Electricity Policy Research Group
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An Analysis of Risk in Nuclear Power

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Overview of Research Program (page 1)

- Key Characteristics of Nuclear
  - High capital cost, very low operating cost
  - Operating cost is independent of oil & gas price volatility
  - Long lead time for construction
  - Unit scale is very large
  - Large fixed costs to shutdown
- In Contrast, for Example, to Natural Gas

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Overview of Research Program (page 2)

- **What are the Consequences for the Risk Profile?**
  - Identify key underlying risk factors such as regional load, weather, factor prices, plant outages
  - Develop a structural model of plant construction, dispatch and price development
  - Identify portion of underlying risk factors allocated to nuclear profit profile
- **Using Financial Derivative Pricing Methodology**
  - i.e., contingent claims methodology built on Black/Scholes/Merton principles
  - Measure the total risk for the industry as a whole
  - Identify how that risk is allocated to the various portions of the industry
    - how much to gas plant, how much to nuclear,
  - Which risks go where
    - Which units bear the load risk
    - Which bear the oil/gas price risk

Long-term Volatility in Load

- **Load evolves unevenly and with uncertainty**
  - Abstracting from daily and seasonal volatility
  - Forecasting load 5 and 10 years out
- **Model load as a stochastic process**
  - Time trend, e.g., constant drift – 2.5%
  - Volatility – 30%
  -

$$\frac{dx}{x} = \mu\, dt + \sigma\, dz$$

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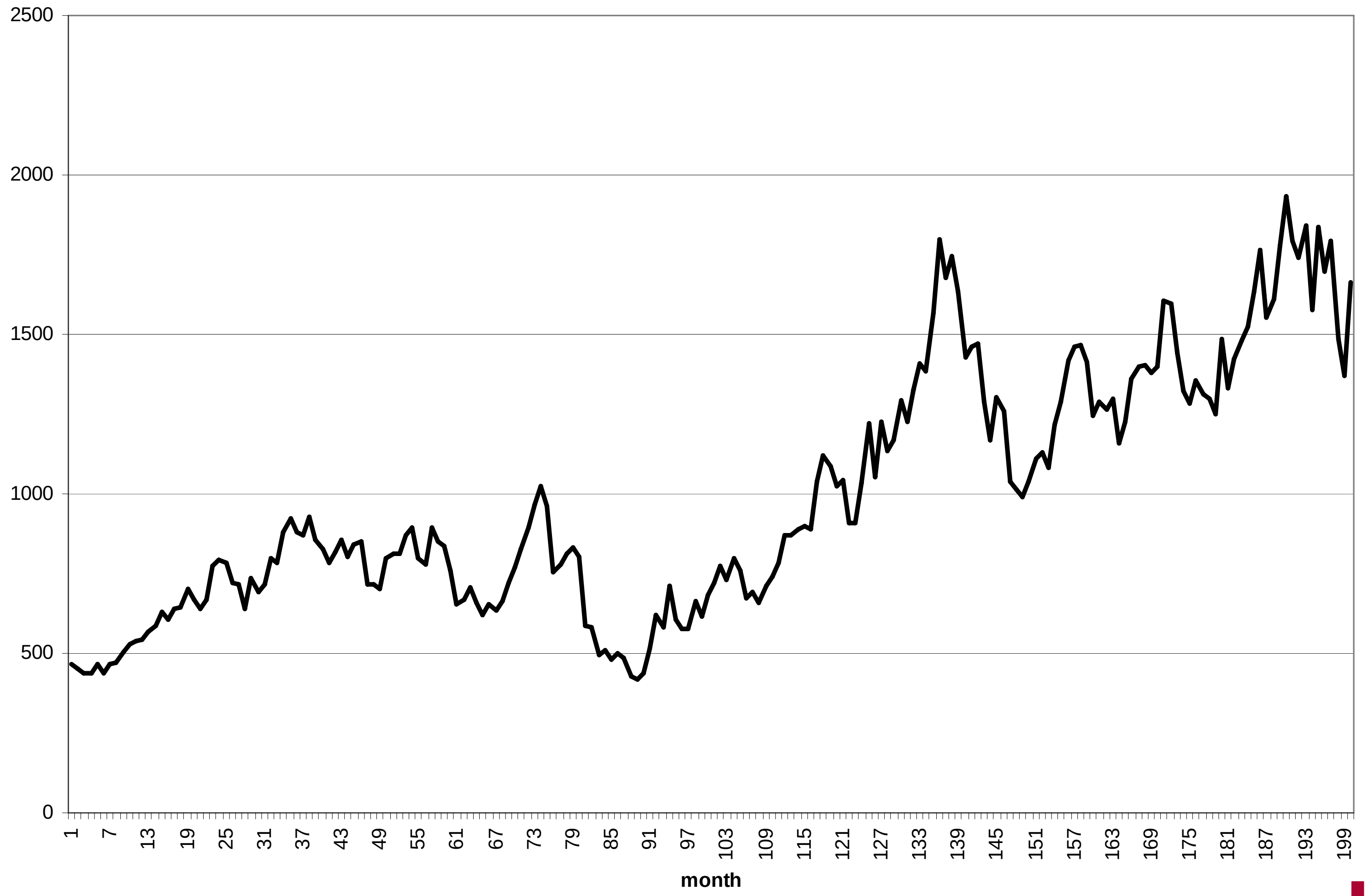
Sample Path of Load, 200 months



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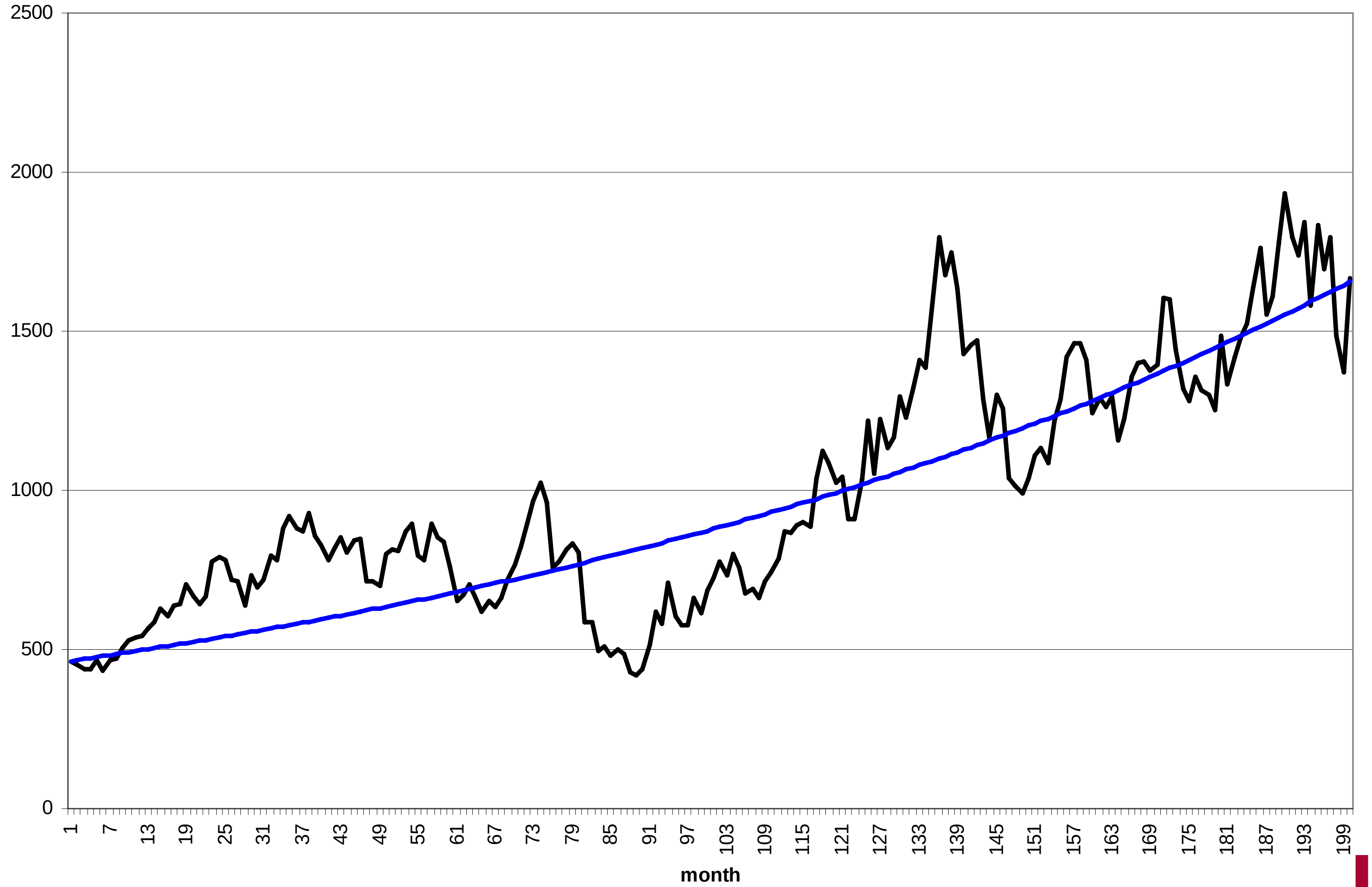
Factor 1: Load Growth

Sample Path of Load, 200 months



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Model Equilibrium Decision to Install Capacity

- Competitive equilibrium following Leahy, QJE 1993
- A single constant returns to scale technology in capacity, q
  - Initially abstract from the time to build nuclear plants – capacity can be instantly added
  - Abstracts from the on/off decision and the premium to gas for operating flexibility
- Inverse demand function, $D^{-1}(x,q)= x\, q^{-1/n}$ where x is the demand factor
- Firms choose a trigger price at which to add capacity
  - Starting from an initially low price due to excess capacity, as load increases, the price increases until it hits the trigger
  - If load continues to increase when price is at the trigger, new capacity is added at the rate load is expanding so that the price stays at the trigger,
  - Whenever load drops, capacity additions stop, and price falls below the trigger to equilibrate supply and demand

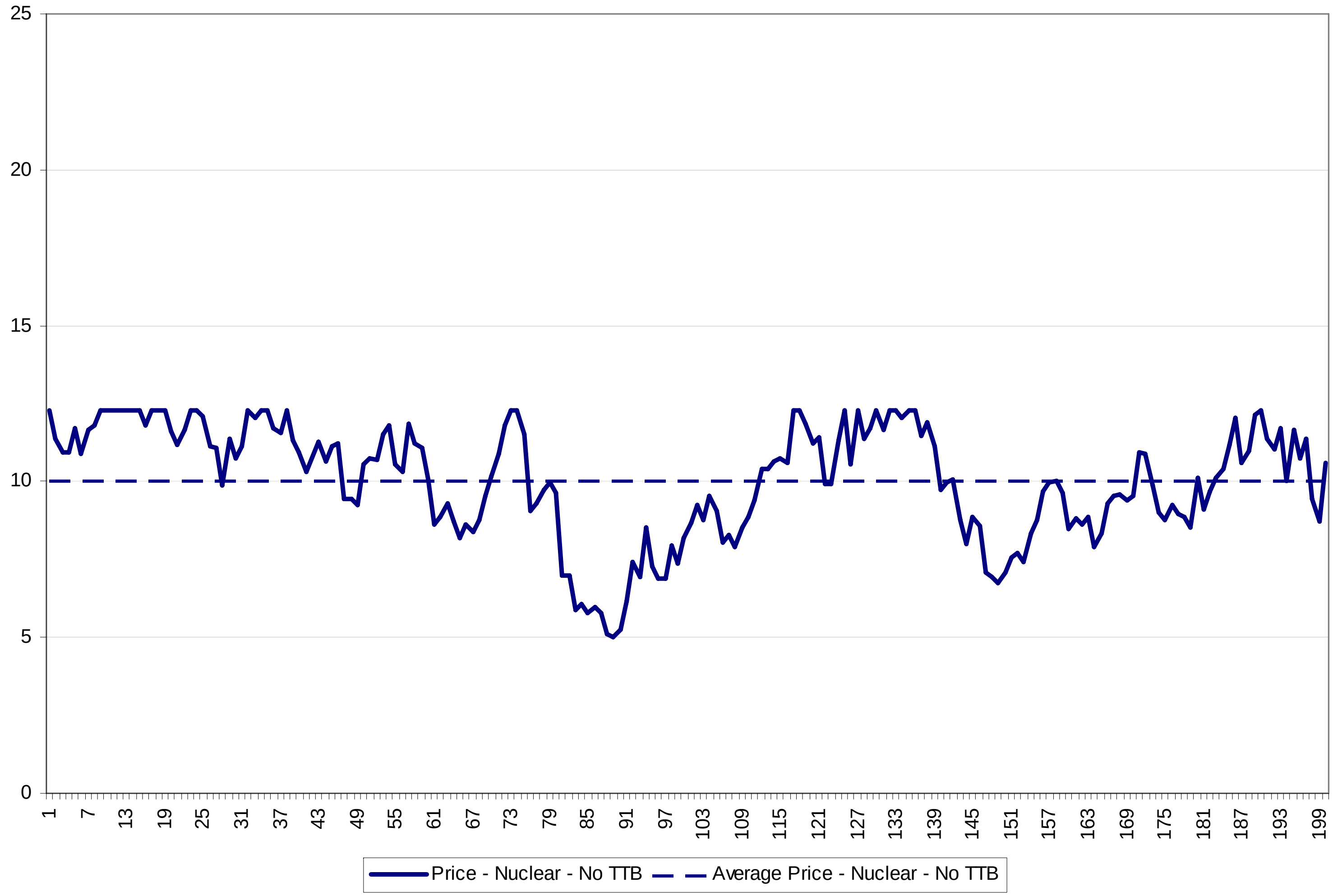
Trigger Price

- If demand growth were certain, then the trigger price would exactly cover marginal cost plus the rental price of capital
- With demand growth uncertainty, there is a danger of periods of low realized demand and therefore excess capacity
- Therefore the trigger price must include a premium to cover this possibility

Scenarios

- **Low Cost Technology (nuclear) – no time to build**
  - Trigger price = $12.30
  - Average realized equilibrium price = $10.04
  - Coefficient of variation of eq. price = 18%
- **High Cost Technology (gas) – no time to build**
  - Trigger price = $18.39
  - Average realized equilibrium price = $14.65
  - Coefficient of variation of eq. price = 18%

Equilibrium Price, low cost technology



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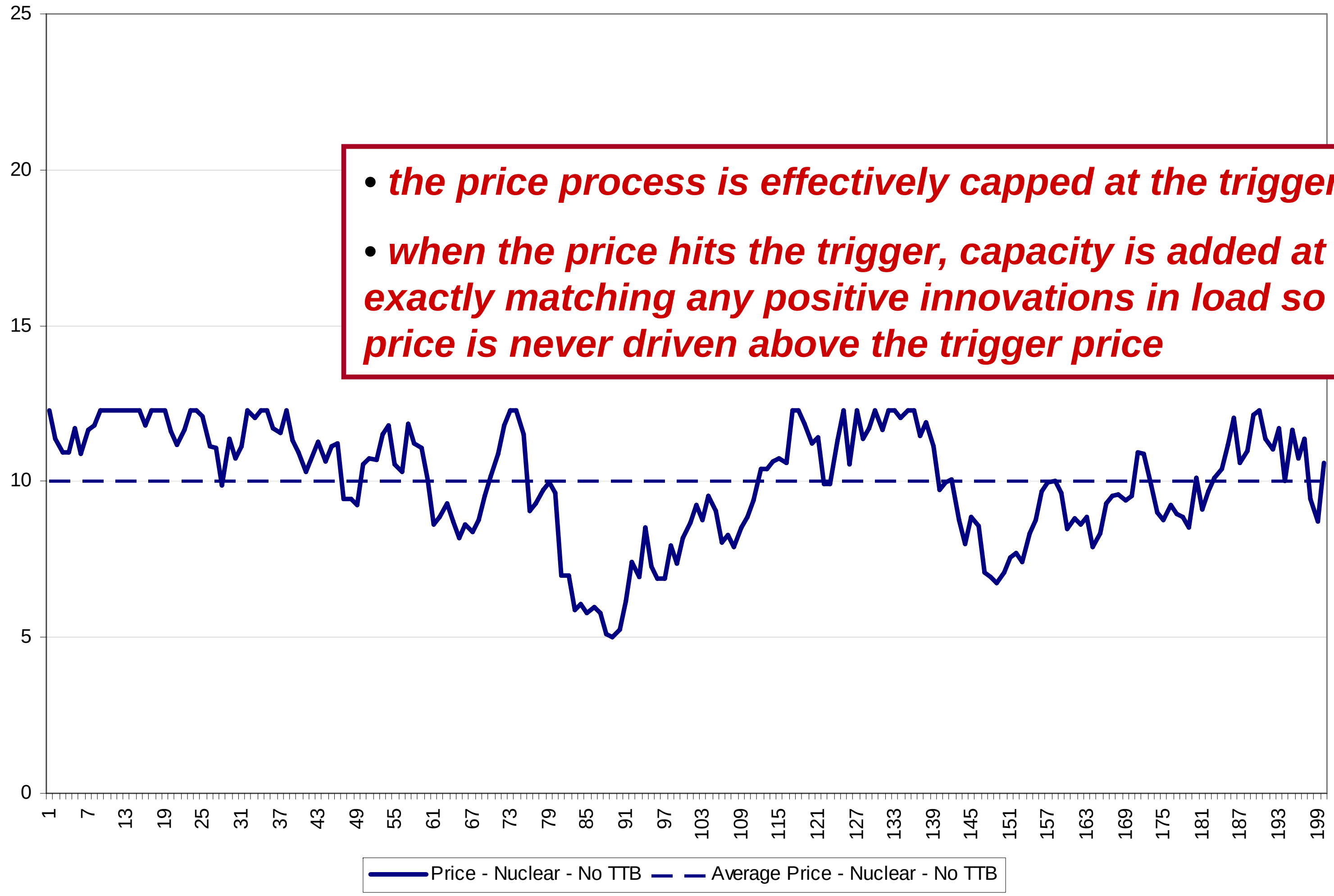
Equilibrium Price, low cost technology

- *the price process is effectively capped at the trigger price*
- *when the price hits the trigger, capacity is added at a rate exactly matching any positive innovations in load so that the price is never driven above the trigger price*



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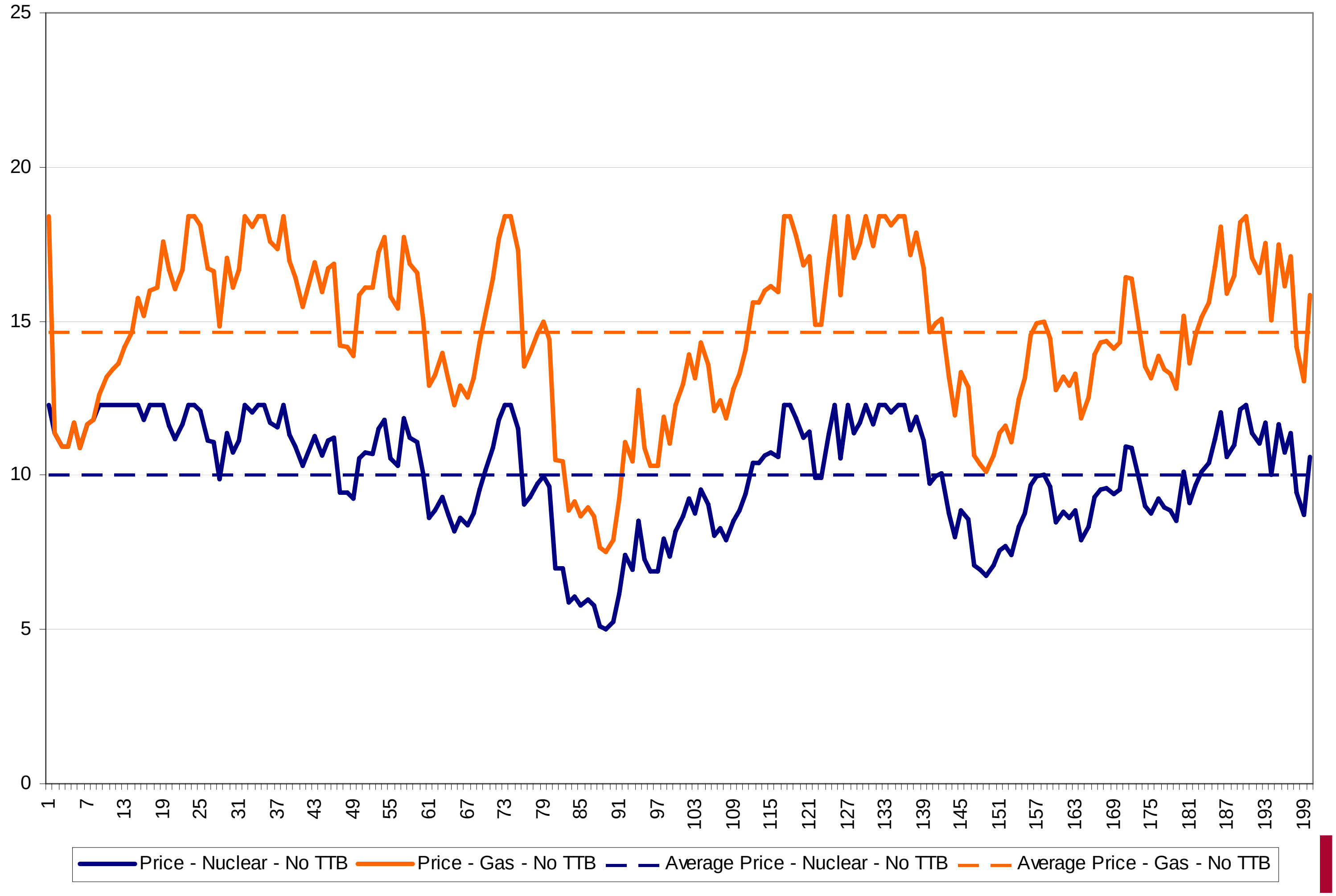
Factor 1: Load Growth

Equilibrium Price, high cost technology



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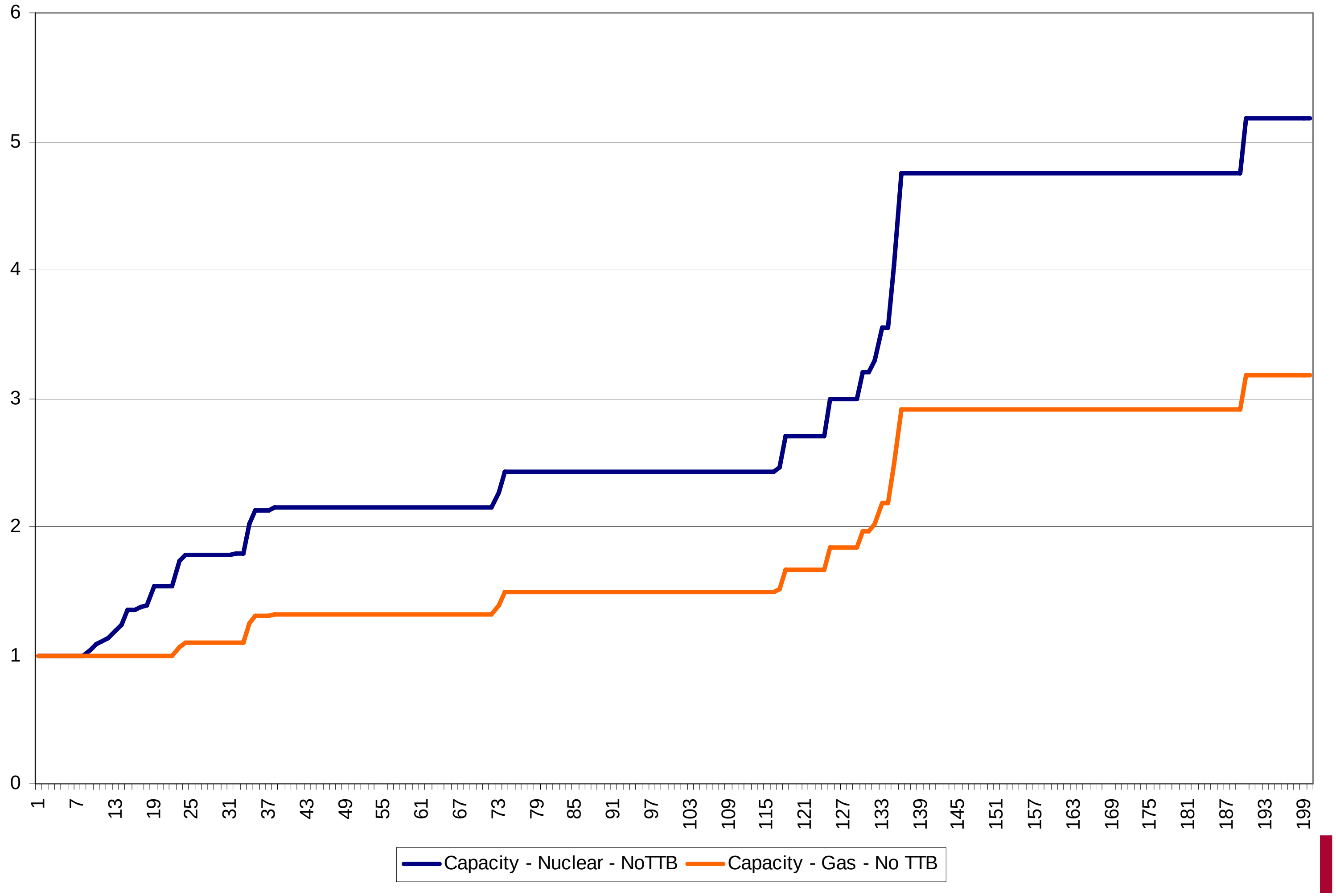
Factor 1: Load Growth

Installed Capacity, low & high cost technologies



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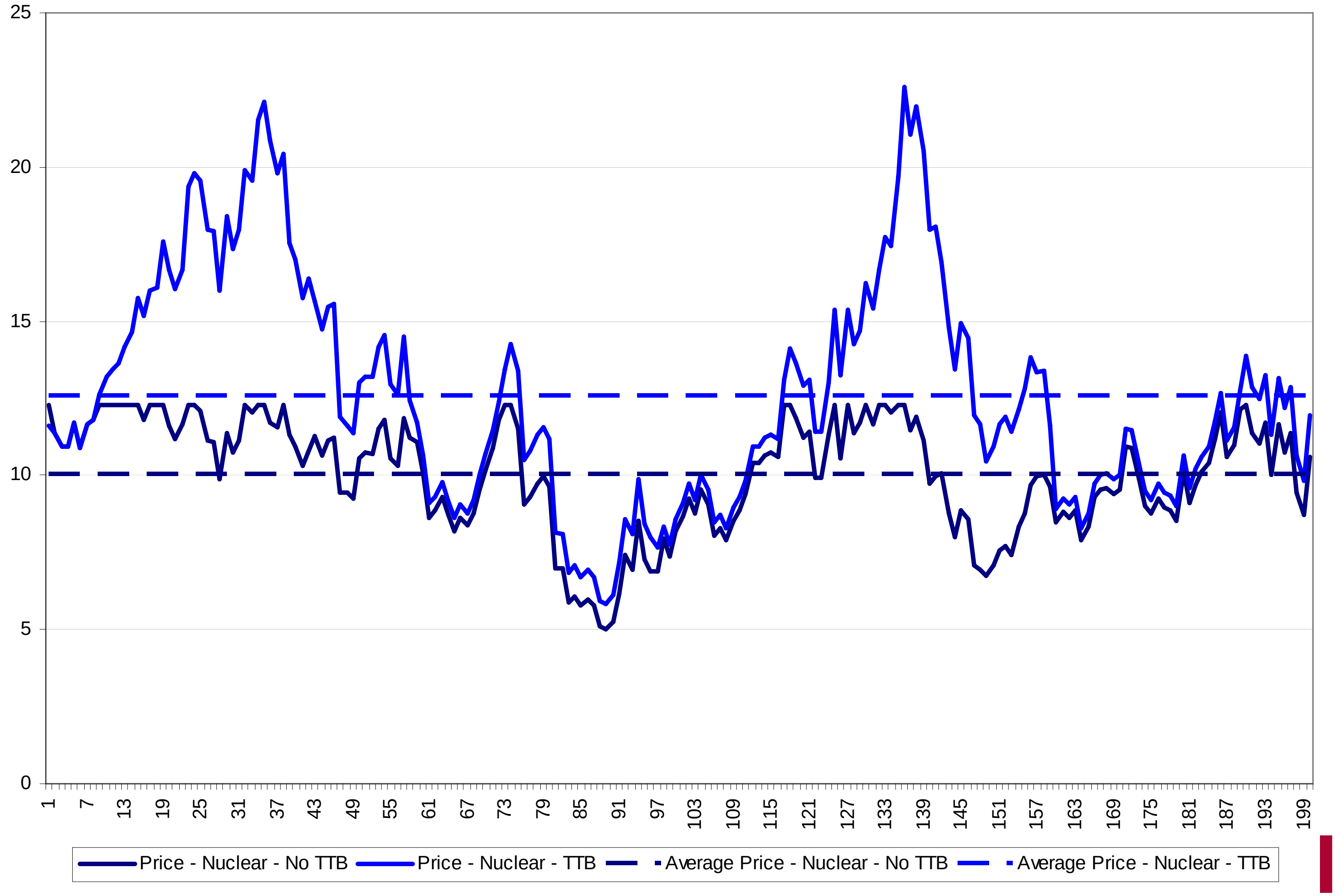
Re-Model Equilibrium Given Time-to-Build

- Competitive equilibrium following Grenadier, RFS 2002
- Equilibrium decisions are altered to forecast price after capacity in construction comes on line
- Firms still choose a trigger price at which point to initiate construction following any period of no construction
- Price is no longer capped, since load may continue to increase while capacity is under construction

Factor 1: Load Growth

Equilibrium Price, with Time-to-Build



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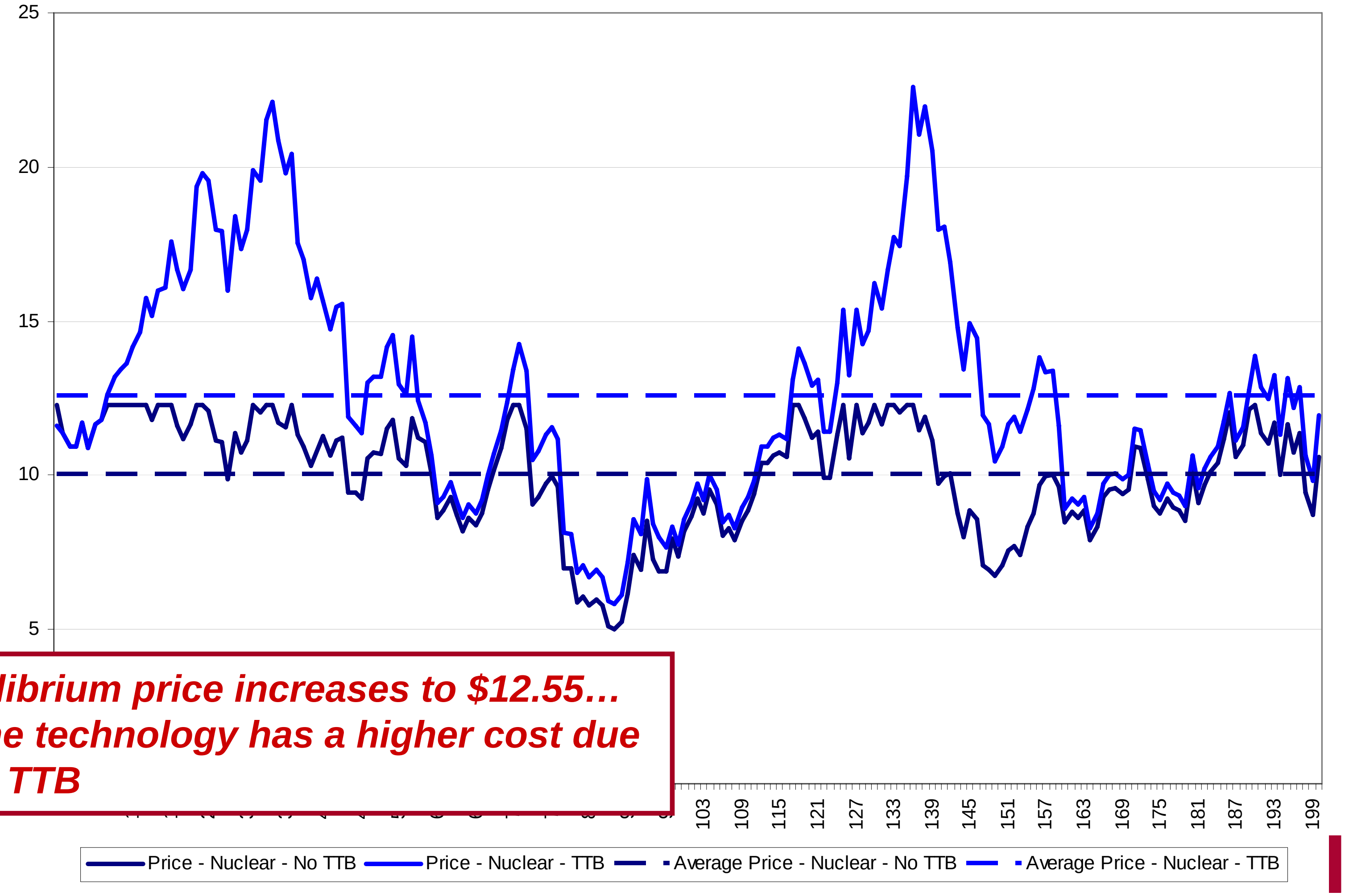
Equilibrium Price, with Time-to-Build



- ***equilibrium price increases to $12.55… i.e., the technology has a higher cost due to the TTB***

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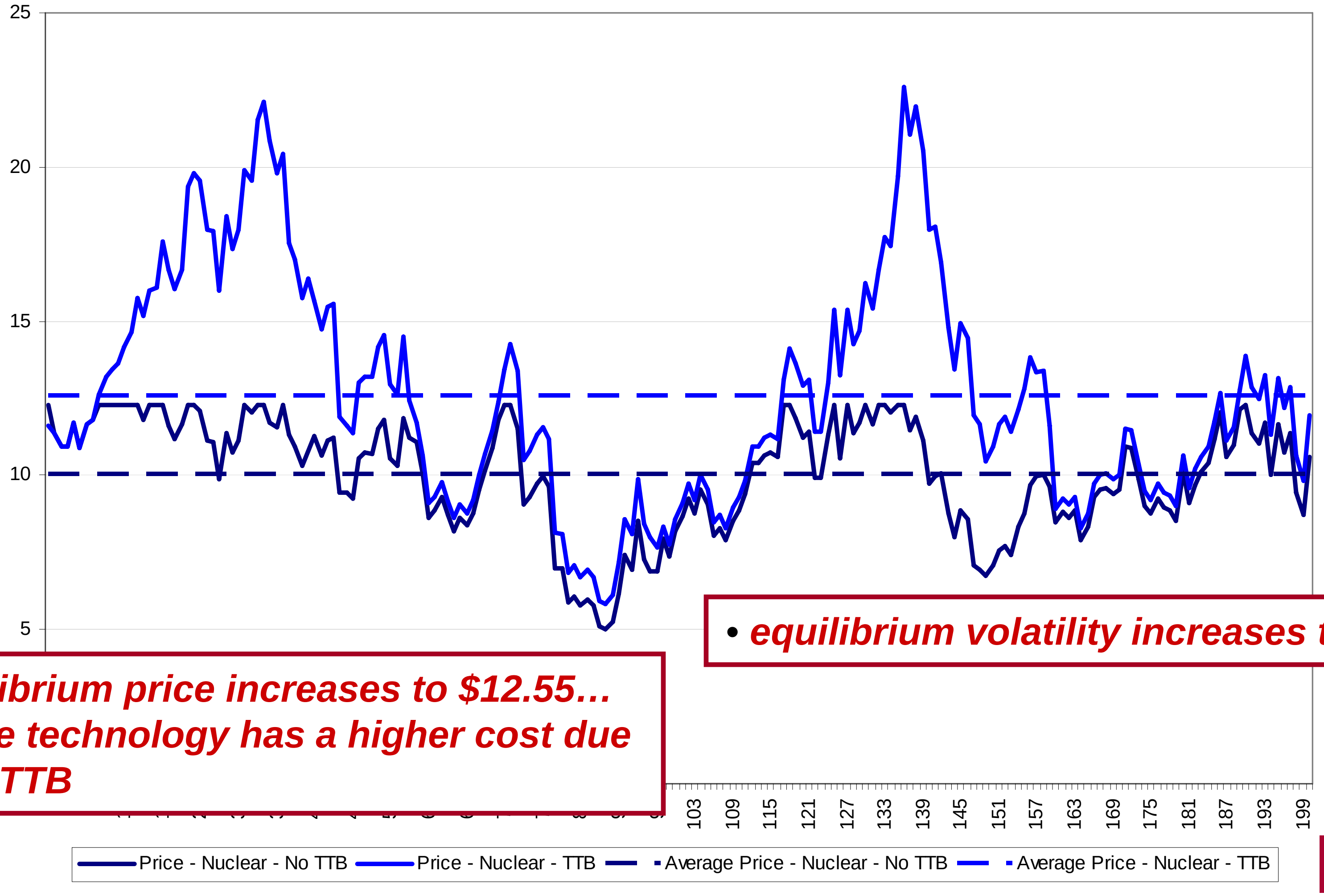
Factor 1: Load Growth

Equilibrium Price, with Time-to-Build



- ***equilibrium volatility increases to 29%***

- ***equilibrium price increases to $12.55… i.e., the technology has a higher cost due to the TTB***

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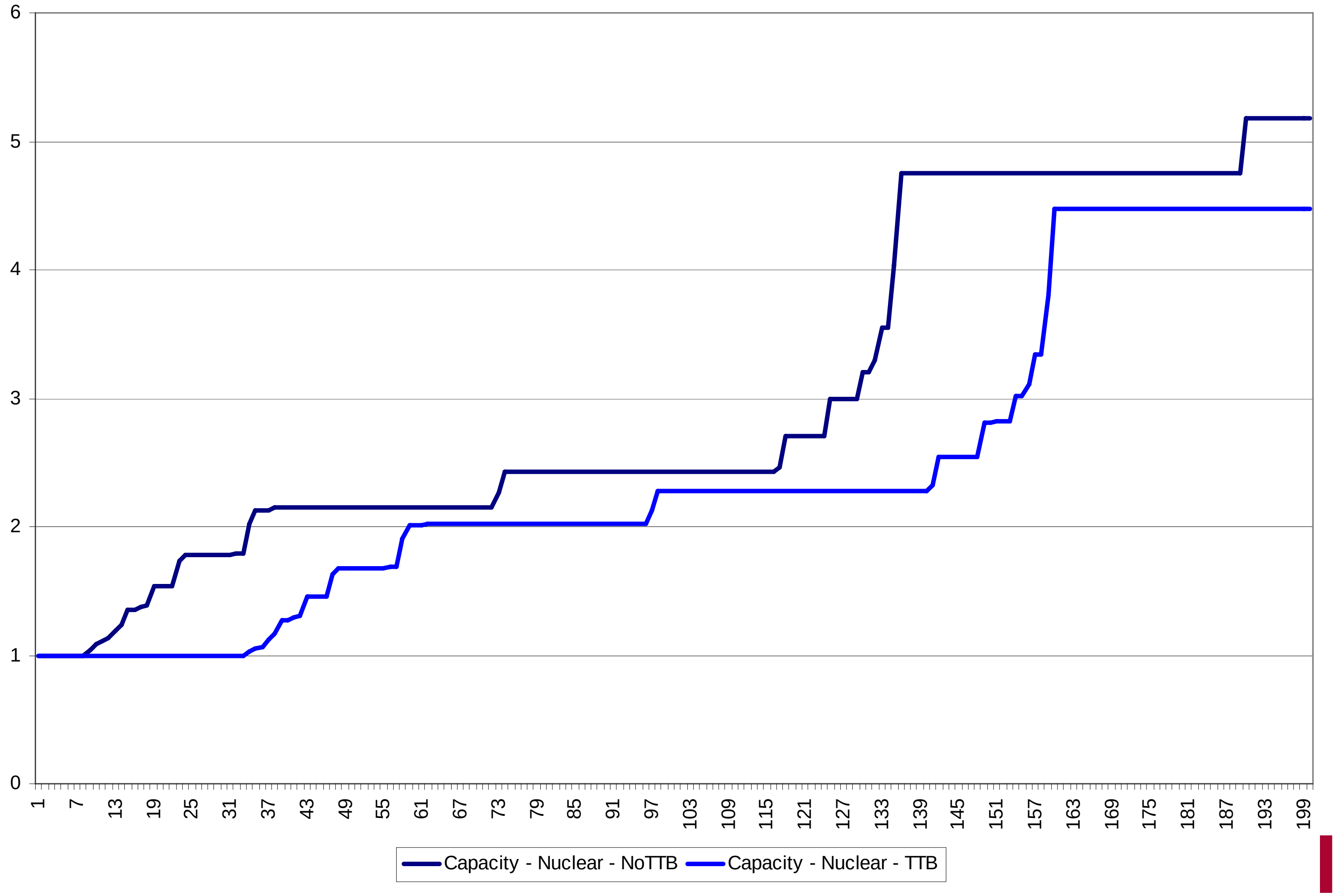
Capacity Installed with Time-to-Build



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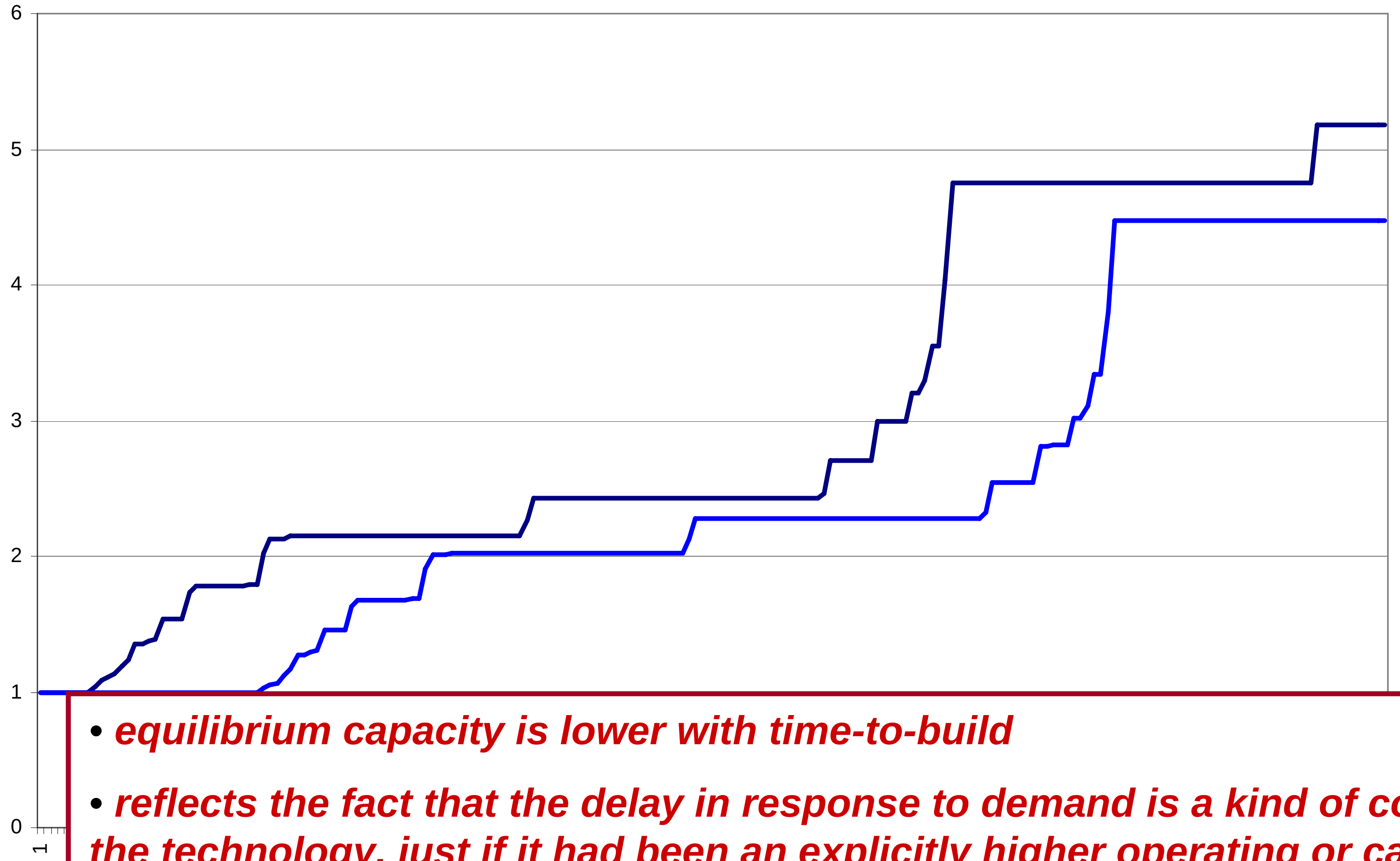
Capacity Installed with Time-to-Build



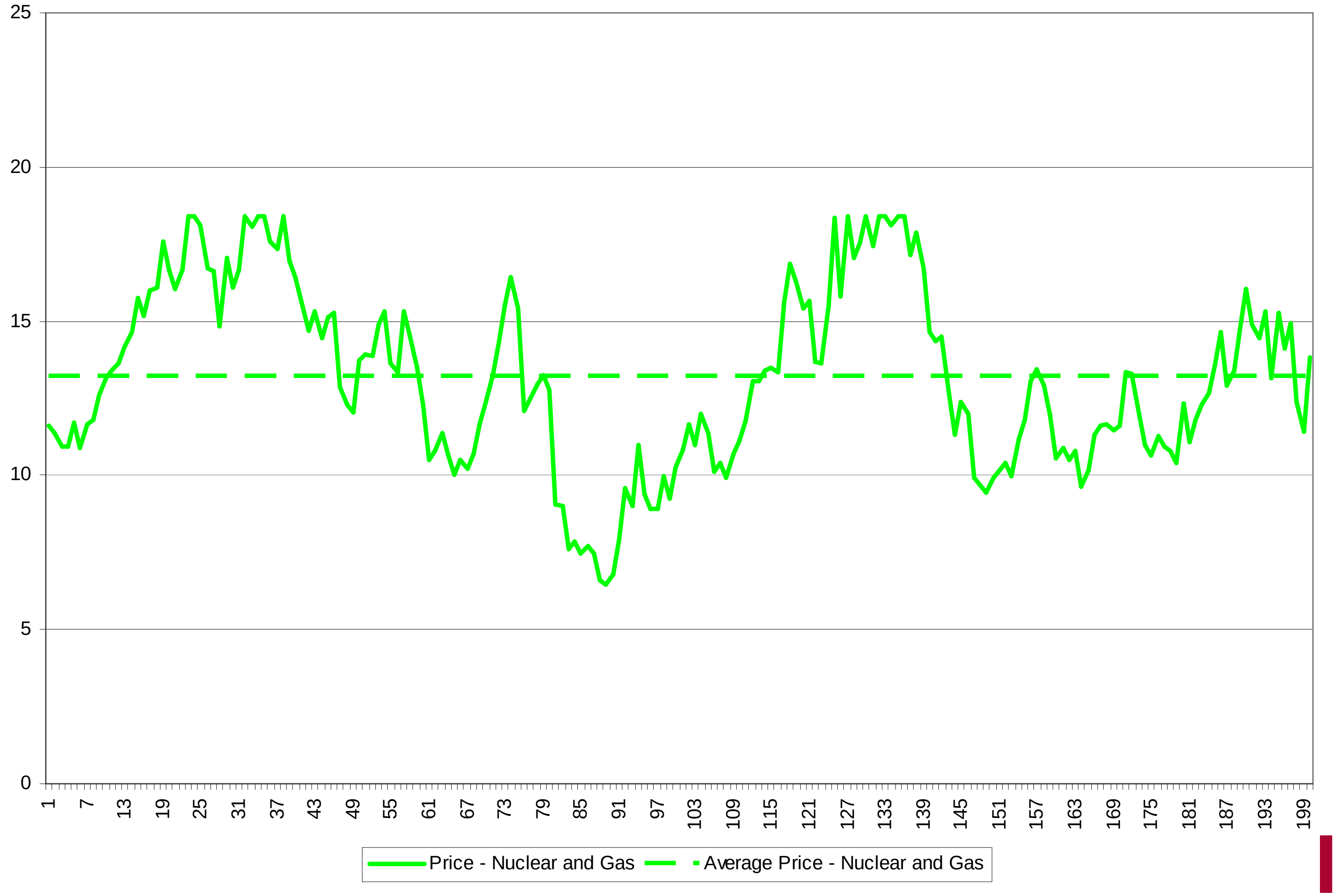
- ***equilibrium capacity is lower with time-to-build***
- ***reflects the fact that the delay in response to demand is a kind of cost of the technology, just if it had been an explicitly higher operating or capital cost element***
- ***the technology cannot readily provide the capacity when it is most needed***

A Two-Technology Equilibrium

- Low Cost with Time-to-Build (nuclear)
- High Cost with no Time-to-Build (gas)
  - But still no option to turn-off
- Berger Solution: iterate optimal industry reactions
  - Start with the Nuclear Time-to-Build strategy
  - Let the Gas industry build whenever the price rises high enough
  - Revise the Nuclear strategy to recognize installed gas capacity
- Note that with the parameters chosen, the low-cost technology, even with time-to-build, dominates the high-cost technology
- But occasional high prices while nuclear is being built creates an opportunity for the high-cost technology to generate value

Factor 1: Load Growth

Equilibrium Price with Two Technologies



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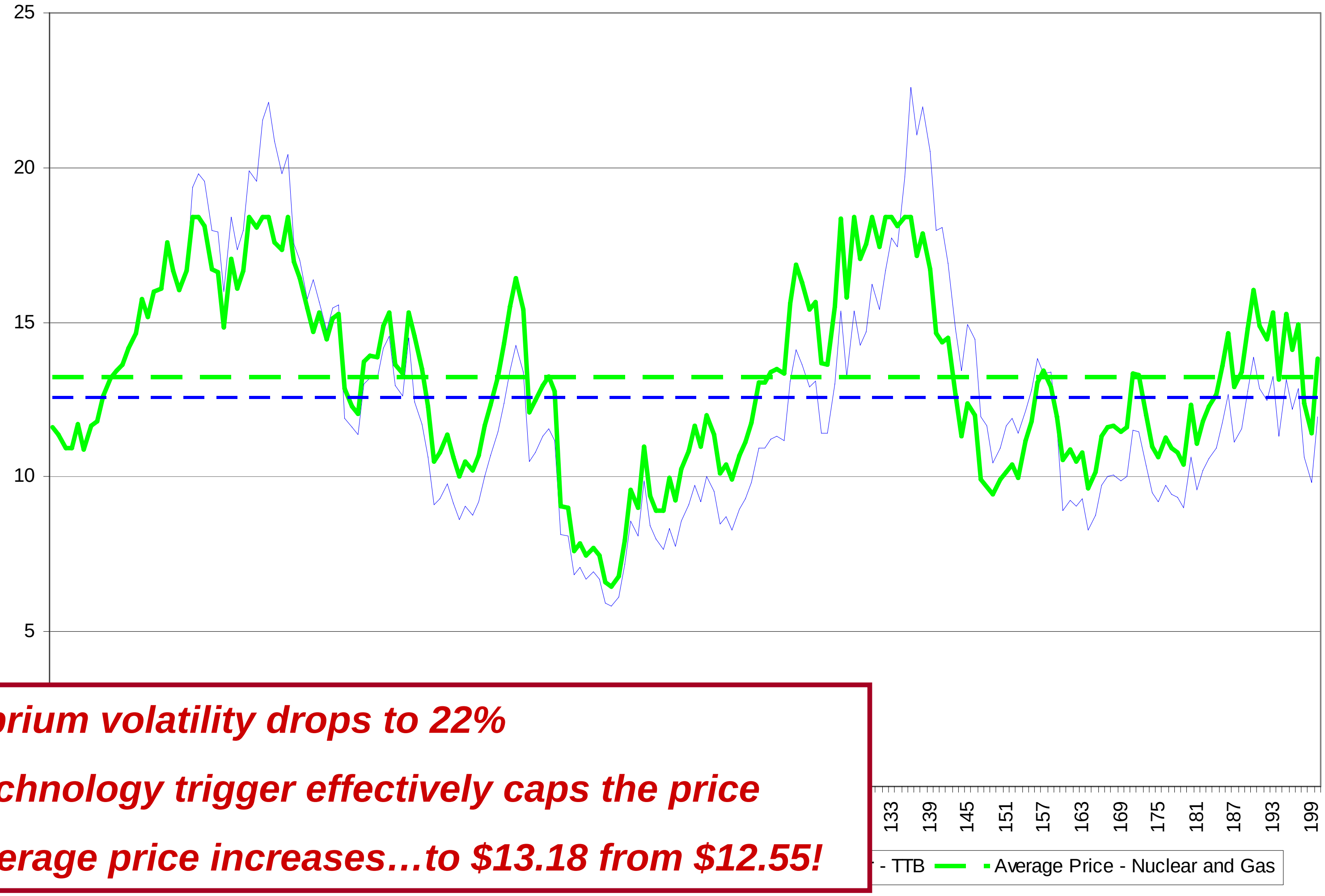
Factor 1: Load Growth

Price Compared to Single Technology Equil.



- *equilibrium volatility drops to 22%*
- *gas technology trigger effectively caps the price*
- *but average price increases…to $13.18 from $12.55!*

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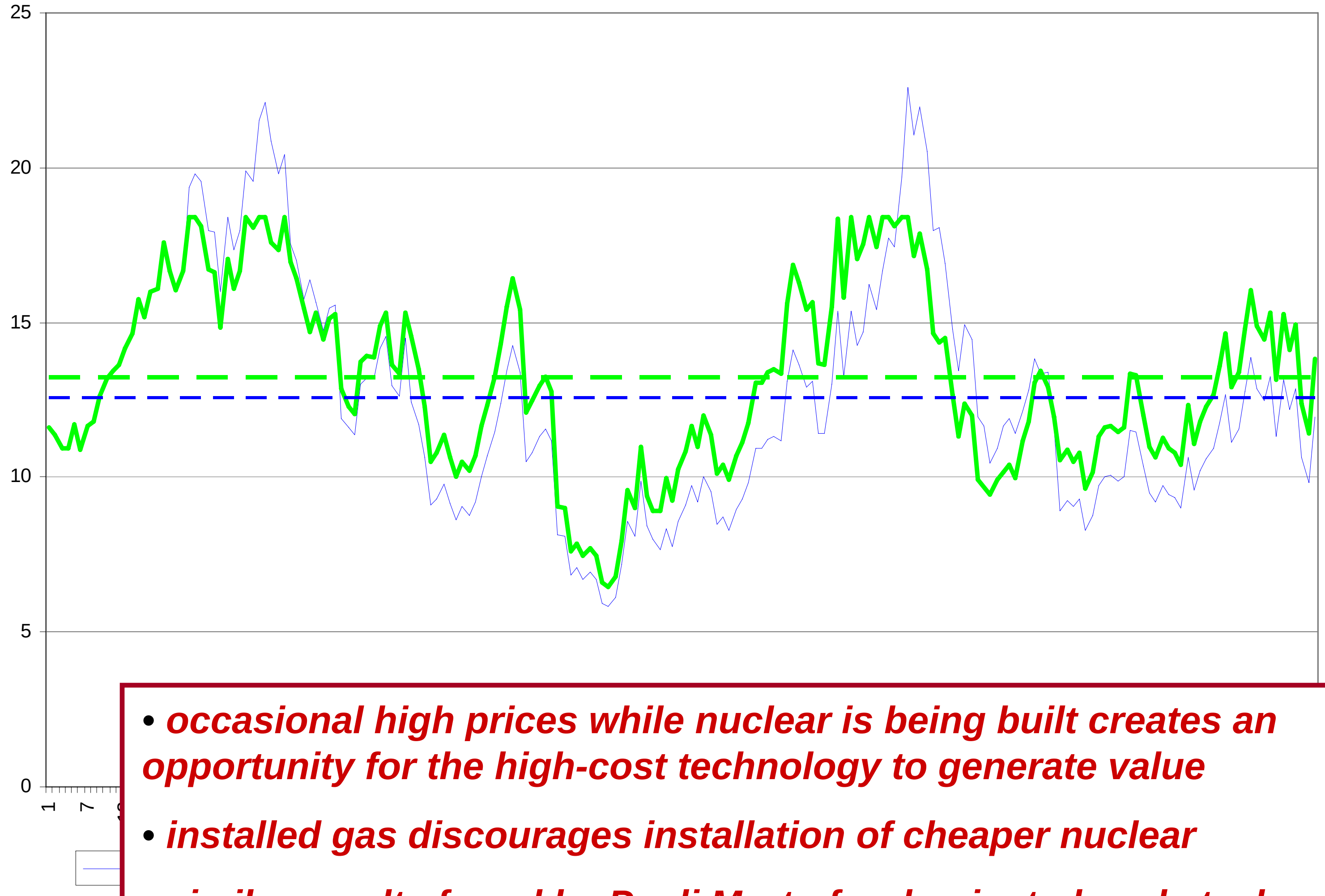
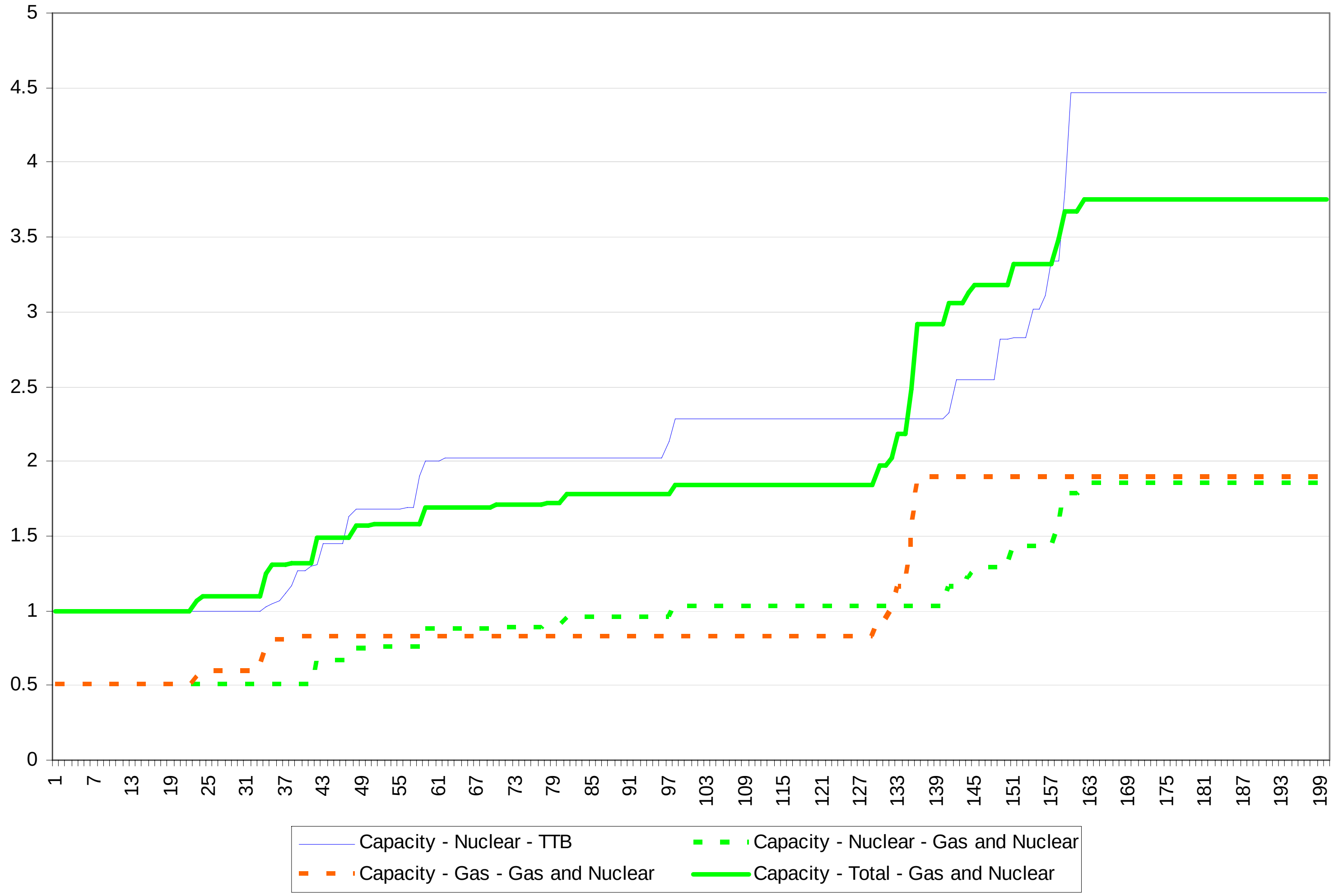
Price Compared to Single Technology Equil.



- *occasional high prices while nuclear is being built creates an opportunity for the high-cost technology to generate value*
- *installed gas discourages installation of cheaper nuclear*
- *similar results found by Pauli Murto for dominated scale technologies*

Capacity for Two Technologies



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