# Estimating US federal wildland fire managers' preferences toward competing strategic suppression objectives

Dave Calkin, USFS Rocky Mountain Research Station
Tyron Venn, The University of Montana
Matthew Wibbenmeyer, Collins Consulting, Inc.
Matthew Thompson, USFS Rocky Mountain Research Station

National Fire Decision Support Center

Rocky Mountain Research Station

# Introduction/context

- Rising suppression costs
- Adoption of risk management as the appropriate paradigm
- Human factors influence costs (Calkin et al. 2011)
  - Incentives
  - Social and political influences over decision-making
  - Decision biases (eg. discounting, status quo bias, loss aversion and risk preferences)

# The Choice Experiment Method

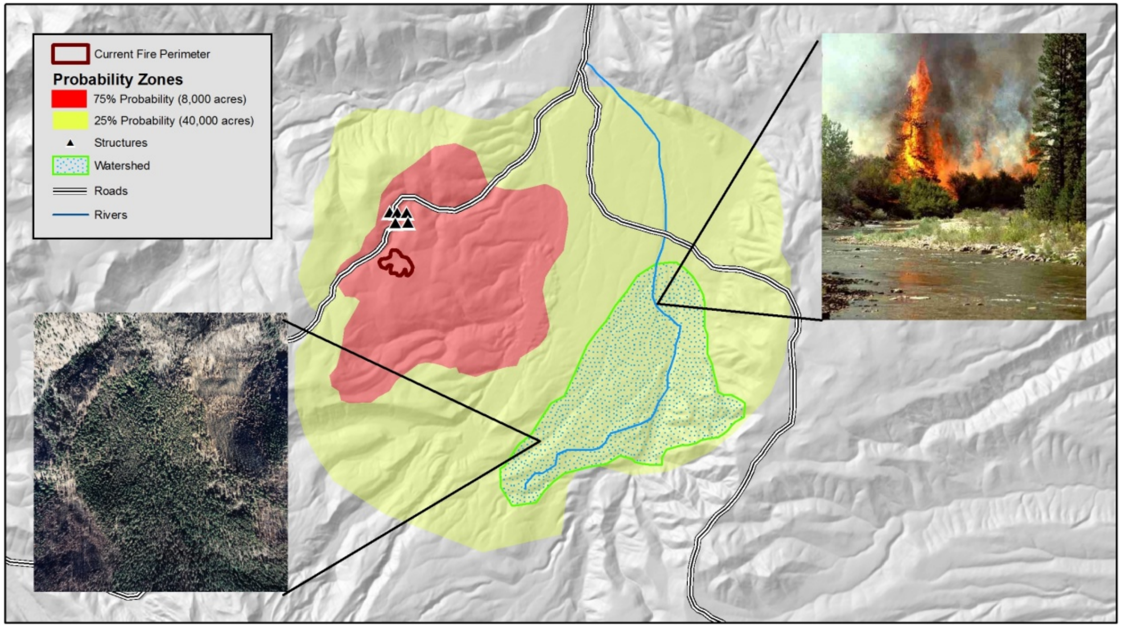
- Present respondents with series of choice sets among alternative goods
- Choices reveal preferences
- Based upon:
  - Characteristics theory of value
  - Random utility theory

$$U_{in} = V_{in} + \varepsilon_{in}$$

$$P(i) = \frac{e^{\mu V_{in}}}{\sum_{j \in C} e^{\mu V_{jn}}}$$

# Two-Tier Experimental Design

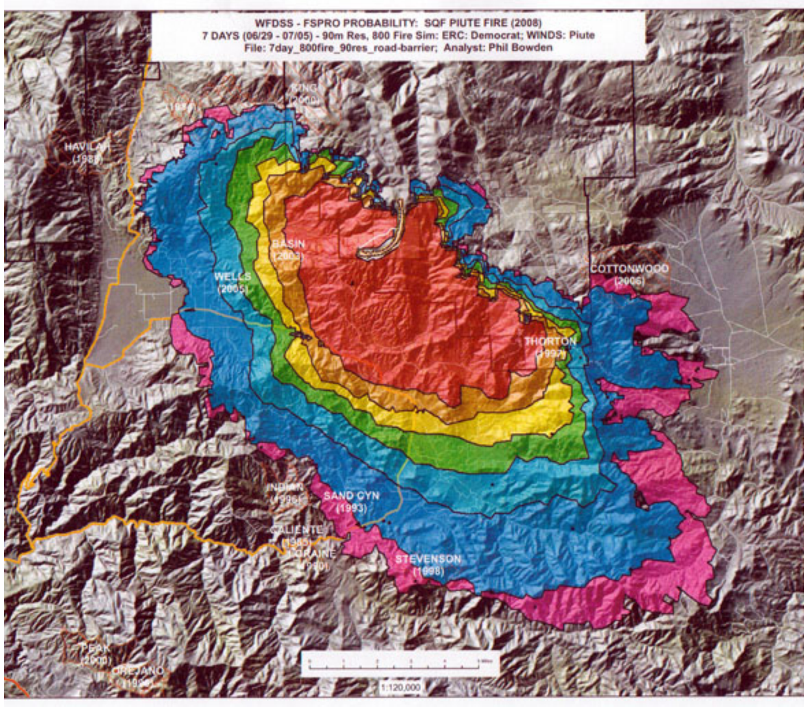
- Wildfire scenarios described hypothetical wildfires
  - Two values-at-risk: homes and a highly-valued watershed
  - Scenarios varied in:
    - Number of homes ϵ {5,30}
    - Potential fire severity in watershed ϵ {moderate, high}




    - Location of homes and watershed relative to fire probability contours ϵ {25%, 75%}

# Two-Tier Experimental Design

- Scenarios emulated contemporary spatial risk assessment tools familiar to wildfire managers
- Probability contours were described as having been estimated with "state-of-the-art wildfire simulation models … given that the fire is burning with no suppression resources applied."



# Two-Tier Experimental Design

- Choice sets described potential wildfire management strategies

| <u>Attribute</u> | A | B | C |
|---|---|---|---|
| **Protect residential homes** | √ | √ | √ |
| **Protect watershed** | 0 | √ | 0 |
| **Personnel exposure** | 100 aviation person **hours**/ 3,000 person **days** direct line production | 100 aviation person **hours**/ 3,000 person **days** direct line production | 100 aviation person **hours**/ 100 person **days** direct line production |
| **Wildfire duration** | <14 days | >30 days | >30 days |
| **Probability of success** | 50% | 90% | 75% |
| **Wildfire cost** | $0.5 million | $4 million | $2 million |
| **Expected response:** | ☐ | ☐ | ☐ |
| **Personal preference:** | ☐ | ☐ | ☐ |

# Management Strategy Attributes

- Protect homes/Protect watershed $\epsilon$ {0, 1}
- Probability of success $\epsilon$ {0.50, 0.75, 0.90}
  - Strategies protected the homes, the watershed, or both at the probability given by the attribute 'Probability of success'
  - For strategies that did not protect homes, "no efforts are made to stop the fire before it reaches homes, but reasonable levels of point protection will be implemented."

# Management Strategy Attributes

- Personnel exposure, in two variables:
  - Aviation-hours ϵ {100, 1000}: person-hours in aviation, assuming an average of three people per flight-hour
  - Ground-days ϵ {100, 3000}: person-days in direct line production activities
  - "Between 2000 and 2007, a total of 153 personnel were killed while on duty; including 40 in aviation accidents, 47 in ground vehicle accidents, 32 from heart attacks, 20 from burnovers/ entrapments, and 8 from snags/felling accidents."

# Management Strategy Attributes

- Duration ϵ {14 days, 30 days}
  - "The length of time that a large fire burns is largely determined by fire weather; however, suppression resources in many instances can take advantage of favorable fire weather to contain an event in a reduced length of time."
  - Impacts of duration include: "reduced air quality, lost recreation opportunities, lost tourism income, displaced outfitters and other special use permittees"

# Management Strategy Attributes

- Wildfire cost ϵ {$0.5mil, $2mil, $4mil, $8mil, $15mil}
  - "Wildfire cost refers to the total suppression and post fire emergency response cost to taxpayers (including federal, state, and local cost) of implementing the fire management strategy. It does not include economic impacts of the fire to the community, resource value losses, or long term restoration costs."
  - "Wildfire cost containment is a priority of the federal wildland fire management."

# Expected response/Personal preference

| | direct line production | direct line production | line production |
|---|---|---|---|
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| **Expected response:** | ☐ | ☐ | ☐ |
| **Personal preference:** | ☐ | ☐ | ☐ |

- "The **expected response** is the strategy that you believe best meets community, agency leadership and political expectations, and conforms with federal fire and land management policies."
- "Your **personal preference** is the strategy you believe would result in the best long term fire management outcomes, ignoring community, agency leadership and political expectations."

# Data Collection

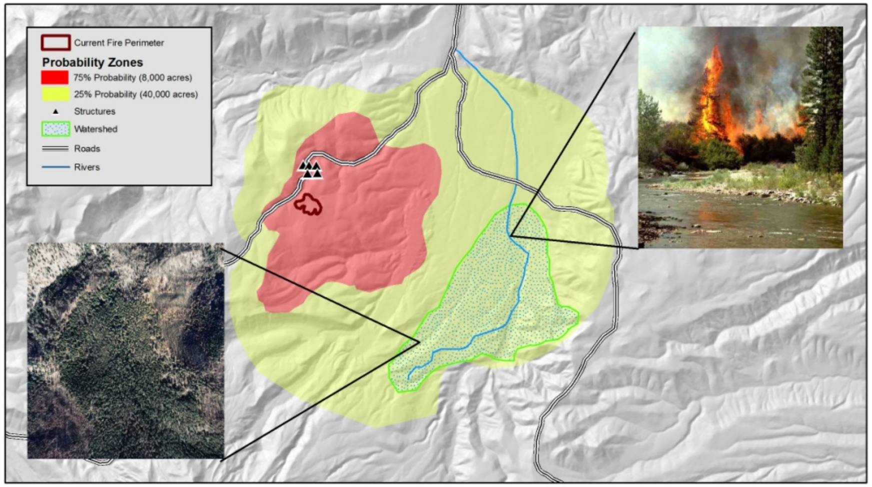
- Each respondent received 3 scenarios, each accompanied by 4 choice sets
- Questionnaire administered online in spring 2009
- 2054 agency administrators and fire and fuels management professionals contacted
- Responses received from 583 managers (response rate = 28.4%)

**Resources at risk**

•Five residential homes are at risk.

•The highly valued watershed has medium tree density, although the riparian zone along the river illustrated has high tree density. Mixed-severity wildfire in non-riparian areas and high-severity fire in the riparian area is projected.

•Photos are illustrative of likely wildfire effects in non-riparian and riparian zones if the fire burns the watershed.




| Attribute | A | B | C |
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# Model Specification

Conditional logit model, estimated for dependent variables *exp* and *pref*

$$P(exp_i = 1) = \frac{e^{\mu V_{in}}}{\sum_{j \in C} e^{\mu V_{jn}}}$$

Estimated utility function

$$V_{in} = \beta_h homes + \beta_{wsm} wsmod + \beta_{wsh} wshigh + \beta_k x_{ink}$$

Risk variables

$$homes = (hrisk) \times (\$0.2\text{mil}) \times (hprob) \times (hprotect) \times (probsucc)$$

$$wsmod = (mod) \times (wsprob) \times (wsprotect) \times (probsucc)$$

$$wshigh = (high) \times (wsprob) \times (wsprotect) \times (probsucc)$$

Marginal rate of substitution

$$MRS_{lk} = \frac{-\beta_l}{\beta_k}$$

# Base Model Results

| | Expected | | | Preferred | | | Chi-square | |
|---|---|---|---|---|---|---|---|---|
| | β | | S.E. | β | | S.E. | | |
| *homes* | 0.8810 | *** | 0.0635 | 0.4044 | *** | 0.0360 | 52.55 | *** |
| *wsmod* | 0.7827 | *** | 0.1166 | 0.0369 | | 0.1253 | 26.39 | *** |
| *wshigh* | 1.2250 | *** | 0.1309 | 0.5695 | *** | 0.1329 | 17.92 | *** |
| *avhours* | -0.0004 | *** | 0.0001 | 0.0001 | | 0.0001 | 18.31 | *** |
| *grounddays* | 4.7E-05 | *** | 1.5E-05 | -7.9E-06 | | 1.5E-05 | 9.58 | *** |
| *duration* | -0.0264 | *** | 0.0025 | -0.0073 | *** | 0.0021 | 44.74 | *** |
| *cost* | **0.0859** | *** | 0.0106 | -0.1044 | *** | 0.0082 | 240.43 | *** |
| No. obs. | 19575 | | | 19578 | | | | |
| Log-Likelihood | -6122.64 | | | -6860.45 | | | | |
| Pseudo R-sq. | 0.1459 | | | 0.0431 | | | | |

Note: ***, **, and * refer to statistical significance at the 0.01, 0.05, and 0.10 levels, respectively. Standard errors are clustered by respondent.

# Expected Value Maximization vs. Non-Expected Utility Theory

- Risk variables assume risk evaluation is linear in probabilities and values
- Non-expected utility theory allows non-linear preferences over probabilities and values

$$homes = (hrisk)\times(\$0.2\text{mil})\times(hprob)\times(hprotect)\times(probsucc)$$
$$wsmod = (mod)\times(wsprob)\times(wsprotect)\times(probsucc)$$
$$wshigh = (high)\times(wsprob)\times(wsprotect)\times(probsucc)$$

$$V = \beta_k x_k + H_{s,v,w}\eta_{s,v,w} + W_{s,v,w}\varphi_{s,v,w}$$

Omitted categories where *probsucc* = 0.90, for every value-burn probability combination

Dummy variables for every value, burn probability, and probability of success combination

# Categorical Non-Expected Utility Model

*Watershed variable coefficients omitted

| Variable | Coeff. | | S.E. |
|---|---|---|---|
| *avhours* | 1.10E-05 | | 1.23E-04 |
| *grounddays* | 5.58E-05 | *** | 1.92E-05 |
| *duration* | -0.0226 | *** | 0.0032 |
| *cost* | -0.0256 | ** | 0.0106 |
| $H_{s=5,v=.25,w=.75}$ | 0.1167 | | 0.0974 |
| $H_{s=5,v=.25,w=.50}$ | -0.7045 | *** | 0.1050 |
| $H_{s=5,v=.25,w=0}$ | -1.5990 | *** | 0.1168 |
| $H_{s=5,v=.75,w=.75}$ | -0.0347 | | 0.0896 |
| $H_{s=5,v=.75,w=.50}$ | -0.9117 | *** | 0.0907 |
| $H_{s=5,v=.75,w=0}$ | -2.1840 | *** | 0.1258 |
| $H_{s=30,v=.25,w=.75}$ | -0.1295 | | 0.0999 |
| $H_{s=30,v=.25,w=.50}$ | -1.0140 | *** | 0.1065 |
| $H_{s=30,v=.25,w=0}$ | -2.0410 | *** | 0.1244 |
| $H_{s=30,v=.75,w=.75}$ | -0.1805 | | 0.1186 |
| $H_{s=30,v=.75,w=.50}$ | -1.4690 | *** | 0.1254 |
| $H_{s=30,v=.75,w=0}$ | -2.7910 | *** | 0.1875 |
| No. of obs. | 19575 | | |
| No. of pars. | 28 | | |
| Log-Likelihood | -5782.7 | | |
| Pseudo $R^2$ | 0.1930 | | |

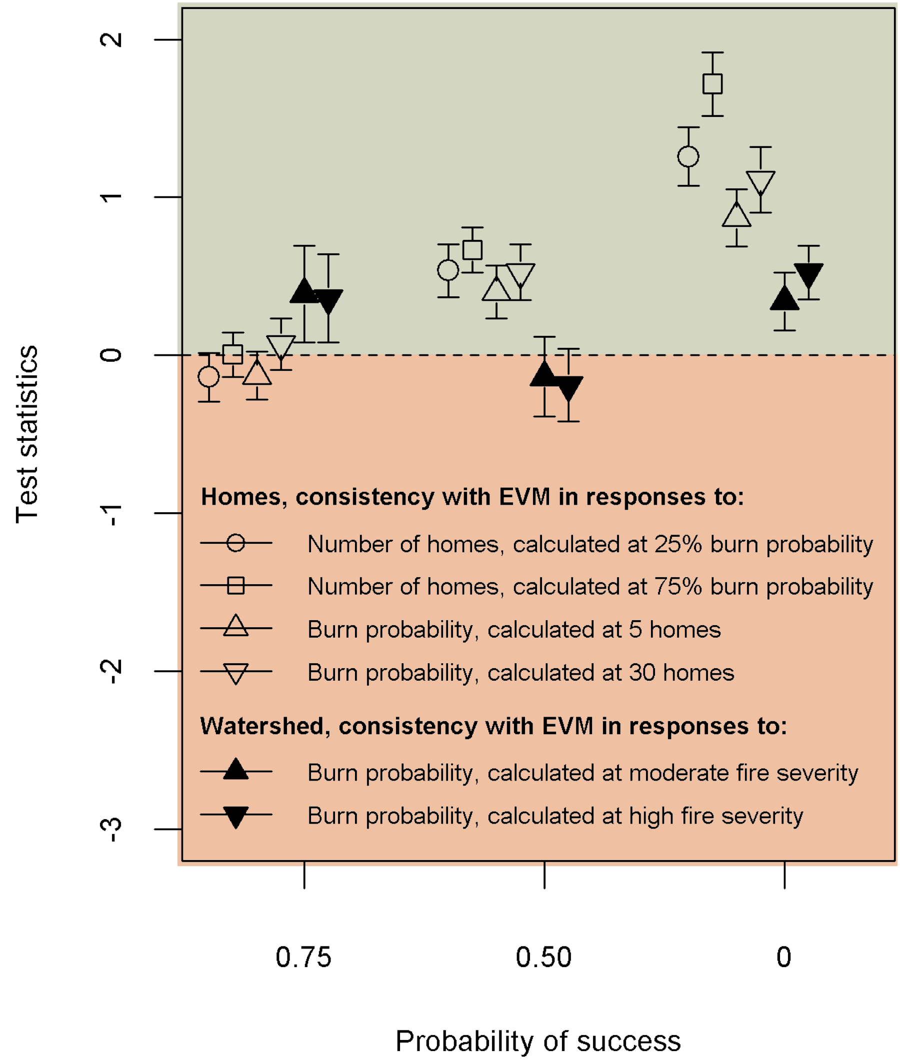
# Tests of consistency with EVM in responses to burn probability and values-at-risk, by probability of success interval

Test statistics based on null hypotheses:

$$\left[\frac{EXPLOSS_{s,v,w}}{EXPLOSS_{s+1,v,w}}\right] - \left[\frac{\eta_{s,v,w}}{\eta_{s+1,v,w}}\right] = 0$$

$$\left[\frac{EXPLOSS_{s,v,w}}{EXPLOSS_{s,v+1,w}}\right] - \left[\frac{\eta_{s,v,w}}{\eta_{s,v+1,w}}\right] = 0$$

- **Positive** values indicate lower sensitivity to increases in risk than EVM would predict
- **Negative** values indicate greater sensitivity to increases risk than EVM would predict

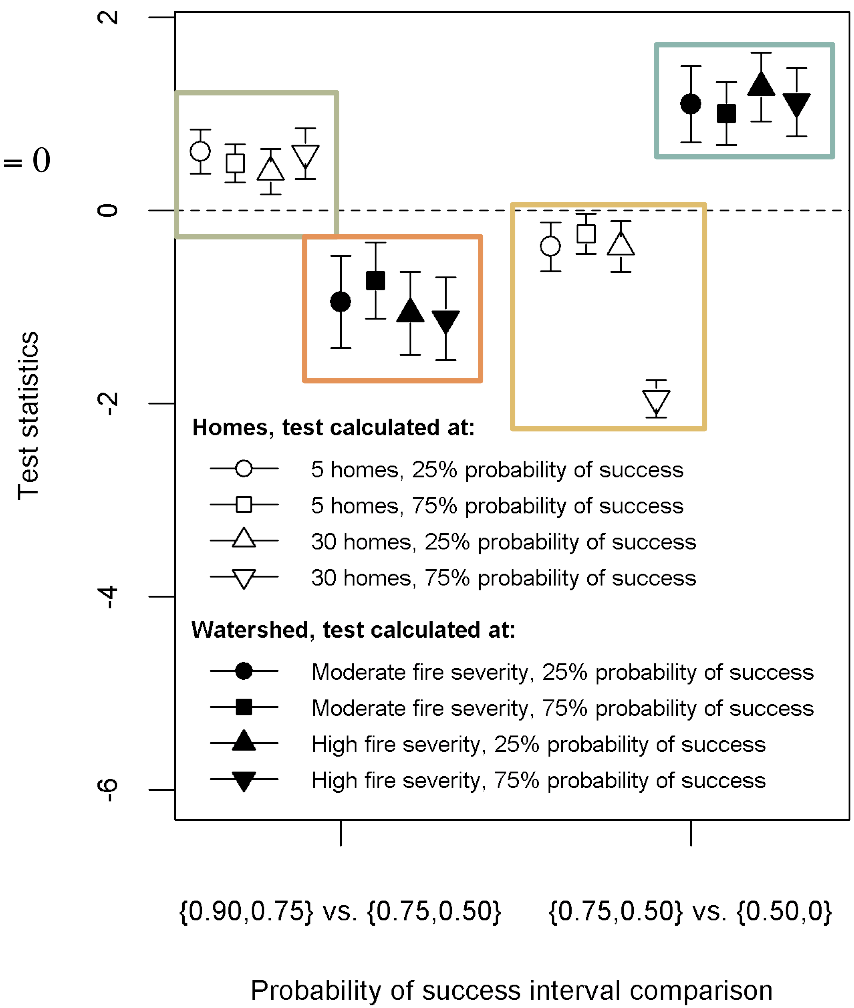


# Tests of consistency with EVM in responses to burn probability and values-at-risk, by probability of success interval

Test statistics based on null hypotheses:

$$\left[\frac{EXPLOSS_{s,v,w-1} - EXPLOSS_{s,v,w}}{EXPLOSS_{s,v,w} - EXPLOSS_{s,v,w+1}}\right] - \left[\frac{\eta_{s,v,w-1} - \eta_{s,v,w}}{\eta_{s,v,w} - \eta_{s,v,w+1}}\right] = 0$$

- Homes, improvement from 75% to 90% **underweighted** relative to improvement from 50% to 75%
- Homes, improvement from 50% to 75% **overweighted** relative to improvement from 75% to 90%
- Watershed, improvement from 75% to 90% **overweighted** relative to improvement from 50% to 75%
- Watershed, improvement from 50% to 75% **underweighted** relative to improvement from 75% to 90%



# Marginal Rates of Substitution – Expected Model

| | *homes* | *wsmod* | *wshigh* | *avhours* | *ground-days* | *duration* | *cost* |
|---|---|---|---|---|---|---|---|
| *homes* | -1 | -1.126 | -0.7193 | 2343.1 | (-18,784) | 33.40 | (-10.26) |
| *wsmod* | -0.8884 | -1 | -0.6391 | 2081.7 | -(16,689) | 29.68 | (-9.118) |
| *wshigh* | -1.390 | -1.565 | -1 | 3257.4 | (-26,114) | 46.44 | (-14.267) |
| *avhours* | 0.0004 | 0.0005 | 0.0003 | -1 | (8.017) | -0.0143 | (0.0044) |
| *grounddays* | (-5.3E-05) | (-6.0E-05) | (-3.8E-05) | (0.1247) | (-1) | (0.0018) | (-0.0005) |
| *duration* | 0.0299 | 0.0337 | 0.0215 | -70.1 | (562.4) | -1 | (0.3072) |
| *cost* | (-0.0974) | (-0.1097) | (-0.0701) | 228.3 | (-1,830) | (3.255) | (-1) |

Note: MRS values calculated from at least one coefficient having the unexpected sign are bracketed in parentheses.

# Marginal Rates of Substitution – Preferred Model

| | *homes* | *wsmod* | *wshigh* | *avhours* | *ground-days* | *duration* | *cost* |
|---|---|---|---|---|---|---|---|
| *homes* | -1 | -10.95 | -0.7101 | (-4165) | 5.1E+04 | 55.20 | **3.874** |
| *wsmod* | -0.0913 | -1 | -0.0648 | (-380.3) | 4.6E+03 | 5.040 | 0.3537 |
| *wshigh* | -1.408 | -15.42 | -1 | (-5865) | 7.2E+04 | 77.73 | 5.456 |
| *avhours* | (-0.0002) | (-0.0026) | (-0.0002) | (-1) | (1.2E+01) | (0.0133) | (0.0009) |
| *grounddays* | 2.0E-05 | 0.0002 | 1.4E-05 | (0.0814) | -1 | -0.0011 | -7.6E-05 |
| *duration* | 0.0181 | 0.1984 | 0.0129 | (75.46) | -9.27E+02 | -1 | -0.0702 |
| *cost* | 0.2581 | 2.827 | 0.1833 | (1075) | -1.3E+04 | -14.25 | -1 |

Note: MRS values calculated from at least one coefficient having the unexpected sign are bracketed in parentheses.

# Conclusions

- Suppression cost was viewed as a positive attribute under expected management response.
- Firefighter exposure did not enter decision makers' strategies in a consistent way.
- Even under preferred strategies, investment in home protection exceeded socially efficient estimates.
- Divergence between expected and preferred response indicate managers do not believe current environment lead to good outcomes.

# Future Work

- Influence of recent risk management training (firefighter safety)
- Role of low likelihood, high impact events
- Framing bias  - exposure versus probability of fatality.
- Paternalism within decision support systems????