# ‘Real Option’ Analysis of Interim Emission Targets

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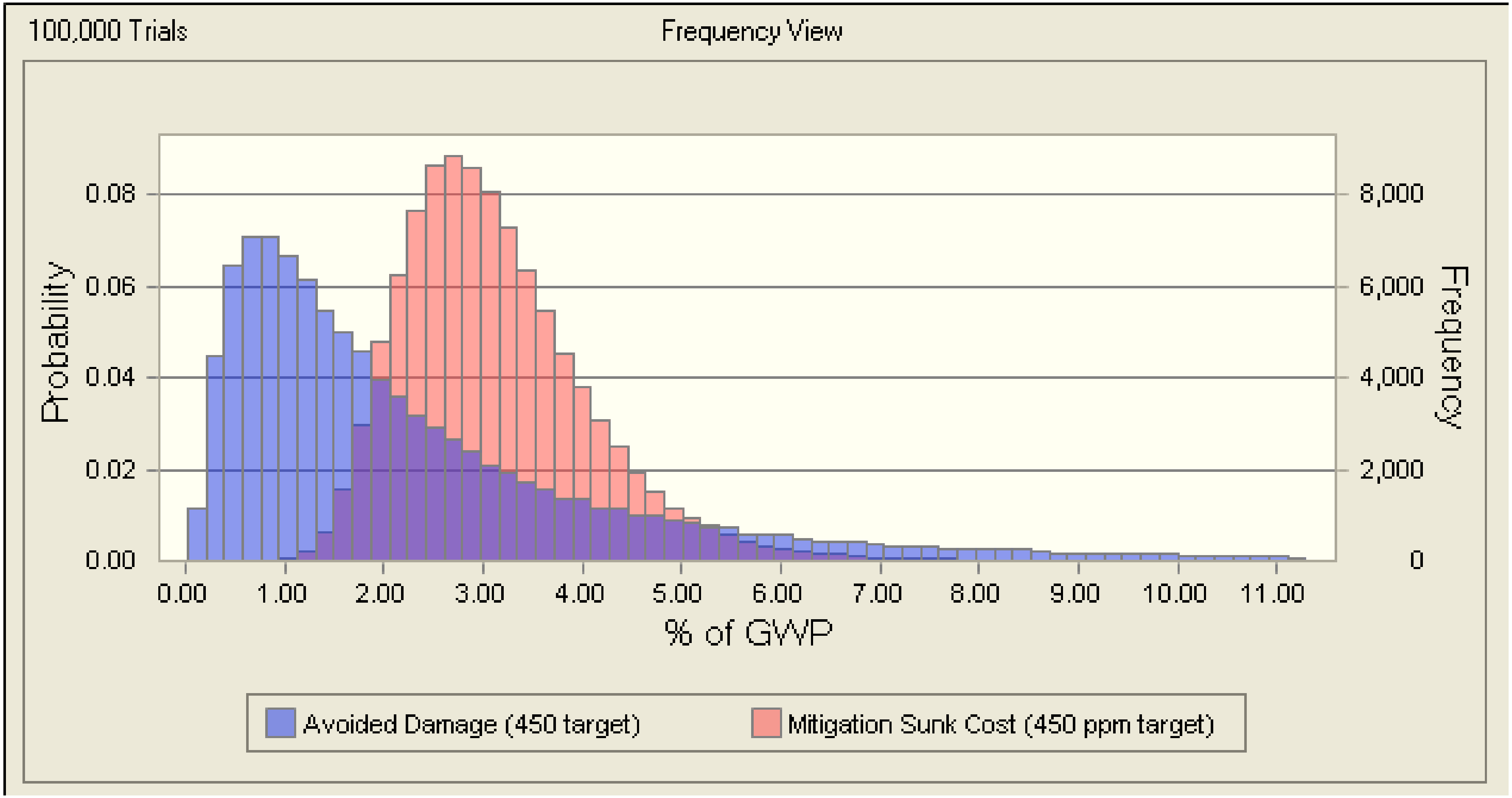
# Shortcomings of Expected Value Approach and Real Option Alternative

- Traditional cost-benefit analysis relies on aggregated estimation of various outcomes of climate policy weighted and averaged by probabilities.
- Therefore the expected value methodology undermines the relative uncertainties in avoided damage and mitigation costs.
- The skewness and kurtosis of the probabulity distributions may be important characteristics of the relative uncertainties but can be easily lost through aggregation.
- The application of a real option analysis better accounts for the specific characteristics of the relative uncertainties in the costs and benefits of climate policy and also more accurately considers it’s irreversible nature.
- The expected value of this interim climate policy may be negative. Nevertheless, this policy may have a positive option value since earlier abatement will ensure more flexibility in the future. A real option analysis presents a method to calculate the economic value of this flexibility.

# Shortcomings of Expected Value Approach: Peak Tail and Variance



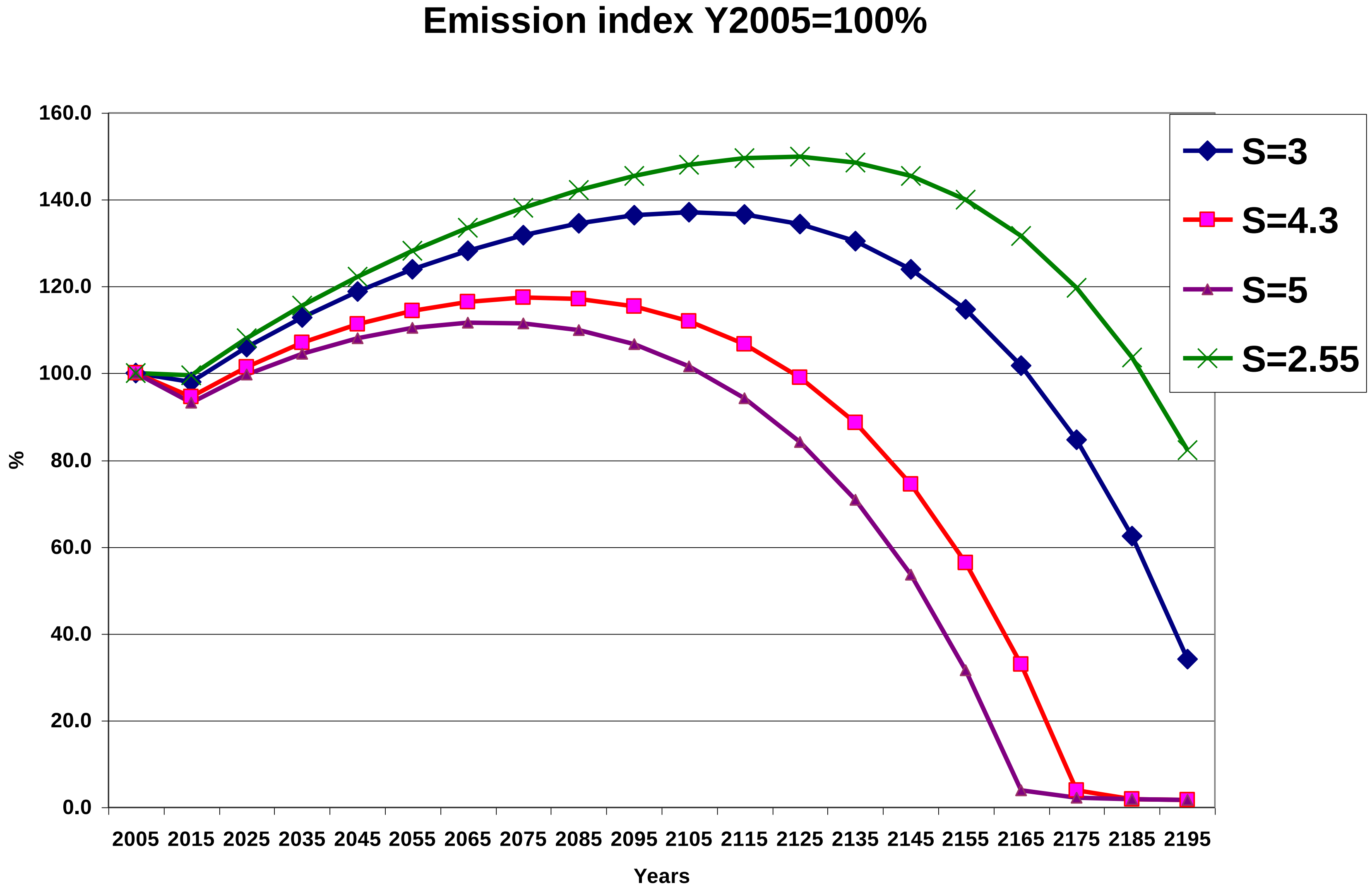
# W. Nordhaus:

The first reservation is that the structure, equations, data, and parameters of the model all have major uncertain elements. Virtually none of the major components is completely understood. Moreover, because the model embodies long-term projections of poorly understood phenomena, the results should be viewed as having growing error bounds the further the projections move into the future.

# For Some Critical Parameters Calibration May Be Impossible

- Critical parameters:
  - Climate sensitivity:
  - Parameters of damage function;
  - Parameters of abatement cost function;
- Solutions:
  - Stochastic optimization;
    - Computational complexity (Bostian Golub 2007)
  - Explicit introduction and quantification of risks;
    - Selection of analytical framework:
      - Monte-Carlo simulation;
      - “Deterministic” run of the model with option value added to conventional criteria

# Uncertainties and Magnitude of Deviations: GHG Emission Trajectories for Different Climate Sensitivities



# Uncertainties, Risks and Catastrophic Climate Change

- Weitzman on “slimming” fat tail;
- Value at risk approach;

Shortcoming: lack of analytical solution and therefore complicated computation

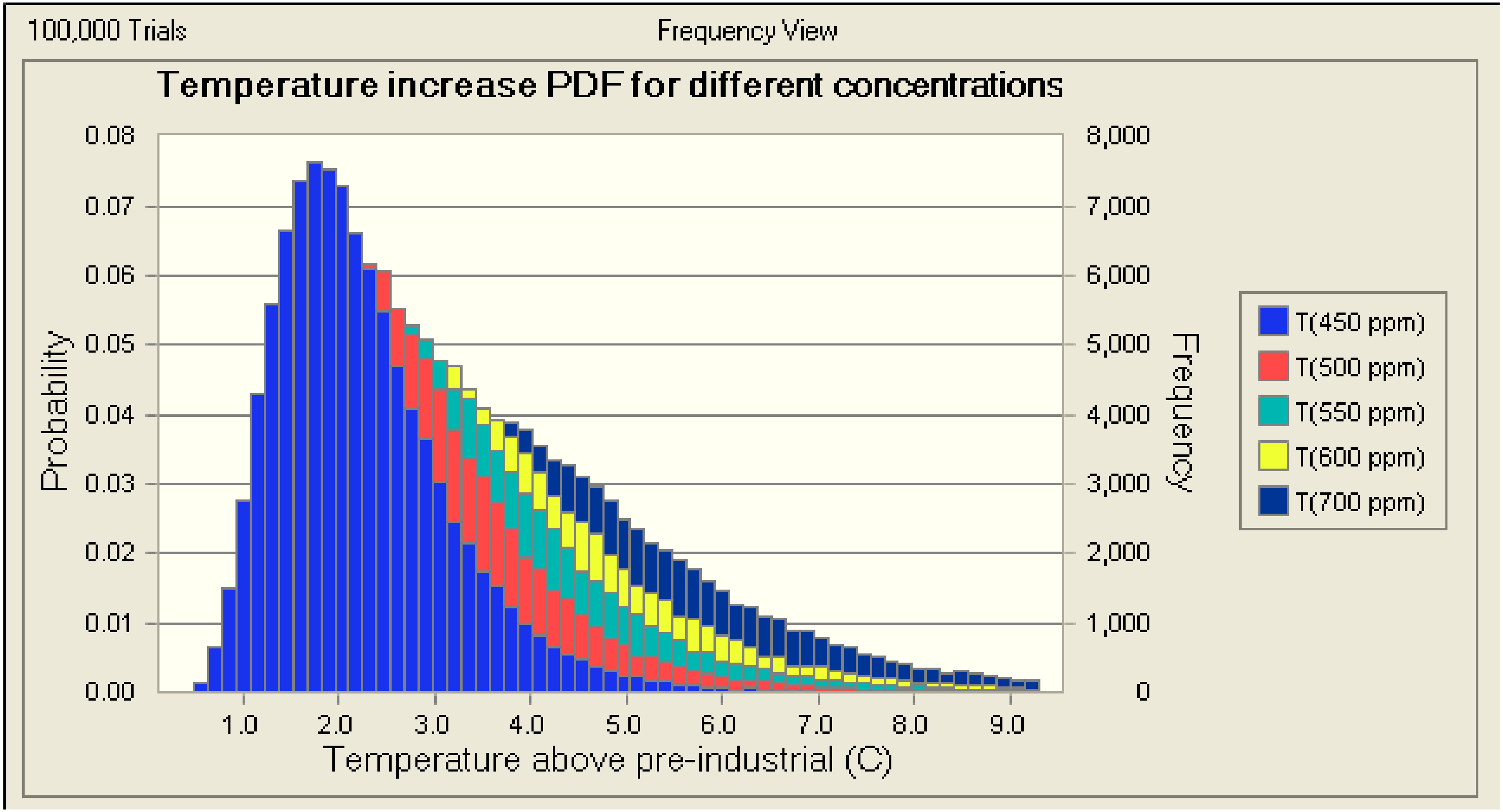
- Mean-variance criteria;
- Black-Scholes option pricing;

Shortcomings: does not capture “fat tail”

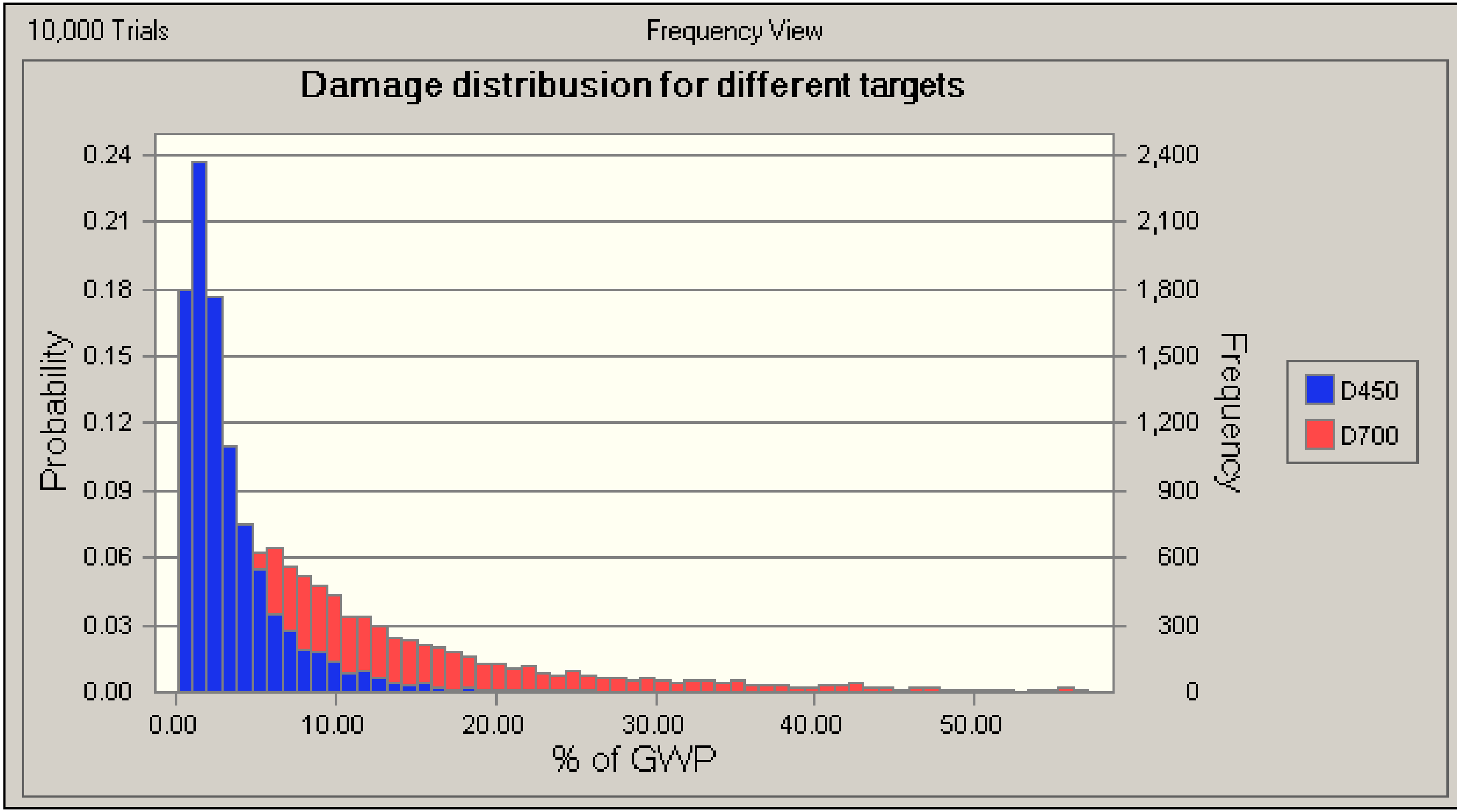
- Gram-Charlier model

Allows to account for skewness and kurtosis

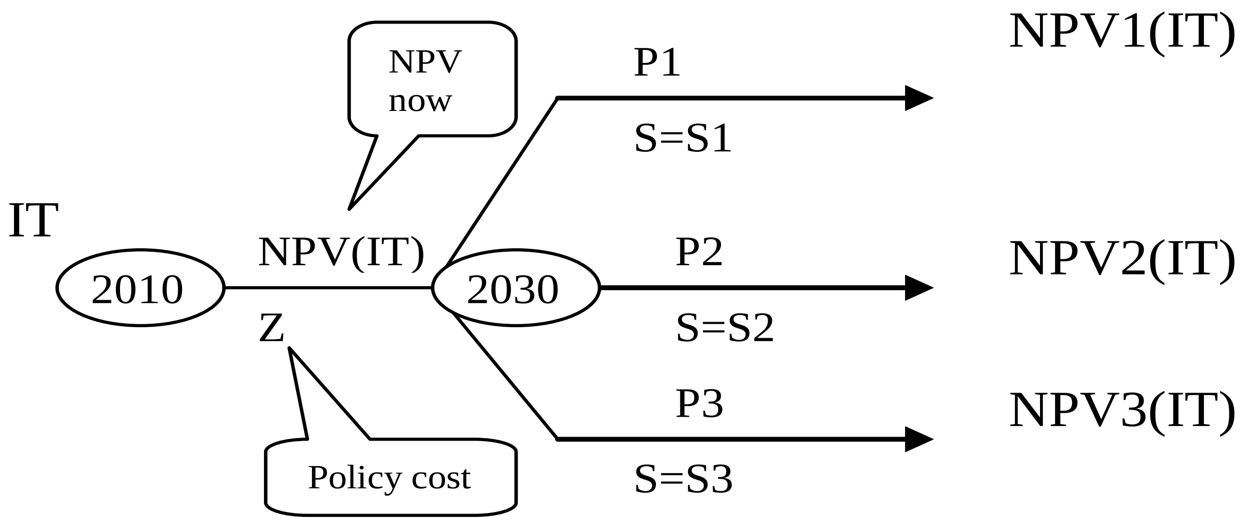
# Slimming a Fat Tail



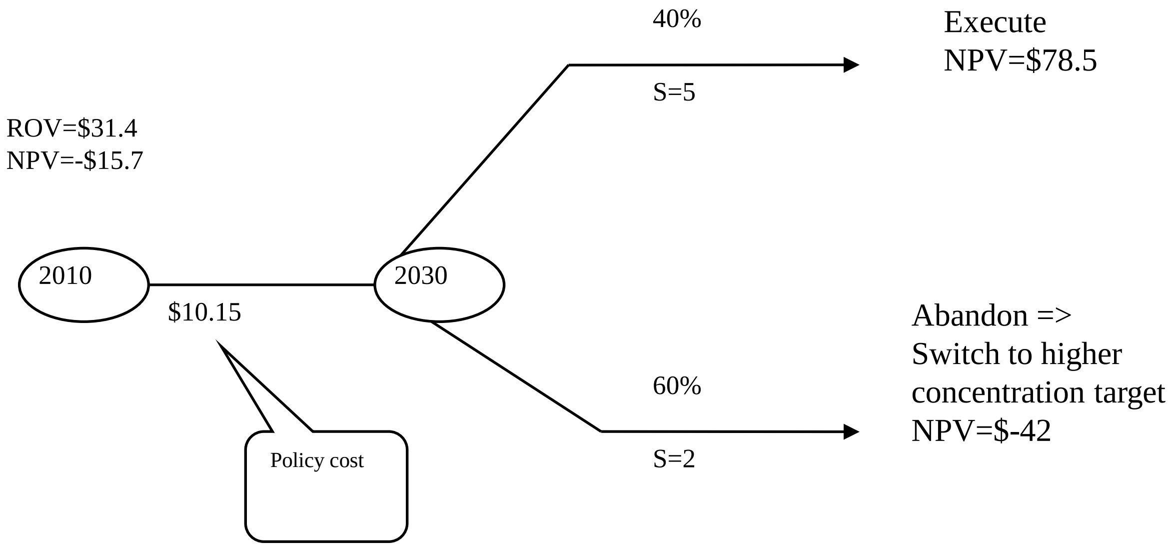
# Economic Damage: Fat Tail Distribution



# Climate Policy Decision Tree 3



# Interim Policy with An Option to Correct Trajectory in 2030



# ROV vs. NPV

- NPV= 0.4*78.5+0.6*(-42) – 10.15 = -15.7
- ROV= 0.4*78.5+***[0.6*(-42)]*0*** = 31.4
- Net value to keep option open =
  ROV minus implementation cost =
  31.4 – 10.15 = 21.25

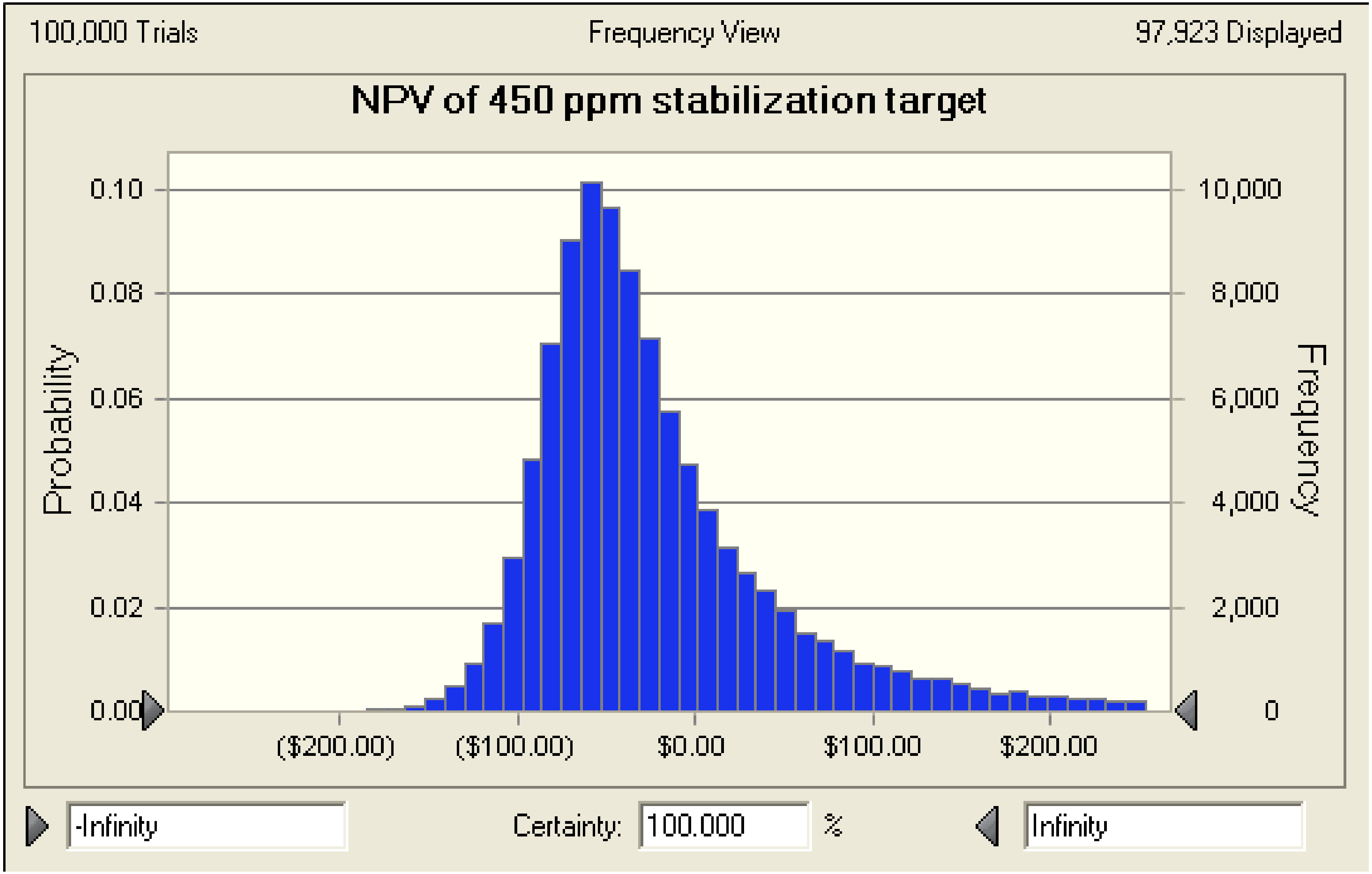
# Option Value & Flexibility Value

- Factors that increase the option value
  - Uncertainties
    - Variance
  - Time horizon
    - Longer time to learn about uncertainties i.e. interim emission target with future flexibility
  - Expected benefits of climate policy
    - The importance of properly including the ancillary benefits
- Factors that decrease option value
  - Expected GHG mitigation costs
    - The importance of creating incentives for induced technological changes in order to reduce long-term average mitigation cost
  - Variance of the mitigation cost

# Comparing Alternative Options

- Option 1
  - Avoid irreversible climate events
    - F(VCC) – option value to avoid climate change
    - VCC – present value of avoided damage
- Option 2
  - Postpone irreversible investment into abatement (sunk cost):
    - F(VSC) – option value to avoid sunk cost;
    - VSC – present value of sunk cost
- Based on approximation of Black-Scholes model:
  - Relatively lower expected value of prevented damage could be compensated by higher variance:
  - $F(VCC)/F(VSC) \sim VCC^{*}\sigma_{vcc}/VSC^{*}\sigma_{vsc}$

# Sunk Cost and Flexibility Tradeoff: Double Tail



# Parameters of the Numerical Example

| | |
|---|---|
| Gross World Product (GWP) in 2010, Trillion USD 2006 | 52 |
| Annual growth rate | 2% |
| Discount rate | 3% |
| BAU scenario | 700 ppm in 2100 |
| Damage function (% GWP) | $D=0.6T^2$; *T* denotes temperature increase |
| Mitigation cost 450 ppm pathway (% GWP) | 2% of GWP in 2030; 4% in 2050 and 5% in 2100; SD=50% |
| Climate sensitivity | Median = 3; logarithm mean equal to 1.09 and ln SD=0.4 |

# Results of Monte-Carlo Simulation

(*Discounted back to 2010 in $ trillion)

| | Avoided Damage | Sunk Cost | NPV (450ppm) |
|---|---|---|---|
| Mean* | 80 | 95 | -15 |
| Median* | 52 | 93 | -39 |
| SD* | 93 | 23 | 95 |
| Skewness | 4.9 | 0.84 | 4.5 |
| Kurtosis | 60 | 4.4 | 53.5 |

# Economic Assessment ROV vs. Expected value

| | |
|---|---|
| NPV | Negative ~ $15 trillion |
| Black-Scholes | Positive ~ $ 37 trillion |
| Gram-Charlier | Positive > $ 50 trillion |

# Experiments with DICE 2007 (idea of algorithm)

- Calibration of uncertain parameters;
- Monte-Carlo simulation in order to obtain PDF for consumption, welfare etc;
- Estimation of implied volatility;
- Modification of criteria (option value included in welfare function);
- Optimization (deterministic run with a new criteria);
- New Monte-Carlo simulation and analysis of differences in implied volatility;
- New iteration if the difference in implied volatility is significant.

# Experiments with DICE 2007 (Results)

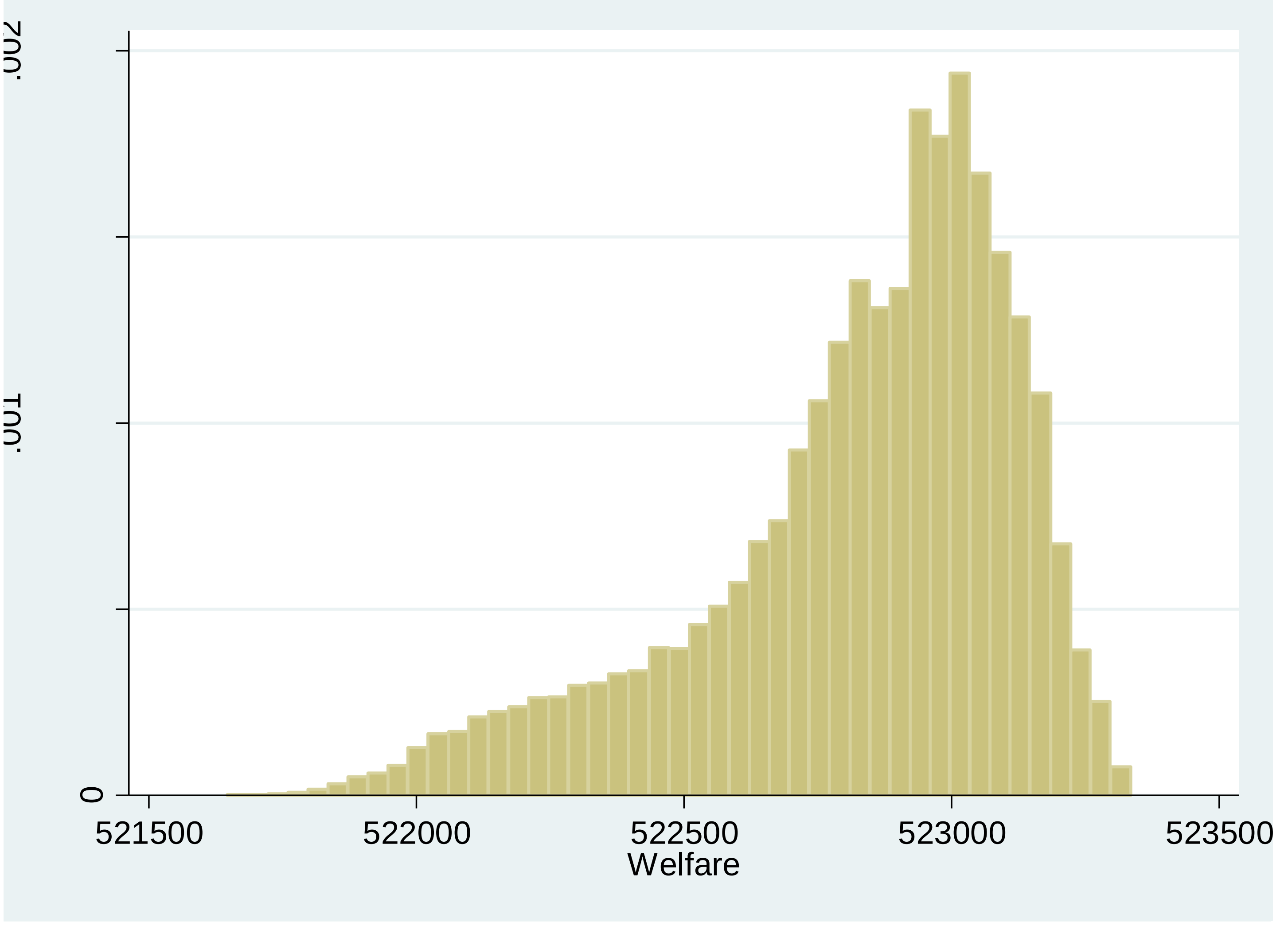
- Theoretical conclusions are confirmed:
  - with option value the model demonstrates relatively lower optimal emission trajectory;
- Shortcomings:
  - Insufficient representation of irreversibility;
  - No destination between intertemporal substitution and risk aversion;
  - No direct impact of climate change on welfare

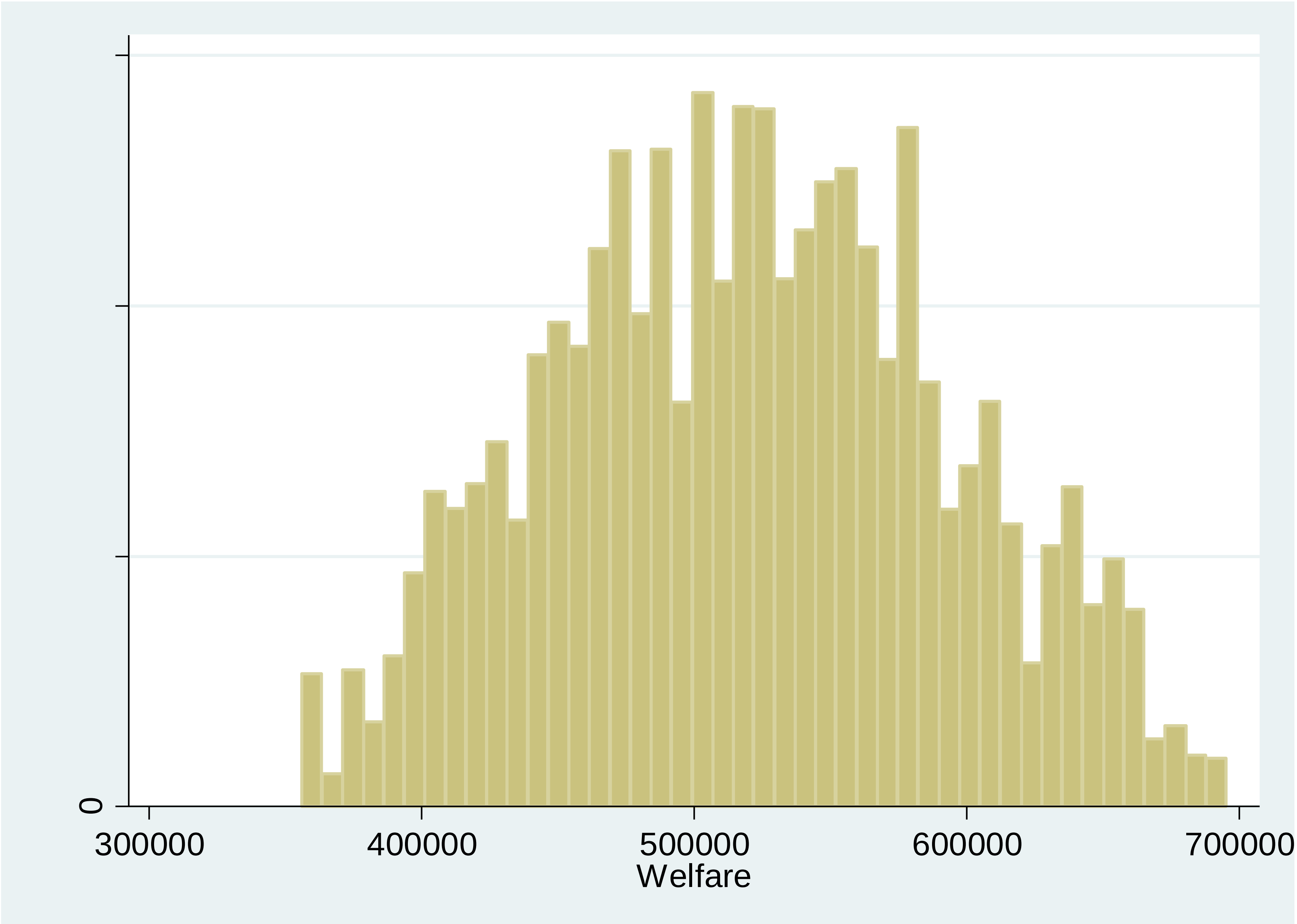
# Conclusions

- Introduction of ROV in IAMs allows to account for the shape of distribution of uncertain parameters including fat tail;
- The initially selected emission target should be stringent enough in order to save flexibility in the future;
- RO has an "expiration date", i.e. the initially selected target will be reevaluated in the future and could be corrected if new knowledge regarding mitigation cost, climate response to accumulated emissions, or the shape of the damage function becomes available.
- Strategy may be implemented in the form of a compound option, narrowing uncertainties over time by correcting emissions targets based on new knowledge.

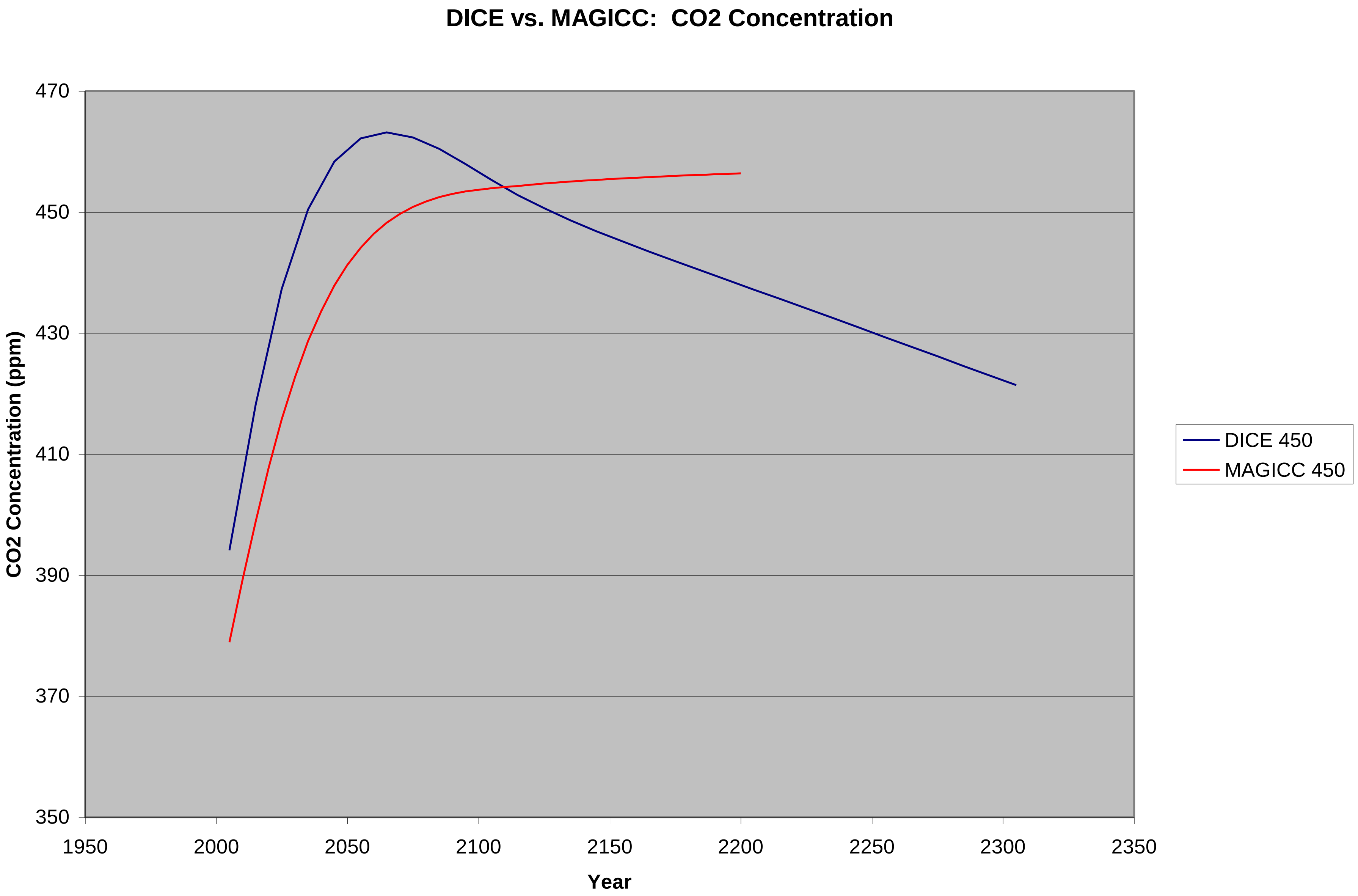
# Experiments with DICE Model

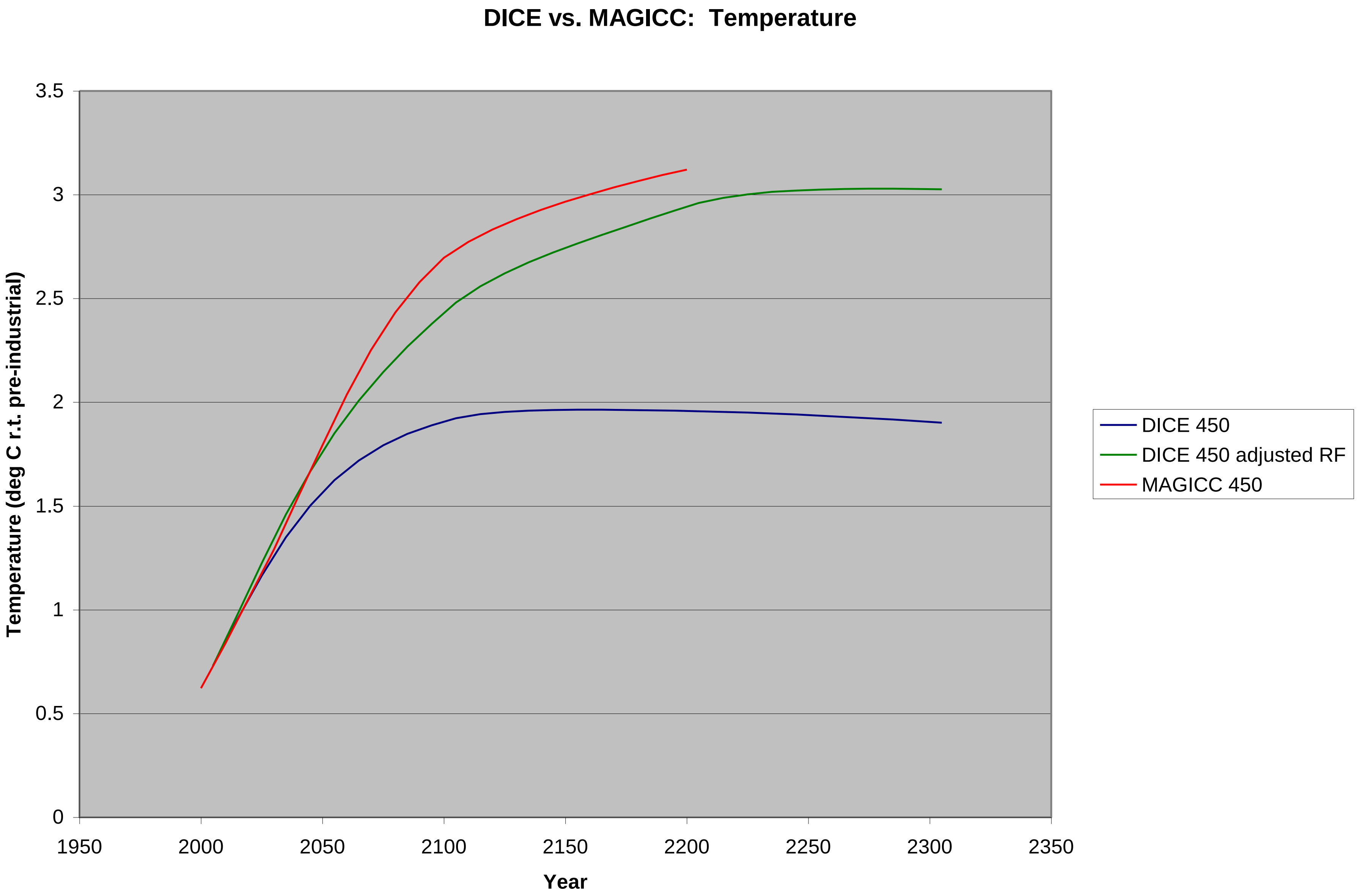
# Welfare as function of climate sensitivity





0
300000
400000
500000
600000
700000
Welfare


DICE vs. MAGICC: CO2 Concentration
CO2 Concentration (ppm)
470
450
430
410
390
370
350
1950
2000
2050
2100
2150
2200
2250
2300
2350
Year
DICE 450
MAGICC 450


DICE vs. MAGICC: Temperature
Temperature (deg C r.t. pre-industrial)
Year
0
0.5
1
1.5
2
2.5
3
3.5
1950
2000
2050
2100
2150
2200
2250
2300
2350
DICE 450
DICE 450 adjusted RF
MAGICC 450

# Mean Variance (EV) and Real Options (ROA) analysis

**EV optimization**: max [EW - RAP*std(W)]

**ROA optimization**: max [EW(t1..t5) + k1*EW(t6..t10) + k2*EW(t11..t15) +k3*EW(t16..t60)]

k1 = 0.4*std(W(t6..t10))

k2 = 0.4*std(W(t11..t15))

k3 = 0.4*std(W(t16..t60))

# Mean-Variance analysis (EV)