Optimal Defensive Allocations in the Face of Uncertain Terrorist Preferences, with an Emphasis on Transportation

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Overview

- We extend current game-theoretic methods for identifying optimal defensive resource allocations to use realistic objective functions:
  - Allowing defender and attacker to have different objectives
- Attacker objectives are modeled as multi-attribute utility functions.
- Defender uncertainty about attacker preferences is addressed by probability distributions over the attacker attribute weights:
  - Allowing for the possibility of attributes that are important to the attacker, but not known to the defender
- Defender beliefs about attacker attribute weights are elicited using partial **ordinal rankings** of attack targets:
  - To ease the elicitation burden

Attacker Utility Function

$$U_j = \sum_{i=1}^{m-1} k_i u_i(x_{ij}) + k_m \varepsilon_j$$

Where:

m = number of attributes (including the unobserved attribute)
k_i = weight on attribute i **(random variable)**
u_i = single-attribute utility function for attribute i
x_{ij} = rating of target j on attribute i
ε_j = utility for target j on the unobserved attribute
(random variable)

Game-Theoretic Model

- Solve for the optimal defensive resource allocation by minimizing the defender's expected loss:
  - Represented by a single-attribute utility function (e.g., property loss)
- Assuming that the attacker will choose the most attractive scenario:
  - In light of any defensive investments
- Success probability of an attack on target ***j*** is

$$p(c_j) = e^{-\lambda c_j}$$

  - λ is cost-effectiveness of defensive investment
  - c_j is defensive investment in target ***j***

Case Study

- Suppose we are going to allocate defensive resources among the following ten major US cities:
  - New York City, Chicago, San Francisco, Washington DC, Los Angeles, Philadelphia, Boston, Houston, Newark, and Seattle
- We consider two sets of known attributes:
  - "Macro" attributes only (property loss and population)
  - Transportation-related attributes: (yearly air departures and average daily bridge traffic)
- Two hypothetical experts:
  - **Expert 1** ranks NYC, Chicago, LA, San Francisco, and DC as the top five cities (in that order), and Houston at the bottom
  - **Expert 2** ranks Chicago, LA, NYC, Houston, and Boston as the top five cities (in that order), and Philadelphia at the bottom

Attribute Values

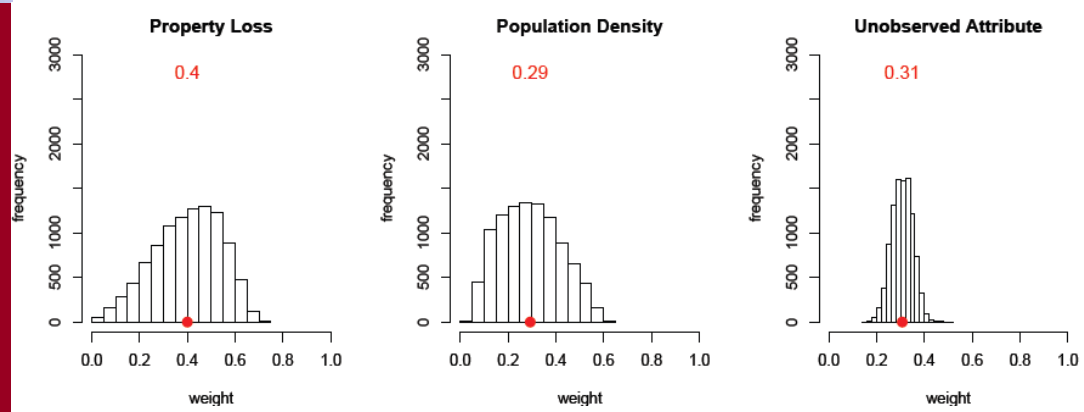
Urban Area	Expected Property Loss from Terrorism[1] ($ million)	Population[1]	Yearly Air Departures[2]	Average Daily Bridge Traffic[2]
New York City	**413**	**9,314,235**	23,599	596,400
Chicago	115	8,272,768	**39,949**	318,800
San Francisco	57	1,731,183	19,142	277,700
Washington DC	36	4,923,153	17,253	254,975
Los Angeles	34	9,519,338	28,816	336,000
Philadelphia	21	5,100,931	13,640	192,204
Boston	18	3,406,829	11,625	**669,000**
Houston	11	4,177,646	20,979	308,060
Newark	7.3	2,032,989	12,827	518,100
Seattle	6.7	2,414,616	13,578	212,000

[1] Data for 2004 taken from Willis et al. (2005)
[2] Data for 2006 taken from Bier et al. (2007)

Elicited Attribute Weights from Expert 1

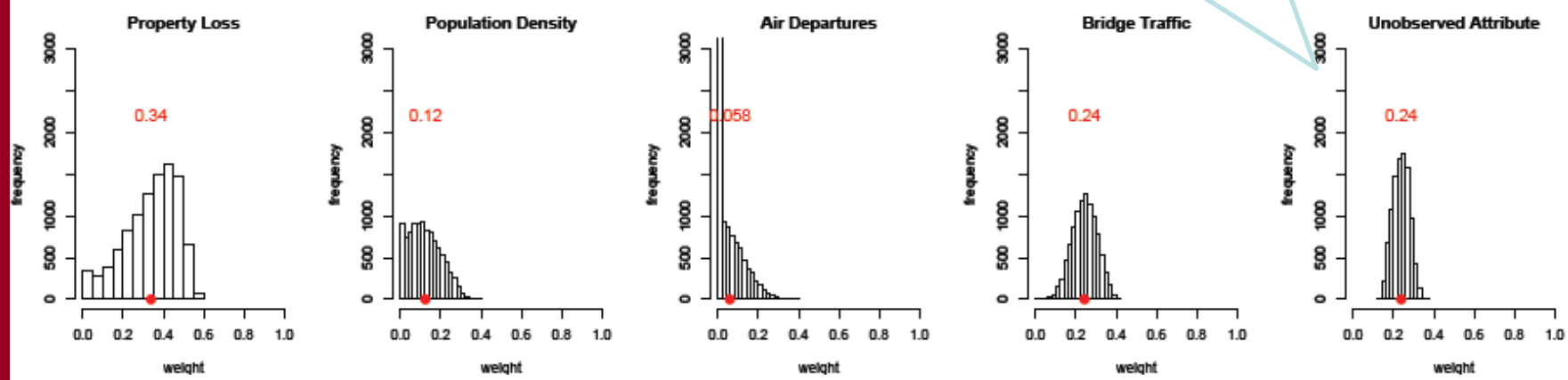
- Top five: NYC, Chicago, LA, San Francisco, DC; Bottom: Houston

Macro Attributes Only



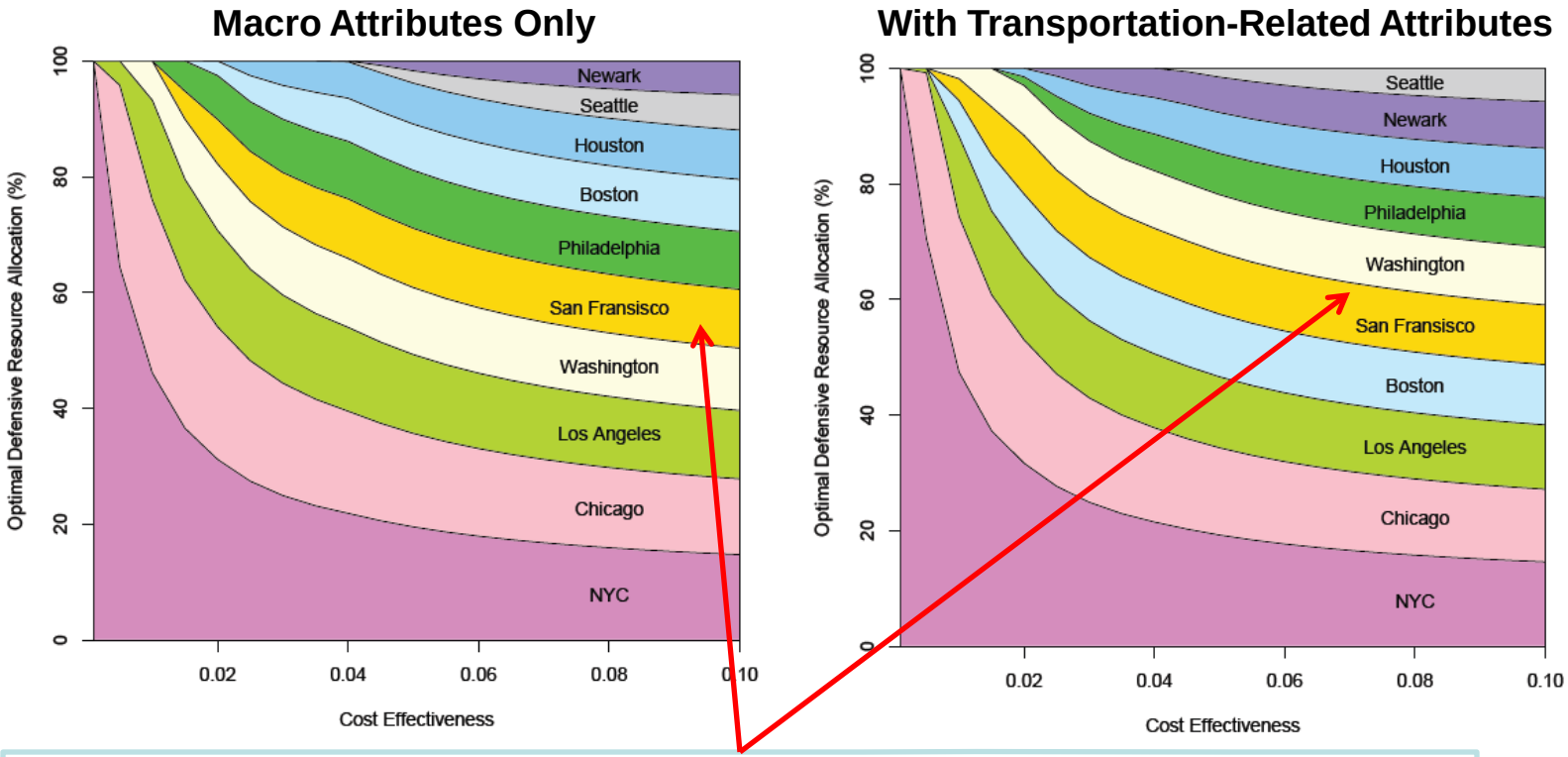
Including transportation-related attributes reduces the weight on the unobserved attribute. However, the weight on the unobserved attribute is still bigger than the weights on some known attributes.

With Transportation-Related Attributes



Optimal Resource Allocation - Expert 1

- Top five: NYC, Chicago, LA, San Francisco, DC; Bottom: Houston

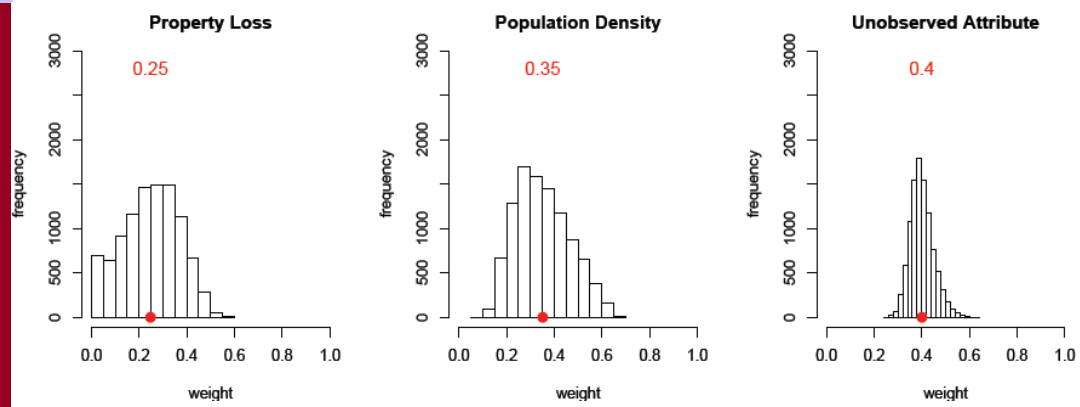


Note that San Francisco is rated higher than DC both by expert 1, and on the defender attribute ("property loss"). However, using only the two macro attributes (property loss and population), the model cannot distinguish well between San Francisco and DC. Including transportation-related attributes allows the model to perform better in this regard.

Elicited Attribute Weights from Expert 2

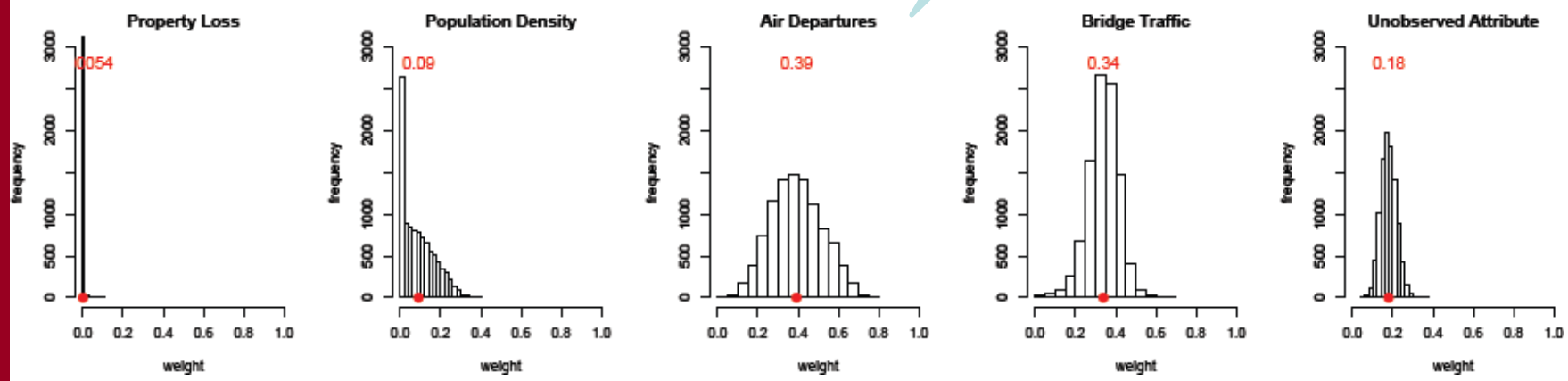
- Top five: Chicago, LA, NYC, Houston, Boston; Bottom: Philadelphia

Macro Attributes Only



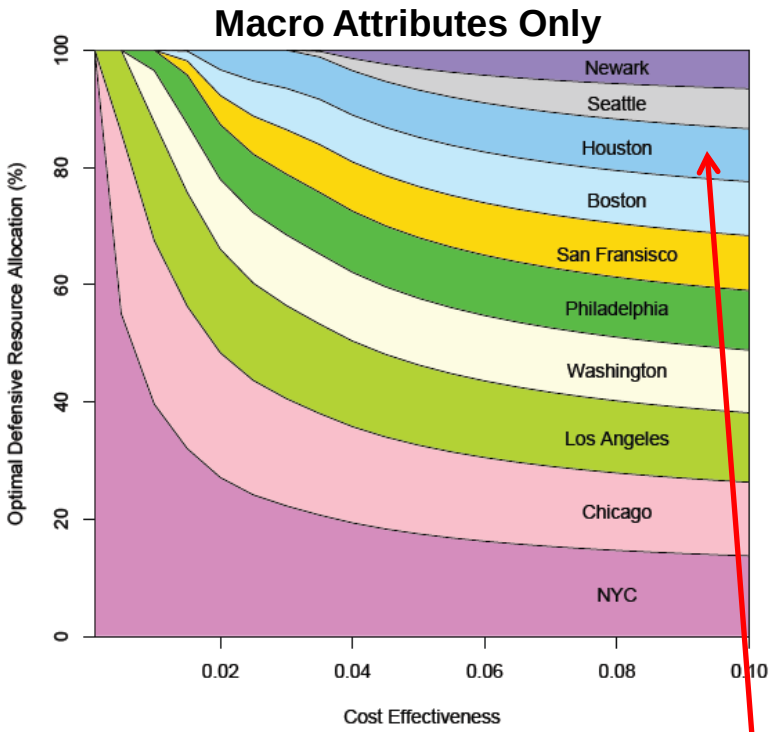
The ratings of expert 2 reflect high weights on air departures and bridge traffic. Without transportation-related attributes, the model puts 40% of the weight on unobserved attributes!

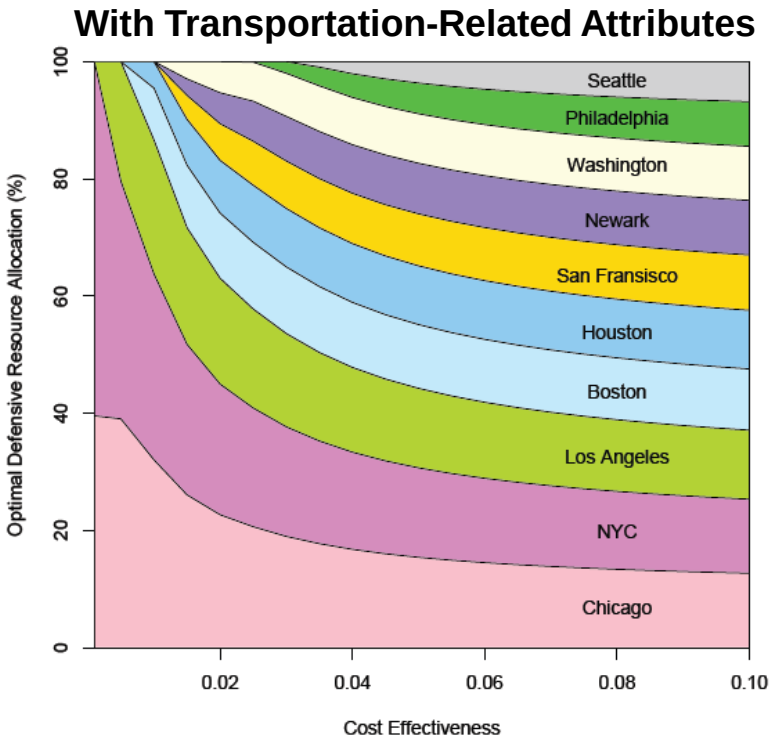
With Transportation-Related Attributes



Optimal Resource Allocation - Expert 2

- Top five: Chicago, LA, NYC, Houston, Boston; Bottom: Philadelphia





Using only macro attributes performs poorly in this case, since the expert's target rankings reflect high weights on transportation-related attributes. For example, Houston is ranked 4th in air departures, but receives only modest funding.

Conclusion

- Results from hypothetical expert judgments show that including transportation-related attributes helps to distinguish between targets:
  - Especially when the expert believes that the attacker puts high weight on transportation-related attributes
- Inclusion of “unobserved attributes” in the model can help to indicate whether we have the right set of attributes
- If experts find it difficult to estimate attacker attribute weights, indirect elicitation may be preferable!
  - In particular, (partial) ordinal rankings of attack targets can ease the elicitation burden
- We believe that the use of ordinal rankings can:
  - Increase the acceptance of quantitative approaches by intelligence experts (who are often reluctant to provide cardinal ratings)
  - Increase the number of experts whose opinions can be elicited
  - Facilitate automated (e.g., web-based) expert elicitation

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