The Cambridge-MIT Institute Electricity Project

UNIVERSITY OF CAMBRIDGE

"Nuclear as a Hedge Against Gas and Carbon Prices Uncertainty"
PRELIMINARY RESULTS

CMI EP Research Seminar, 6 November 2004

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Objectives

1. Illustrate the limits of the **levelised cost methodology** for assessing power investments;

2. Demonstrate the relevance of **Monte-Carlo simulations** for assessing uncertainties and their inter-correlation;

3. Capture the ‘portfolio value’ of diversifying power plants technologies/fuel mix for a large utility by applying **portfolio theory**;

4. Apply **Real Option theory** to value the possibility of choosing between nuclear and gas for a utility.

The Base Model

- **Discounted Cash Flow** (DCF) **spreadsheet** model: can compute levelised costs or Net Present Value (NPV).
- Compares **nuclear**, **coal** and **gas** technologies (costs and operational data for a start of production in **2010**).
- Data from various sources:
  - Technical and cost data from MIT report '*The future of Nuclear Power*' and AP1000 cost data.
  - Electricity, fuel, and carbon prices data for the English market from DTI, OFGEM, and Heren.

Parameters	Unit	Nuclear	Coal	NGCC
Technical parameters				
Net capacity	Mwe	1000	1000	1000
Capacity factor	%	85%	85%	85%
Heat rate	BTU/KWh	10400	8600	7000
Carbon intensity	kg-C/mmBTU	0	25.8	14.5
Construction time	years	5	4	2
Site selection time	years	0	0	0
Post-construction time	years	0	0	0
Plant life	years	40	40	40
Cost parameters				
Overnight cost	£/Kwe	1140	740	285
Incremental capital costs	£/Kwe/yr	11.4	8.6	3.4
Fuel costs	£/mmBTU	0.27	1.22	1.9
Real fuel escalation	%	0.00%	0.50%	1.20%
Nuclear waste fee		0	0	0
Fixed O&M	£/Kwe/year	36	13	9
Variable O&M	£mill/Kwe	0.23	1.93	0.3
O&M real escalation rate	%	1.00%	1.00%	1.00%
Decommissioning cost	£million	300	0	0
Financing parameters				
Projected annual Inflation rate	%	3%	3%	3%
Discount rate	%	8.0%	8.0%	8.0%
Marginal Corporate Tax rate	%	30%	30%	30%
Regulatory actions				
Carbon tax	£/tC	5	5	5
Revenues				
Electricity price	£cents/KWh	3	3	3

The Flaws of the Levelised Cost Methodology

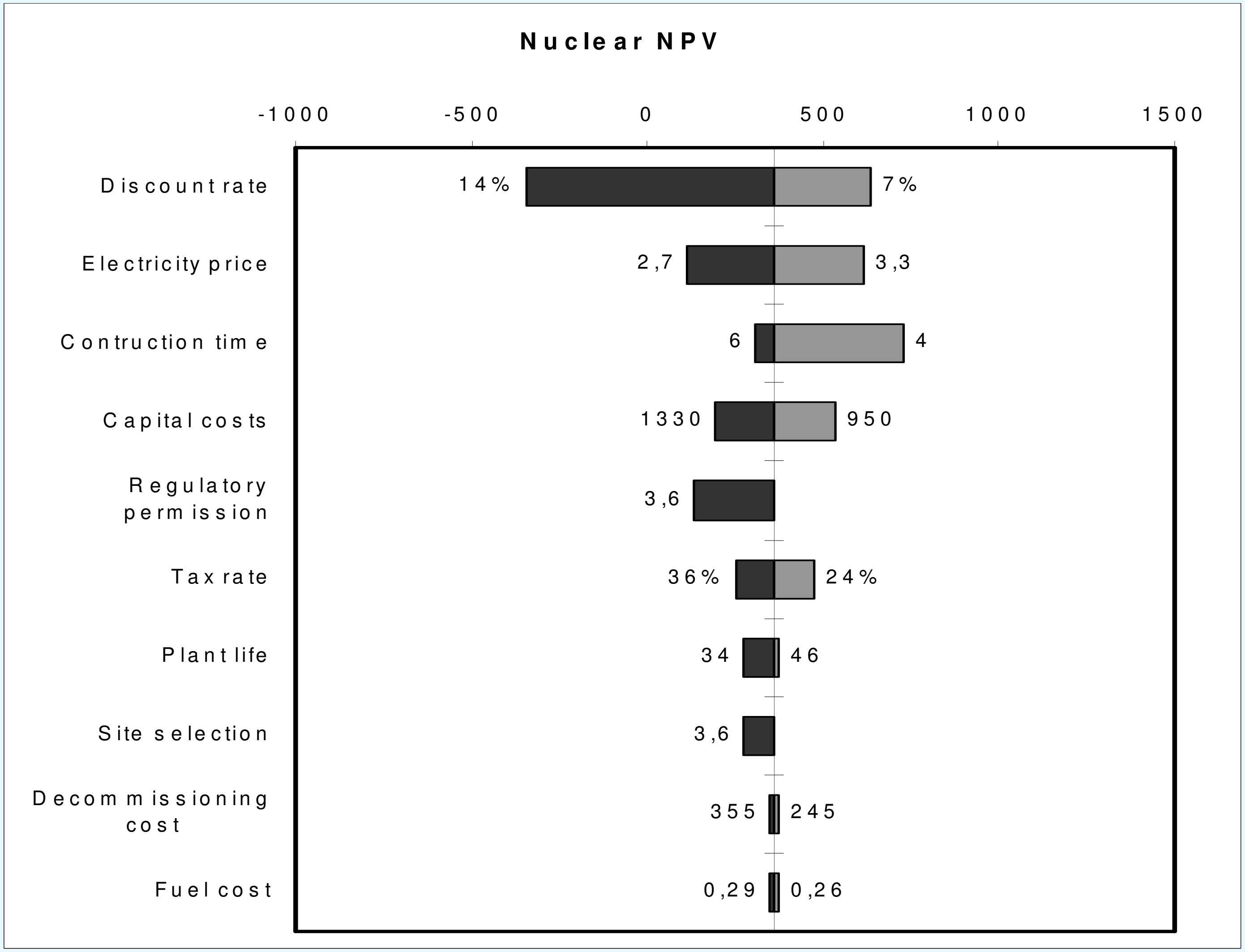
- Does not depict the **risk profile** of the project:
  - ⇒ Investors look at the risk/return perspectives
  - ⇒ A higher cost project can be less risky (e.g. nuclear vs gas with uncertain gas/carbon prices)

Comparison of Levelised Unit Energy Cost Estimates with different discount rates (US$/MWh) – Sources: IEA 2003, MIT 2003

Technology	MIT study base case	Levelised cost at 5% discount rate	Levelised cost at 10% discount rate
Nuclear	67	44	55
CCGT	41	44	45
Coal	42	33	40

- Limits treatment of **uncertainties**
  - ⇒ Sensitivity analysis varies one variable 'everything else being constant'
  - ⇒ Can't handle variables correlations

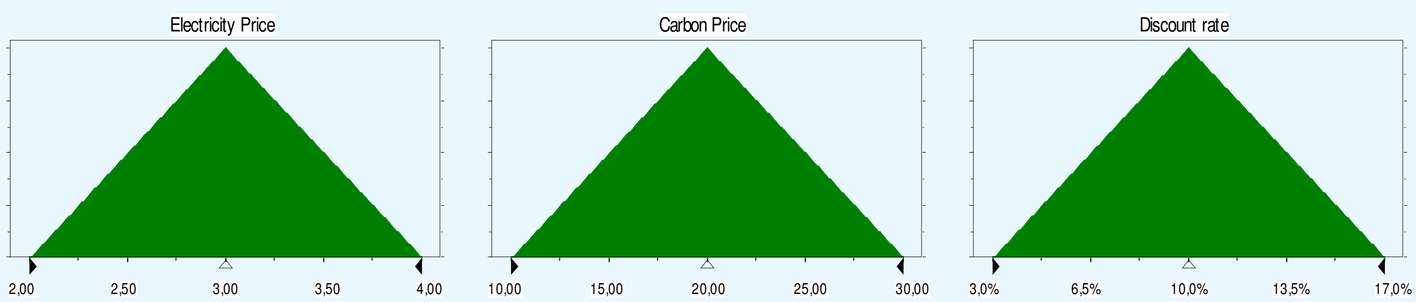
Sensitivity analysis: Tornado chart



Monte Carlo Simulations

- **Distributions** represent uncertainties
  - Gives likelihood of each value from the **shape of the distribution** (triangular, normal…)
  - **Correlations** between the different uncertainties (e.g. gas and electricity prices) can be introduced

Electricity price **Carbon price** **Discount rate**



⇒ Outcome is **expected NPV (ENPV) distribution**

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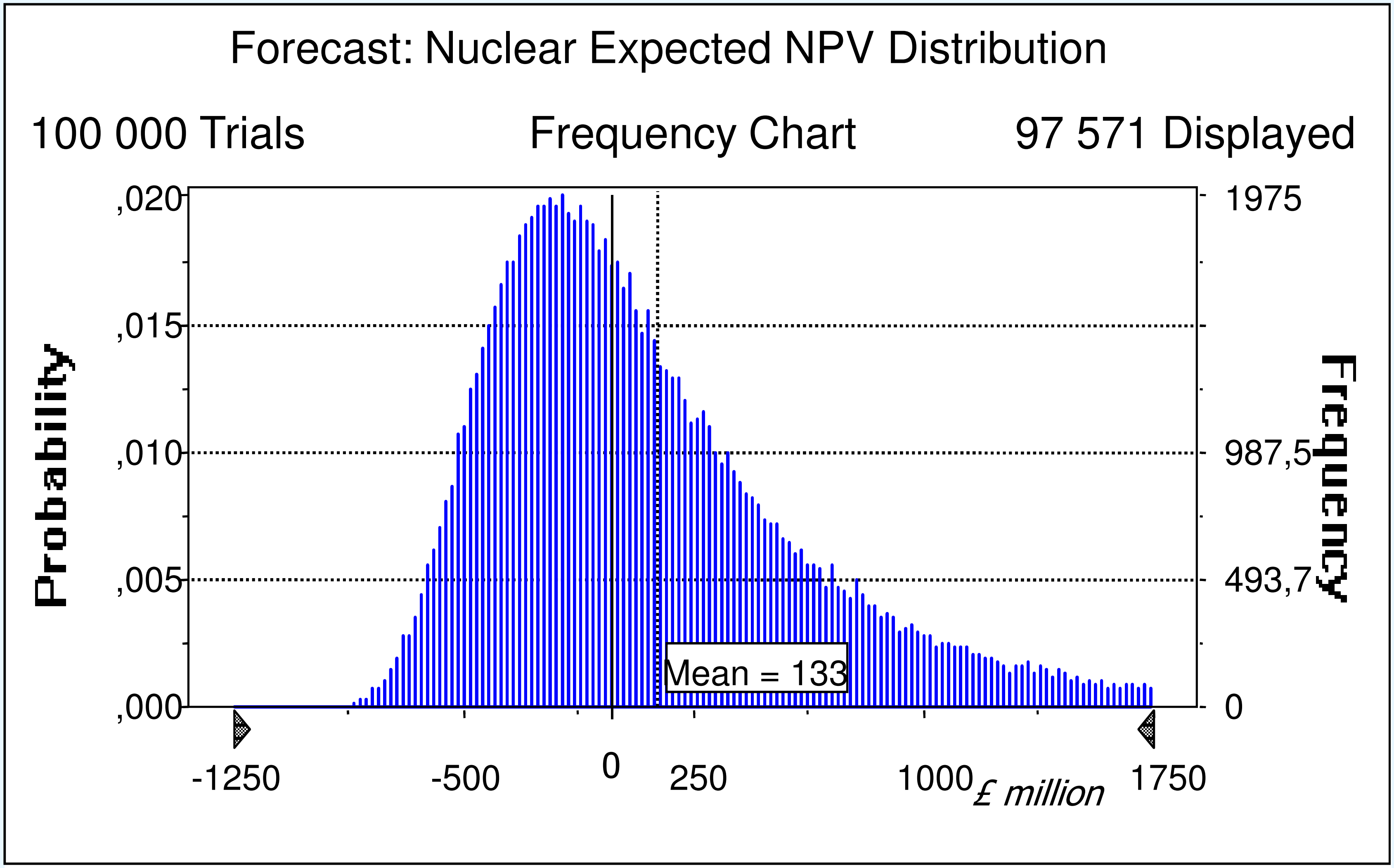
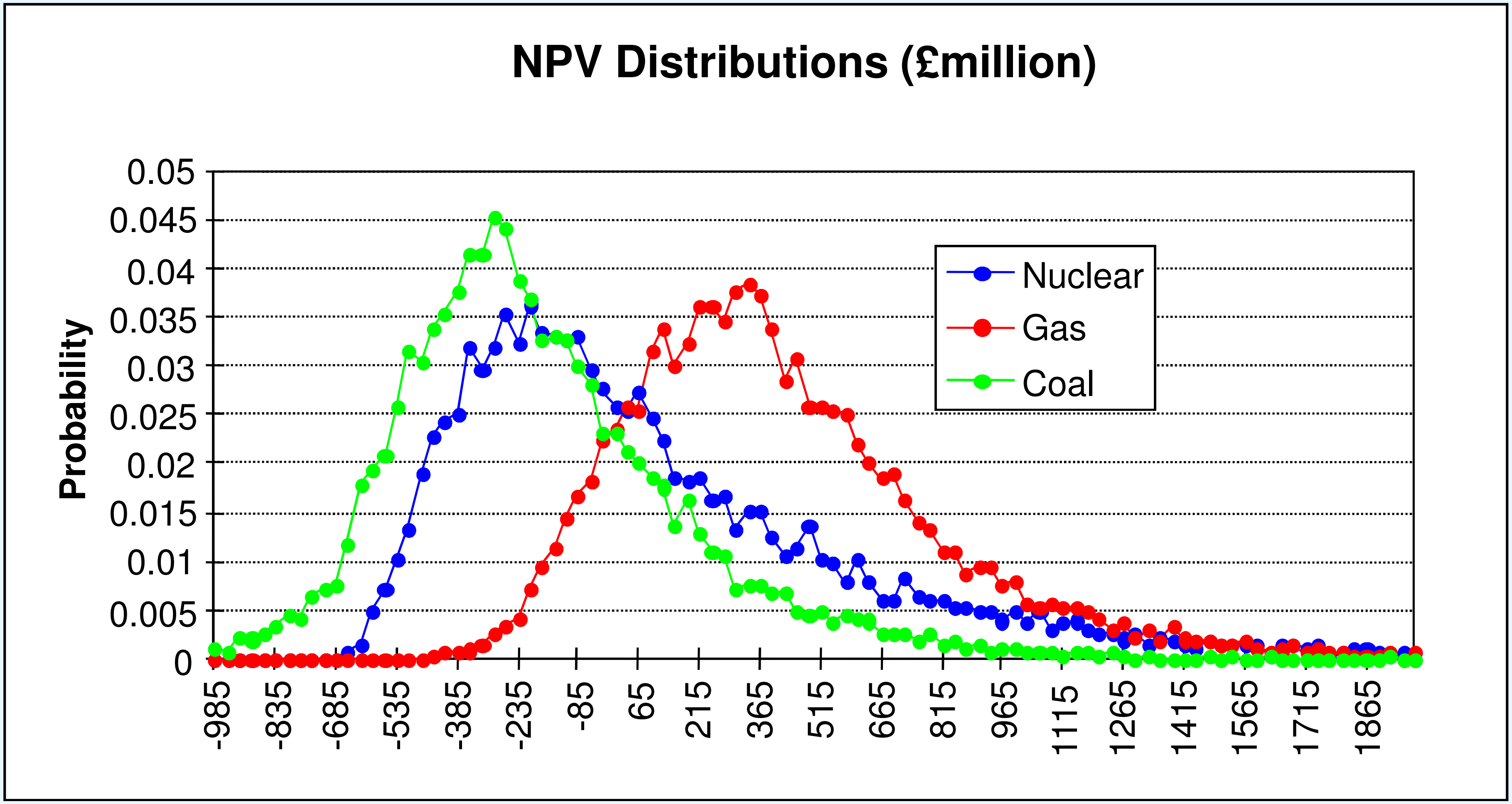
ENPV Distribution for Nuclear with 12 Uncertain Parameters (Triangular Distributions)



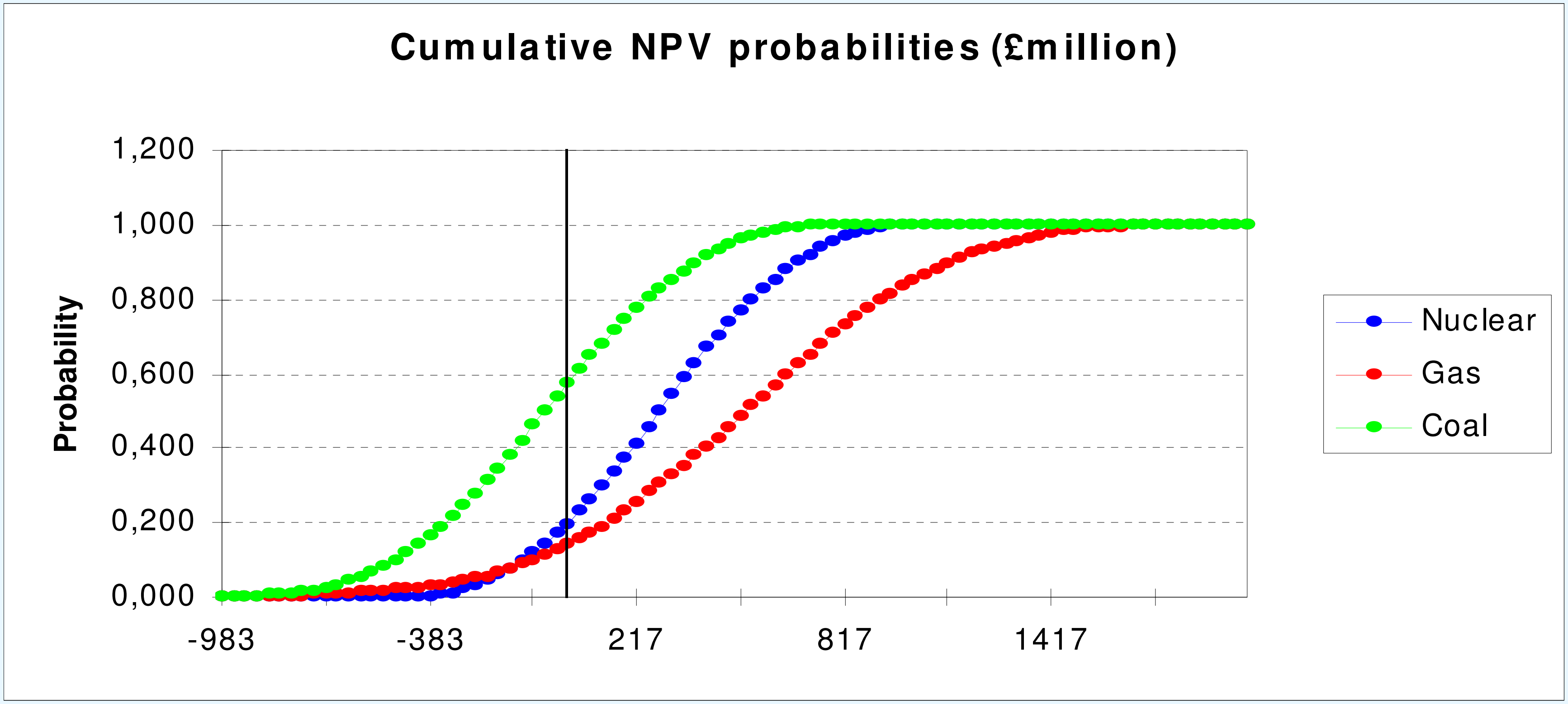
Monte Carlo Simulations Results

NPVs distribution with gas, carbon, and electricity price uncertainties
(triangular distributions)



Cumulative NPVs Comparison

Cumulative NPVs with gas, carbon, and electricity price uncertainty (triangular distributions)



=> Gas has the higher mean NPV

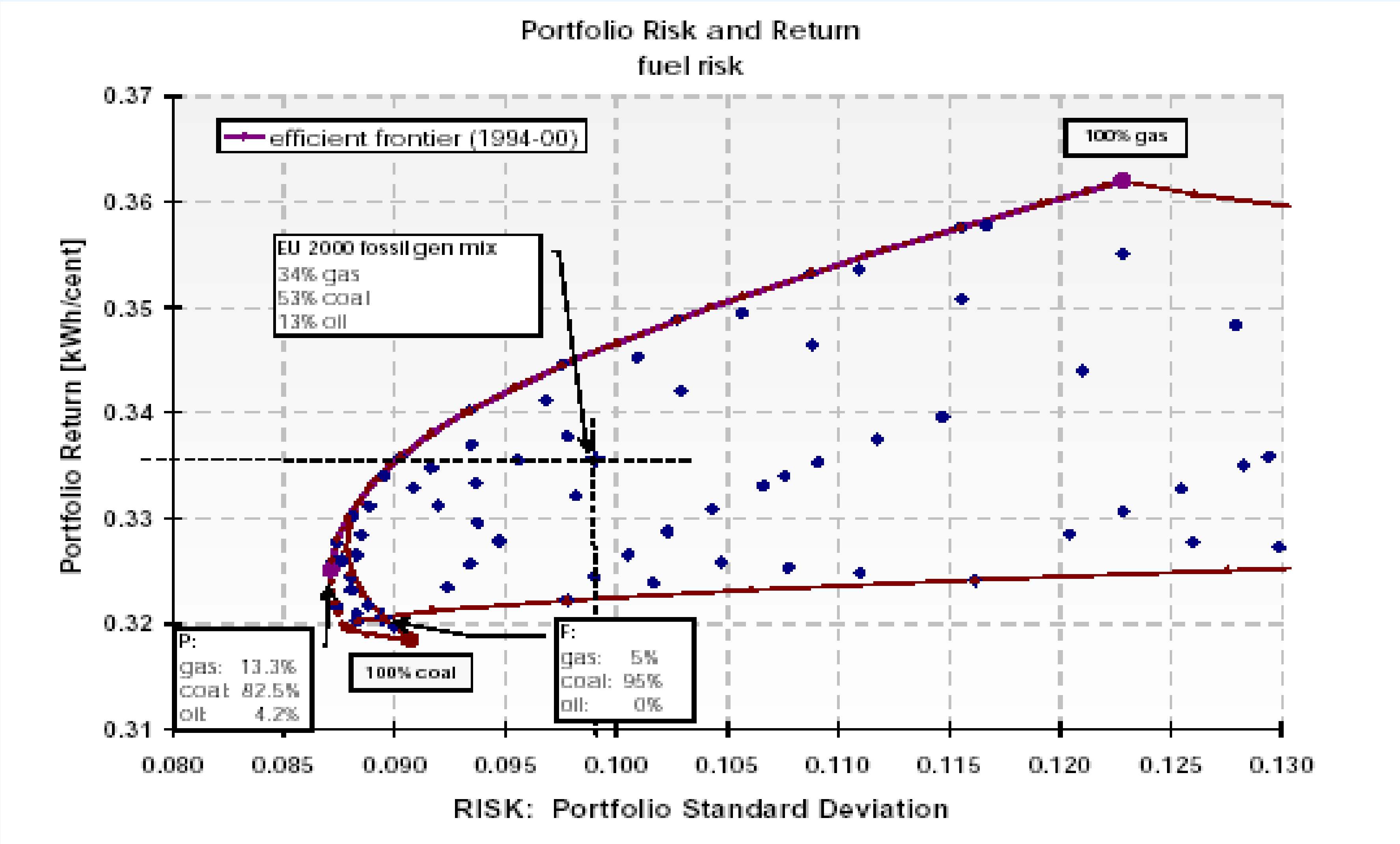
=> But nuclear is less likely to make large losses

Valuing Technological Diversity from a Utility Perspective

- Reports comparing nuclear with other technologies ignore **existing stock of plant**;
- Plant types combine to give a **portfolio with a value for diversity**;
- This diversity value should favour nuclear:
  - Nuclear and gas plant returns correlated with electricity prices;
  - But nuclear returns are not correlated with gas and carbon prices

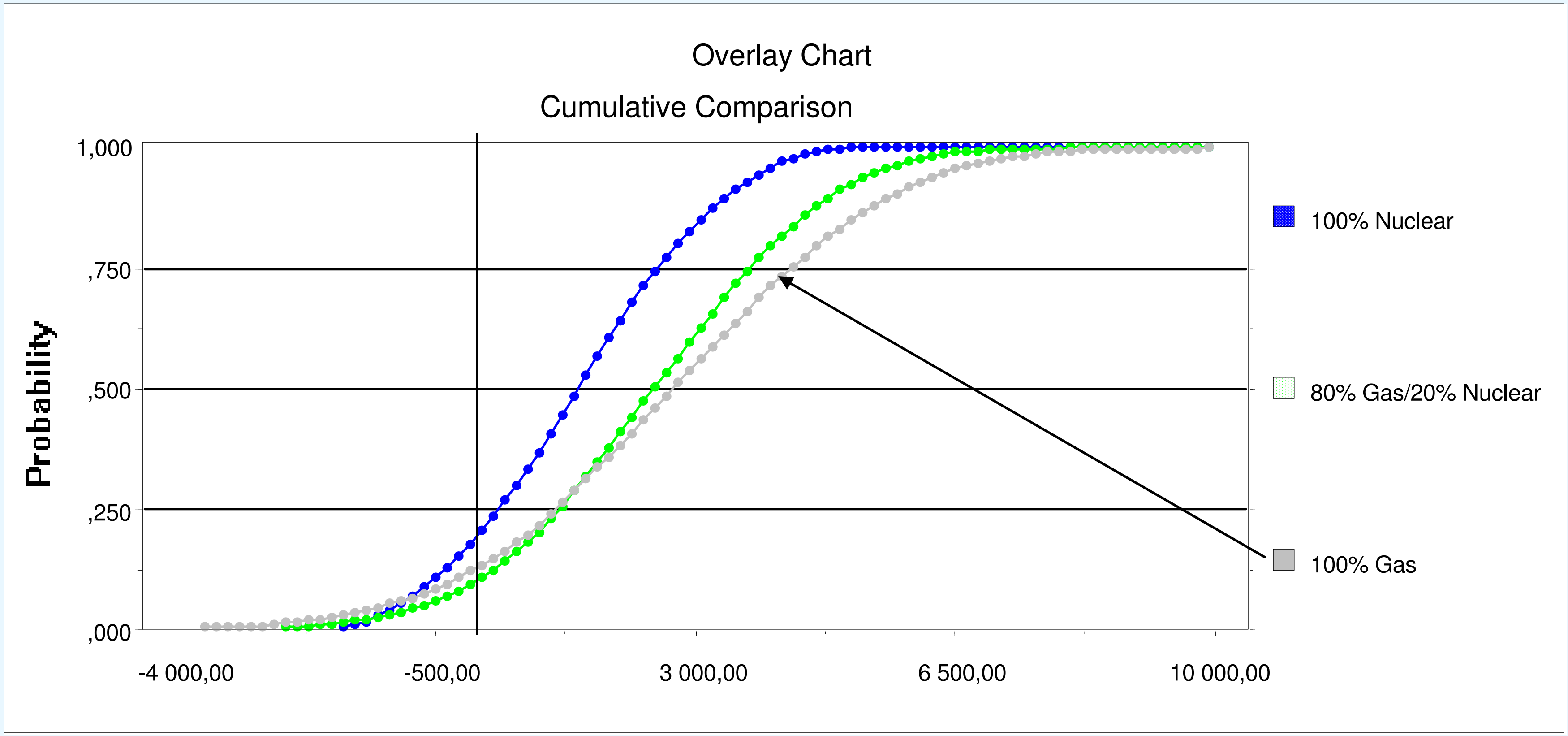
=> **Nuclear plants improve the risk-return frontier in the portfolio of power plants if gas and/or carbon prices are uncertain.**

European Fuel Mix Portfolio Risk-return Efficient Frontier (gas, coal, oil)
Source: Awerbuch 2003



Nuclear as a hedge against Gas and Carbon Price Increases: 1. Application of PORTFOLIO THEORY

Different combinations of 5 plants with gas, carbon, and electricity price uncertainty



=> A combination of **(4 gas; 1 nuclear)** plants is more robust to gas and carbon prices uncertainty than a combination of **5 gas plants**, without losing too much expected NPV.

Nuclear as a Hedge against Gas and Carbon Price Increases: 2. Application of REAL OPTION THEORY

- Assume initially 5 gas plants of varying ages.
- Attrition rate: e.g. 5 years, one plant has to be replaced in year 0, 5, 10, 15, 20.
- If the nuclear option is kept open replacement could be nuclear or gas, otherwise gas is the only possibility.

=> Nuclear investment offers an option to hedge against rising gas/carbon prices.

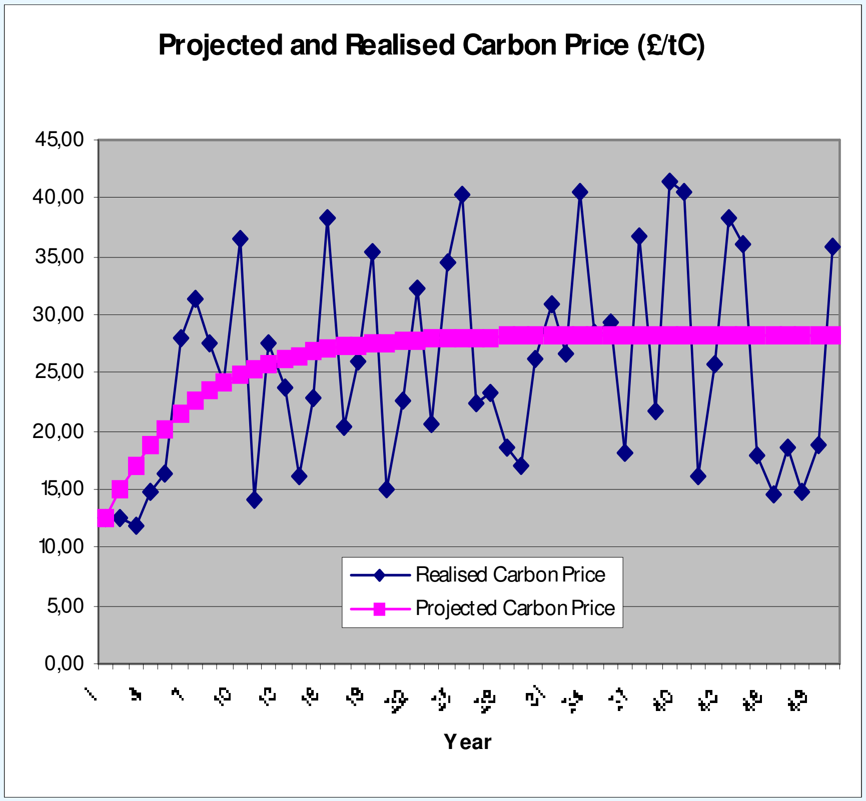
The stochastic model for Electricity/Gas/Carbon Prices

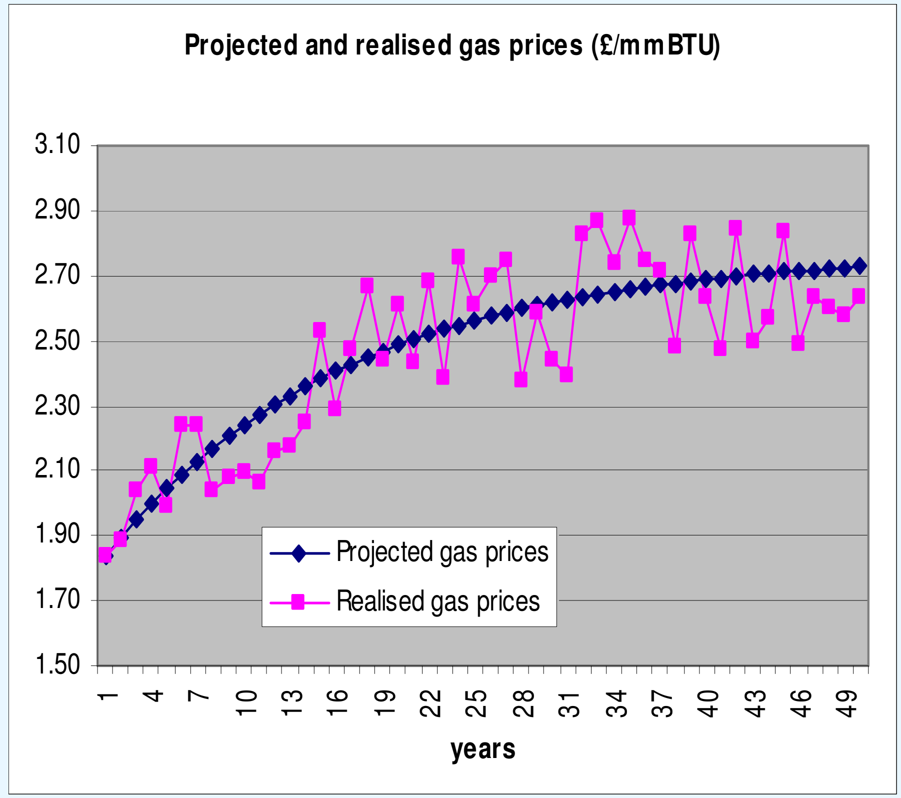
Projected prices are an exponential function (its parameters are price in year 0 and price forecasts in year 10 and year 20, as well as an error percentage for all of these 3 points).

Realised prices are projected prices plus a yearly volatility.

Randomised Electricity price model		
Projected Electricity Price in year 1	2.80	£cents/KWh
Realised Electricity Price in year 0	2.62	
Additional Electricity Price by year 10	0.50	£cents/KWh
Realised additional Electricity price by year 10	0.26	
Additional Electricity price after year 10	1.00	
Realised additional Electricity price after year 10	1.38	£cents/KWh
UNCERTAINTY ASSUMPTIONS		
Realised Electricity Price in yr 1 within	10%	of Electricity price projection
Additional Electricity Price by year 10	50%	of projection
Additional Electricity Price after year 10	50%	of Electricity Price projection
Annual volatility of Electricity Price growth	5%	points of growth projection

One Realisation of the Stochastic Gas and Carbon Prices





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The Option Valuation

- Simulate many realisations and associated NPVs with and without nuclear option

  => Option value is difference between the two expected NPVs

  => Option value depends on Gas/Nuclear ENPV distribution mean and spread.

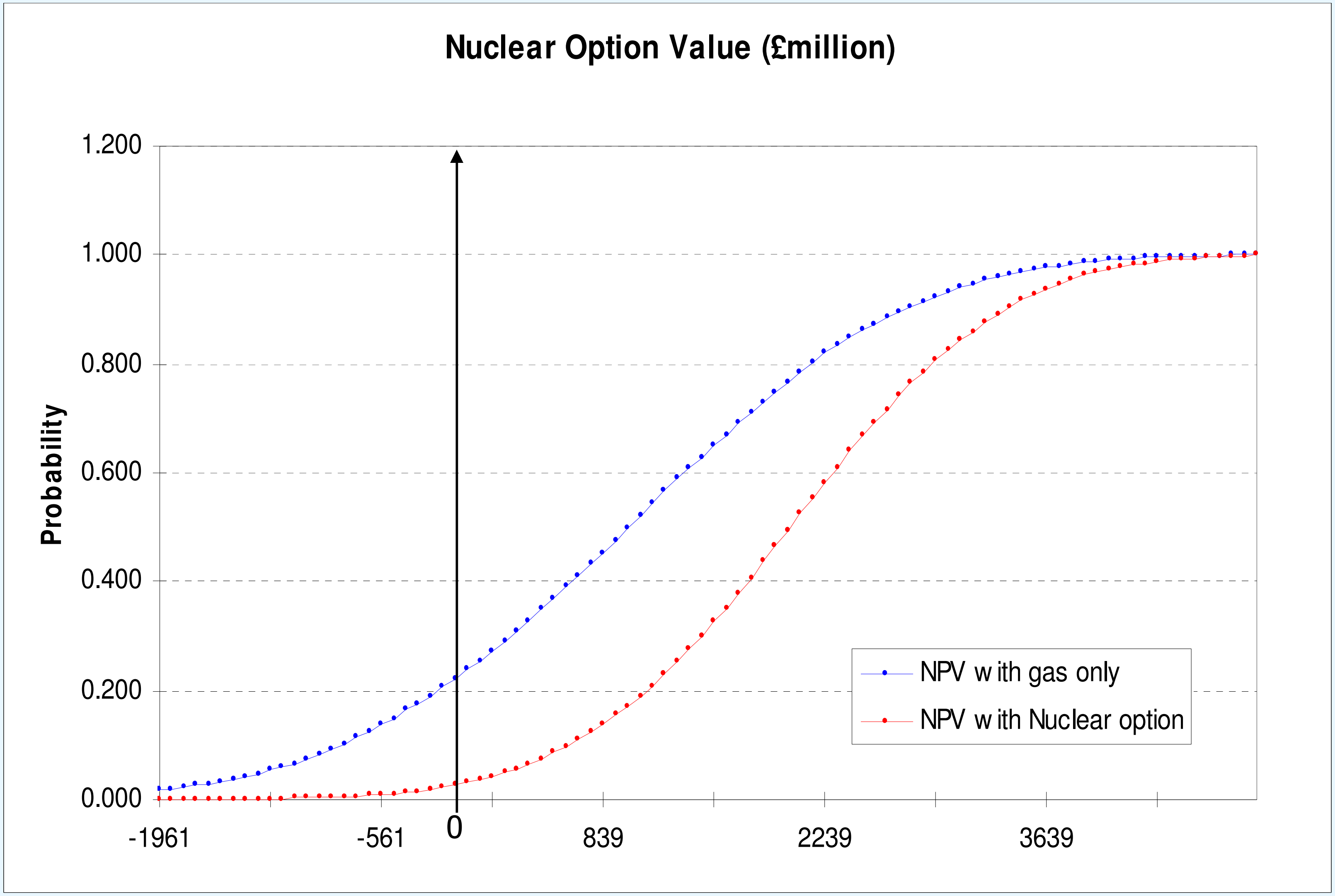
- The curse of dimensionality rules out recursive programming:

  => need a simple decision rule based on the past evolution of gas and/or carbon prices.

  => e.g. 'invest in nuclear if gas prices above *p**

    - can vary *p** and choose the best value
    - will ***understate*** the true option value - unlikely to be optimal (recursive) decision rule.

Distribution of the Option Value



Result of Decision Rule:
"Invest in nuclear if the sum of the gas prices for the last five years is greater than £12/MMBTU"

NPV with nuclear option (£million)	2,053
NPV without option (£million)	1,017
Option value for 5 plants (£million)	**1,036**

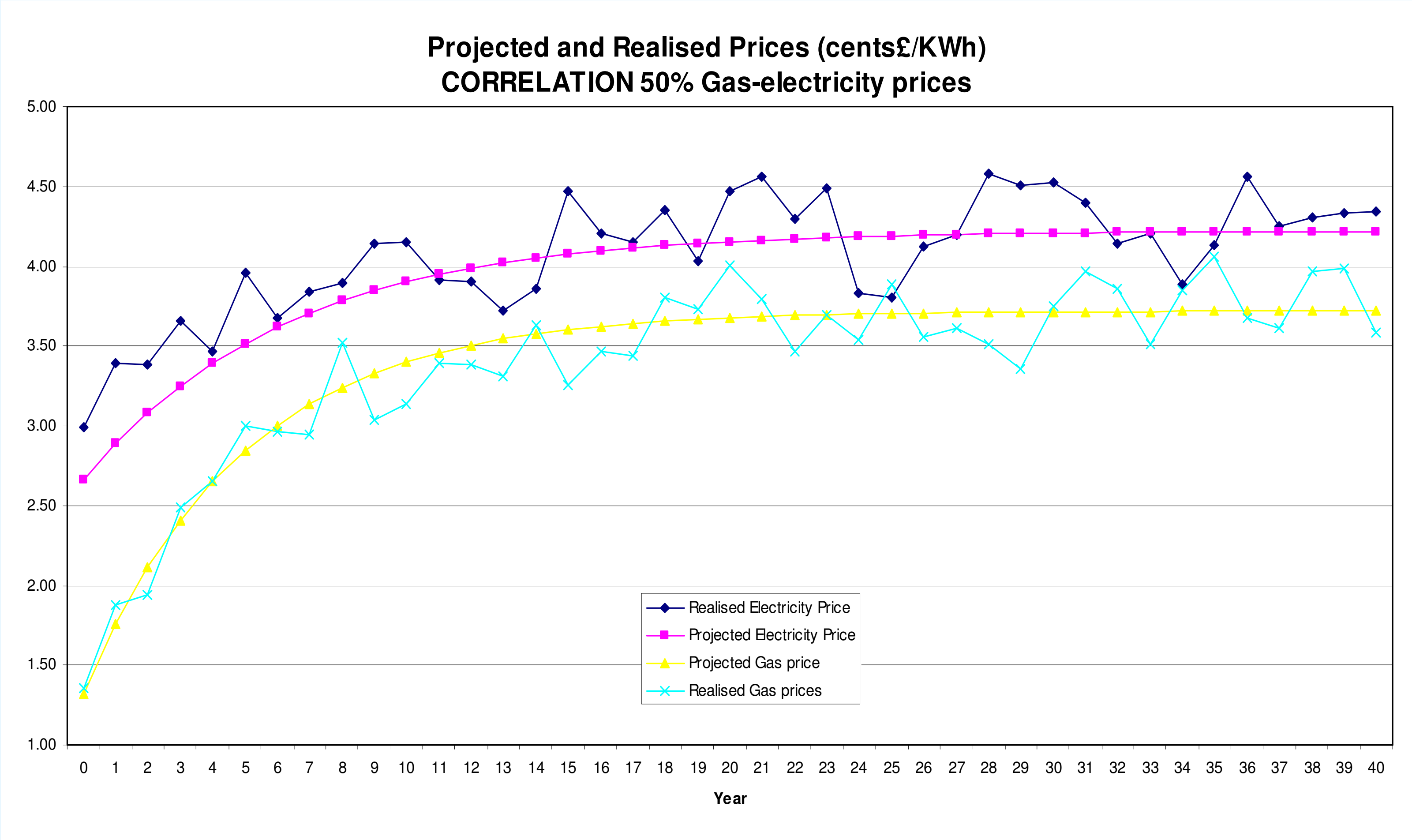
!Not realistic! No uncertainties correlation nor decision rule optimisation

On-going extensions:

=> Introduce correlation between gas, carbon, and electricity prices;

=> Optimise decision rule.

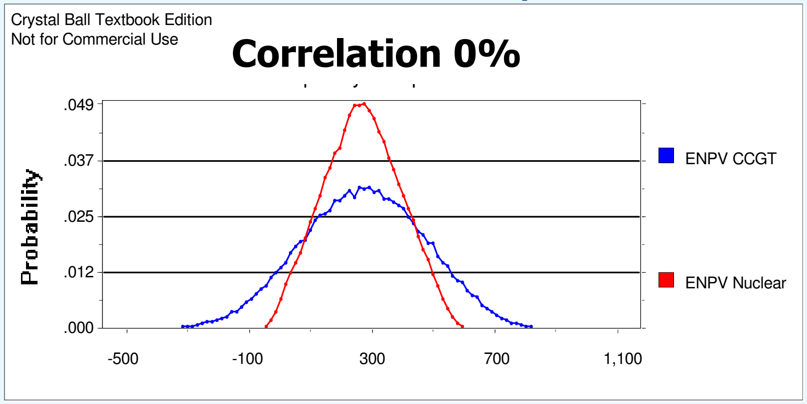
Correlations between Gas/Electricity/Carbon Prices

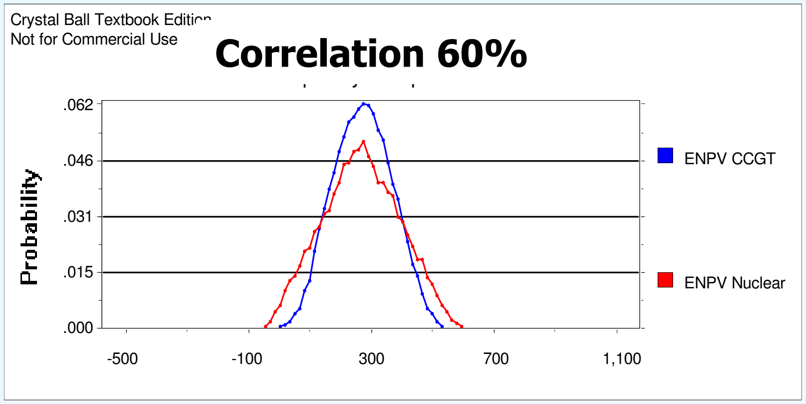


=> Correlation factor can vary between 0 and 100%.

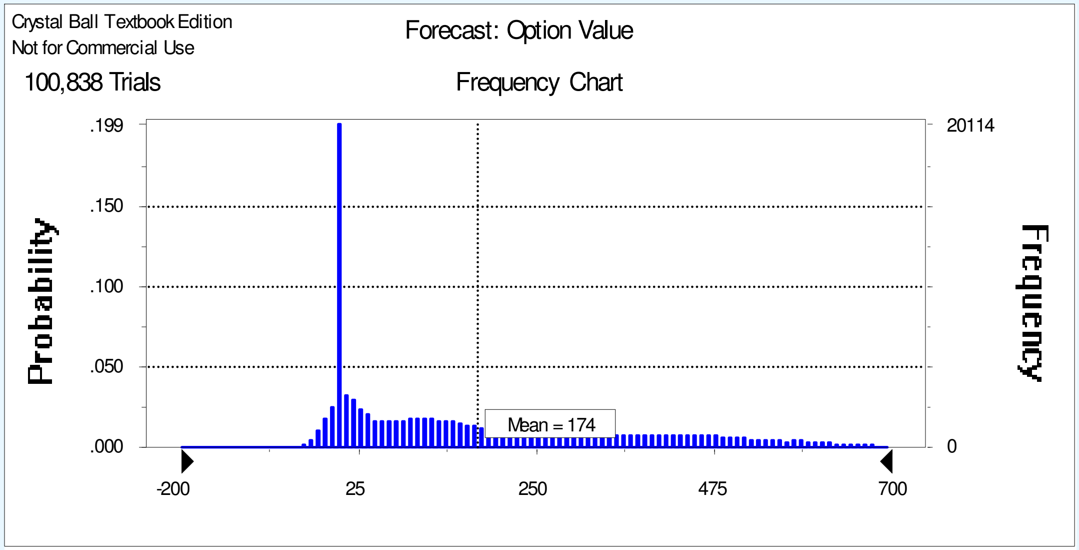
Impact of Gas/Electricity Prices Correlation on CCGT NPV

Gas-electricity prices correlation does not change the ENPV, but squeezes the Gas NPV distribution:



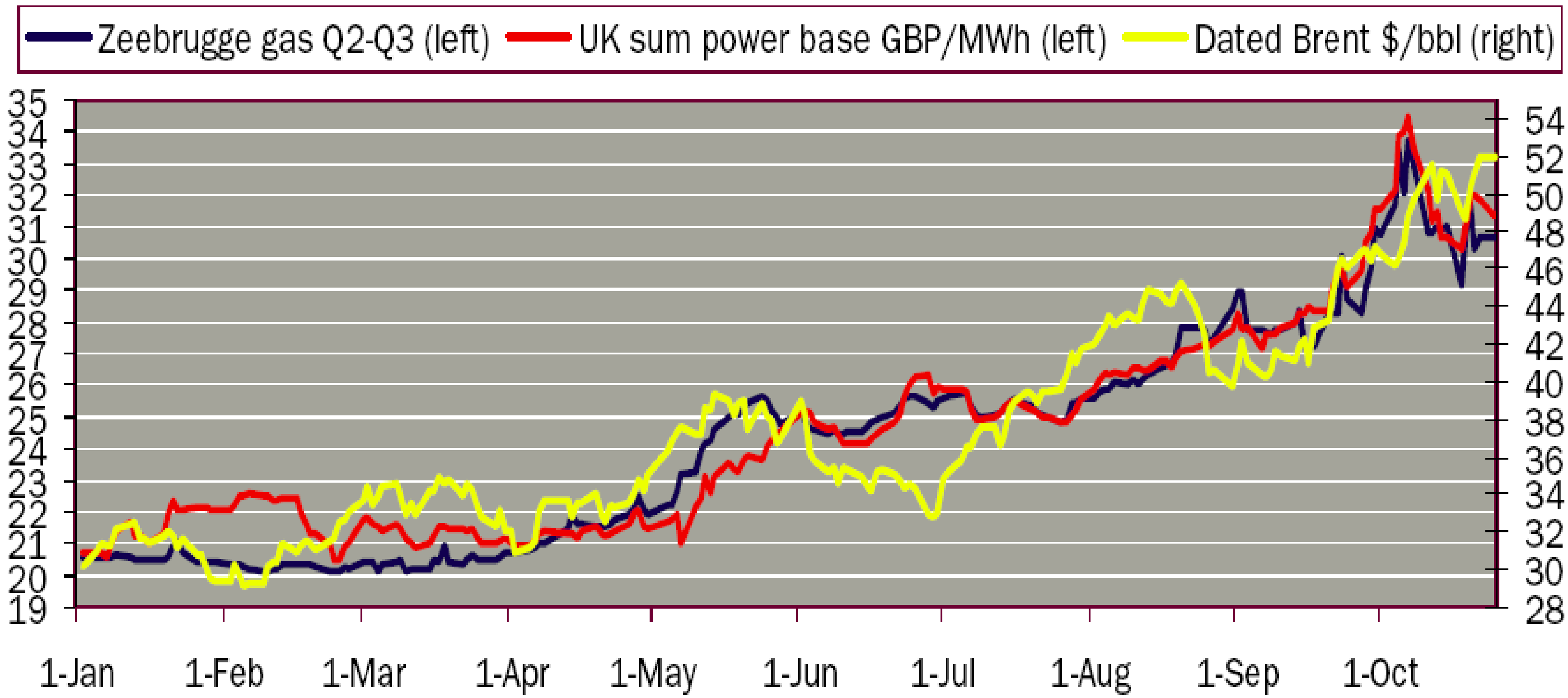


This considerably lowers the option value:



What Determines the Correlation Factor?

Power, Oil and gas prices rose together in 2004
(Source Platts)



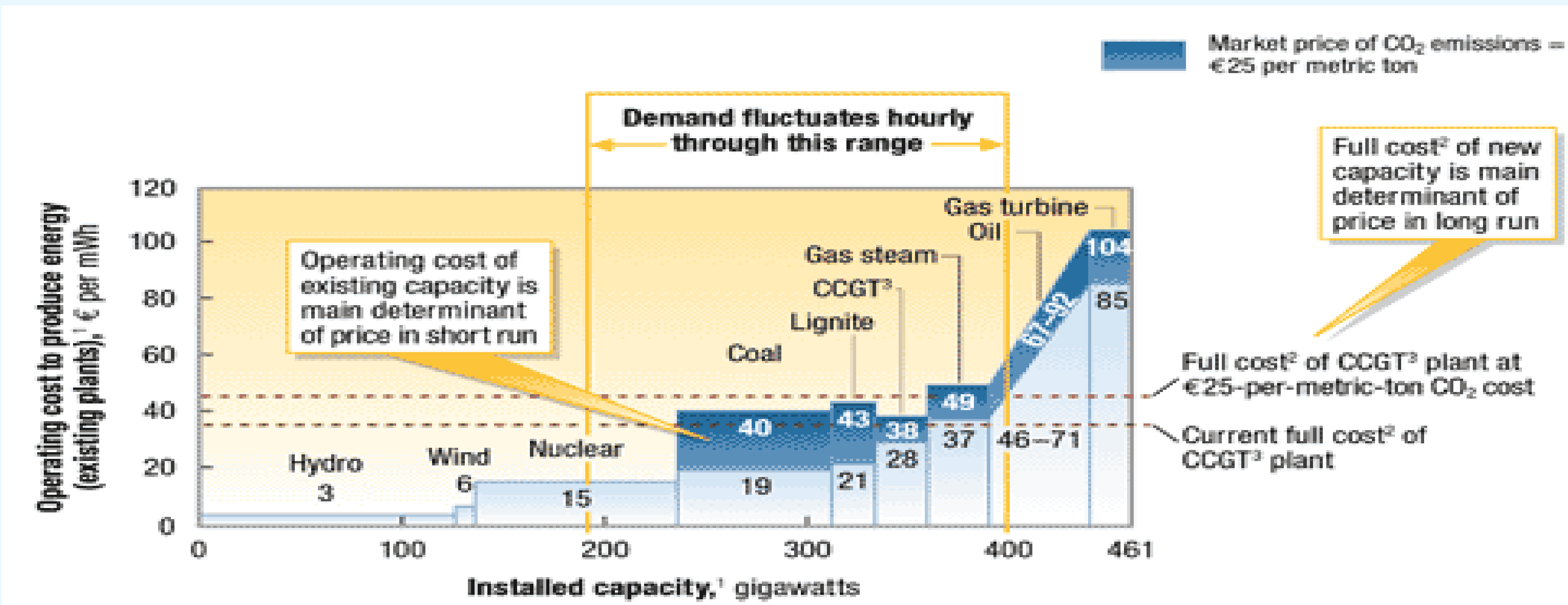
Source: Platts data

Fuels Prices Increases May Change the Plants Merit Order

- Complex correlation of gas/electricity/carbon prices requires market stacking model

  => simulate merit order and marginal plant cost

McKinsey 2003 study of EUTS impact on European Electricity Prices



¹For Austria, Belgium, Finland, France, Germany, Luxembourg, Netherlands, Norway, Sweden, and Switzerland; costs shown are simplified—actual model examines costs on a plant-by-plant basis.

²Includes capital costs.

³Combined-cycle gas turbine.

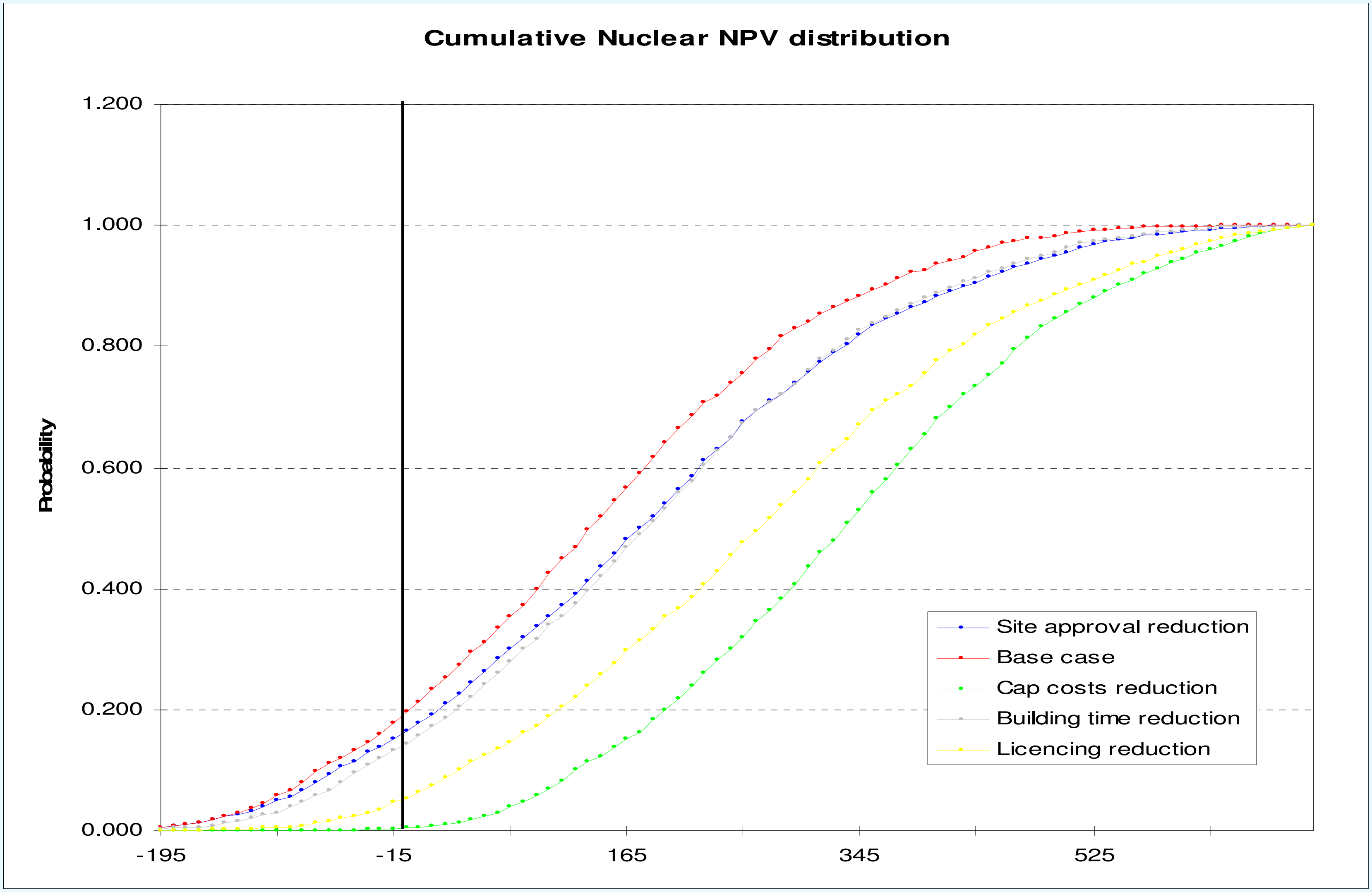
What can be done in practice to 'Keep the Nuclear Option Open'?

- Shortening lead times: e.g. US DOE 'Nuclear 2010' funding program
- Option value of spending money to reduce:
  - Site licensing time
  - Actual building time
  - Post construction plant licensing time

Scenario	Site permission (years)	Construction time (years)	Plant licensing time (years)	Capital costs (£ millions)
Base Case	2	5	2	1140
Capital costs reduction	2	5	2	900
Site permission reduction	0	5	2	1140
Construction time reduction	2	4	2	1140
Plant licensing time reduction	2	5	0	1140

=> Results depend greatly on the discount rate…

8 % Discount rate



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Comments welcome!

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