

# Value of Flexibility in Irrigation Projects

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**ANJULI JAIN FIGUEROA**

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**ESD. 710**

# Outline

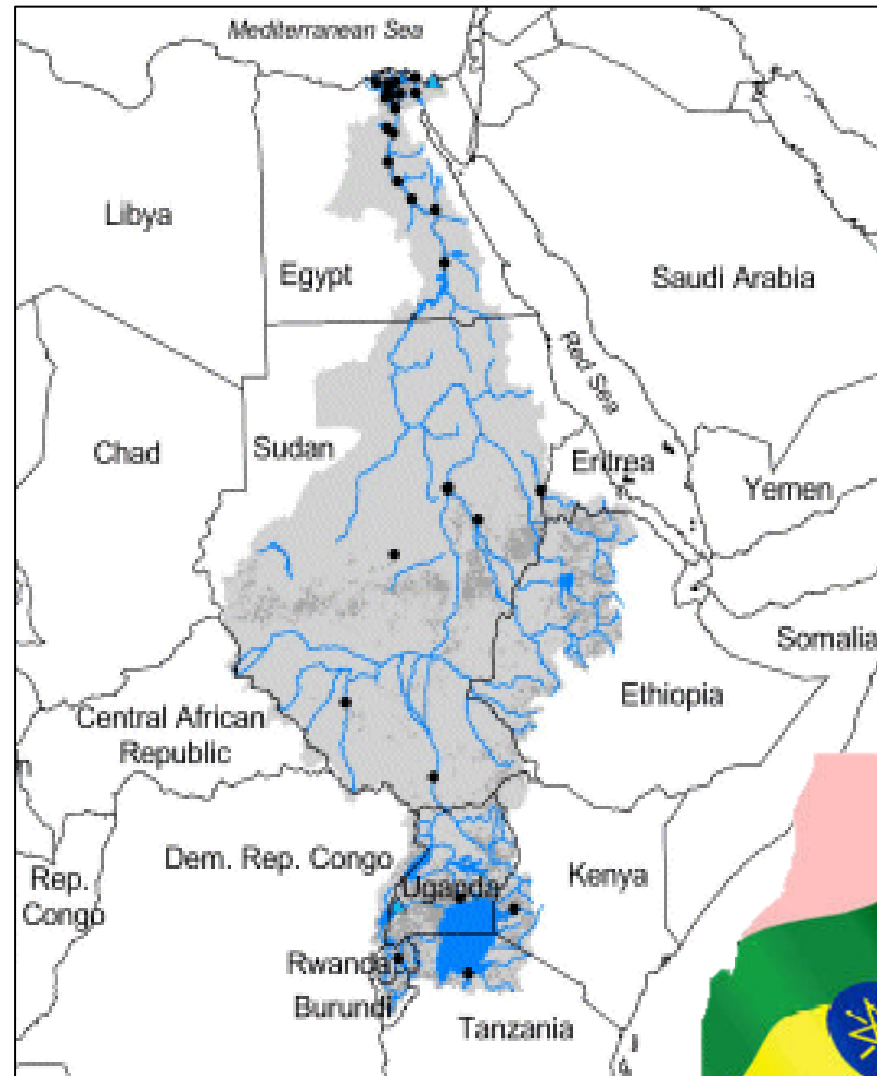
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- Big Picture
- AP6 Scope and Assumptions
- Deterministic
- Accounting For Uncertainty
- Incorporating Flexibility

## The Big Picture

- **Nile Basin Initiative:** 10 countries disputing Nile waters
- Ethiopia vs. Egypt
- **Ethiopian Irrigation Drainage Project** -feasibility study for an 80,000ha irrigation plan
- **Goal:** mutually beneficial solution >> food security, drought prevention, agricultural productivity

## Nile Basin-



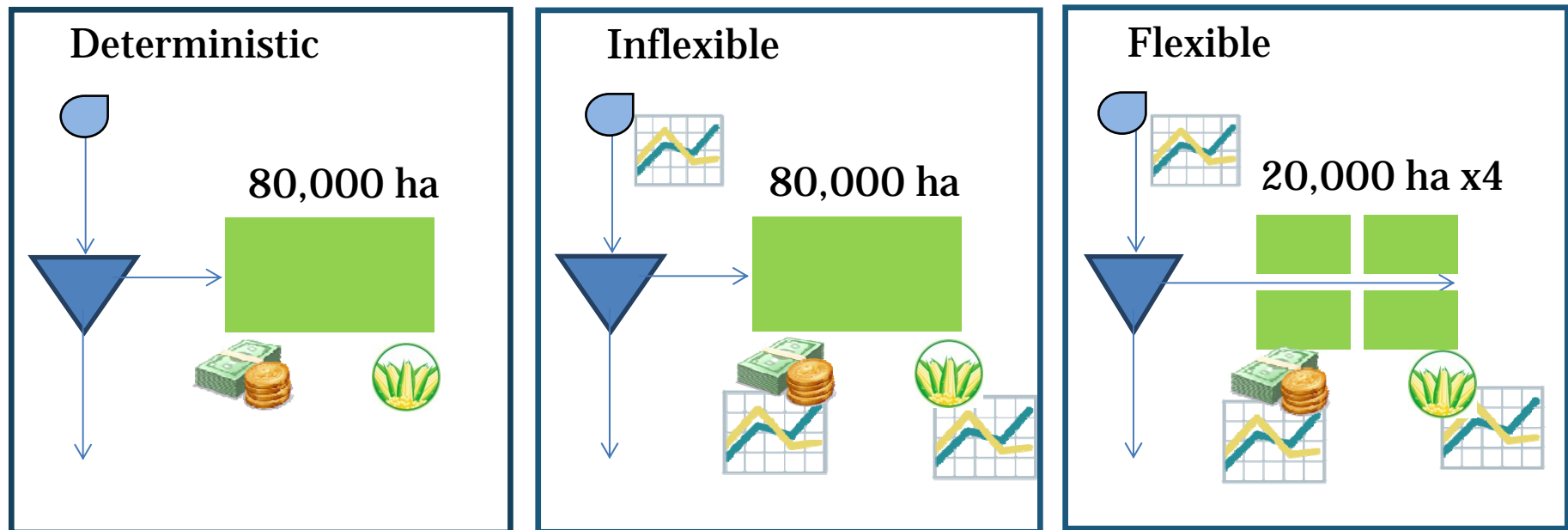
<http://www.ess.co.at/WATERWARE/NILE/background.html>



# Project Scope

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Compare big and small irrigations projects on basis of ENPV,  $P(<0)$ , range, 5% and 95% and B/C ratio



## Key

 Variable/Stochastic

 Crop Yield

 Reservoir

 Water Flow

 Crop Price

 Irrigation Plot

# Simplifying Assumptions

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|                      |                 |
|----------------------|-----------------|
| <b>Crop</b>          | <b>Corn</b>     |
| <b>Time horizon</b>  | <b>20 years</b> |
| <b>Discount rate</b> | <b>12%</b>      |

## **Irrigation Project Costs**

|                                     |                    |
|-------------------------------------|--------------------|
| <b>Land Lease</b>                   | <b>\$8.15/ha</b>   |
| <b>Fixed Irrigation System Cost</b> | <b>\$419.90/ha</b> |
| <b>O&amp;M Irrigation System</b>    | <b>\$30.88/ha</b>  |
| <b>Cost of Crop Production</b>      | <b>\$40/ha</b>     |

\*If the average change in water level in the past 2 years is negative then the corn yield will decrease at a rate of 0.9% for every 1% decrease in water level

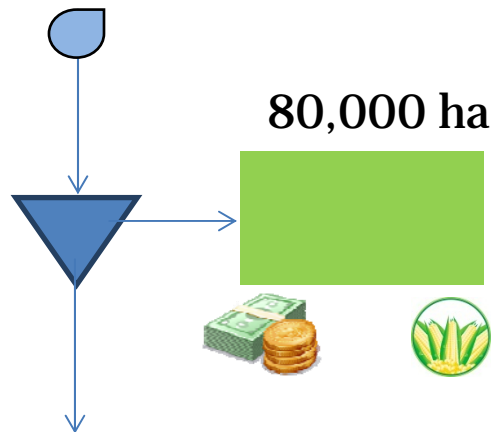
\*Uncertainties sampled from historical data's fitted distributions



# Deterministic

| DETERMINISTIC                                             | Year        | 0 | 1              | 2              | 3              | 4               | 5...           | 19             | 20             |
|-----------------------------------------------------------|-------------|---|----------------|----------------|----------------|-----------------|----------------|----------------|----------------|
| Avg Monthly Water Level (MCM)                             |             |   | 4805           | 4805           | 4805           | 4805            | 4805           | 4805           | 4805           |
| Demand for Ethiopia (MT corn)                             |             |   | 1558000        | 1589160        | 1620943        | 1653362         | 1686429        | 2225208        | 2269712        |
| Price of Corn (\$/MT)                                     |             |   | 116            | 116            | 116            | 116             | 116            | 116            | 116            |
| Production (MT corn/ha)                                   |             |   | 1.4            | 1.4            | 1.4            | 1.4             | 1.4            | 1.4            | 1.4            |
| Land Size (ha)                                            |             |   | 80000          | 80000          | 80000          | 80000           | 80000          | 80000          | 80000          |
| Total Yield (MT corn)                                     |             |   | 112000         | 112000         | 112000         | 112000          | 112000         | 112000         | 112000         |
| Revenue                                                   |             |   | 12992000       | 12992000       | 12992000       | 12992000        | 12992000       | 12992000       | 12992000       |
| Fixed Irr. System Cost (US \$ 419.5/ha)                   | 33592000.00 |   |                |                |                |                 |                |                |                |
| Land Lease Cost (US \$ 8.15/ha)                           |             |   | 652000         | 652000         | 652000         | 652000          | 652000         | 652000         | 652000         |
| Variable Irr. Cost (US \$ 30.88/ha)                       |             |   | 1976329        | 1976329        | 1976329        | 1976329         | 1976329        | 1976329        | 1976329        |
| Cost of Production (fertilizer, seeds, labor, \$US 40/ha) |             |   | 3200000        | 3200000        | 3200000        | 3200000         | 3200000        | 3200000        | 3200000        |
| <b>Cash Flow</b>                                          |             |   | <b>7163671</b> | <b>7163671</b> | <b>7163671</b> | <b>7163671</b>  | <b>7163671</b> | <b>7163671</b> | <b>7163671</b> |
| DCF                                                       | 0.12        |   | 53508639.32    |                |                |                 |                |                |                |
| NPV                                                       |             |   | \$19,916,639   |                | Average        | \$19,916,639.32 |                |                |                |
| B/C                                                       |             |   | 1.59           |                | p(<=0)         | 0.00            |                |                |                |

## Deterministic



## Deterministic Inputs

|                         |            |
|-------------------------|------------|
| Average corn price      | \$116/MT   |
| Average demand          | 1558 MT/ha |
| Average flow            | 4805 MCM   |
| Average corn production | 1.4 MT/ha  |

## Deterministic Output

|        |                 |
|--------|-----------------|
| NPV    | \$19.92 Million |
| P(<=0) | 0               |

# Accounting For Uncertainty

## -Forecasting by Sampling Distributions-

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**WATER INPUT**

**CROP PRICE**

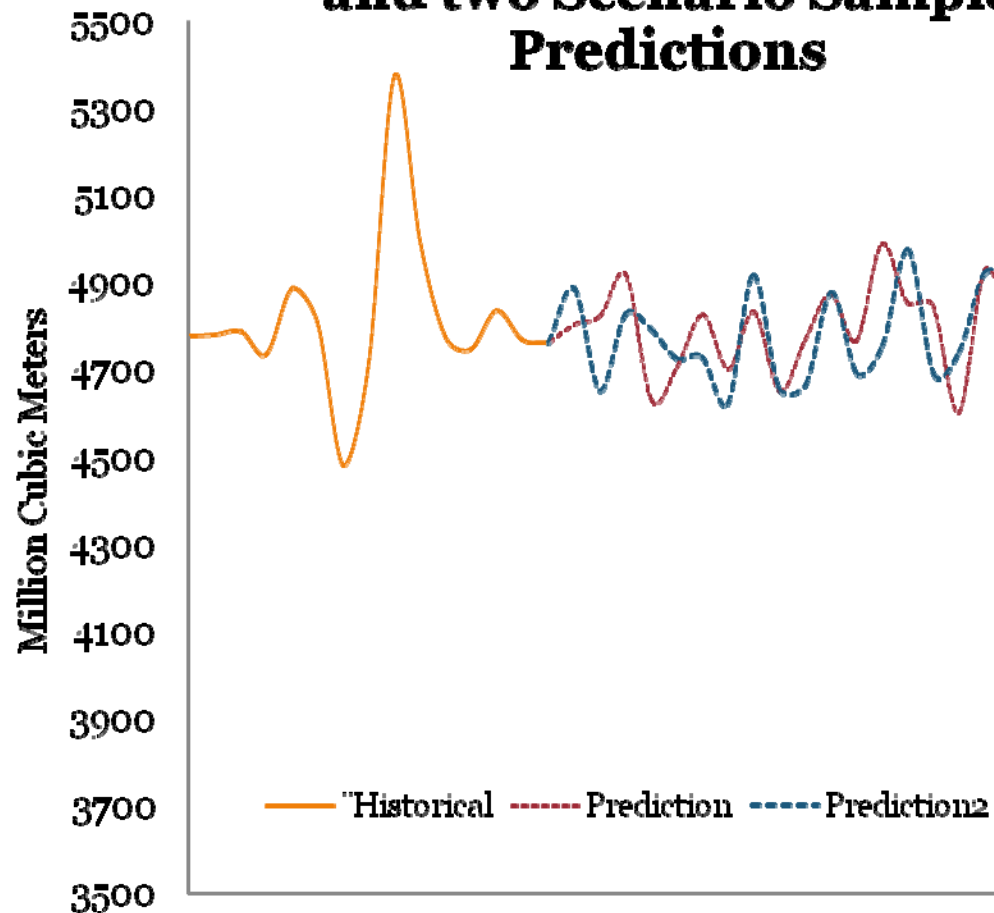
**CORN DEMAND**

**CORN YIELD**

**INFLEXIBLE DESIGN**

# Water Input

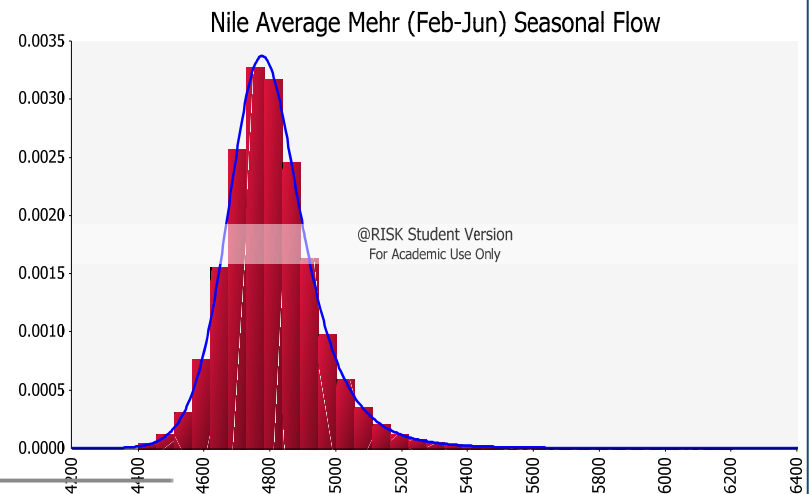
**Figure 13: Average Historical Flow for Mehr (Feb-Jun) Crop Season and two Scenario Sample Predictions**



Sample from  
Log logistic Distribution

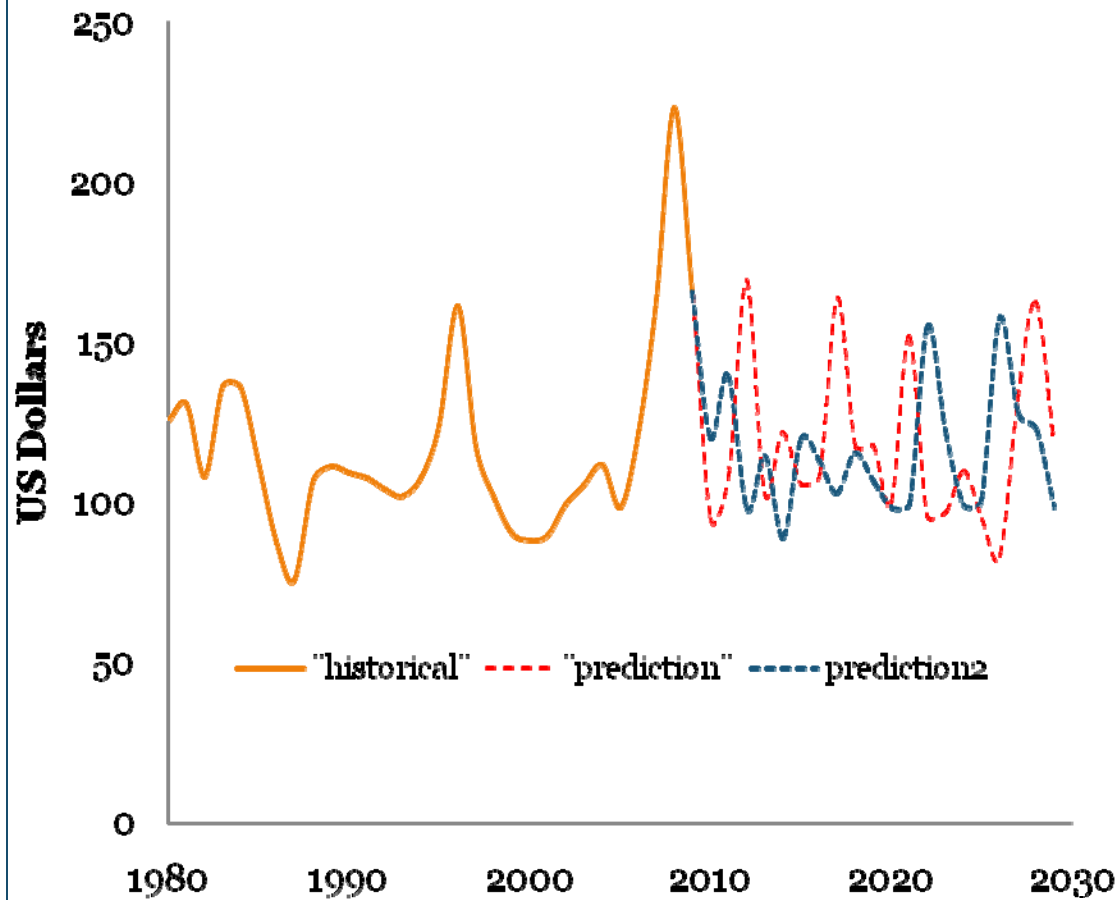
Mean 4806

St Dev. 142



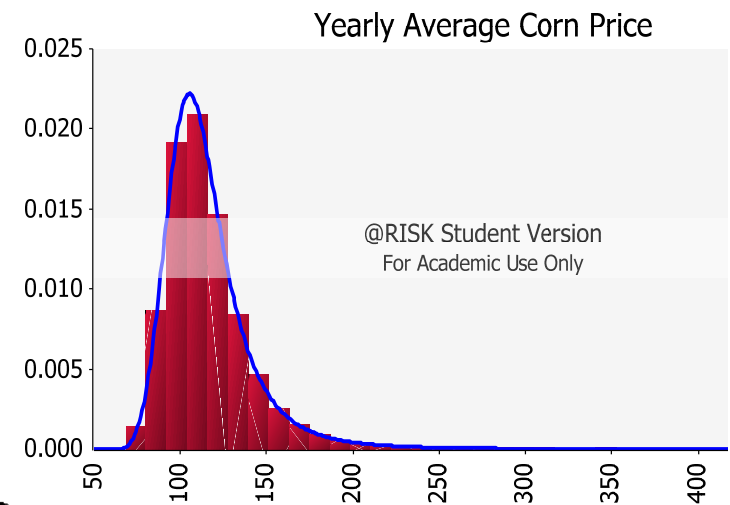
# Crop Price

## Average Yearly Historical Corn Price



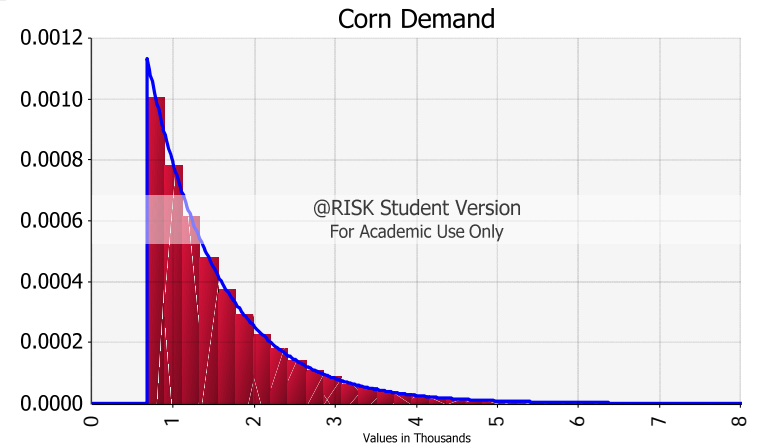
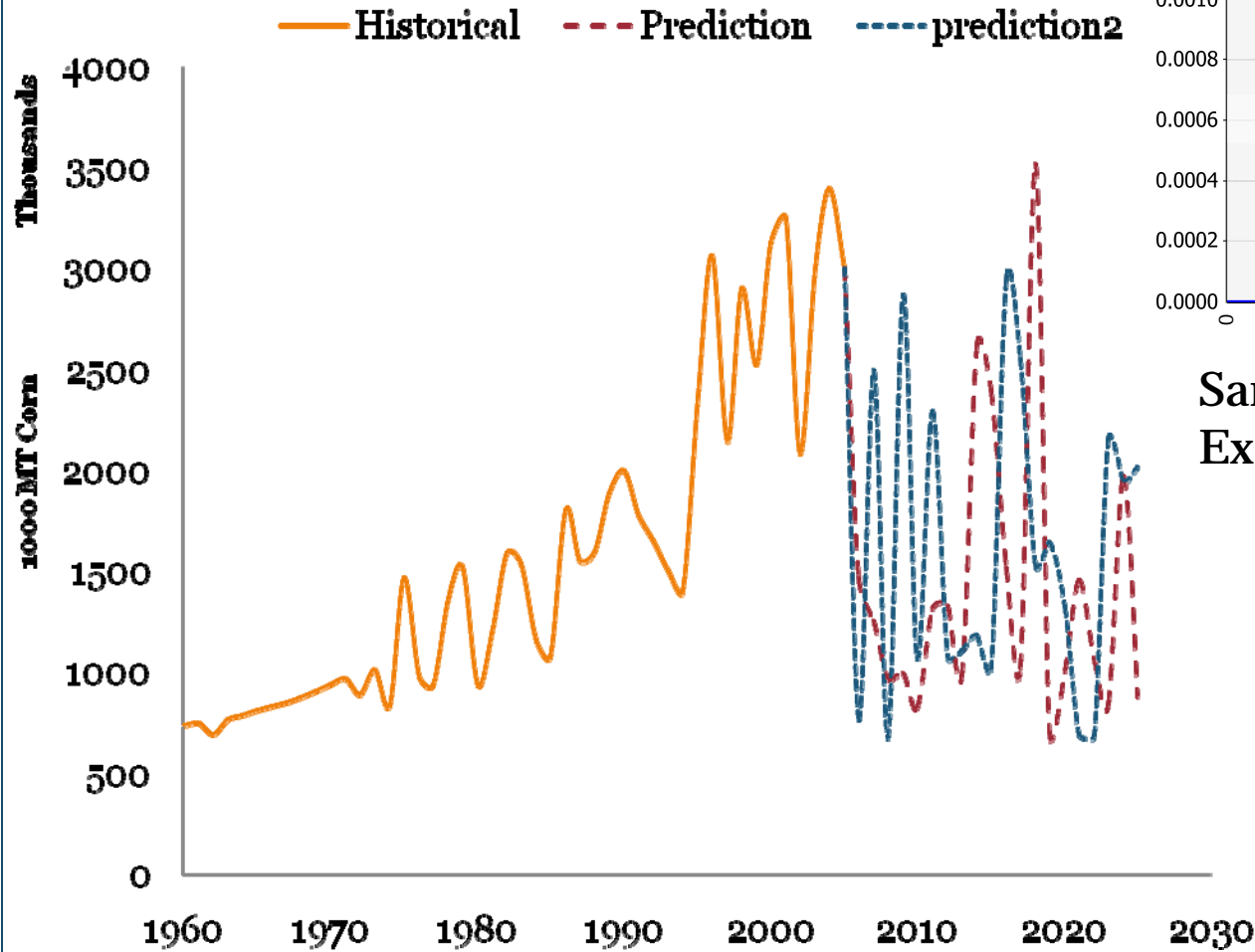
Sample from  
Log logistic Distribution

|         |      |
|---------|------|
| Mean    | 116  |
| St Dev. | 27.8 |



# Corn Demand

## Demand for Ethiopian Corn Historical & Example Prediction



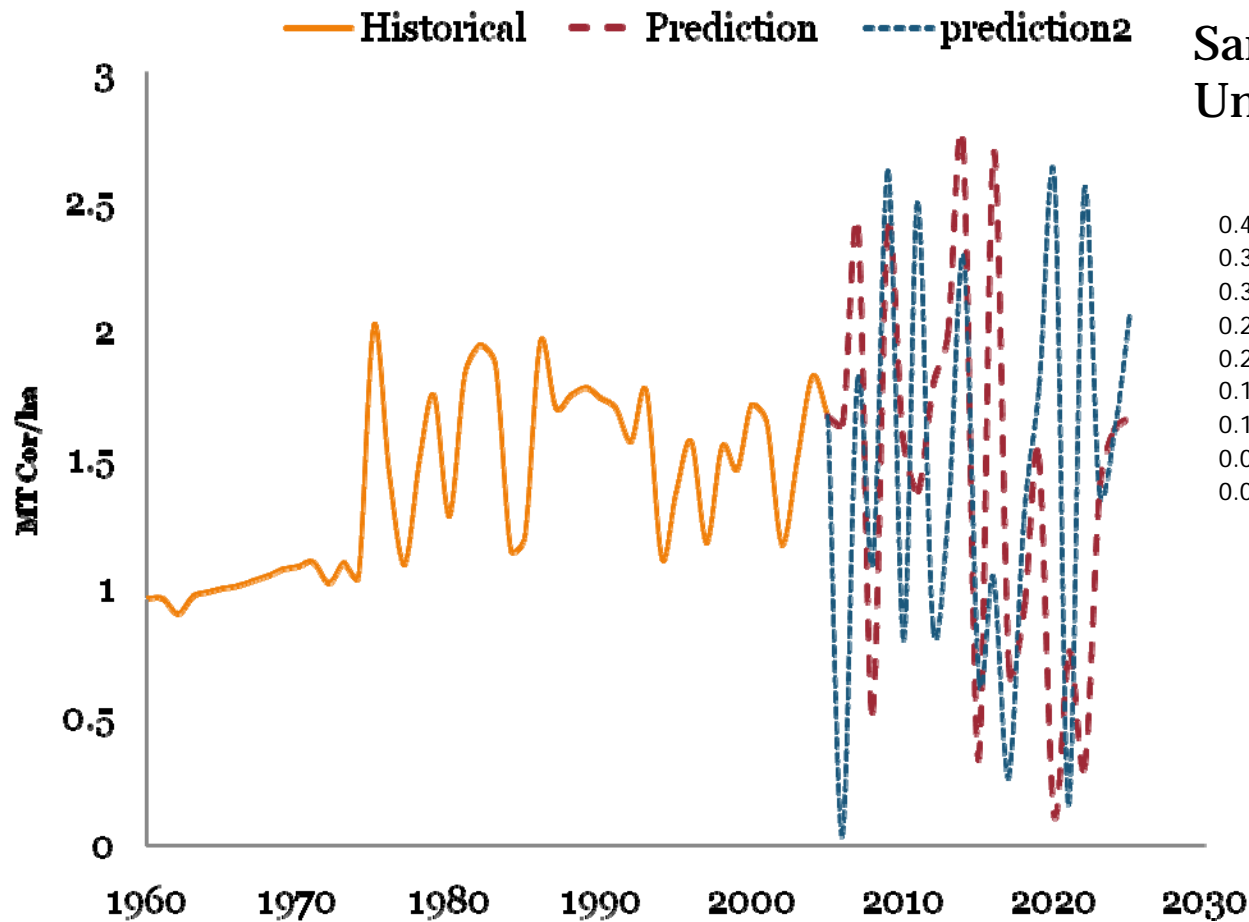
### Sample from Exponential Distribution

|         |      |
|---------|------|
| Mean    | 1558 |
| St Dev. | 882  |

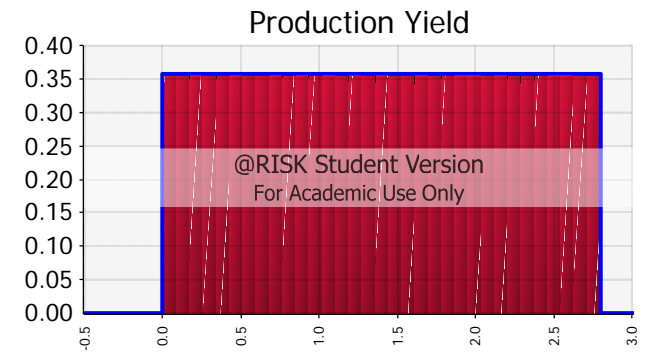
\* Ignored trend

# Corn Production Yield

**Figure 11: Corn Yield Historical and Two Scenario Sample Predictions**



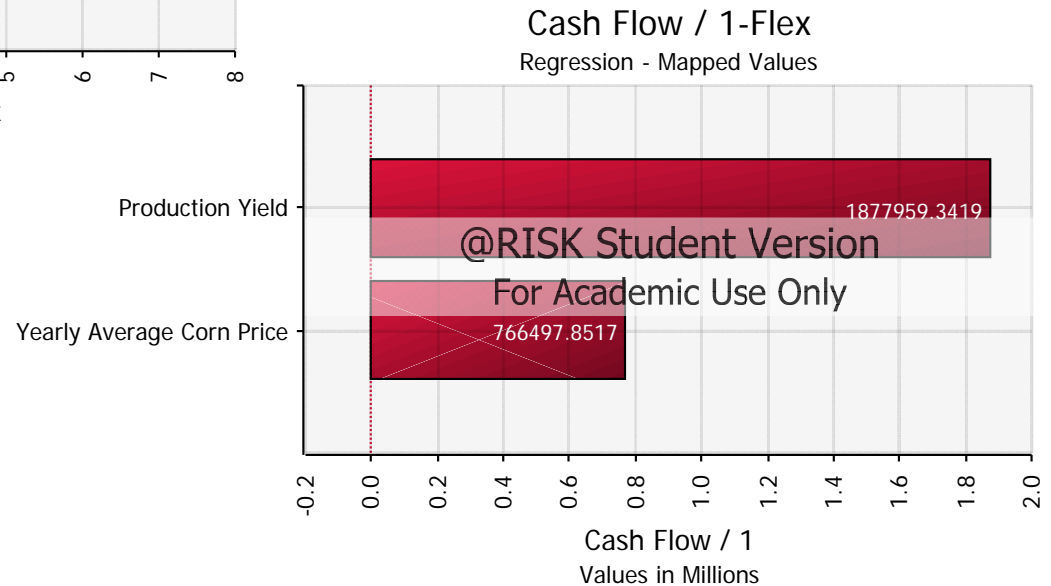
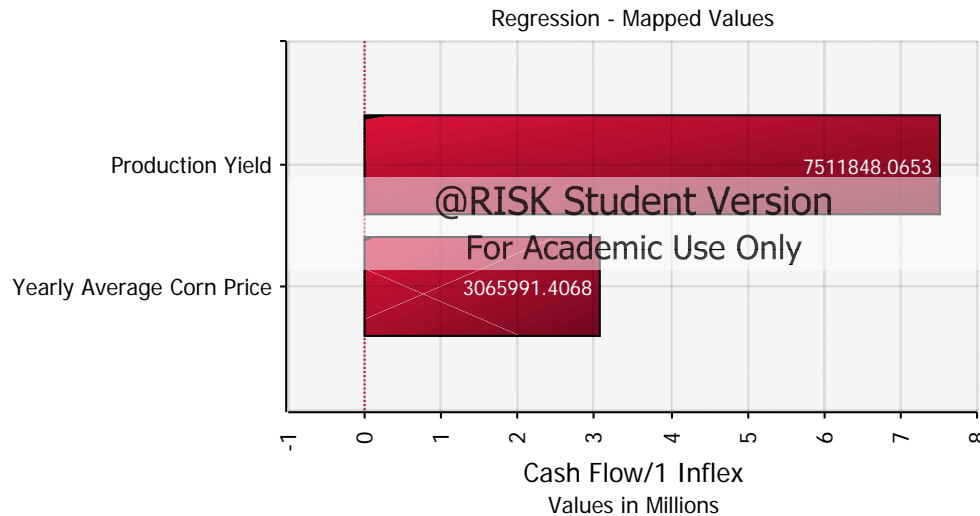
Sample from  
Uniform Distribution



|         |     |
|---------|-----|
| Mean    | 1.4 |
| St Dev. | 0.8 |

# Input Sensitivity

When the input changes by +1 standard deviation, the output will change by the X-axis value associated with the length of the bar




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**St Dev. Price**  
**\$/MT**                      **27.8**

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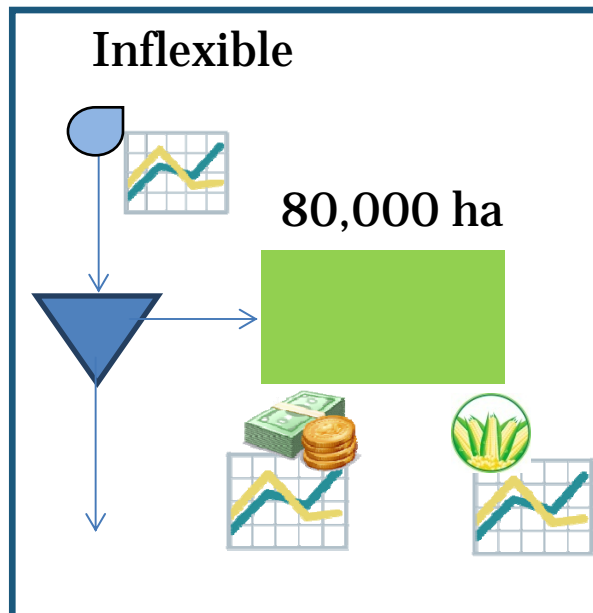
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**St Dev. Yield**            **0.8**  
**MT/ha**

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# Inflexible

| INFLEXIBLE                                | Year | 0           | 1                 | 2                   | 3                 | 4                  | 5..               | 19                | 20                |
|-------------------------------------------|------|-------------|-------------------|---------------------|-------------------|--------------------|-------------------|-------------------|-------------------|
| Avg Seasonal Water Level (MCM)            |      | 4763.58     | 4807.11           | 4825.63             | 4920.26           | 4632.91            | 4708.40           | 5139.82           | 4737.91           |
| Avg change in water level in last 2 years |      |             |                   | 0.00%               | 0.01%             | -0.11%             | -0.10%            | -0.06%            | -0.42%            |
| Demand for Ethiopia (MT corn)             |      | 3000000.00  | 1323541.71        | 1821993.61          | 796699.88         | 914454.92          | 895696.55         | 977584.79         | 1391571.27        |
| Price of Corn (S/MT)                      |      | 167.27      | 94.76             | 108.11              | 169.47            | 103.01             | 121.89            | 162.50            | 119.72            |
| Production (MT corn/ha)                   |      |             | 1.58              | 0.12                | 0.86              | 2.36               | 0.85              | 1.21              | 1.33              |
| Land Size (ha)                            |      |             | 80000.00          | 80000.00            | 80000.00          | 80000.00           | 80000.00          | 80000.00          | 80000.00          |
| Total Yield (MT corn)                     |      |             | 126457.09         | 9698.96             | 68832.42          | 188993.36          | 67566.36          | 96998.24          | 105809.21         |
| Revenue                                   |      |             | 11982621.89       | 1048531.93          | 11664723.96       | 19468996.42        | 8235348.92        | 15762481.55       | 12667724.61       |
| Fixed Irr. System Cost (US \$419.9/ha)    |      | 33592000.00 |                   |                     |                   |                    |                   |                   |                   |
| Land Lease Cost (US \$ 8.15/ha)           |      |             | 652000.00         | 652000.00           | 652000.00         | 652000.00          | 652000.00         | 652000.00         | 652000.00         |
| Variable Irr Cost (US \$ 30.88/ha)        |      |             | 1976326.97        | 1976320.00          | 1976320.00        | 1976320.00         | 1976320.00        | 1976320.00        | 1976320.00        |
| Cost of Production (SUS 40/ha)            |      |             | 3200000           | 3200000             | 3200000           | 3200000            | 3200000           | 3200000           | 3200000           |
| <b>Cash Flow</b>                          |      |             | <b>6154294.92</b> | <b>(4779788.07)</b> | <b>5836403.96</b> | <b>13640676.42</b> | <b>2407028.92</b> | <b>9934161.55</b> | <b>6839404.61</b> |
| DCF                                       |      | 0.12        | 57721326.93       |                     |                   |                    |                   |                   |                   |
| ENPV                                      |      |             | \$24,129,326.93   |                     | Average           | \$20,051,384.30    |                   |                   |                   |
| B/C (profitability index)                 |      |             | 1.72              |                     | p(<=0)            | 10.87%             |                   |                   |                   |



## Inflexible Output

ENPV \$20.12 Million

P(<=0) 10.54%

Min \$-31.14 Million

Max \$125.65 Million

10,000 sims

# Incorporating Flexibility

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**EXPANSION RULES**

**FLEXIBLE DESIGN**

**COMPARISONS**

**VALUE OF FLEXIBILITY**

# Expansion Rules

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Start with 20,000 ha instead of 80,000 ha

\*Assume no additional upfront cost or cost to exercise flexibility

IF:

1. Price of corn is greater than \$63 and,  
(in deterministic model this price gives NPV of 0)
2. Demand this year is greater than last year and,  
(increasing demand)
3. Change in water level in last two years is greater than 0, and  
(increasing water level)
4. Land size has not reached capacity of 80,000 ha

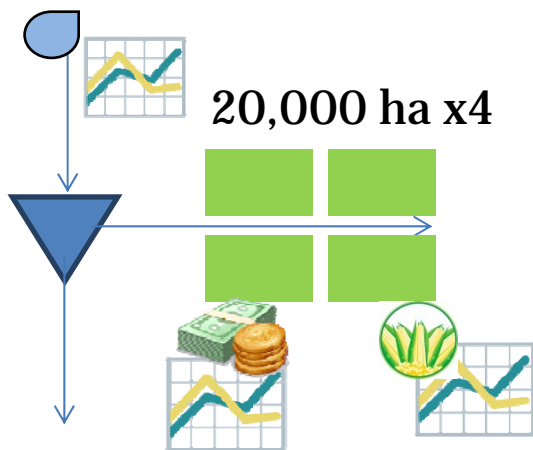
THEN:

Expand by 20,000 ha

# Flexible

| FLEXIBLE                                                  | Year | 0       | 1               | 2               | 3              | 4               | 5..            | 19             | 20             |
|-----------------------------------------------------------|------|---------|-----------------|-----------------|----------------|-----------------|----------------|----------------|----------------|
| Avg Monthly Water Level (MCM)                             |      | 3541    | 4807            | 4826            | 4920           | 4633            | 4708           | 5140           | 4738           |
| Avg change in water level in last 2 years                 |      |         |                 | 0.14%           | 0.01%          | -0.11%          | -0.10%         | -0.06%         | -0.42%         |
| Demand for Ethiopia (MT corn)                             |      | 3000000 | 1323542         | 1821994         | 796700         | 914455          | 895697         | 977585         | 1391571        |
| Price of Corn (\$/MT)                                     |      | 167     | 95              | 108             | 169            | 103             | 122            | 163            | 120            |
| Production (MT corn/ha)                                   |      |         | 2               | 0               | 1              | 2               | 1              | 1              | 1              |
| Land Size (ha)                                            |      |         | 20000           | 20000           | 40000          | 40000           | 40000          | 80000          | 80000          |
| Expand?                                                   |      |         |                 | expand          |                |                 |                |                |                |
| Expansion Size                                            |      |         | 0               | 20000           | 0              | 0               | 0              | 0              | 0              |
| Total Yield (MT corn)                                     |      |         | 31614           | 2425            | 34416          | 94497           | 33783          | 96998          | 105809         |
| Revenue                                                   |      |         | 2995655         | 262133          | 5832362        | 9734498         | 4117674        | 15762482       | 12667725       |
| Fixed Irr. Svmstem Cost (US \$419.9/ha)                   |      | 8398000 |                 |                 |                |                 |                |                |                |
| Land Lease Cost (US \$ 8.15/ha)                           |      |         | 163000          | 163000          | 326000         | 326000          | 326000         | 652000         | 652000         |
| Variable Irr Cost (US \$ 30.88/ha)                        |      |         | 494087          | 494080          | 988160         | 988160          | 988160         | 1976320        | 1976320        |
| Cost of Production (fertilizer. seeds. labor. \$US 40/ha) |      |         | 800000          | 800000          | 1600000        | 1600000         | 1600000        | 3200000        | 3200000        |
| <b>Cash Flow</b>                                          |      |         | <b>1538568</b>  | <b>-1194947</b> | <b>2918202</b> | <b>6820338</b>  | <b>1203514</b> | <b>9934162</b> | <b>6839405</b> |
| <b>DCF</b>                                                | 0.12 |         | 39714989.45     |                 |                |                 |                |                |                |
| <b>ENPV</b>                                               |      |         | \$31,316,989.45 |                 | Average        | \$16,649,535.64 |                |                |                |
| <b>B/C (profitability index)</b>                          |      |         | 4.73            |                 | p(<=0)         | 1%              |                |                |                |

## Flexible



## Flexible Output

ENPV **\$16.76 Million**

P(<=0) **1%**

Min **\$-9.28 Million**

Max **\$74.38 Million**

**10,000 sims**

# Comparisons

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**ENPV**

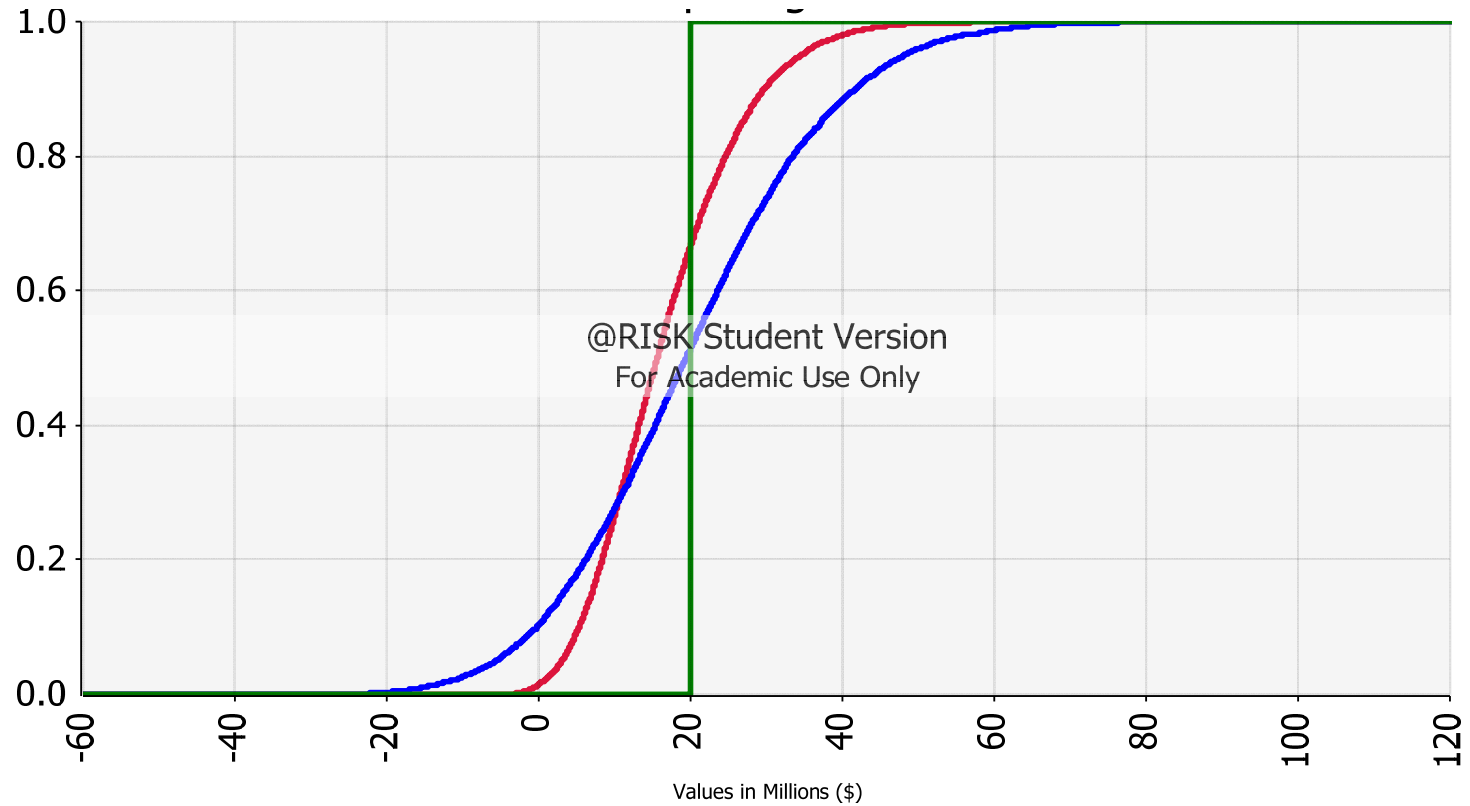
**PROBABILITY OF LOSING MONEY**

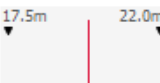
**RANGE**

**5<sup>TH</sup> AND 95<sup>TH</sup> PERCENTILES**

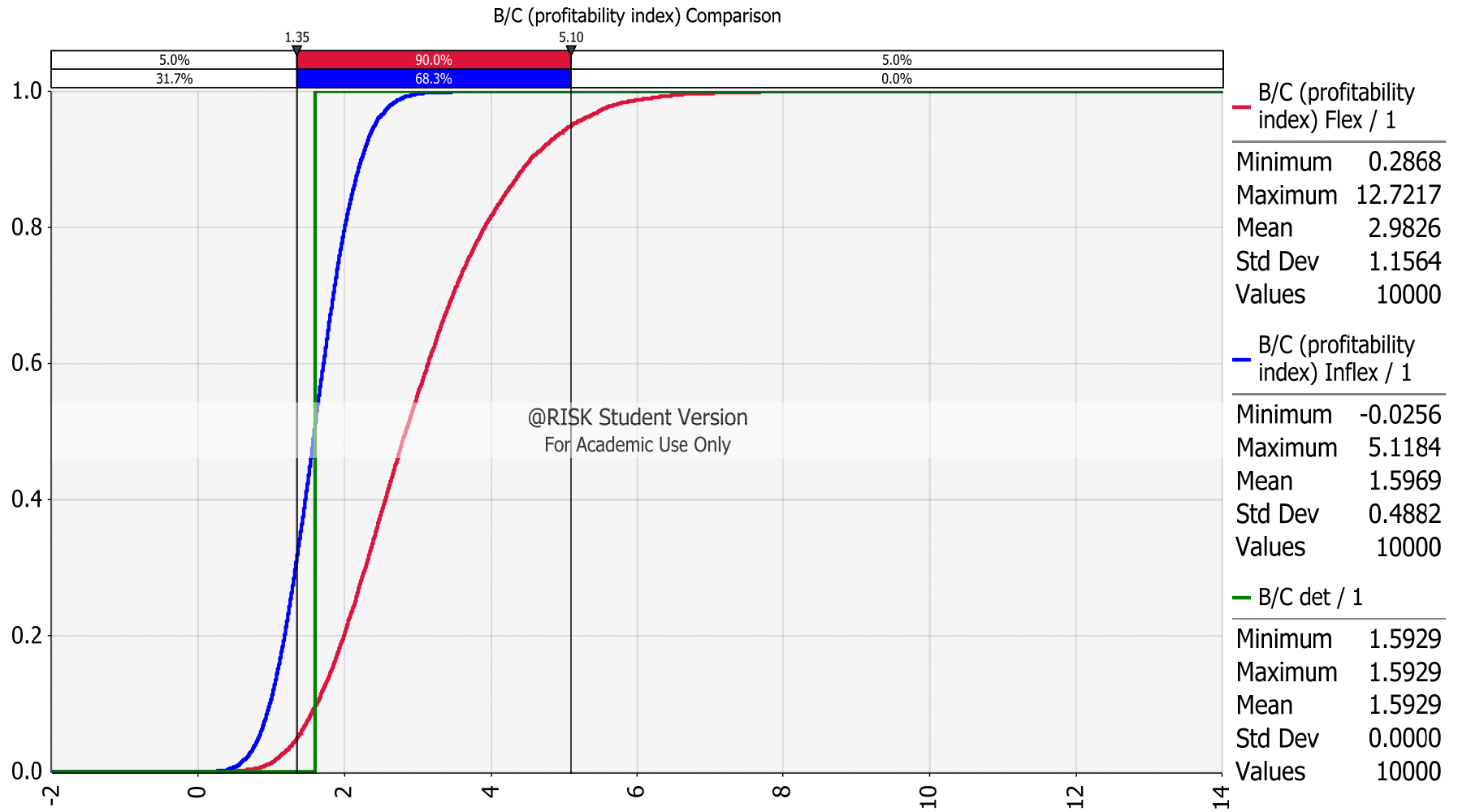
**B/C RATIO**

# ENPV Comparisons



|                                                                                     |                | ENPV  | P( $\leq 0$ ) | Min    | Max       | 5%        | 95%     |          |
|-------------------------------------------------------------------------------------|----------------|-------|---------------|--------|-----------|-----------|---------|----------|
|  | <b>Det.</b>    | ----- | \$19.92M      | -      | -         | -         | -       |          |
|  | <b>Inflex.</b> | ----- | \$20.12M      | 10.54% | \$-31.14M | \$125.65M | \$-6.3M | \$47.62M |
|  | <b>Flex.</b>   | ----- | \$16.76M      | 1%     | \$-9.28M  | \$74.38M  | \$2.79M | \$33.88M |

# B/C Comparisons



No “all-time” best

“Best Project” depends on the evaluation metric used and risk tolerance of project manager.

If a plan is made on a deterministic basis, there may be a lot of surprises.

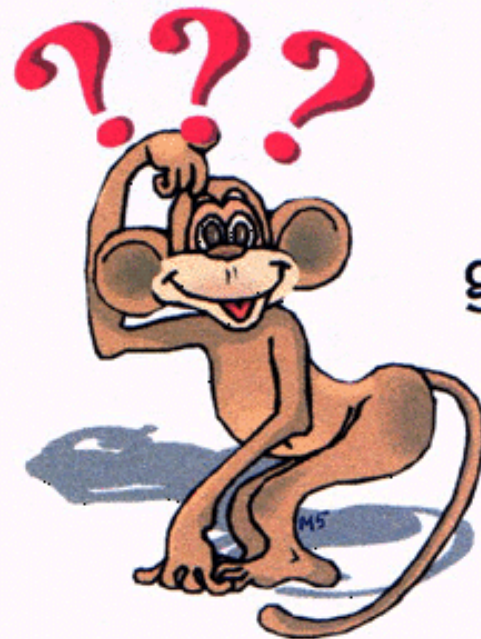
## Conclusions

|                  | <b>Inflexible</b> | <b>Flexible</b> |
|------------------|-------------------|-----------------|
| <b>ENPV</b>      | X                 |                 |
| <b>P(&lt;=0)</b> |                   | X               |
| <b>Min</b>       |                   | X               |
| <b>Max</b>       | X                 |                 |
| <b>5%</b>        |                   | X               |
| <b>95%</b>       | X                 |                 |
| <b>B/C</b>       |                   | X               |



# QUESTIONS?

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Questions  
are  
guaranteed in  
life;  
Answers  
aren't.

<http://www.themillionairesecrets.net/4-questions-that-will-lead-you-to-success/>