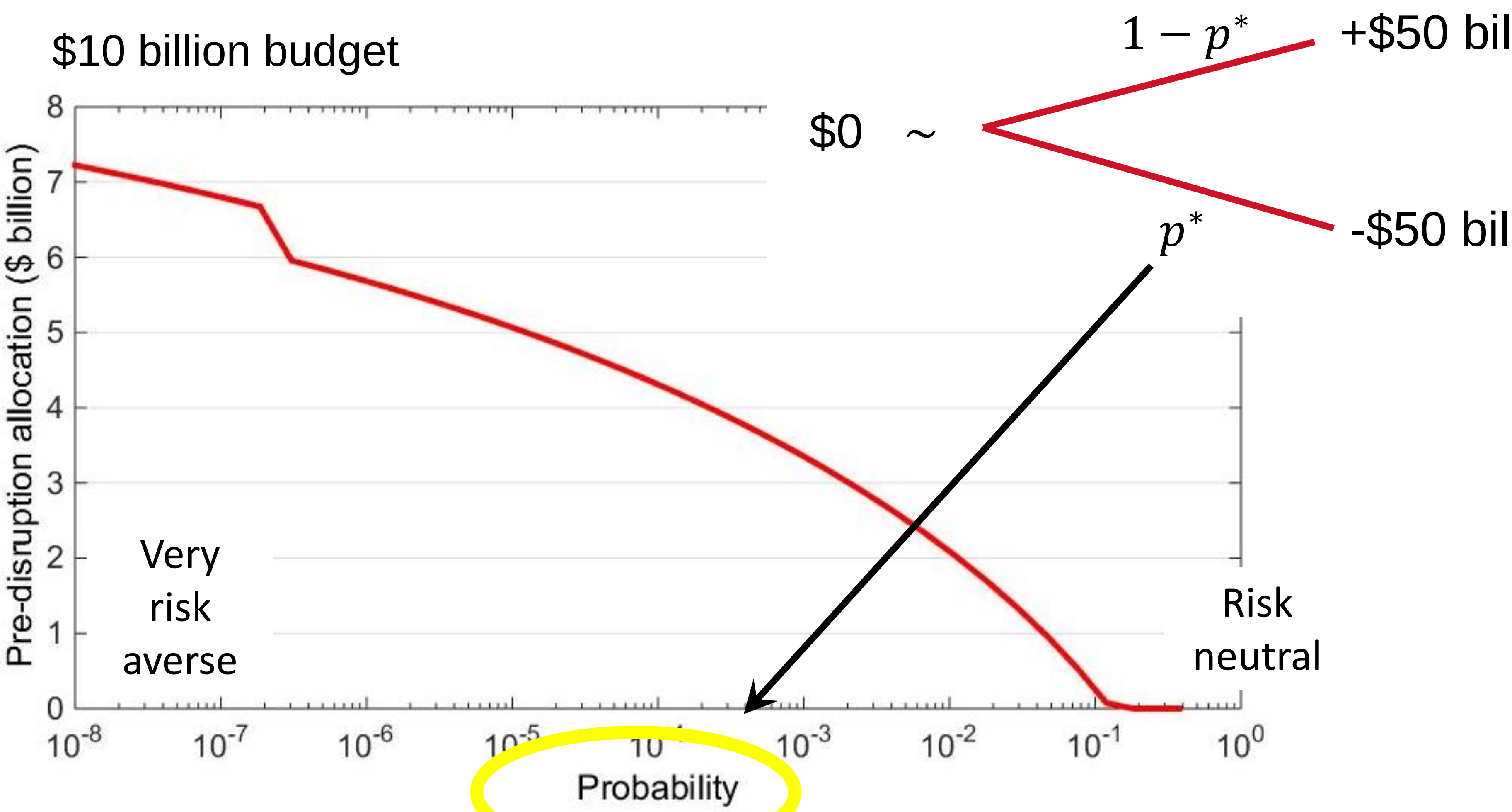


Sensitivity analysis

$10 billion budget



Allocation with risk aversion



Future research

- Multiple disruptions: allocating resources prior to disruption can help prevent and prepare for multiple disruptions
- Application to other disruptions
- Budget constraint or impact constraint?
- Temporal aspects

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