

**TEaM**

# **Meta-analysis of elicitation results**

## **Approach and preliminary results for nuclear and solar PV**

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# Meta-analysis of elicitation data

## 1. General approach

- Meta-analysis: what is it? and why do it?
- Dependent and Independent variables

2. Example output: Nuclear  
Solar PV

3. Outstanding questions and next steps

# Approach

- Goals:**
- a. consistent elicitations across studies
  - b. inform future elicitations

1. Individual participant data (not just study results)
2. Code characteristics:
  - for elicitation approaches across studies (a)
  - across experts within studies (b)
3. Regress characteristics on elicited technology performance outcomes
  - Effects of R&D and survey characteristics
4. Produce alternative set of results controlling for differences in survey characteristics

# Dependent variables:

## *Technology performance outcomes*

### *Common denominator*

- Levelized cost: \$/MWh

### *Intermediate measures*

- Capital cost: \$/kW
- Operating cost, fuel cost
- Efficiency, energy penalty, etc.

### *Other parameters of interest*

- Cost uncertainty range:  $(p90-p10)/p50$
- Normalized cost:  $p50_{2030}/p50_{2010}$

# Independent variables

## Technology performance

- Tech sub-category
- Year of endpoint
- Probability elicited
- Metric elicited
- LEC assumptions

## R&D Investment

- Funding /year
- Funding duration
- Location of funds
- Demos included?

## Other characteristics

- Year of elicitation
- Elicitation method
- Expert affiliation type
- Expert location
- Number of experts
- Sequence of question
- Published results

# Anticipated results

## 1. Results for future elicitation design

- Descriptive statistics and coefficients

## 2. Understanding R&D production function

- Shape (increasing vs. decreasing; logistic?)
- Continuous or binned variable (low,high)  
...range, pdf

## 3. Consistent elicitation results

- Robustness checks on variation in study design
- Produce alternative set of elicitation values
- Potentially use values to generate aggregated PDFs of technology performance

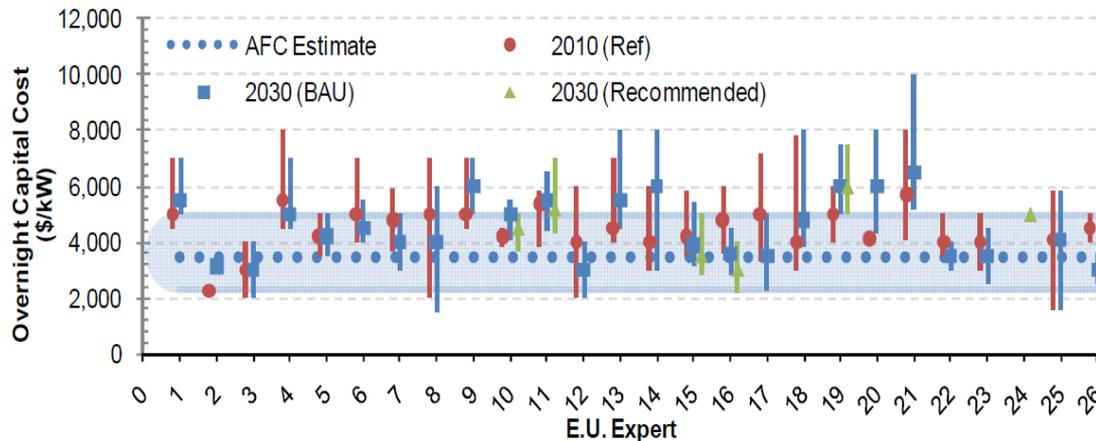
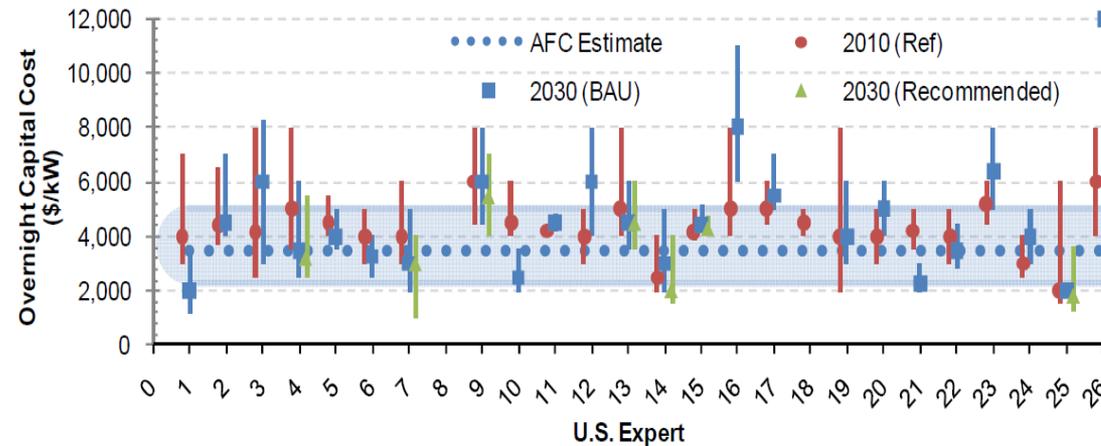
# Example:

## NUCLEAR FISSION

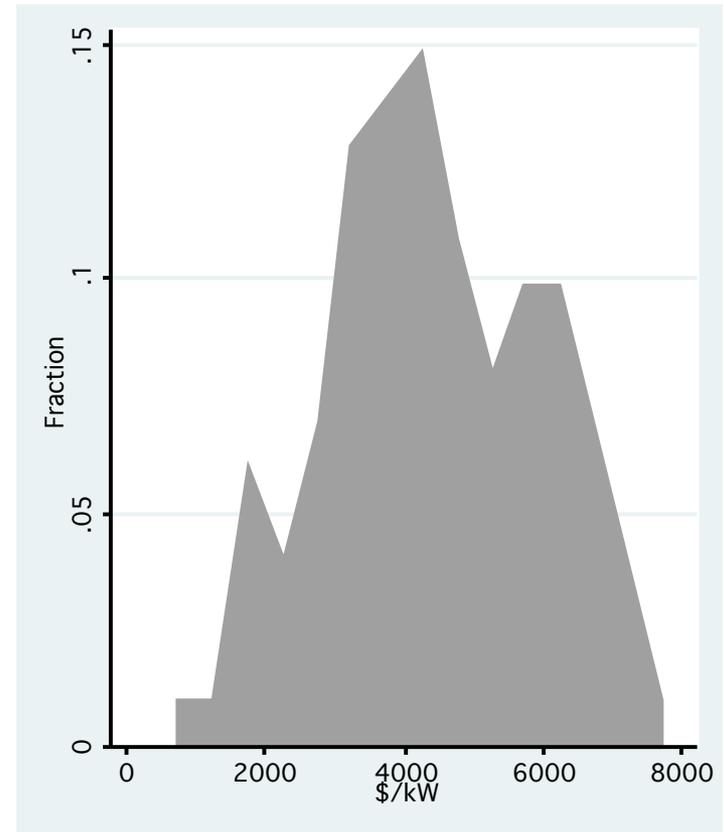
### Overnight capital costs

# Elicitation results (nuc, \$/kW):

## Large-scale Gen III/III+ designs



Anadon, Bosetti et al. (2011)



# Descriptive statistics: nuclear

| Variable  | Obs | Mean  | Std.Dev. | Min  | Max    |
|---|-----|-------|----------|------|--------|
| <b>Dependent variable, 2030 overnight capital costs (\$/kW)</b> |     |       |          |      |        |
| Median (p50)  | 393 | 4,872 | 1,816    | 506  | 14,156 |
| 10th %tile  | 389 | 3,781 | 1,548    | 253  | 11,000 |
| 90th %tile  | 389 | 6,463 | 2,389    | 758  | 20,222 |
| p50/(p50 <sub>2010</sub> )                                      | 372 | 1.15  | 0.51     | 0.22 | 4.00   |
| (p90-p10)/p50   | 389 | 0.58  | 0.31     | 0.10 | 1.83   |
| <b>Investment</b>   |     |       |          |      |        |
| R&D (\$m)   | 393 | 5,324 | 10,386   | 400  | 80,000 |
| R&D rec.  | 393 | 0.22  | 0.41     | 0    | 1      |
| R&D high  | 393 | 0.21  | 0.41     | 0    | 1      |
| <b>Elicitation characteristics</b>                              |     |       |          |      |        |
| In-person   | 393 | 0.03  | 0.16     | 0    | 1      |
| public  | 393 | 0.45  | 0.50     | 0    | 1      |
| industry  | 393 | 0.27  | 0.45     | 0    | 1      |
| USA   | 393 | 0.55  | 0.50     | 0    | 1      |
| PRONUKE   | 393 | 0.07  | 0.25     | 0    | 1      |
| Gen IV  | 393 | 0.38  | 0.49     | 0    | 1      |
| SMR   | 393 | 0.36  | 0.48     | 0    | 1      |

*Includes results for: FEEM (2011), Harvard (2010), and CMU (2011).*

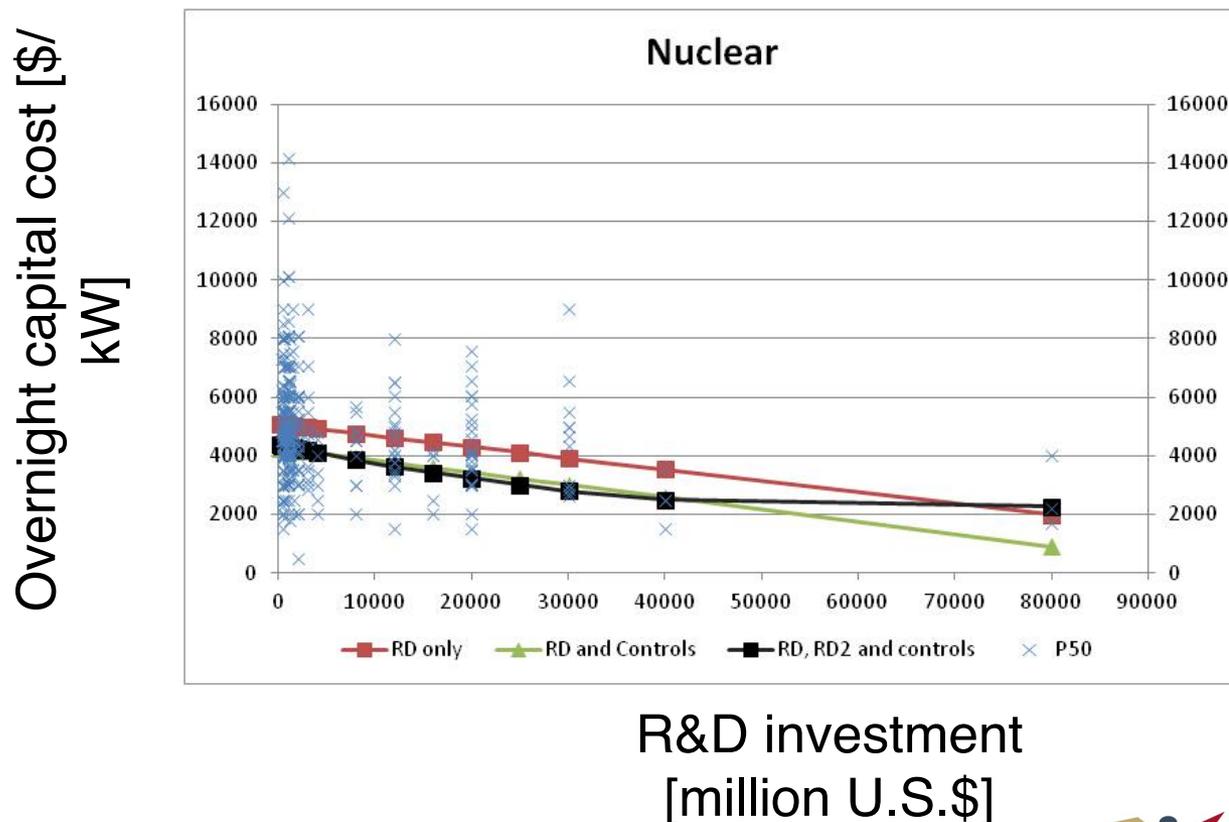
# Estimates of effects on median cost of nuclear

|  | 1                     | 2                     | 3                    |
|--|-----------------------|-----------------------|----------------------|
|  | R&D                   | R&D <sup>2</sup>      | R&D bins             |
| <b>Investment</b>                            |                       |                       |                      |
| R&D  | -0.0388***<br>[-5.36] | -0.0535***<br>[-3.43] |                      |
| R&D <sup>2</sup>                             |                       | 2.92e-07<br>[1.31]    |                      |
| R&D rec.                                     |                       |                       | -485.7**<br>[-2.22]  |
| R&D high                                     |                       |                       | -983.8***<br>[-4.69] |
| <b>Expert and technology characteristics</b> |                       |                       |                      |
| in-person                                    |                       |                       |                      |
| public                                       |                       |                       |                      |
| industry                                     |                       |                       |                      |
| USA  |                       |                       |                      |
| PRONUKE                                      |                       |                       |                      |
| Gen IV                                       |                       |                       |                      |
| SMR  |                       |                       |                      |
| Constant                                     | 5,078***              | 5,117***              | 5,179***             |
| Observations                                 | 393                   | 393                   | 393                  |
| Adjusted R <sup>2</sup>                      | 0.047                 | 0.047                 | 0.042                |

Robust t-statistics in brackets

# Example nuclear: effect of R&D

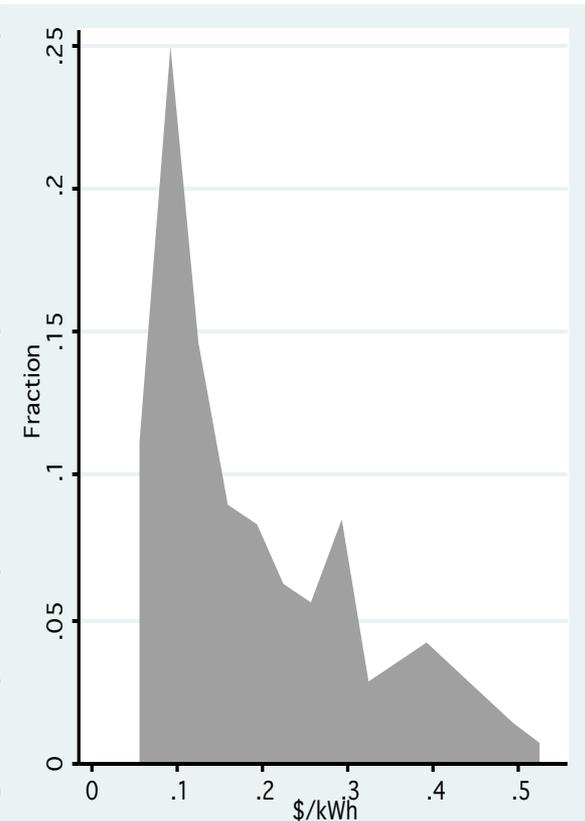
1. *R&D + constant* [model #1]
2. *R&D + controls + constant* [model #4]
3. *R&D + R&D<sup>2</sup> + controls + constant* [model #5]



# SOLAR PV

# Descriptive stats: Solar PV

| Variable  | Obs | Mean  | Std.Dev. | Min   | Max    |
|---|-----|-------|----------|-------|--------|
| <b>Dependent variable, 2030 levelized electricity cost (\$/kWh)</b> |     |       |          |       |        |
| Median (p50)  | 144 | 0.178 | 0.107    | 0.040 | 0.540  |
| 10th %tile  | 144 | 0.147 | 0.099    | 0.026 | 0.480  |
| 90th %tile  | 144 | 0.225 | 0.120    | 0.060 | 0.660  |
| (p90-p10)/p50   | 144 | 0.547 | 0.339    | 0.091 | 1.771  |
| <b>Investment</b>   |     |       |          |       |        |
| R&D (\$m)   | 186 | 926   | 1,737    | 25    | 10,000 |
| R&D rec.  | 186 | 0.18  | 0.38     | 0     | 1      |
| R&D high  | 186 | 0.18  | 0.38     | 0     | 1      |
| <b>Elicitation characteristics</b>                                  |     |       |          |       |        |
| inperson  | 186 | 0.29  | 0.46     | 0     | 1      |
| public  | 186 | 0.34  | 0.47     | 0     | 1      |
| industry  | 186 | 0.47  | 0.50     | 0     | 1      |
| USA   | 186 | 0.76  | 0.43     | 0     | 1      |
| Commercial  | 186 | 0.24  | 0.43     | 0     | 1      |
| Utility   | 186 | 0.49  | 0.50     | 0     | 1      |



*Includes results for: UMass (2007), FEEM (2011), Harvard (2010).*

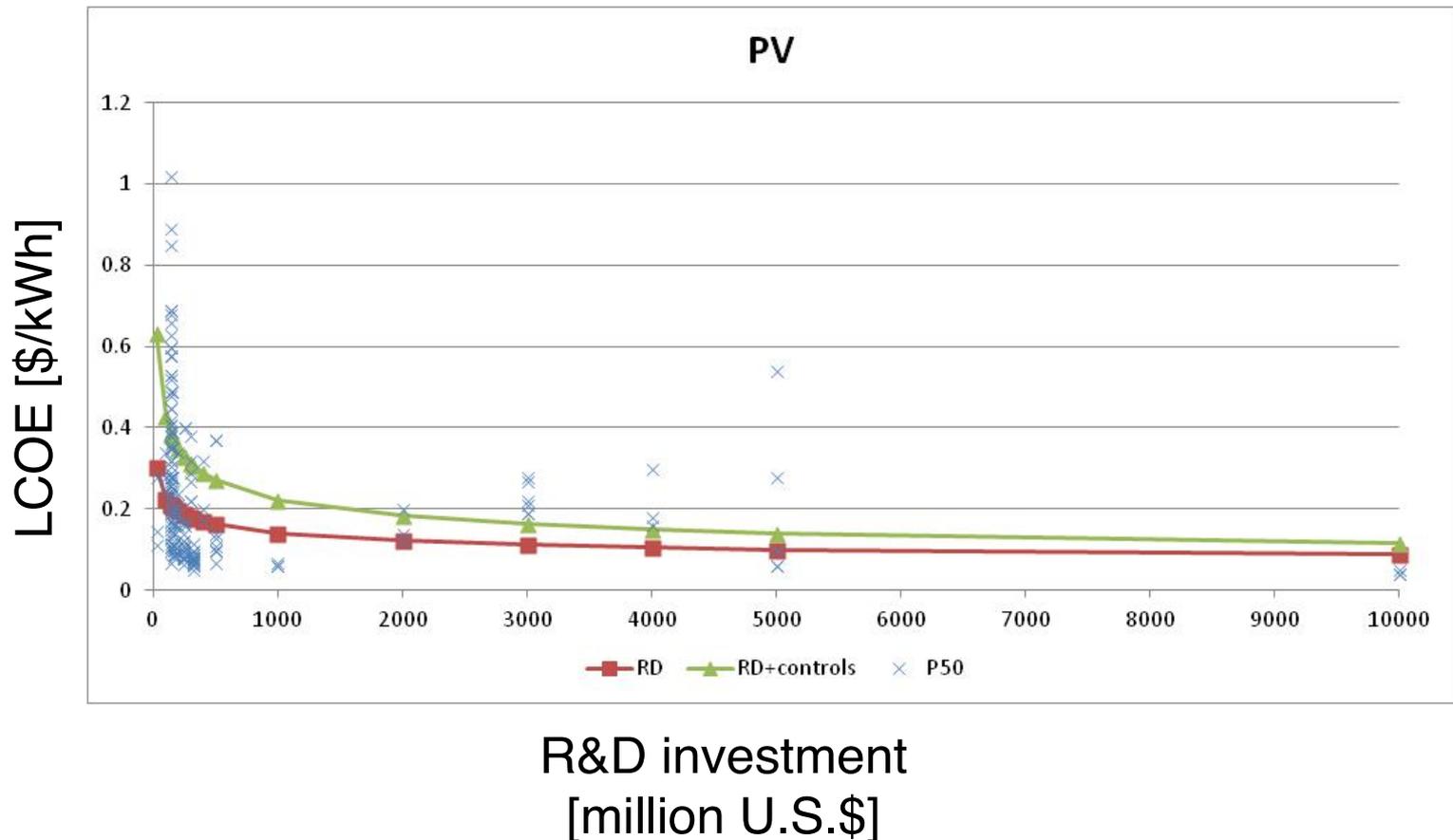
# Estimates of effects on median cost of PV

| Y=<br>lnP50                        | 1                    | 2                 | 3                  |
|------------------------------------|----------------------|-------------------|--------------------|
|                                    | R&D                  | R&D <sup>2</sup>  | R&D bins           |
| <b>Investment</b>                  |                      |                   |                    |
| ln(R&D)                            | -0.207***<br>[-4.17] | -0.781<br>[-1.42] |                    |
| ln(R&D) <sup>2</sup>               |                      | 0.0441<br>[1.05]  |                    |
| R&D rec.                           |                      |                   | -0.0538<br>[-0.38] |
| R&D high                           |                      |                   | -0.290*<br>[-1.72] |
| <b>Elicitation characteristics</b> |                      |                   |                    |
| in-person                          |                      |                   |                    |
| public                             |                      |                   |                    |
| industry                           |                      |                   |                    |
| USA                                |                      |                   |                    |
| Utility                            |                      |                   |                    |
| Constant                           | -0.533*              | 1.244             | -1.661***          |
| Observations                       | 171                  | 171               | 171                |
| Adjusted R <sup>2</sup>            | 0.099                | 0.104             | 0.005              |
| Robust t-statistics in brackets    |                      |                   | *** p<0.01, **     |

*Includes results for: UMass (2007), FEEM (2011), Harvard (2010).*

# Example results: effect of R&D

1. *R&D + constant* [model #1]
2. *R&D + controls + constant* [model #4]



# Insights for future elicitations?

*Only preliminary results...*

*...some hypotheses to look at:*

- Affiliation might matter:  
Industry (pessimistic), academic (least)?
- U.S. experts generally predict lower costs
- Be careful about mode of survey:  
optimism for “in-person”?
- R&D scenarios might benefit from:  
filling between modes,  
frame as low/medium/high

# Open questions

1. R&D continuous or as dummies?
2. Clarify tech. specificity: in R&D vs in Outcomes
3. R&D functional form: Linear, quadratic, logistic
4. Estimating the full 90th-10th distribution
  - percentile dummies
  - Separate regressions
  - $y = \text{variation } (p_{90} - p_{10}) / p_{50}$
  - Quantile regressions for  $p_{90}$  and  $p_{10}$

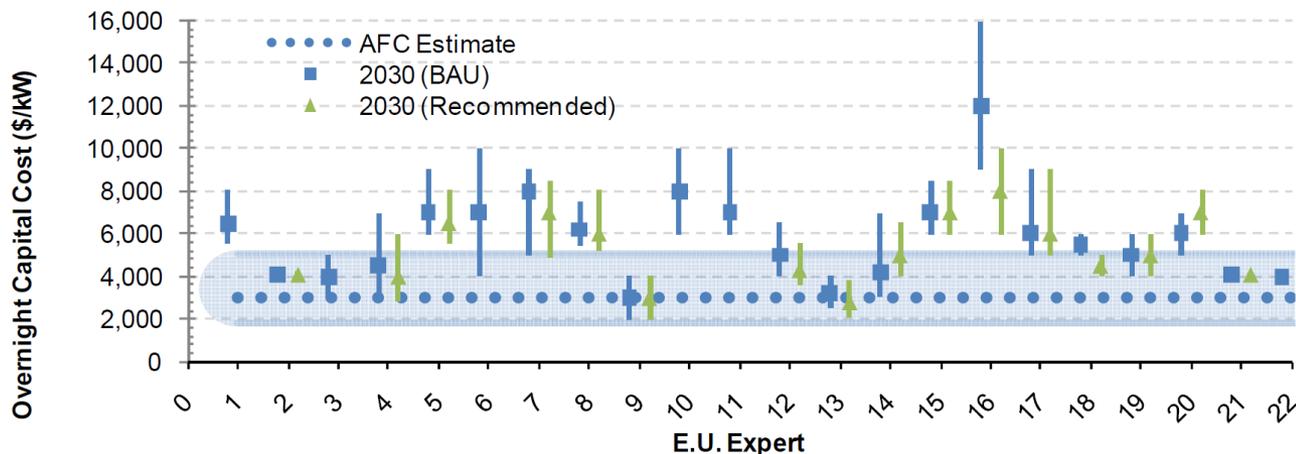
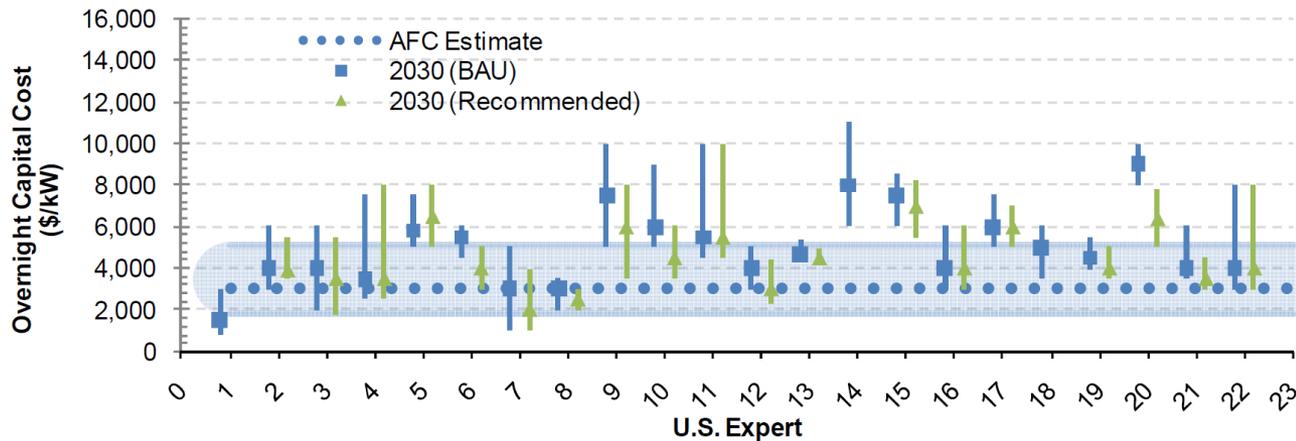
# Next steps

1. **Clean data for more studies and technologies**
2. R&D as depreciating knowledge stock
3. Expert fixed effects
4. Investigate R&D effect: dummies, form
5. Incorporate distribution of results
6. Compare aggregated distributions with adjusted data to aggregated PDF with original data

# APPENDIX

# Example results (nuc, \$/kW): original elicitation results for 2 similar studies

## Large-scale Gen IV designs



Anadon, Bosetti et al. (2011)

# Estimates of effects on normalized cost of nuclear

|  | 1            | 2                | 3         | 4                              | 5                | 6         |
|--|--------------|------------------|-----------|--------------------------------|------------------|-----------|
|  | R&D          | R&D <sup>2</sup> | R&D bins  | with expert controls           |                  |           |
|  | R&D          | R&D <sup>2</sup> | R&D bins  | R&D                            | R&D <sup>2</sup> | R&D bins  |
| <b>Investment</b>                            |              |                  |           |                                |                  |           |
| R&D  | -7.24e-06*** | -1.55e-05***     |           | -8.12e-06***                   | -1.83e-05***     |           |
|  | [-2.90]      | [-3.31]          |           | [-3.16]                        | [-4.11]          |           |
| R&D <sup>2</sup>                             |              | 1.62e-10**       |           |                                | 2.01e-10***      |           |
|  |              | [2.11]           |           |                                | [2.95]           |           |
| R&D rec.                                     |              |                  | -0.121*   |                                |                  | -0.169*** |
|  |              |                  | [-1.92]   |                                |                  | [-2.78]   |
| R&D high                                     |              |                  | -0.220*** |                                |                  | -0.268*** |
|  |              |                  | [-3.26]   |                                |                  | [-4.11]   |
| <b>Expert and technology characteristics</b> |              |                  |           |                                |                  |           |
| in-person                                    |              |                  |           | 0.0758                         | 0.0956**         | 0.0890*   |
|  |              |                  |           | [1.57]                         | [2.03]           | [1.93]    |
| public                                       |              |                  |           | 0.184***                       | 0.171***         | 0.163***  |
|  |              |                  |           | [4.27]                         | [4.03]           | [3.96]    |
| industry                                     |              |                  |           | 0.308***                       | 0.311***         | 0.321***  |
|  |              |                  |           | [4.38]                         | [4.43]           | [4.56]    |
| USA  |              |                  |           | 0                              | 0                | 0         |
|  |              |                  |           | [.]                            | [.]              | [.]       |
| PRONUKE                                      |              |                  |           | -0.0747                        | -0.0893          | -0.103    |
|  |              |                  |           | [-0.95]                        | [-1.16]          | [-1.35]   |
| Gen IV                                       |              |                  |           | 0.236***                       | 0.249***         | 0.265***  |
|  |              |                  |           | [5.68]                         | [5.99]           | [6.32]    |
| SMR  |              |                  |           | 0.298***                       | 0.310***         | 0.326***  |
|  |              |                  |           | [4.83]                         | [5.03]           | [5.25]    |
| Constant                                     | 1.189***     | 1.211***         | 1.222***  | 0.799***                       | 0.814***         | 0.829***  |
| Observations                                 | 372          | 372              | 372       | 372                            | 372              | 372       |
| Adjusted R <sup>2</sup>                      | 0.020        | 0.026            | 0.026     | 0.112                          | 0.123            | 0.130     |
| Robust t-statistics in brackets              |              |                  |           | *** p<0.01, ** p<0.05, * p<0.1 |                  |           |

# Estimates of effects on variation in cost of nuclear

|                                    | 1         | 2                | 3        | 4                              | 5                | 6         |
|------------------------------------|-----------|------------------|----------|--------------------------------|------------------|-----------|
|                                    | R&D       | R&D <sup>2</sup> | R&D bins | with expert controls           |                  |           |
|                                    | R&D       | R&D <sup>2</sup> | R&D bins | R&D                            | R&D <sup>2</sup> | R&D bins  |
| <b>Investment</b>                  |           |                  |          |                                |                  |           |
| R&D                                | 3.22e-06* | 2.10e-08         |          | 2.80e-06                       | 1.50e-06         |           |
|                                    | [1.71]    | [0.01]           |          | [1.60]                         | [0.44]           |           |
| R&D <sup>2</sup>                   |           | 6.35e-11         |          |                                | 0                |           |
|                                    |           | [1.05]           |          |                                | [0.45]           |           |
| R&D rec.                           |           |                  | 0.00716  |                                |                  | 0.0104    |
|                                    |           |                  | [0.18]   |                                |                  | [0.27]    |
| R&D high                           |           |                  | 0.00107  |                                |                  | 0.00268   |
|                                    |           |                  | [0.02]   |                                |                  | [0.06]    |
| <b>Elicitation characteristics</b> |           |                  |          |                                |                  |           |
| in-person                          |           |                  |          | -0.171*                        | -0.173*          | -0.179*   |
|                                    |           |                  |          | [-1.73]                        | [-1.74]          | [-1.81]   |
| public                             |           |                  |          | 0.0935**                       | 0.0919**         | 0.103**   |
|                                    |           |                  |          | [2.23]                         | [2.18]           | [2.43]    |
| industry                           |           |                  |          | -0.00625                       | -0.00587         | -0.00716  |
|                                    |           |                  |          | [-0.14]                        | [-0.13]          | [-0.16]   |
| USA                                |           |                  |          | 0.0408                         | 0.0366           | 0.0384    |
|                                    |           |                  |          | [0.39]                         | [0.35]           | [0.37]    |
| PRONUKE                            |           |                  |          | 0.267***                       | 0.265***         | 0.269***  |
|                                    |           |                  |          | [4.50]                         | [4.45]           | [4.57]    |
| Gen IV                             |           |                  |          | -0.0332                        | -0.0317          | -0.0305   |
|                                    |           |                  |          | [-0.85]                        | [-0.81]          | [-0.76]   |
| SMR                                |           |                  |          | -0.0806**                      | -0.0792**        | -0.0785** |
|                                    |           |                  |          | [-2.09]                        | [-2.03]          | [-1.97]   |
| Constant                           | 0.567***  | 0.576***         | 0.583*** | 0.611***                       | 0.617***         | 0.622***  |
| Observations                       | 389       | 389              | 389      | 389                            | 389              | 389       |
| Adjusted R <sup>2</sup>            | 0.009     | 0.010            | -0.005   | 0.082                          | 0.080            | 0.071     |
| Robust t-statistics in brackets    |           |                  |          | *** p<0.01, ** p<0.05, * p<0.1 |                  |           |

# Estimates of effects on median cost of PV

| Y=<br>P50                          | 1                       | 2                    | 3                              | 4                       | 5                       | 6                    |
|------------------------------------|-------------------------|----------------------|--------------------------------|-------------------------|-------------------------|----------------------|
|                                    | R&D                     | R&D <sup>2</sup>     | R&D bins                       | with expert controls    |                         |                      |
|                                    |                         |                      |                                | R&D                     | R&D <sup>2</sup>        | R&D bins             |
| <b>Investment</b>                  |                         |                      |                                |                         |                         |                      |
| R&D                                | -1.96e-05***<br>[-3.97] | -2.64e-05<br>[-1.62] |                                | -3.27e-05***<br>[-6.00] | -5.56e-05***<br>[-3.37] |                      |
| R&D <sup>2</sup>                   |                         | 8.75e-10<br>[0.58]   |                                |                         | 2.91e-09*<br>[1.85]     |                      |
| R&D rec.                           |                         |                      | -0.0424<br>[-1.48]             |                         |                         | -0.144***<br>[-4.59] |
| R&D high                           |                         |                      | -0.0734**<br>[-2.38]           |                         |                         | -0.175***<br>[-5.21] |
| <b>Elicitation characteristics</b> |                         |                      |                                |                         |                         |                      |
| in-person                          |                         |                      |                                | -0.177***<br>[-5.70]    | -0.181***<br>[-5.75]    | -0.200***<br>[-6.06] |
| public                             |                         |                      |                                | -0.0152<br>[-0.61]      | -0.0120<br>[-0.48]      | 0.00152<br>[0.06]    |
| industry                           |                         |                      |                                | 0.00483<br>[0.18]       | 0.00627<br>[0.23]       | 0.00836<br>[0.31]    |
| USA                                |                         |                      |                                | -0.0292<br>[-0.96]      | -0.0305<br>[-1.01]      | -0.0208<br>[-0.70]   |
| Utility                            |                         |                      |                                | -0.102***<br>[-3.49]    | -0.102***<br>[-3.50]    | -0.103***<br>[-3.62] |
| Constant                           | 0.252***                | 0.254***             | 0.251***                       | 0.392***                | 0.400***                | 0.402***             |
| Observations                       | 171                     | 171                  | 171                            | 171                     | 171                     | 171                  |
| Adjusted R <sup>2</sup>            | 0.027                   | 0.021                | 0.009                          | 0.342                   | 0.344                   | 0.377                |
| Robust t-statistics in brackets    |                         |                      | *** p<0.01, ** p<0.05, * p<0.1 |                         |                         |                      |

*Includes results for: UMass (2007), FEEM (2011), Harvard (2010).*

# Estimates of effects on variation in cost of PV

| Y=                                 | 1                  | 2                    | 3                              | 4                     | 5                   | 6                   |
|------------------------------------|--------------------|----------------------|--------------------------------|-----------------------|---------------------|---------------------|
| Urange                             | R&D                | R&D <sup>2</sup>     | R&D bins                       | with expert controls  |                     |                     |
|                                    | R&D                | R&D <sup>2</sup>     | R&D bins                       | R&D                   | R&D <sup>2</sup>    | R&D bins            |
| <b>Investment</b>                  |                    |                      |                                |                       |                     |                     |
| R&D                                | 9.26e-06<br>[0.76] | -3.36e-05<br>[-0.83] |                                | 2.86e-05***<br>[2.69] | 1.72e-05<br>[0.45]  |                     |
| R&D <sup>2</sup>                   |                    | 5.52e-09<br>[1.43]   |                                |                       | 1.45e-09<br>[0.40]  |                     |
| R&D rec.                           |                    |                      | -0.0982<br>[-1.55]             |                       |                     | 0.0487<br>[0.84]    |
| R&D high                           |                    |                      | -0.0910<br>[-1.18]             |                       |                     | 0.0558<br>[0.77]    |
| <b>Elicitation characteristics</b> |                    |                      |                                |                       |                     |                     |
| in-person                          |                    |                      |                                | 0.168*<br>[1.88]      | 0.166*<br>[1.85]    | 0.163*<br>[1.82]    |
| public                             |                    |                      |                                | -0.182**<br>[-2.10]   | -0.181**<br>[-2.06] | -0.186**<br>[-2.11] |
| industry                           |                    |                      |                                | -0.0837<br>[-1.13]    | -0.0829<br>[-1.11]  | -0.0769<br>[-1.03]  |
| USA                                |                    |                      |                                | -0.137<br>[-1.36]     | -0.138<br>[-1.36]   | -0.142<br>[-1.40]   |
| Utility                            |                    |                      |                                | 0.0342<br>[0.73]      | 0.0343<br>[0.73]    | 0.0341<br>[0.71]    |
| Constant                           | 0.513***           | 0.527***             | 0.543***                       | 0.624***              | 0.628***            | 0.635***            |
| Observations                       | 171                | 171                  | 171                            | 171                   | 171                 | 171                 |
| Adjusted R <sup>2</sup>            | -0.004             | -0.002               | 0.004                          | 0.224                 | 0.220               | 0.202               |
| Robust t-statistics in brackets    |                    |                      | *** p<0.01, ** p<0.05, * p<0.1 |                       |                     |                     |

# New table comparing our R&D elasticities to existing

- Ours
- Macro results
- 2F LC results