Performance-based engineering for simulation of regional post-earthquake recovery and resilience

Jack W. Baker

Thanks to Greg Deierlein, Anne Hulsey, Maryia Markhvida, Gemma Cremen, Curt Haselton, Stephane Hallegatte, Brian Walsh

STANFORD URBAN RESILIENCE INITIATIVE

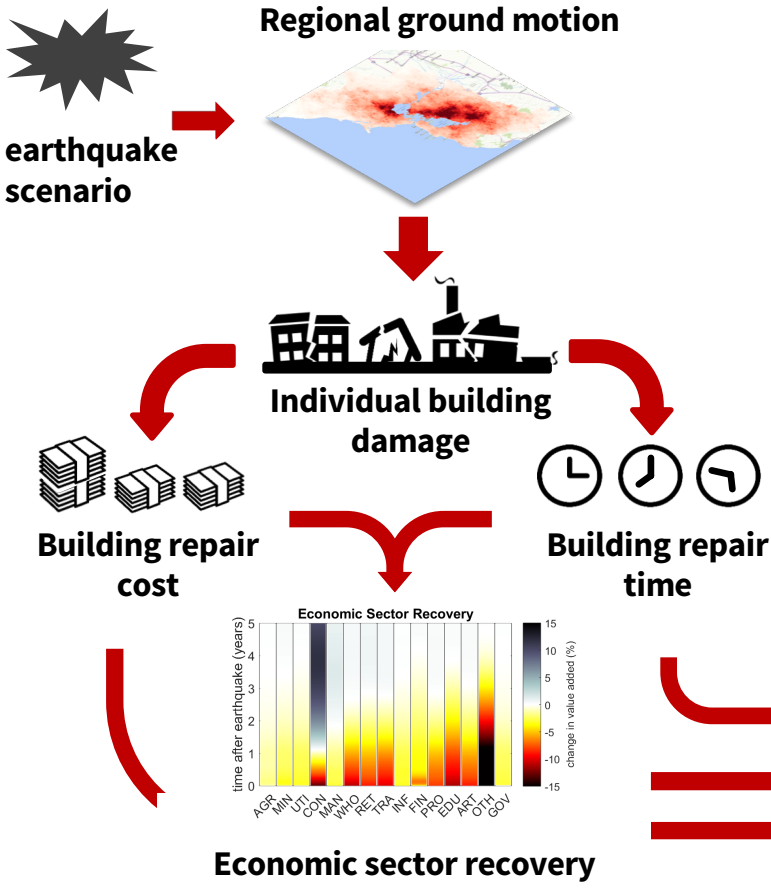
Regional disaster resilience and functional recovery are topics of great public interest

How can we help stakeholders achieve these goals?

1. Performance-based earthquake engineering for individual buildings
   - Predict performance in terms of downtime metrics
   - This is increasingly feasible for thousands of buildings

2. Regional recovery simulation
   - Buildings are not islands
   - Recovery encompasses safety, infrastructure, economics

Regional recovery simulation



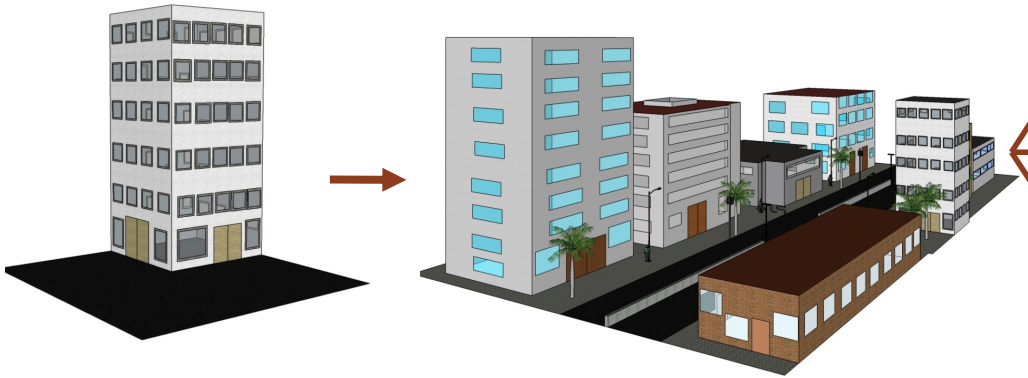
Ground motion simulation

Performance-based engineering assessment

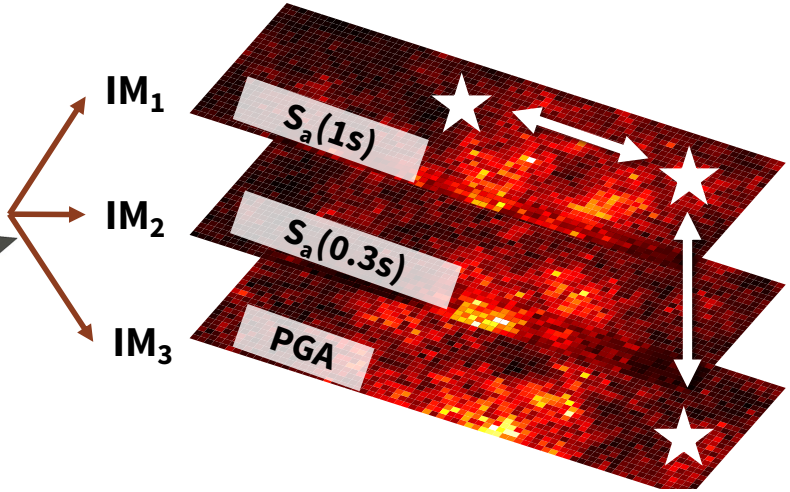
Regional recovery simulation

Step 1: Ground motion simulation

one intensity measure (IM) + one location



multiple IMs + many locations



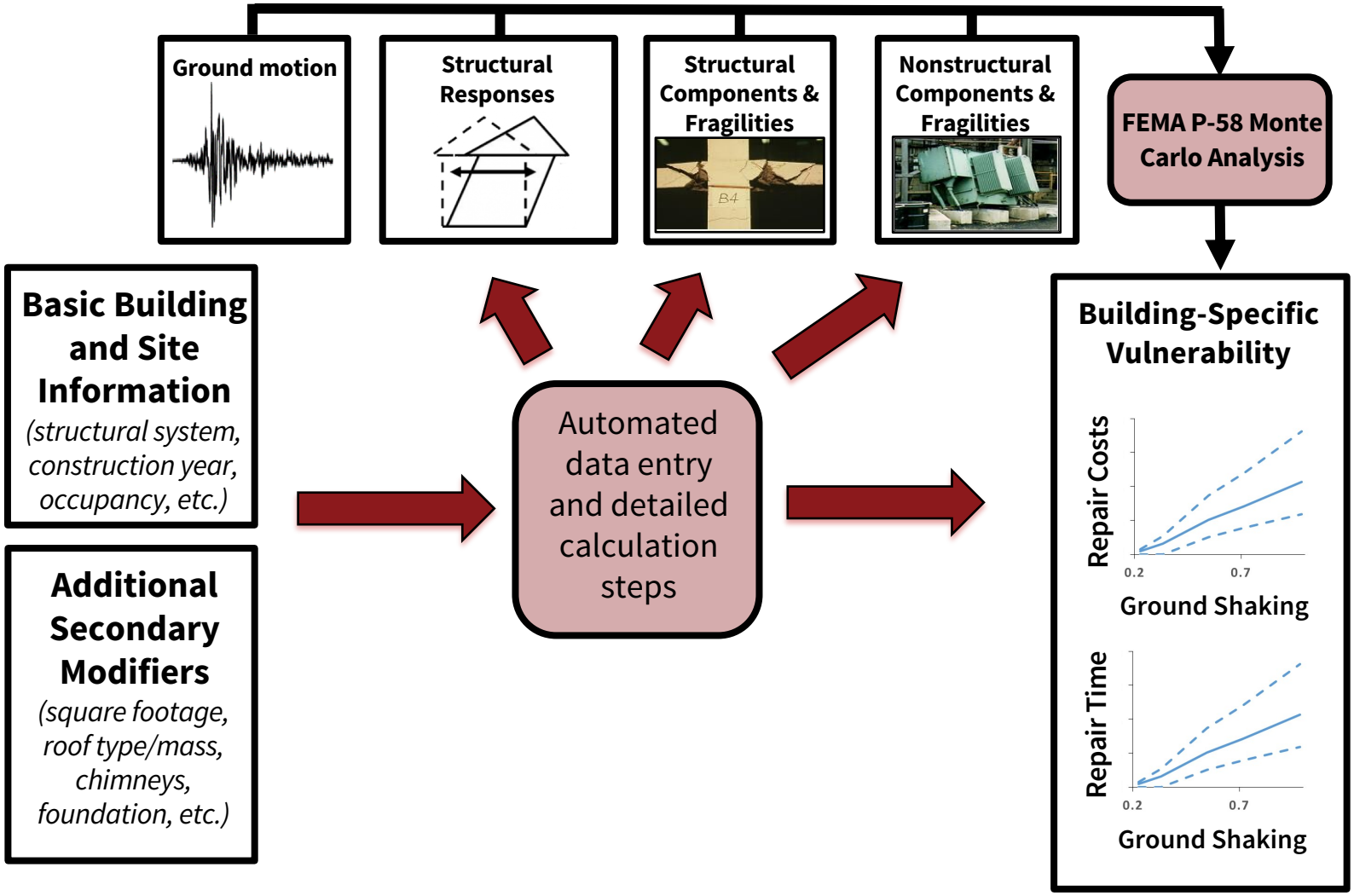
Two types of correlation:

1) Spatial correlation
2) Cross-correlation (between IMs)

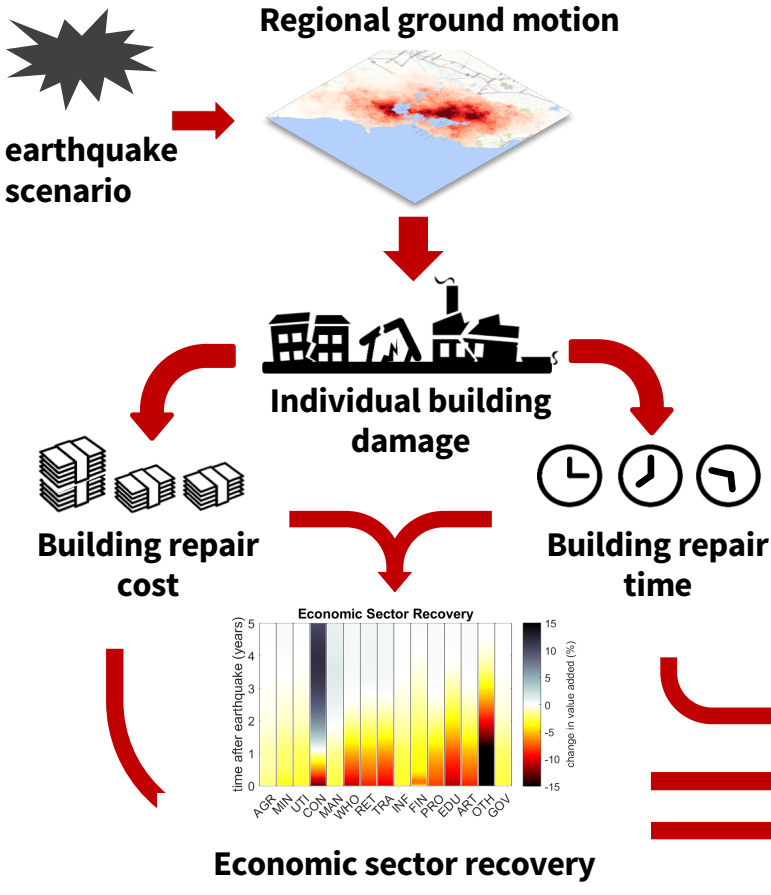
[Images courtesy of Jeltsin Obregon]

Markhvida et al. (2018) *EESD*.

P-58 building analysis for large numbers of buildings



Regional recovery simulation



Ground motion simulation

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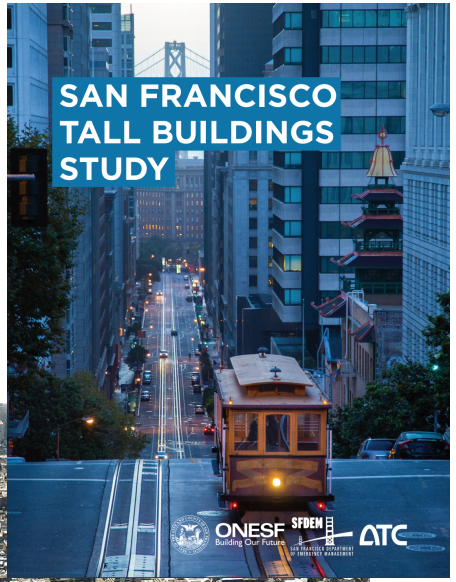
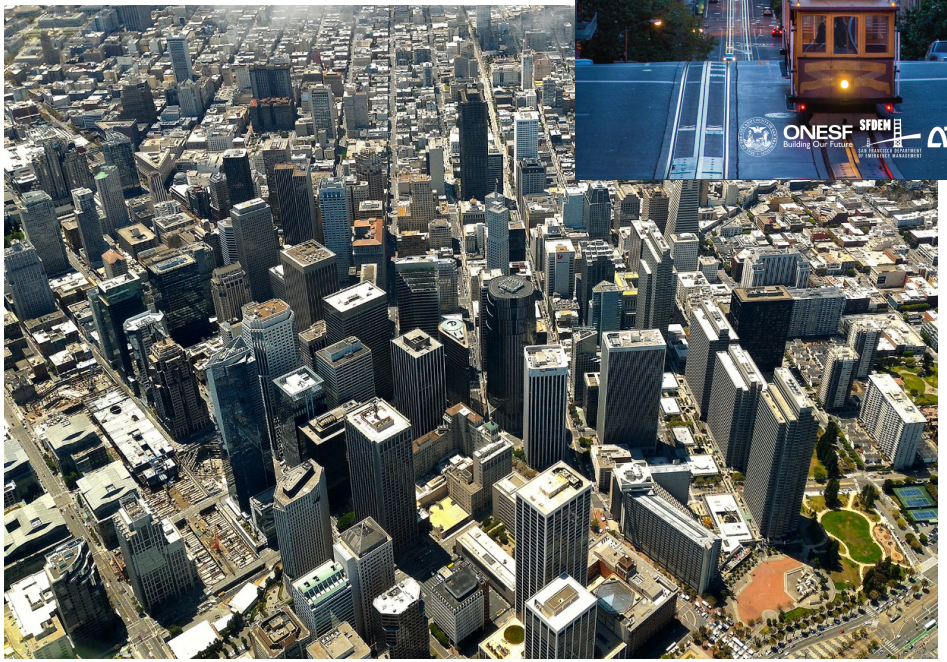
Application #1: Safety Cordons

Clarendon Tower (right of image)
2011, Christchurch, New Zealand

San Francisco





http://wozawanderer.blogspot.com/2011/03/christchurch-quake-zone-1-cordon-best.html
https://commons.wikimedia.org/wiki/File:San_Francisco_downtown_aerial_2015.jpg

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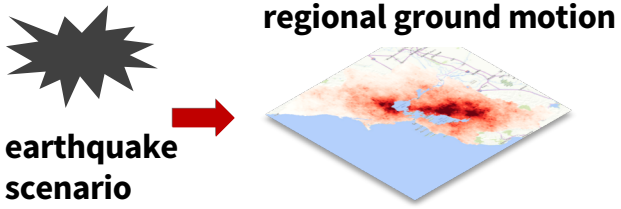
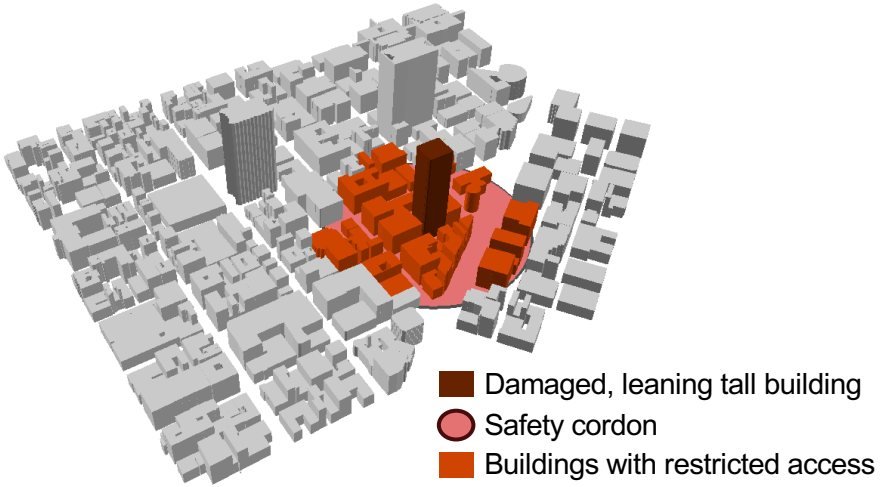
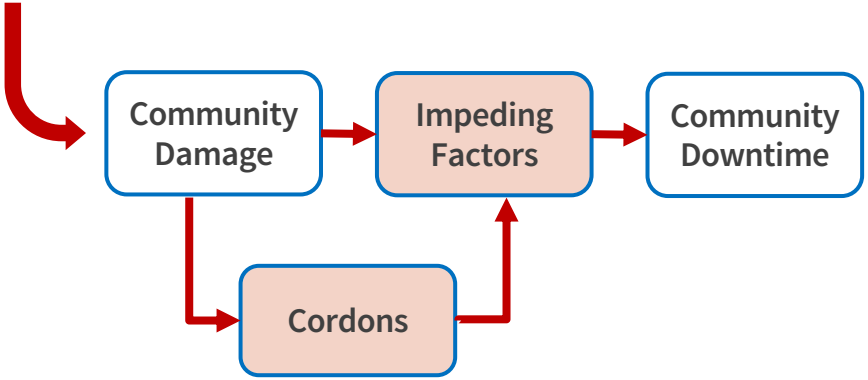
Incorporating Safety Cordon Effects







See Anne Hulsey poster this afternoon for more details

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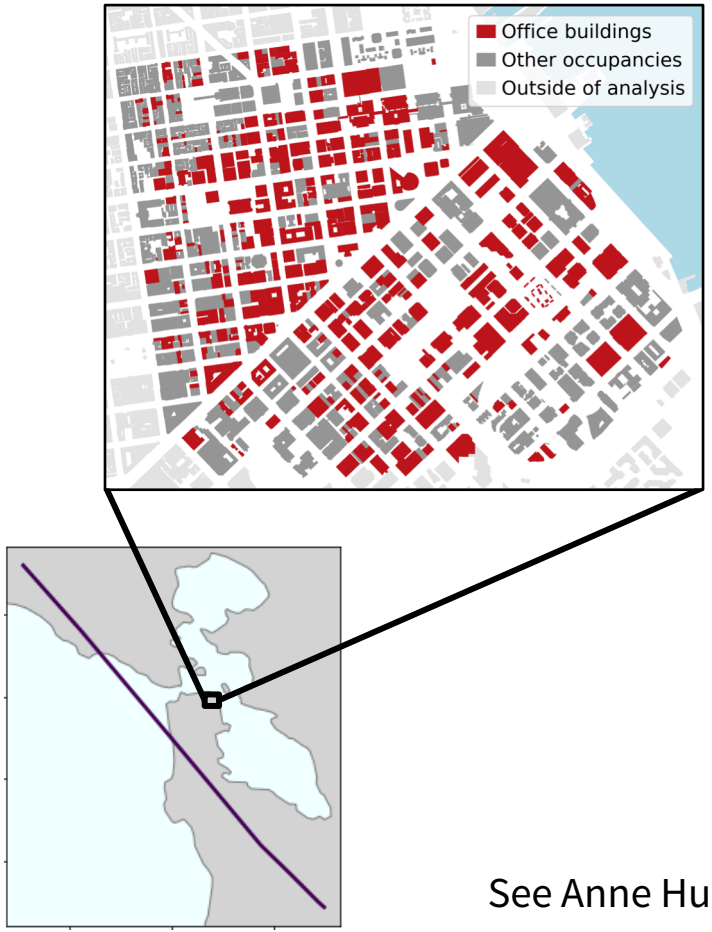
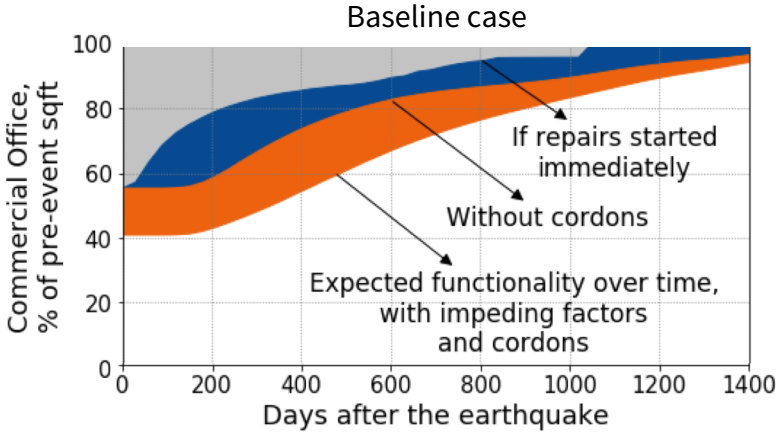
San Francisco Central Business District recovery simulations (M_w 7.2 San Andreas Earthquake)





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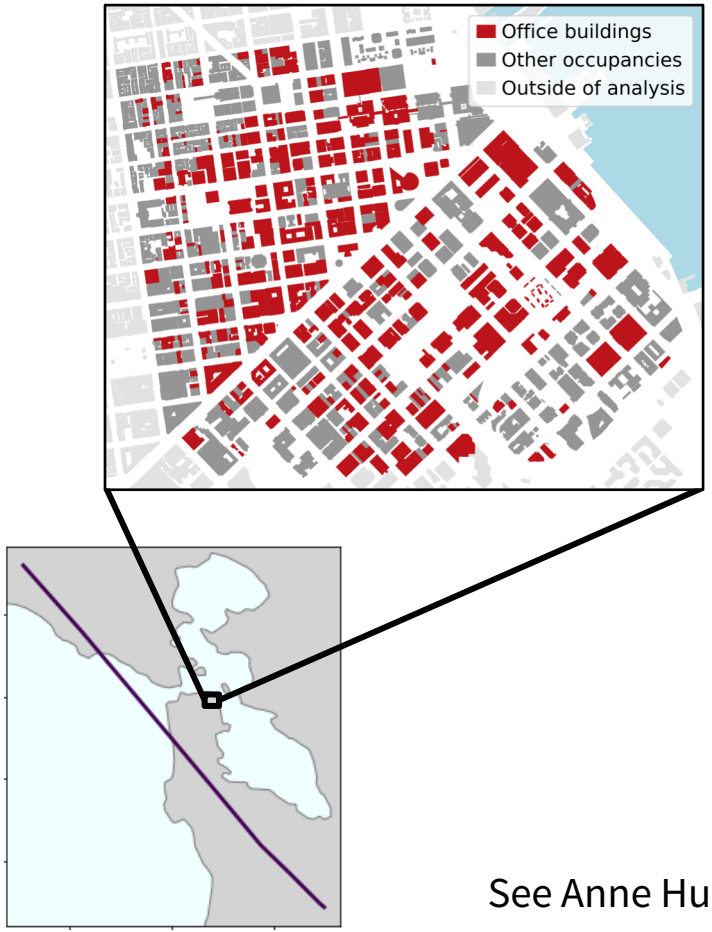

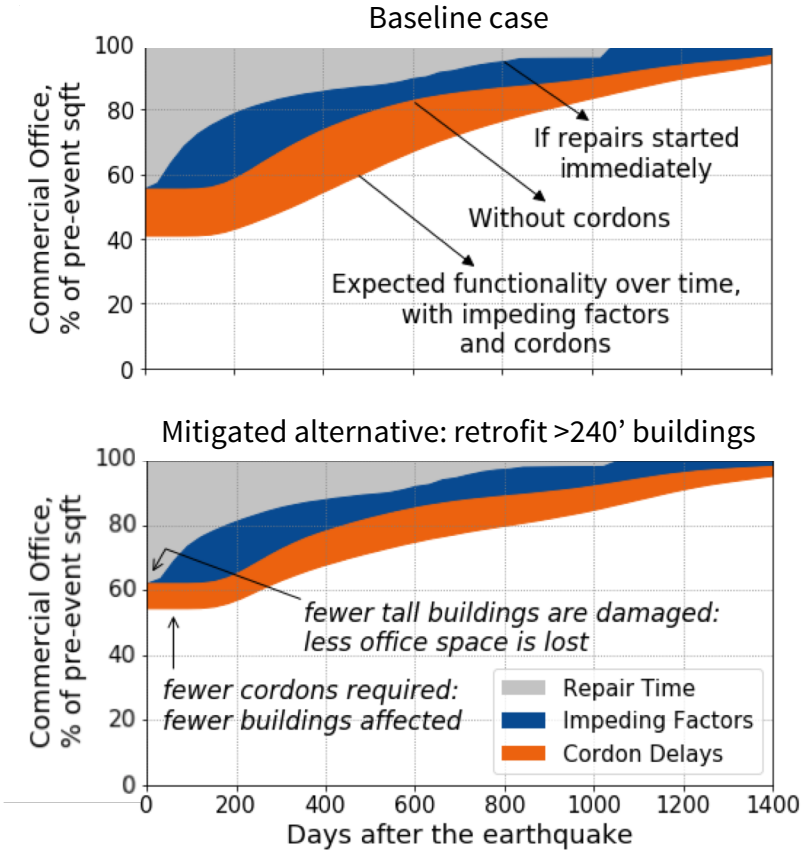

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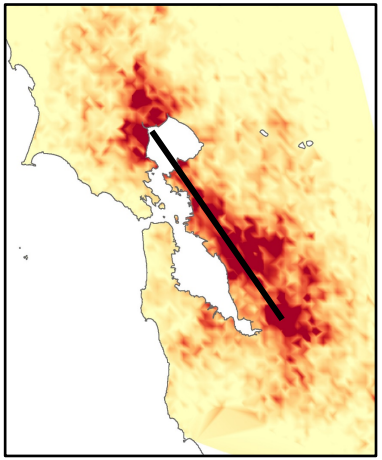
Application #2: Regional Economic Recovery (Under a M_w 7.2 Hayward earthquake)

Total economic losses = Direct economic losses + Indirect economic losses

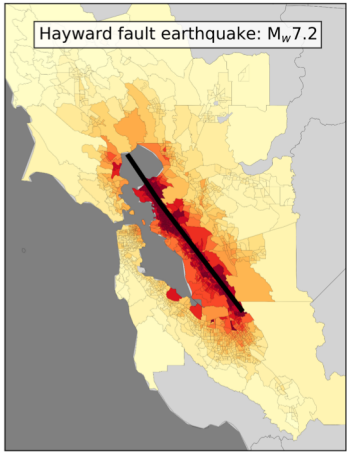
cost of repairing or replacing damaged assets

disruption of services (typically measured in loss of value added ~GDP)

Ground shaking



Damage & direct losses



Indirect losses

?

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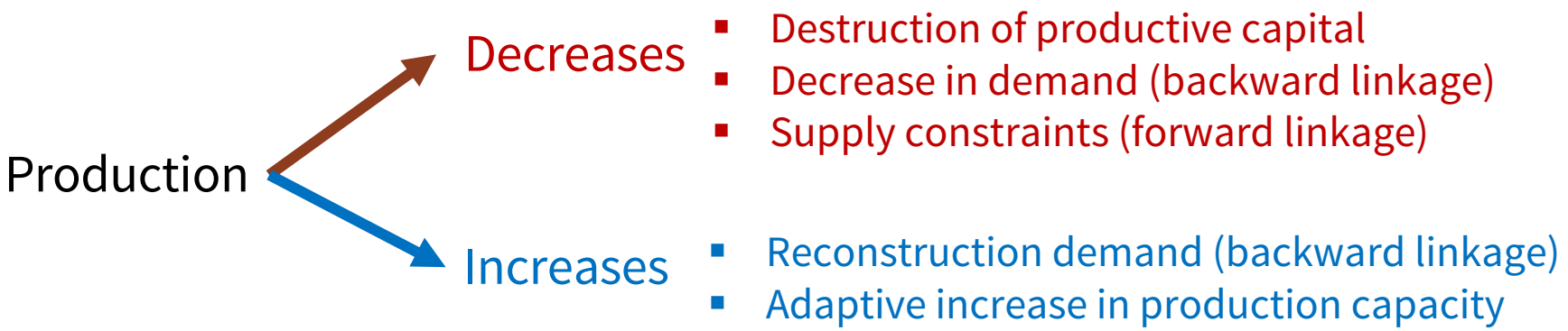
Adaptive Regional Input-Output (ARIO) model

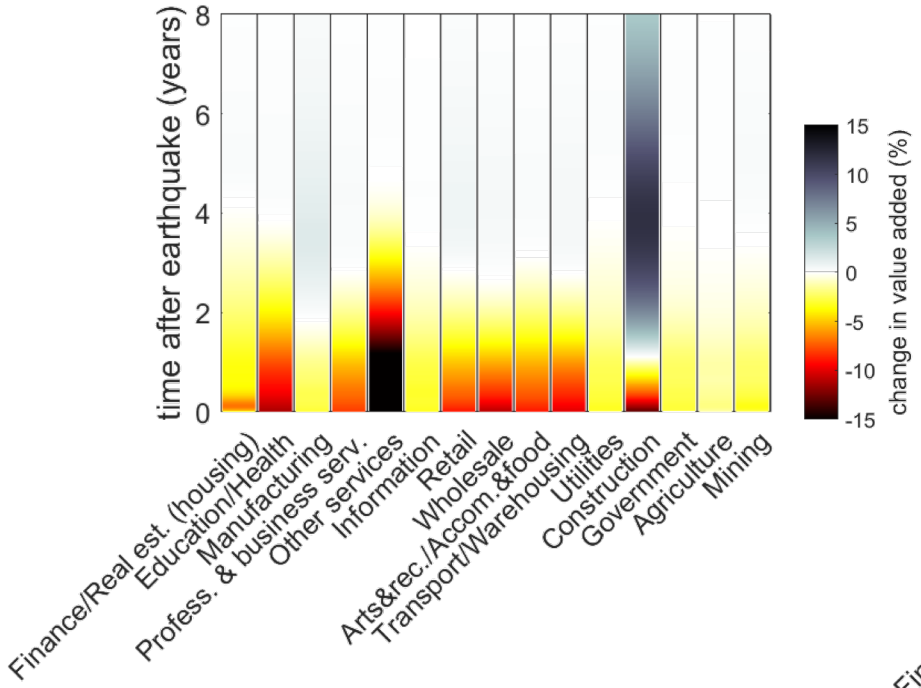


- Captures industry inter-dependencies and the use of inventories
- Simulates value added at each time step after the earthquake (per industry)
- Here we also add reconstruction constraints from our engineering models

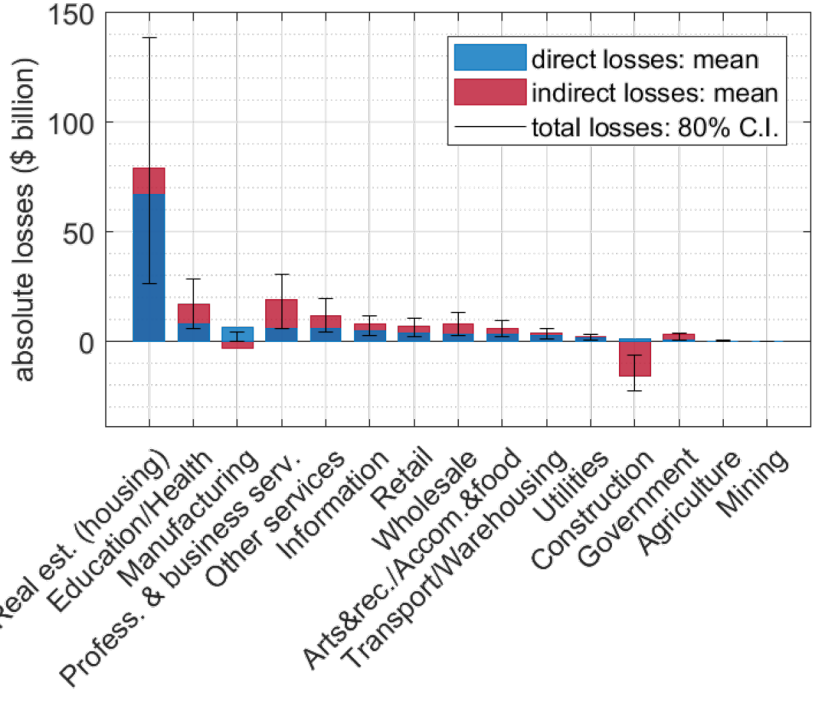
Hallegatte (2014). "Modeling the role of inventories and heterogeneity in the assessment of the economic costs of natural disasters." *Risk analysis*.

Economic impacts: indirect losses of economic sectors

Production over time per sector



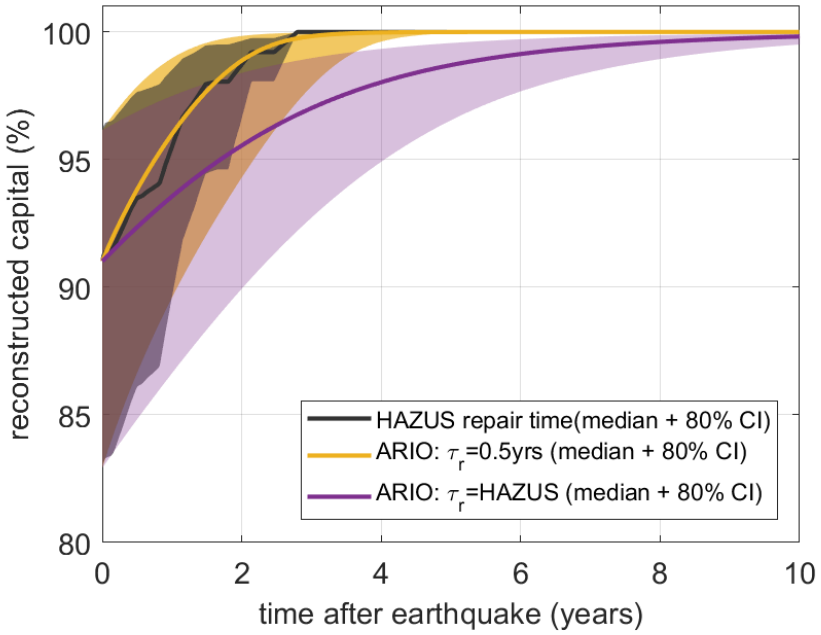
Direct and indirect losses per sector
(indirect > direct in 4 sectors)



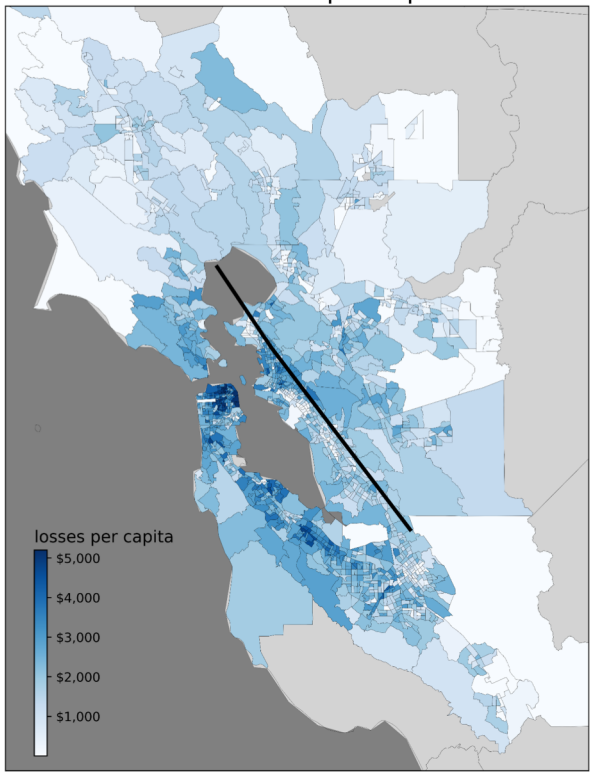
Economic impacts: reconstruction time & employment loss

Sectors reconstruct based on physical repair time plus economic constraints
Lost production also means lost employment (36,200 employee-years on average)

Reconstruction over time



Income losses per capita



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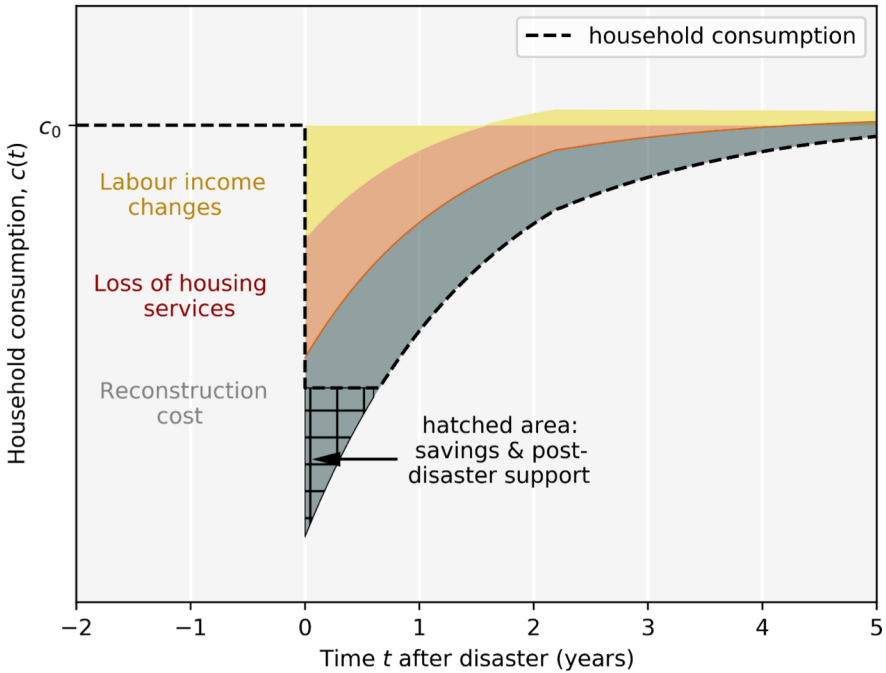
Application #3: Impact on household consumption

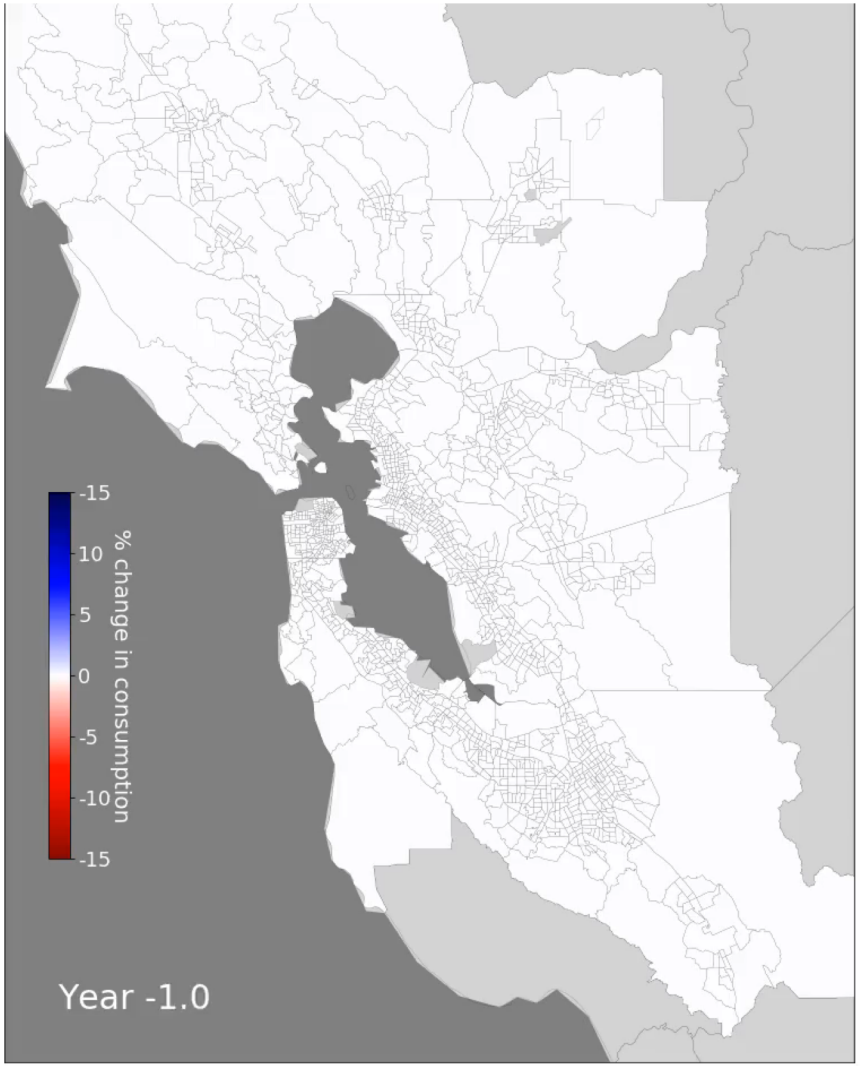
Post-disaster consumption through time, $c(t)$:

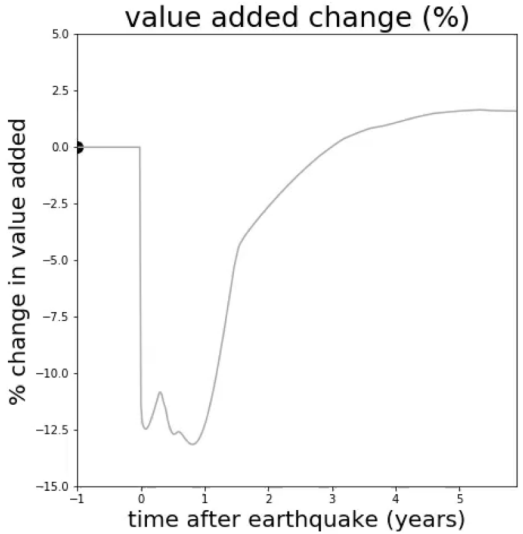
loss of labour income | loss of housing services | reconstruction cost | savings

$$c(t) = c_o - \left(\Delta i^L(t) + \pi v k_o^h e^{-\lambda t} - v p_o^{rent} e^{-\lambda t}\right) - \lambda v k^{str} f^o e^{-\lambda t} + S(t)$$



Regional simulation





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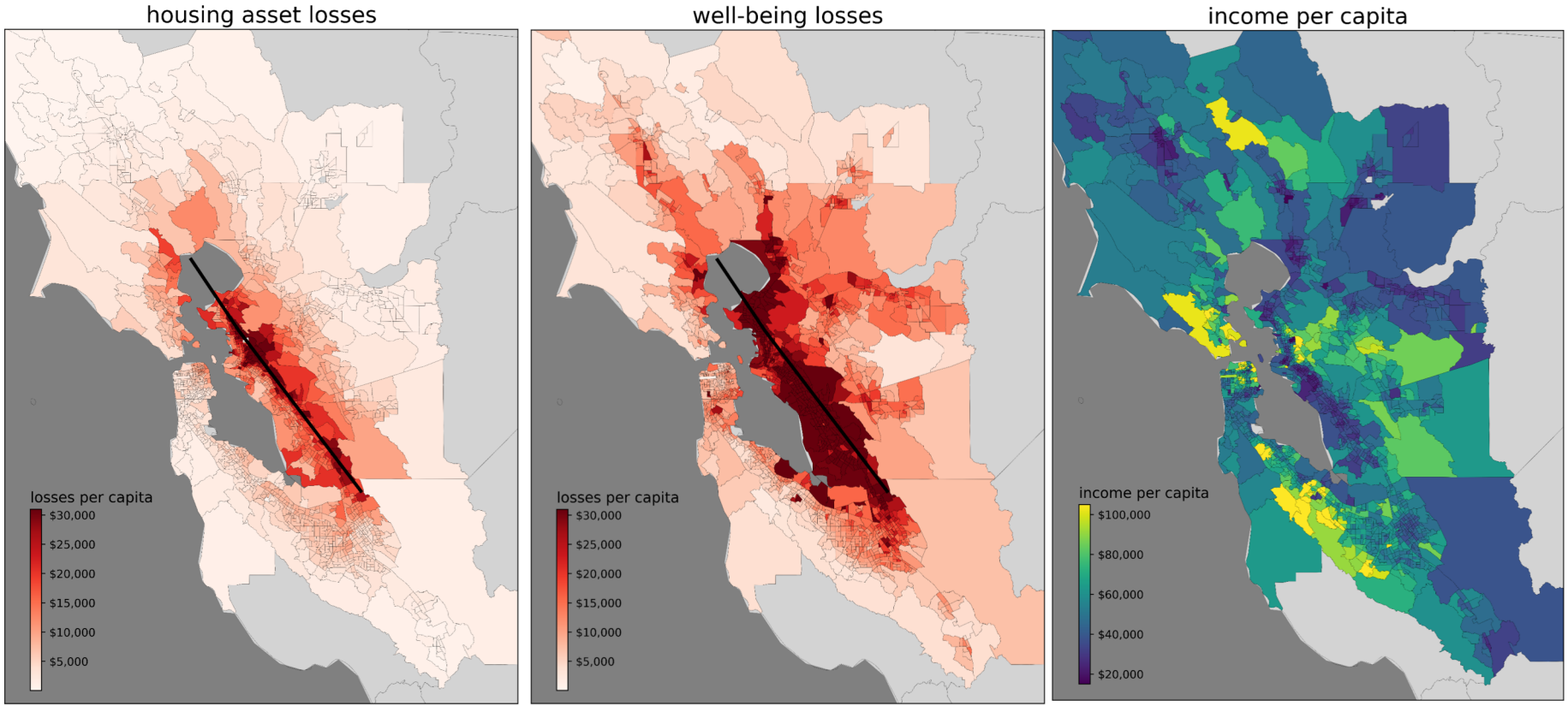
Translate consumption loss into “well-being losses” (income-adjusted)



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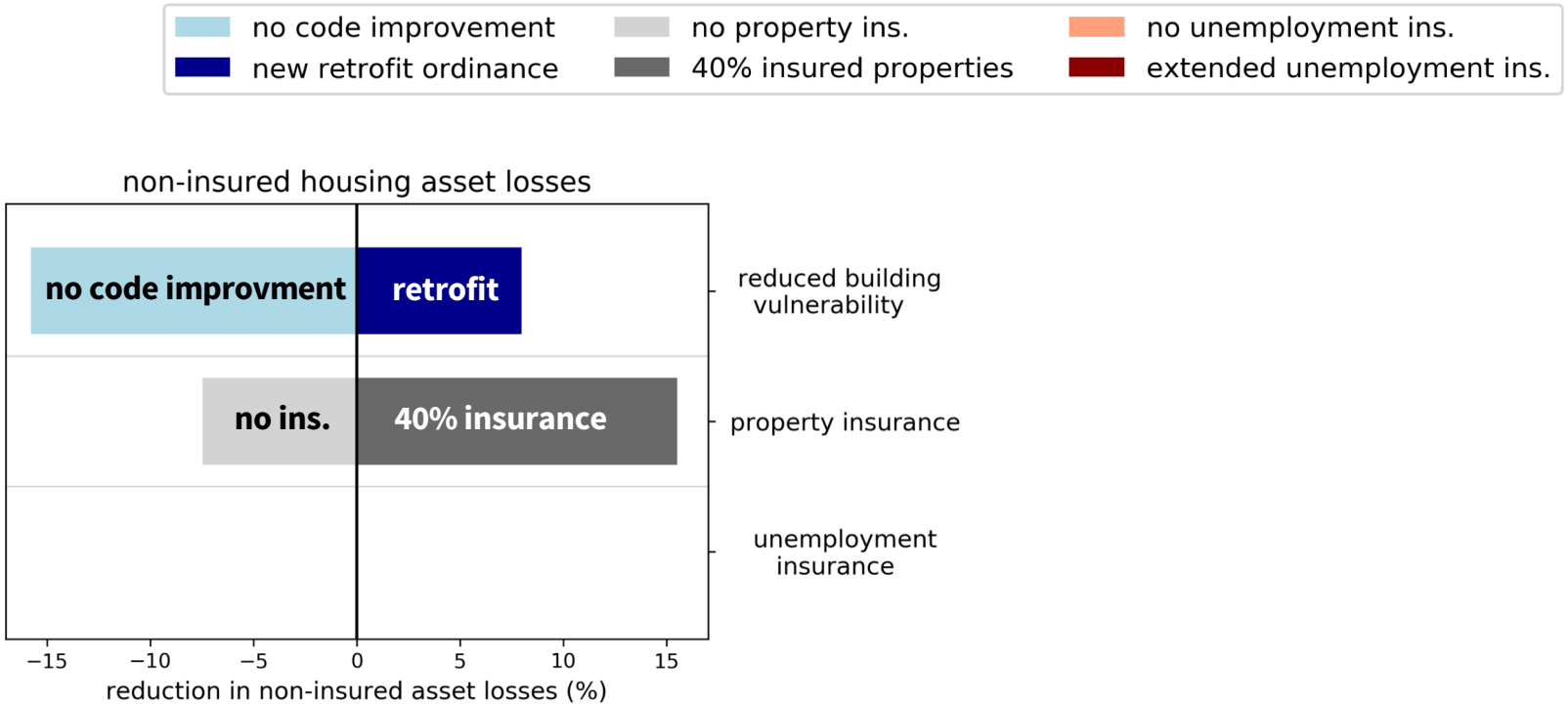
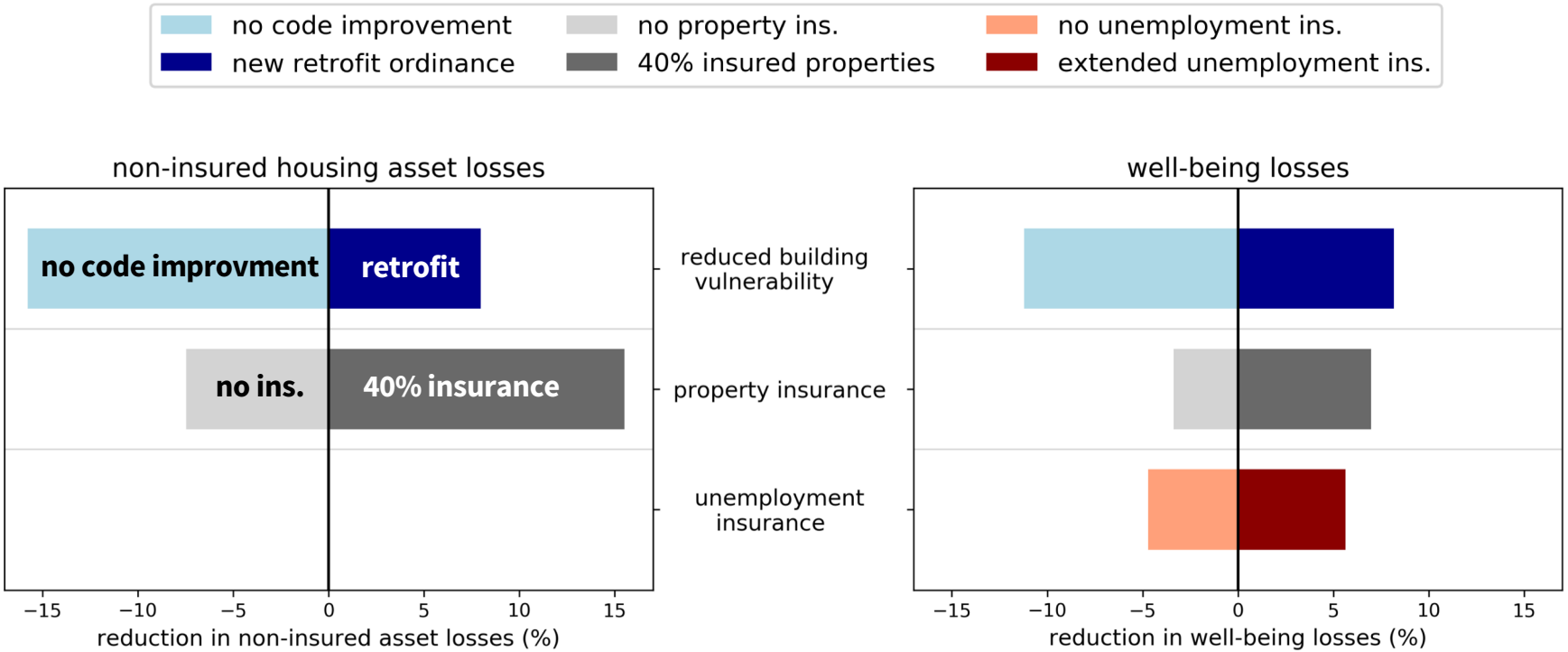
Quantifying the impact of mitigation policies

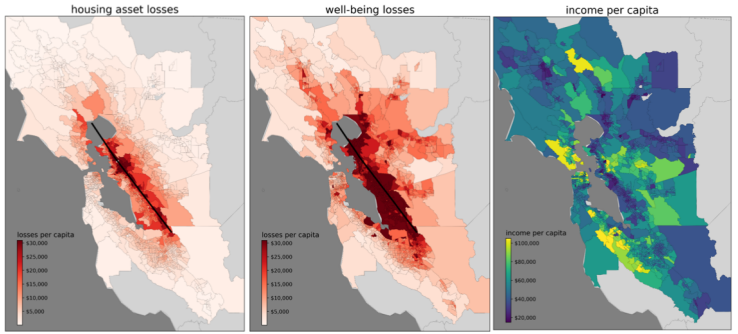


Quantifying the impact of mitigation policies



Markhvida et al.(2019)

Enabling software and data



Regional ground motion

OpenSHA

OpenQuake
calculate share explore

FEMA P-58 analysis

SP3 Seismic Performance Prediction Program
by Haselton Baker Risk Group

DesignSafe-CI
A Natural Hazards Engineering Community
pelicun

ATC PACT

Regional impacts

DesignSafe-CI
A Natural Hazards Engineering Community
rWHALE

GEM
Global Earthquake Model
working together to assess risk

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Conclusions

- We have exciting opportunities to facilitate resilience-enhancing policies
- Predicting recovery requires an understanding of:
  - Regional-scale ground shaking
  - Predictions of time to repair physical damage
  - Recovery effects beyond physical repair (cordons, economic output, household behavior)
- These are complex problems, but are increasingly feasible due to new methodologies and software tools

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