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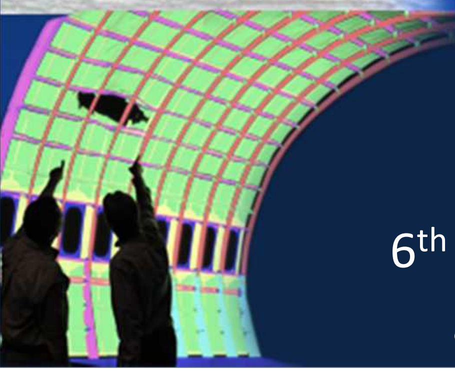
Economic Resilience Analysis: Metrics and Methods



Vanessa N. Vargas

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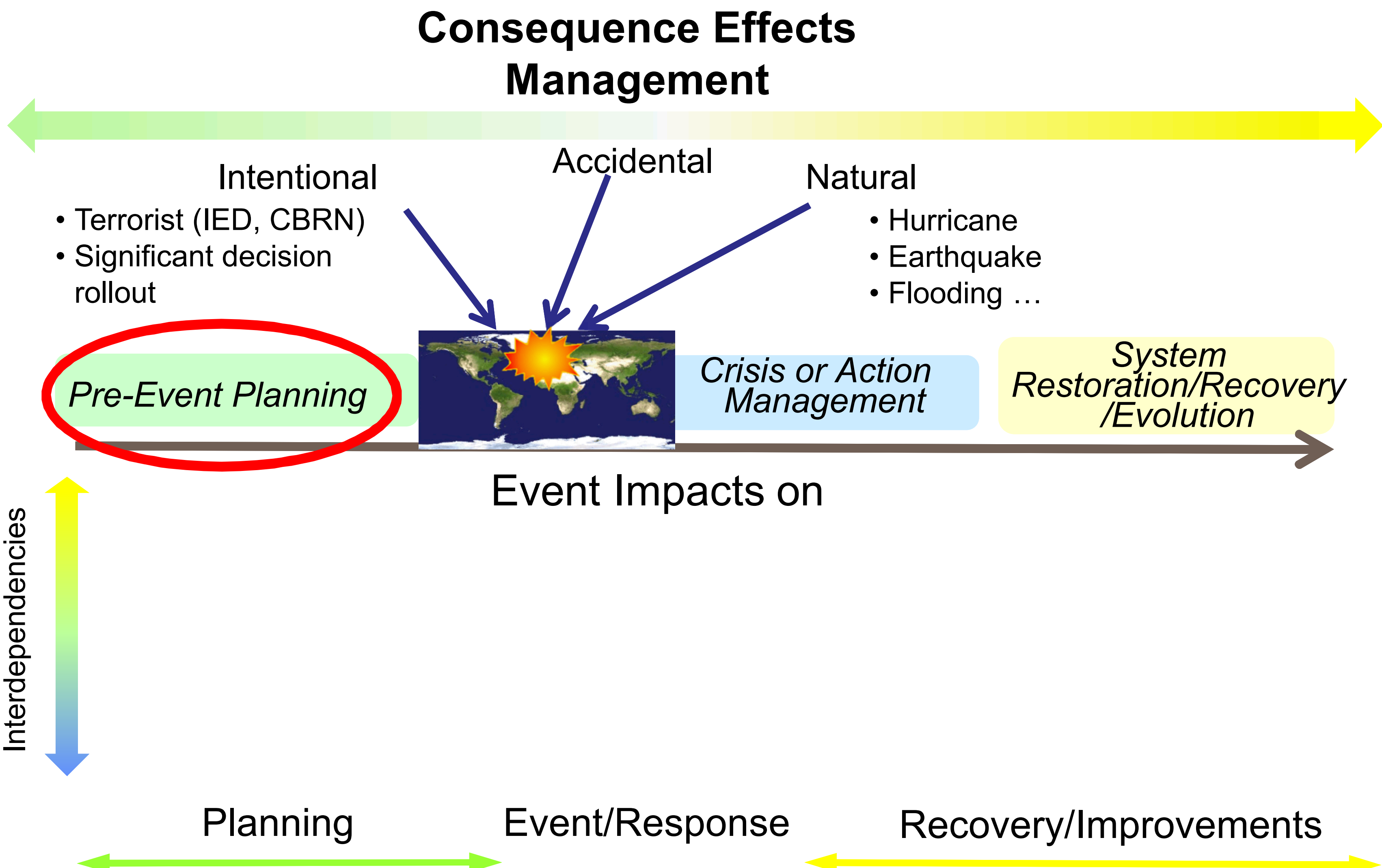
Resilience: Background

- Concept of resilience has broad appeal
  - Not a new concept, history within ecological, engineering, and mental-health disciplines
  - No widely accepted metrics or methodology
- Important criteria and features of infrastructure and community resilience:
  - Quality and supply of infrastructure
  - Economic metrics

Efforts should concentrate on long-term resilience improvements, ex-ante

Different Decision and Analysis Lifecycles



Why Pursue Operational Economic Resilience for Infrastructure Systems?

- Contributing factors to variations in economic impact
  - Magnitude and duration of disruption
  - Geographic characteristics
  - Size and specialization of regional economy
  - Publicly funded (or regulated) infrastructure (e.g., telecom, electric power)
- Proposed metrics should be operationally available to policymakers tasked with allocating resources and prioritizing disaster response
- Qualitative assessments not ideal
  - Often rely on individual stakeholder input
  - May incentivize stakeholders to improve their own resilience but may not signal resilience to decision makers

Signaling resilience to decision makers who allocate resources and prioritize disaster response is not currently incentivized

Economic Indicators for Infrastructure Resilience

Infrastructure

Ex-post

- Yu et al. (2014) – Vulnerability index comprised of three components:
  - Economic impact
  - Propagation length
  - Sector size
  - Economic impact determined using input-output methods

Ex-ante

- Oswald et al. (2011) – Performance indicators are sorted based on importance and contribution
  - Weights to indicators based on their overall contribution to the region
    - Industry economic data for 366 MSAs
    - Economic sectors linked to infrastructure sector
    - Economic contribution of infrastructure sector to regional/U.S. economy

Economic Indicators for Community and Social Resilience

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Ex-ante

- Community—Sherrieb et al. (2010) do not quantify their findings, but test correlations of 88 resilience indicators informed by 3 key elements of economic development
  - Level of economic resources
  - Degree of equality in the distribution of resources
  - Scale of diversity in economic resources
- Social—Cutter (2003) focuses on a person's "social vulnerability" and includes economic indicators:
  - Rent or own status; insurance to replace damaged goods
  - Education to indicate income bracket, social dependence, possibly crime level
  - Population growth and occupational diversity indicate why people move into or out of an area

Infrastructure, social and community resilience are informed by economic metrics/indicators and can be assessed ex-ante

Concepts and Methods from Economics

- Measures of economic health, growth, or expansion are not sufficient for measuring resilience
- Economics discipline encompasses skills and experience that can be coupled with the IRAM for evaluating resilience-enhancing projects
  - Benefit-cost analysis
  - Economic impact
  - Environmental and socioeconomic impact
  - Volatility model rooted in portfolio theory

Benefit-Cost Analysis & Economic Impact Analysis

- Benefit-Cost Analysis – Flexible economic accounting methodology to estimate social welfare impacts from changes in policies and regulations
  - Identify all potential future and current costs/benefits
  - Monetize all future and current costs/benefits
  - Must monetize any identified non-market effects for direct comparison to market effects
- Economic Impact Analysis –
  - Can vary by region and timeframe
  - Three main classes of economic impact models:
    1. Input-output (IO)
    2. Computable General Equilibrium (CGE)
    3. Econometric models

Resilience as a Public Good

- Properties of a Public Good:
  - Non-excludability—If a good is supplied, no consumer can be excluded from consuming it
  - Non-rivalry—Consumption of a good by one consumer does not reduce the quantity available for consumption by any other consumer
- Social and environmental impacts are identified in studies of energy infrastructure (e.g., land-based wind energy farms)
- Incentivize private/public entities to accept additional risk
  - Firm—convinced of their return on investment
  - Government—justify expansions/investments to the public

Quantitative assessment is preferable to qualitative but subject to data limitations—new metrics and statistical approaches may be required

New Metrics for Quantitative Assessment

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- Objective: Novel approaches to evaluating infrastructure quality at the state and local level → quantity is not equivalent to quality
- Activities
  - Volatility model based on Portfolio Theory to compare actual road infrastructure revenue portfolios to variance-minimizing revenue portfolios
  - Based on Garret (2006), who extends Markowitz (1952), volatility-based Portfolio Theory to examine variability in state revenue sources

Minimizing infrastructure revenue variance while maximizing supply of infrastructure may provide a useful metric for comparison of resilience

New Orleans Grid Resilience

- Coordinated effort with the city of New Orleans, the Rockefeller Foundation, and Sandia

- Hypothesis: Improved modernization of electric power grid will improve the resilience of the local community
- Analysis: Inform the volatility model based on Portfolio Theory with local data and use in conjunction with required benefit cost analysis

- Coordinated effort with local government, infrastructure owner/operators, and resilience experts

Conclusion

- Incremental buildup of financial, economic, social, and environmental layers
- Inclusion of equity effects
  - Determine if “winners” compensate “losers”
- Inclusive of Microeconomic principles
  - Translate cost guidelines to estimation into industry production functions
  - Cost structures to enable development of more rigorous, comparative, and analytically defensible benefit cost analyses
- Creative solutions
  - Expansion of the range of financing options for resilience improvements to be more adoptable

Limitations and Future Direction

- Should consider how revenue sources are used
  - Federal funds may be used to make capital investments in road infrastructure, which may introduce variance to infrastructure revenues, but will likely increase system performance
- Should consider multiple revenue sources simultaneously
  - Property taxes and fuel tax distributions both comprise large portions of variance-minimizing portfolios
- Could consider welfare implications of alternative revenue sources
  - Fuel tax is a relatively regressive tax; property taxes are more progressive
- Should also include consideration of business cycles
  - Can use existing parametric models to estimate how business cycles affect specific revenue sources

Quantitative Assessment of Infrastructure Resilience

- Resilience of publicly funded infrastructure likely correlated with quality and supply
- Estimating resilience based on supply data alone may not be adequate
  - May produce simultaneity bias (i.e., more cars results in more roads and vice-versa)
- Standardized data on quality is difficult to obtain and often does not sufficiently scale
- Potential solution: proxy for quality
  - If the resilience of an infrastructure can also be defined of as the invariance of infrastructure performance,
  - And variance of infrastructure performance is highly correlated with the variance of (publicly funded) infrastructure revenues,
  - Then variance of revenues which support infrastructure may act as a reasonable proxy for infrastructure resilience

Quantitative assessment is preferable to qualitative but subject to data limitations—new metrics and statistical approaches may be required

Variance-Minimizing Revenue Portfolio

- Approach based on Garret (2006), who extends Markowitz (1952) volatility-based Portfolio Theory, to examine variability in state revenue sources
- The question: How well is the infrastructure's revenue portfolio constructed in order to minimize the variance of total revenue?
- Evaluated each source of revenue against the sum of all other sources
- Percentage change in total revenue $(\boldsymbol{P_t})$ is weighted average of the percentage change in the revenue source of interest $(\boldsymbol{R})$ and all other sources $(\boldsymbol{O})$:

$$\boldsymbol{P_t = w_{t-1} * R_t + (1 - w_{t-1}) * O_t} \quad (1)$$

- Where $\boldsymbol{w_{t-1}}$ is the share of total revenues of the source of interest in period $\boldsymbol{t-1}$
- The variance of $\boldsymbol{P}$ (denoted $\boldsymbol{V_P}$) gives the variance in total revenues

$$\boldsymbol{V_P = w^2 V_R + (1-w)^2 V_O + 2w(1-w) * \mathrm{cov}(R, O)} \quad (2)$$

Variance-Minimizing Revenue Portfolio

- Total revenue variance is differentiated with respect to $\boldsymbol{w}$, and solved for the variance minimizing portfolio share ($\boldsymbol{w}^*$)

$$\boldsymbol{w}^* = \frac{\boldsymbol{V_O} - \mathrm{cov}(\boldsymbol{R}, \boldsymbol{O})}{\boldsymbol{V}(\boldsymbol{R} - \boldsymbol{O})} \qquad (3)$$

- $\boldsymbol{w}^*$ is a function of variance of $\boldsymbol{R}$ and $\boldsymbol{O}$ and the covariance between $\boldsymbol{R}$ and $\boldsymbol{O}$
- Using a time series of infrastructure revenue data, one can compute $\boldsymbol{V_R}$, $\boldsymbol{V_O}$, $\mathrm{cov}(\boldsymbol{R}, \boldsymbol{O})$ and thus solve for $\boldsymbol{w}^*$
- This model is applied to road infrastructure in Washington State

Data

- Annual road revenue data for all 39 Washington Counties from 2000 to 2010; revenue sources included:
  - Property Taxes
  - Special Assessments
  - General Fund Appropriations
  - Local Road User Taxes
  - State Fuel Tax Distributions
  - Other State Funds
  - Federal Revenues
  - Bond Proceeds
  - Ferry Tolls
- Solved for w^* for four separate revenue sources in King, Clark, and Spokane counties

Results: Spokane County

	Federal Revenues	Other State Revenues	Property Taxes	Fuel Tax Distribution
w^*	1.84%	0.78%	72.71%	95.49%
w_{mean}	10.55%	9.69%	35.34%	25.04%
w_{2010}	17.11%	1.14%	36.33%	22.65%

- Optimal portfolio share of Federal Revenues is much lower than the average observed ($\boldsymbol{w_{mean}}$) or the most recent ($\boldsymbol{w_{2010}}$)
- Optimal portfolio share of Property Taxes & Fuel Taxes both exceed 90%
  - Each revenue source is evaluated separately against the sum of all other sources
- Overall:
  - Property Taxes & Fuel Taxes comprise large shares of revenue-minimizing portfolio
  - Fuel Tax share is trending downward; Property Tax share is moving upward

Results: Clark County

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	Federal Revenues	Other State Revenues	Property Taxes	Fuel Tax Distribution
w^*	-0.39%	7.23%	94.67%	98.66%
w_{mean}	9.59%	7.94%	46.22%	10.99%
w_{2010}	8.10%	5.34%	49.57%	11.09%

- Optimal portfolio share of federal revenue for Clark County is negative
  - Not mathematically bounded at zero
  - Interpretation: Clark County's variance-minimizing portfolio does not include any Federal Revenues
- Overall:
  - Decreasing portfolio shares of Federal Revenues and Other State Revenues
  - Increasing shares of Property Taxes and Fuel Taxes would decrease volatility (it appears Clark County is doing this)

Results: King County

	Federal Revenues	Other State Revenues	Property Taxes	Fuel Tax Distribution
w^*	14.08%	9.57%	97.95%	96.16%
w_{mean}	9.10%	2.94%	51.87%	10.91%
w_{2010}	5.11%	0.42%	47.74%	8.00%

- Results suggest that increasing the portfolio share of all four taxes would decrease volatility (list is not exhaustive; does not necessarily suggest increasing total revenue)
- Overall: King County is moving toward less reliance on all these revenue sources (perhaps toward more volatile sources)

Limitations and Future Direction

- Results rely on assumptions
  - Revenue variance translates to road infrastructure system variance
  - System invariance is equivalent to resilience
- Next step: merging quality and quantity data to generate estimates of infrastructure efficiency using data envelopment analysis
  - Minimizing infrastructure revenue variance while maximizing supply of infrastructure may provide a useful metric for comparing across distinct geographical areas