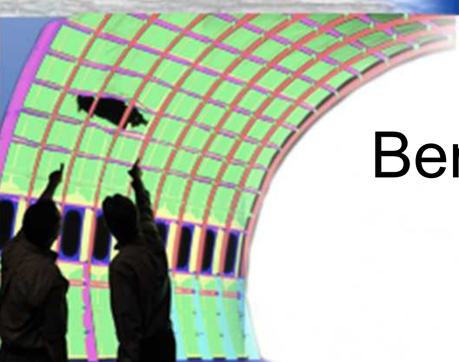
SAND2015-4656C

# Sandia National Laboratories

# The Impact of Revenue Portfolio on the Resilience of Critical Infrastructure



Bern C. Dealy and Vanessa N. Vargas

Prepared for:
The 83rd Military Operations Research Symposium (MORS)
22-25 June 2015 Alexandria, VA

# Why pursue operational resilience for infrastructure systems?

- **Contributing factors to variations in economic impact (independent of magnitude or duration):**
  - Geographic characteristics
  - Size and specialization of regional economy
  - Publicly-funded (or regulated) infrastructure (e.g., roads, telecommunications, etc)
- **Resilient system metrics may be of use to understand the economic resiliency of a geography or community**
- **Proposed metrics should be quantitative and operationally available to policymakers who could be tasked with allocating resources and prioritizing disaster response**
- **Qualitative assessments are not ideal because they often rely on individual stakeholder input**
  - Although the stakeholders queried may be incentivized to improve their own resilience, there may not be an incentive to signal resilience to decision-makers.

**Signaling resilience to decision-makers allocating resources and prioritizing disaster response is not currently incentivized**

# Ex-Post Quantitative Assessment of Critical Infrastructure Resilience

- **Infrastructure Resilience Analysis Methodology (IRAM) (Biringer, Vugrin, and Warren, 2013)**
  - *Definition:* given the occurrence of a particular disruptive event (or set of events), the resilience of a system to that event (or events) is the ability to reduce efficiently both the magnitude and duration of the deviation from targeted system-performance levels.

- **The IRAM method consists of 7-Steps**
  1. Define infrastructure
  2. Define disruption scenario or event
  3. Define metrics
  4. Obtain system performance and recovery data
  5. Calculate resilience costs
  6. Perform structural assessment
  7. Identify resilience enhancement features

# Ex-Ante Quantitative Assessment of Critical Infrastructure Resilience

- **The IRAM framework can also be applied to ex-ante evaluations of critical infrastructures**
  - This requires quantitative metrics of critical infrastructures

- **3 of the 7-Step process can be conducted ex-ante**

1. Define infrastructure
   - Limited to infrastructures where data are available (e.g., publicly-funded infrastructure)

3. Define metrics
   - Metrics limited by specific data gathered
   - Must be useful for allocating resources and prioritizing response (i.e., must be able to scale across entire affected region to provide meaningful comparisons)

4. Obtain system performance and recovery data

# 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 scale sufficiently**
- **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

- **We base our approach on Garret (2006) who extends Markowitz (1952) volatility-based Portfolio Theory to examine variability in state revenue sources.**
- **The question we are attempting to answer is:**
  - How well is the infrastructure's revenue portfolio constructed in order to minimize the variance of total revenue?
- **We evaluate each source of revenue against the sum of all other sources**
- **Percentage change in total revenue $(P_t)$ is a weighted average of the percentage change in the revenue source of interest $(R)$ and all other sources $(O)$:**

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

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

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

Sandia National Laboratories

# Variance-Minimizing Revenue Portfolio

- **We differentiate total revenue variance with respect to $w$, and solve for the variance minimizing portfolio share ($w^*$)**

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

- **$w^*$ is function of variance of $R$ and $O$ and the covariance between $R$ and $O$**
- **Using a time series of infrastructure revenue data, we can compute $V_R$, $V_O$, $\mathrm{cov}(R, O)$ and thus, solve for $w^*$**

- **Here, we apply this model to road infrastructure is 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
- **For this presentation, we will present preliminary results.**
  - Solving for $w^*$ for 4 separate revenue sources (Property Taxes, Federal Revenues, Fuel Tax Distributions and Other State Revenues) in three WA counties (King, Clark and Spokane)

# 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 revenue is much lower than the average observed ($w_{mean}$) or the most recent ($w_{2010}$).**
- **Optimal portfolio share of Property Taxes & Fuel Taxes both exceed 90%**
  - Each revenue source is evaluated separately against the sum of all other sources (not necessarily a problem)
- **Overall: Property taxes and fuel taxes comprise large shares of revenue-minimizing portfolio. While fuel tax share is trending downward, property tax share is moving up.**

# Results: Clark County

| | 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 revenue
- **Overall: decreasing portfolio shares of federal revenues and other state revenues while increasing shares of property taxes and fuel taxes would decrease volatility (and it appears that Clark County is doing just that)**

Sandia National Laboratories

# 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 4 of these taxes would decrease volatility (list not exhaustive, does not necessarily suggest increasing total revenue)**
- **Overall: King County is moving towards less reliance on all of these revenue sources (perhaps towards more volatile sources)**

# Conclusion

- We use a volatility model based on portfolio theory to compare actual road infrastructure revenue portfolios to variance-minimizing revenue portfolios

- The results suggest that all three counties could leverage either fuel taxes or property taxes more in order to minimize the variance of road infrastructure revenues.

- The results also suggest that some counties are currently moving toward greater reliance on less-volatile revenue sources, other counties (King) may be moving toward greater reliance on more-volatile revenue sources

# Limitations and Future Direction

- **These results rely on assumption that revenue variance translates to road infrastructure system variance and that 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.

# Limitations and Future Direction

- **Future work should consider how revenue sources are used**
  - Federal funds may be used to make capital investments in road infrastructure. While they may introduce variance to infrastructure revenues, they also likely increase system performance.
- **Future work should consider multiple revenue sources simultaneously**
  - Property taxes and fuel tax distributions both comprised large portions of variance-minimizing portfolios.
- **Future work could consider welfare implications of alternative revenue sources**
  - Fuel tax is a relatively regressive tax, while property taxes are somewhat more progressive.
- **Future work should also include consideration of business cycles**
  - Existing parametric models can be used to estimate how business cycles affect specific revenue sources.