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
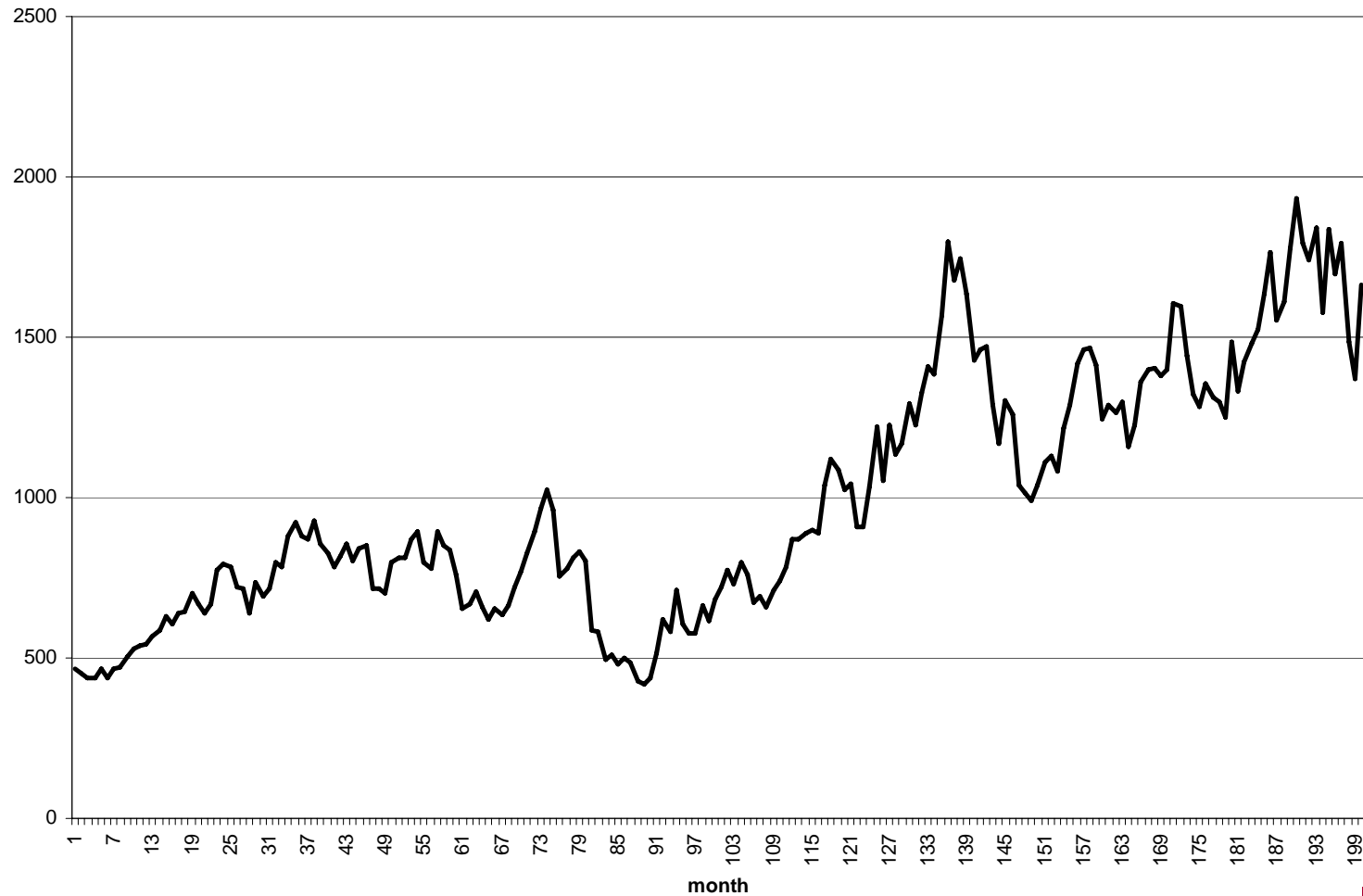 - Which bear the oil/gas price risk

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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%
  -

$$\frac{dx}{x} = \mu \, dt + \sigma \, dz$$
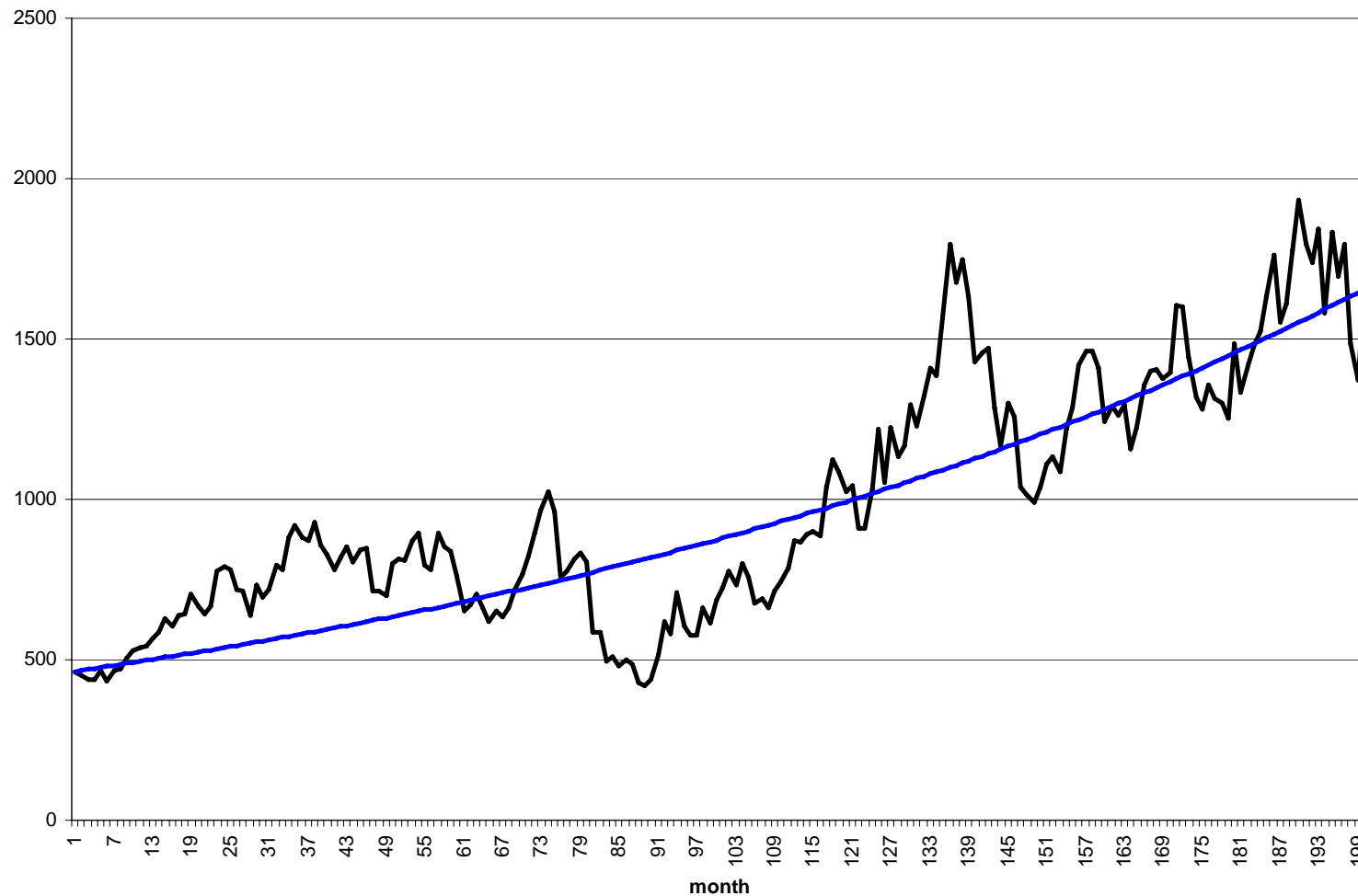
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Sample Path of Load, 200 months

Sample Path of Load, 200 months

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

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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**

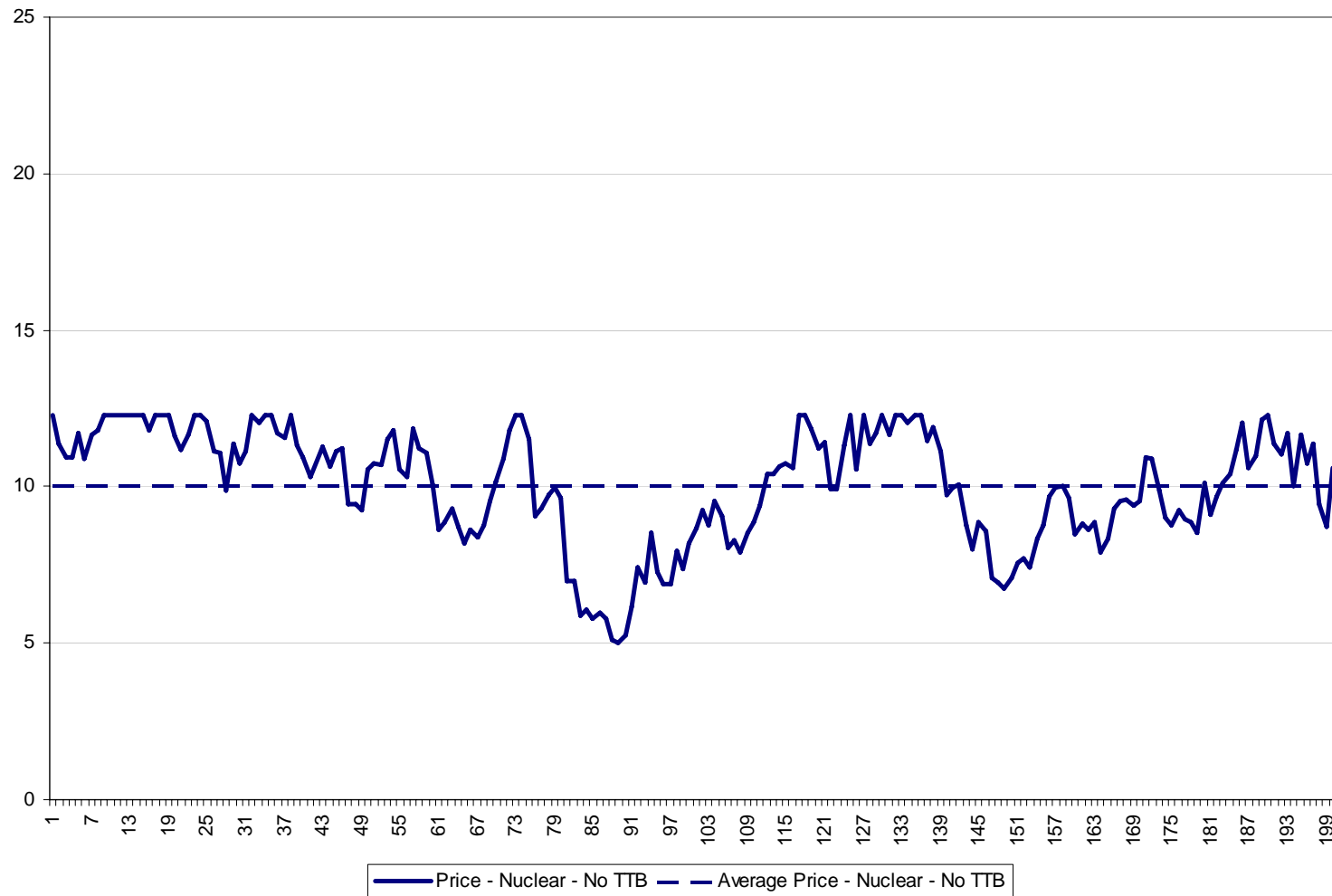- **Therefore the trigger price must include a premium to cover this possibility**

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
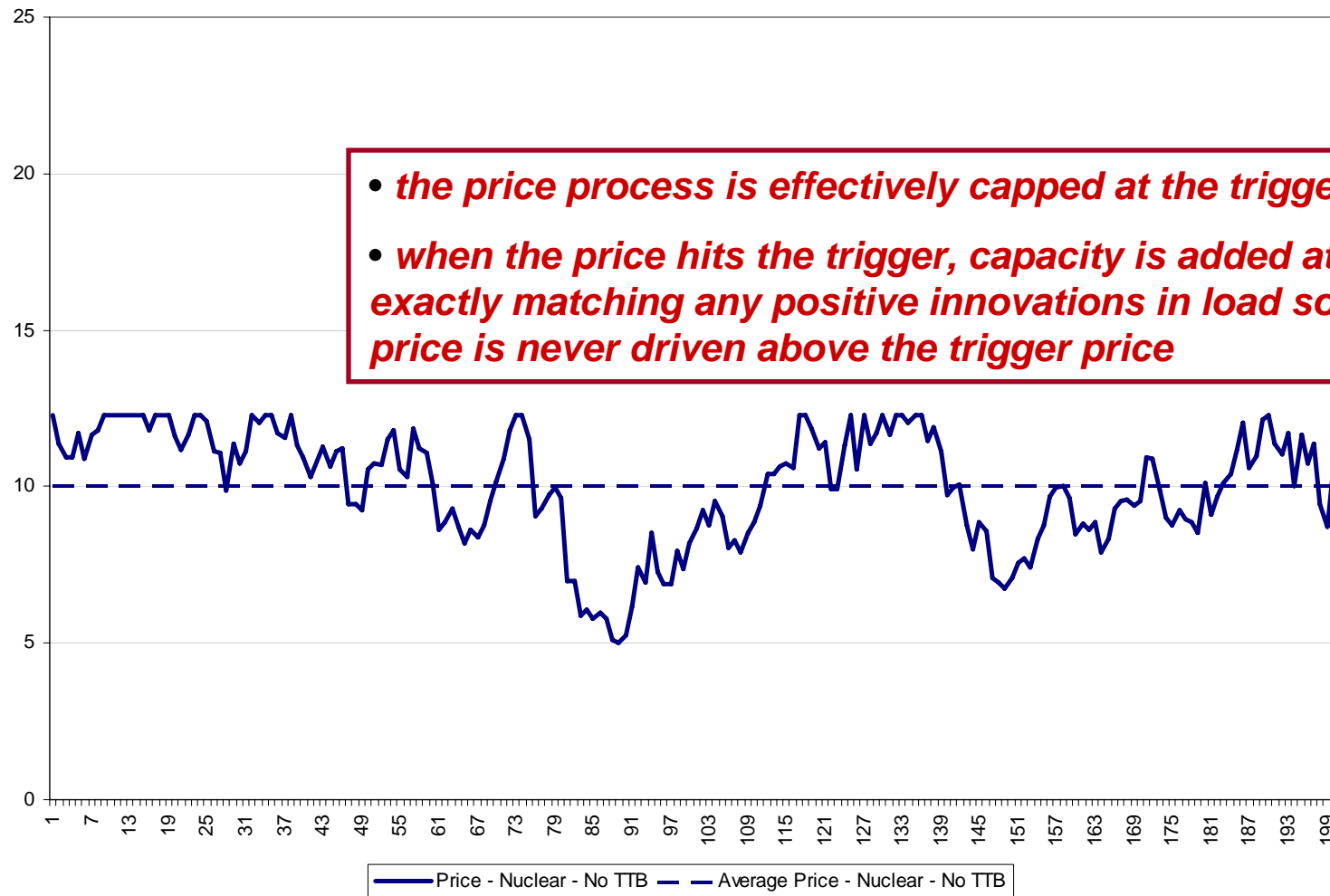 - Coefficient of variation of eq. price = 18%
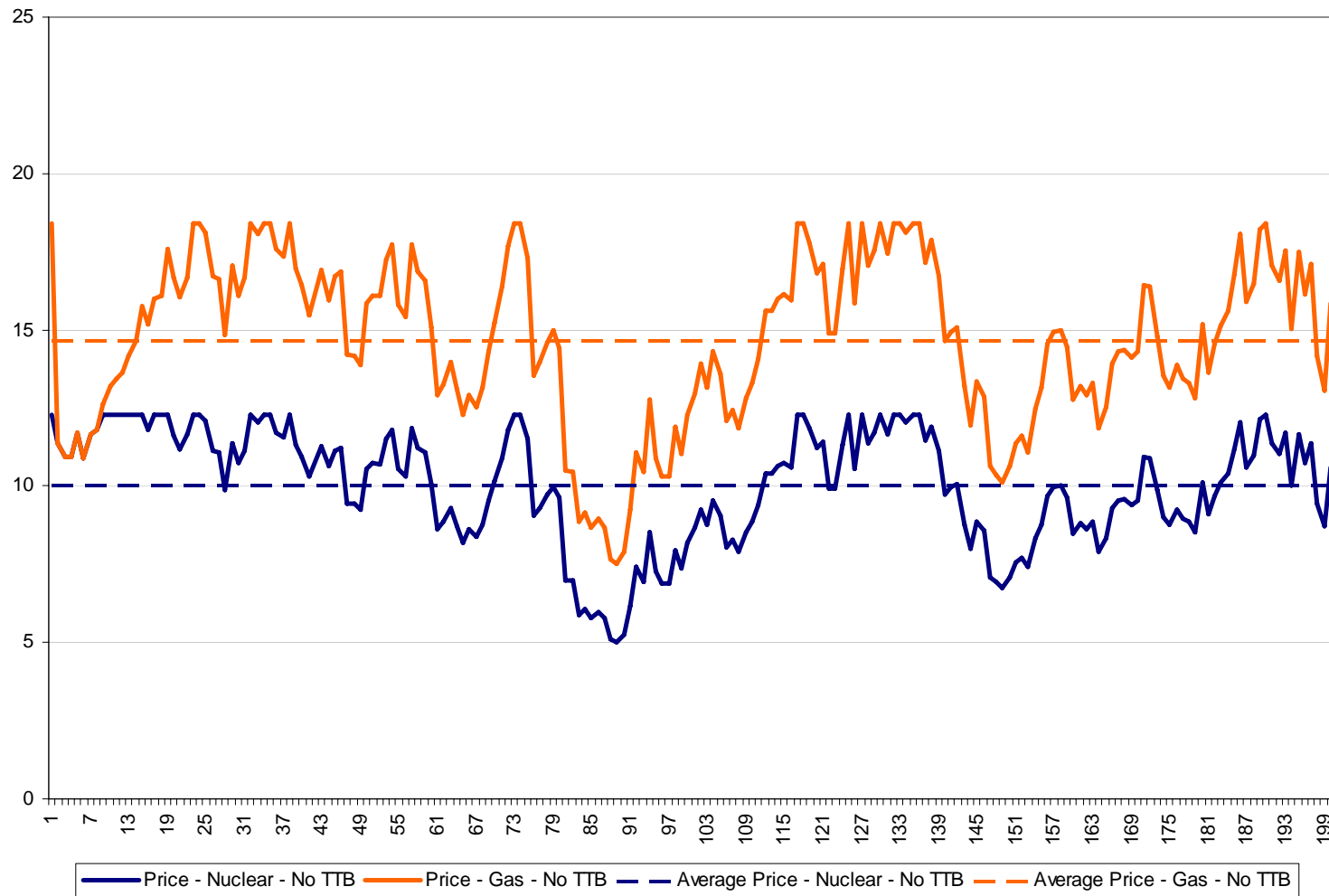
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Equilibrium Price, low cost technology

Legend: —— Price - Nuclear - No TTB   — — Average Price - Nuclear - No TTB

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*

Price - Nuclear - No TTB — — Average Price - Nuclear - No TTB

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Equilibrium Price, high cost technology

Legend: Price - Nuclear - No TTB | Price - Gas - No TTB | Average Price - Nuclear - No TTB | Average Price - Gas - No TTB

Installed Capacity, low & high cost technologies

Capacity - Nuclear - NoTTB   Capacity - Gas - No TTB
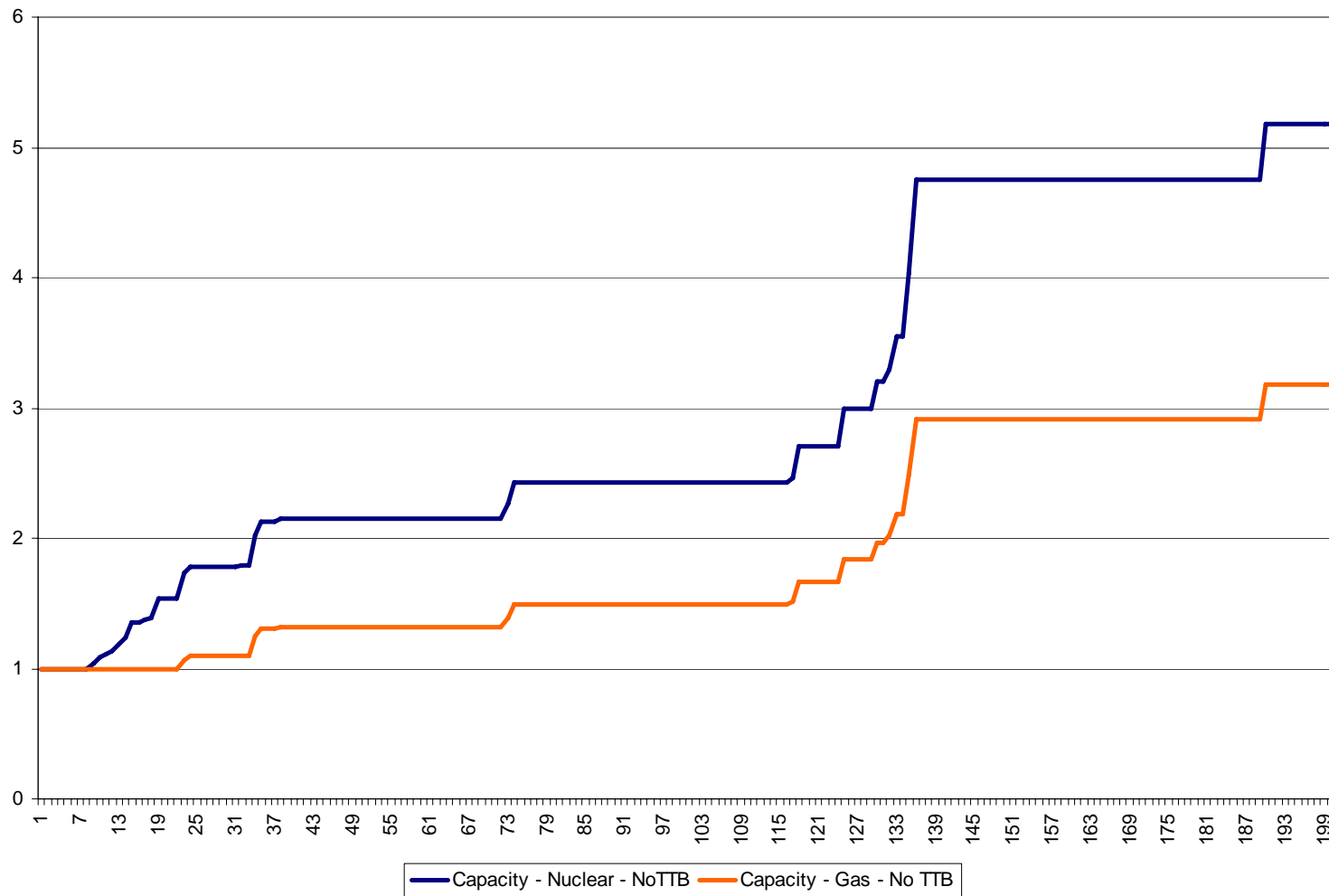
Re-Model Equilibrium Given Time-to-Build

- **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**

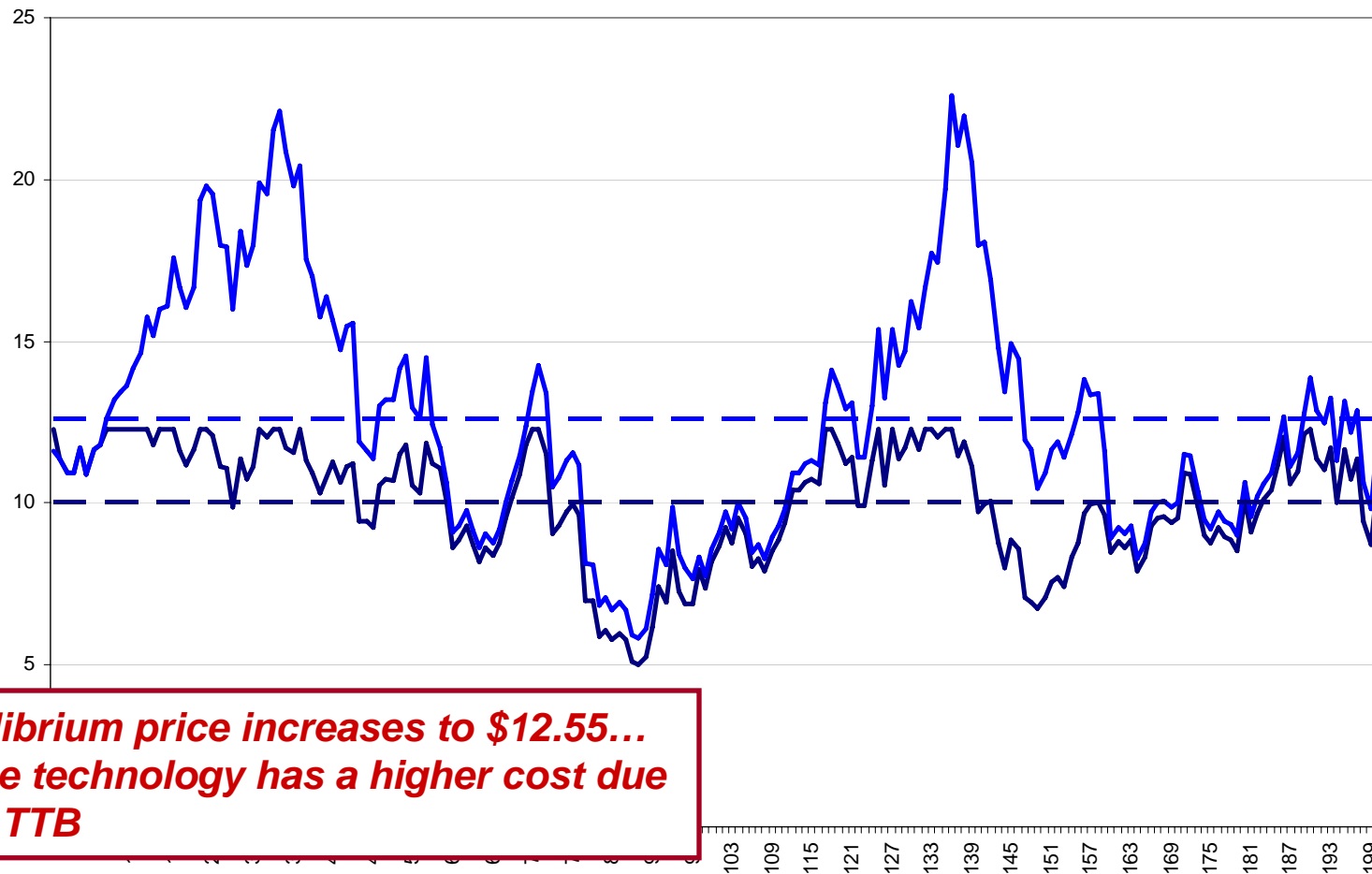- **Price is no longer capped, since load may continue to increase while capacity is under construction**
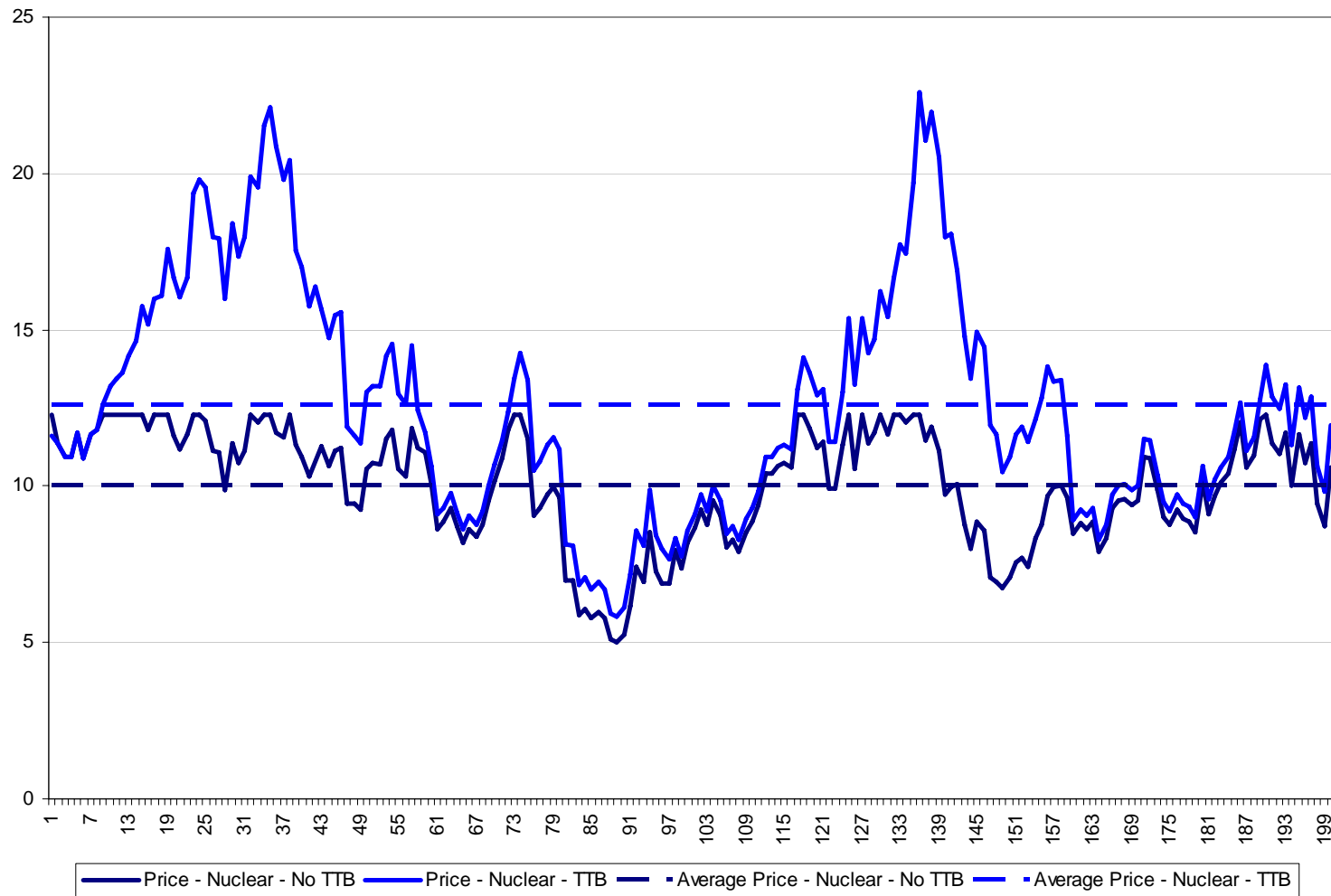
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Equilibrium Price, with Time-to-Build
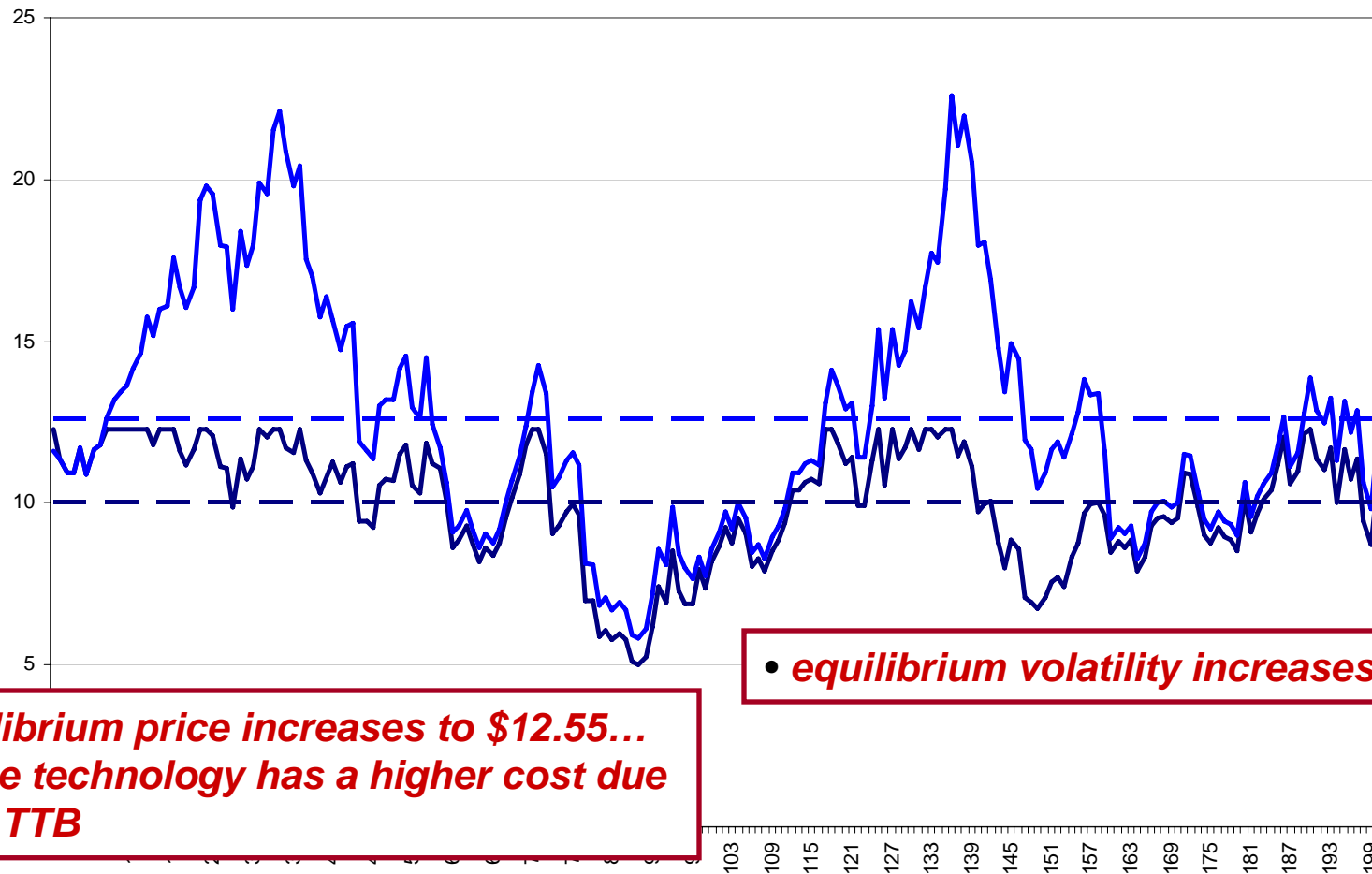
Equilibrium Price, with Time-to-Build

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

Legend: Price - Nuclear - No TTB Price - Nuclear - TTB Average Price - Nuclear - No TTB Average Price - Nuclear - TTB

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Equilibrium Price, with Time-to-Build
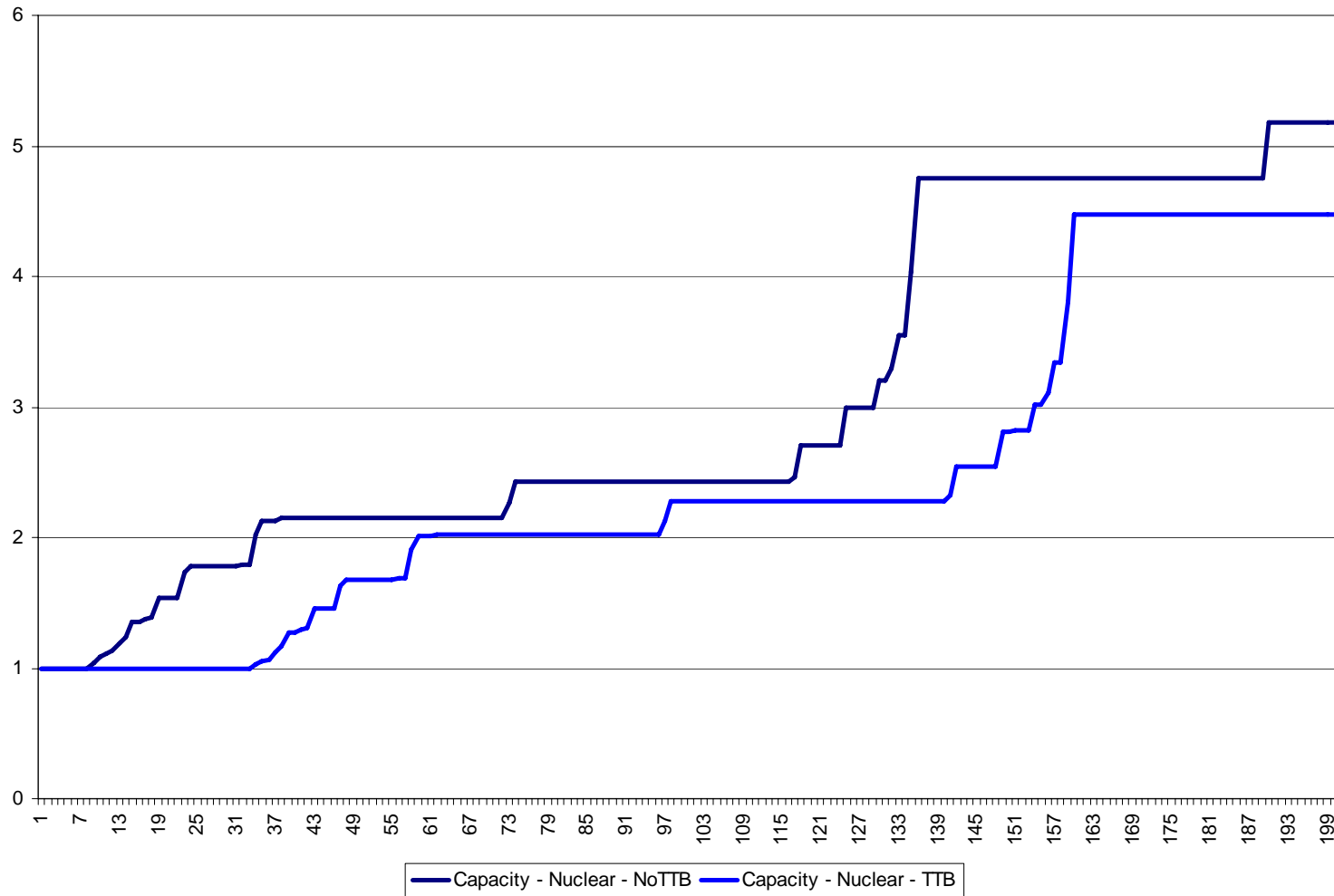

- *equilibrium price increases to $12.55…
i.e., the technology has a higher cost due
to the TTB*

- *equilibrium volatility increases to 29%*

Legend: Price - Nuclear - No TTB Price - Nuclear - TTB Average Price - Nuclear - No TTB Average Price - Nuclear - TTB
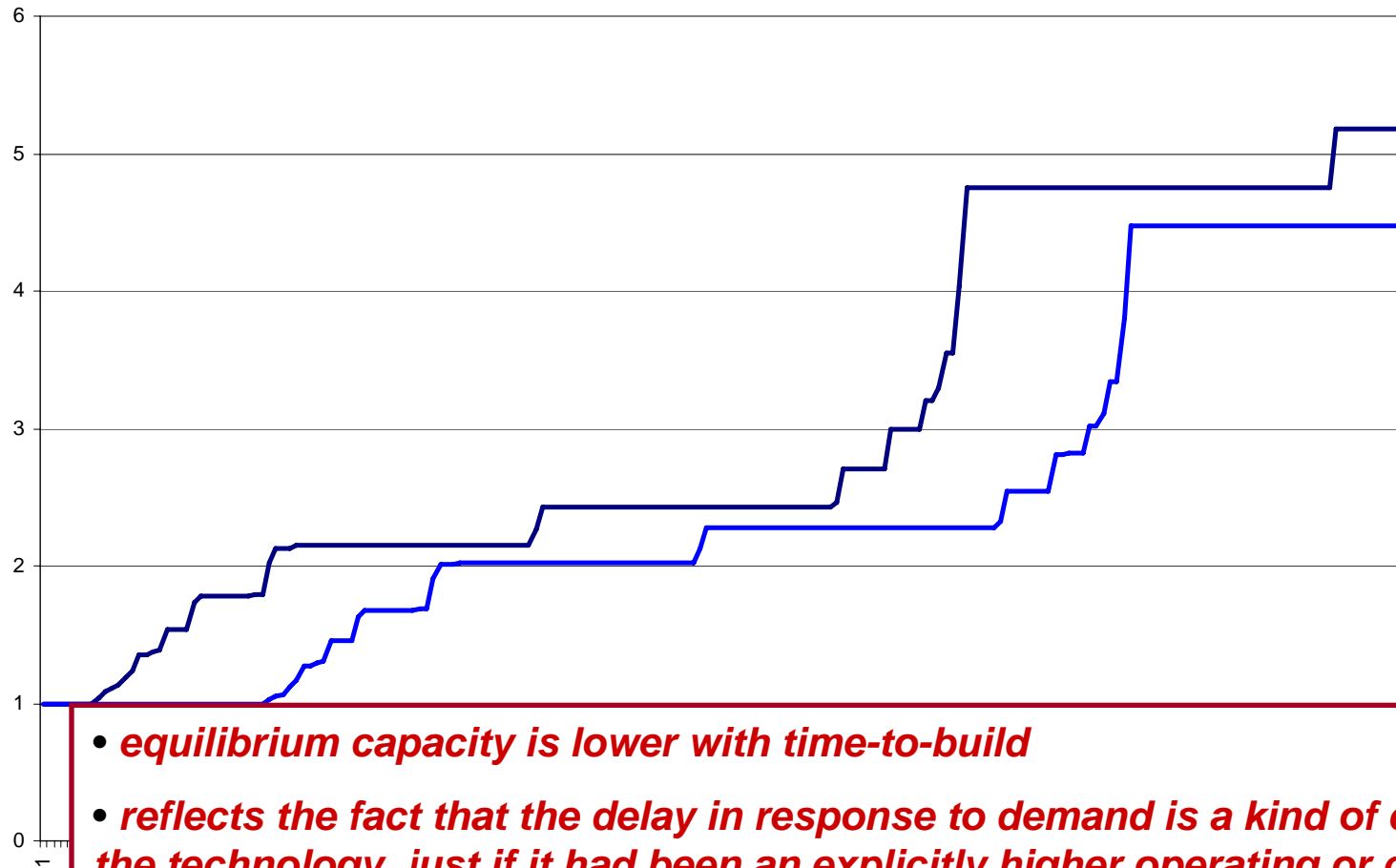
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Capacity Installed with Time-to-Build

Capacity - Nuclear - NoTTB   Capacity - Nuclear - TTB

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**
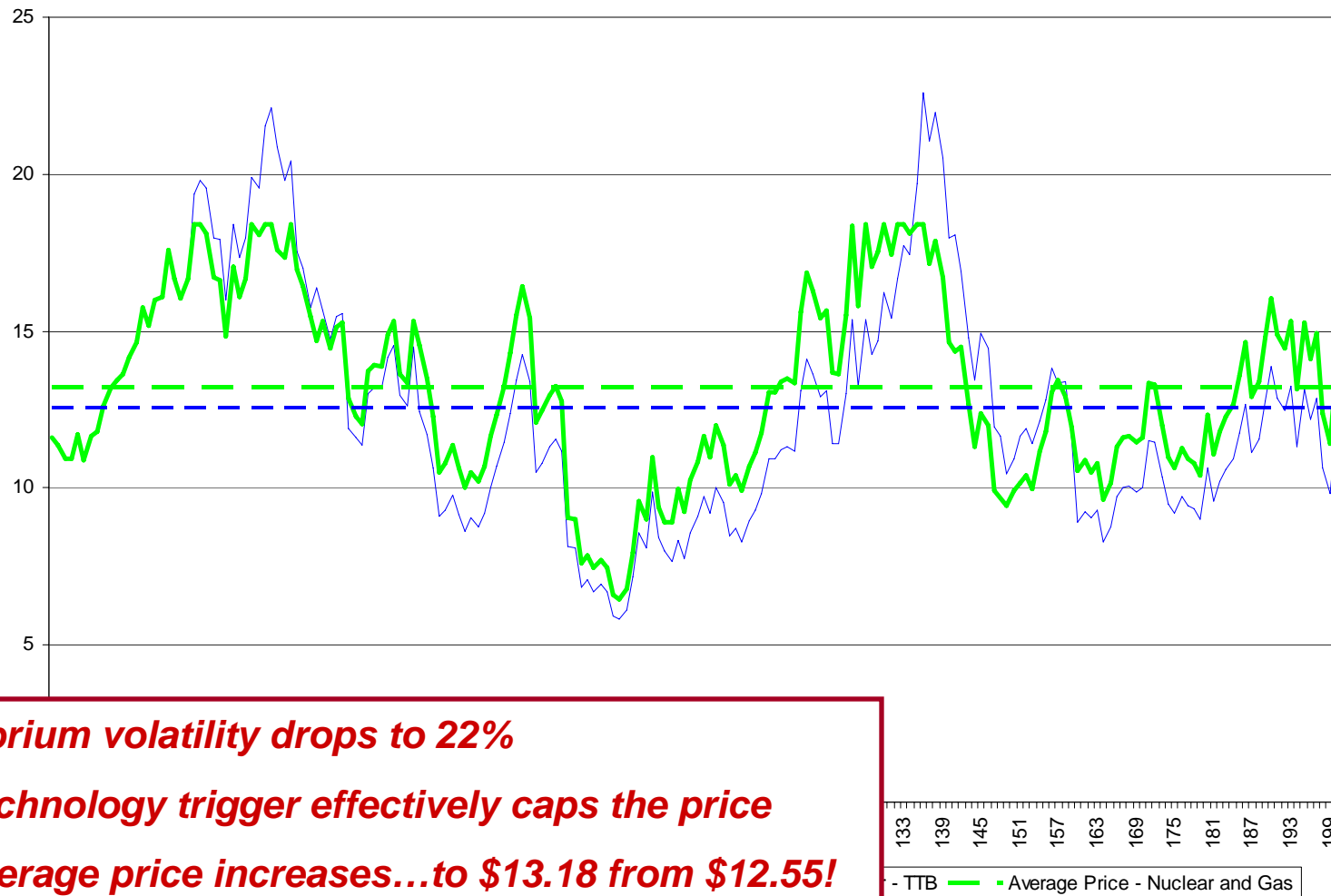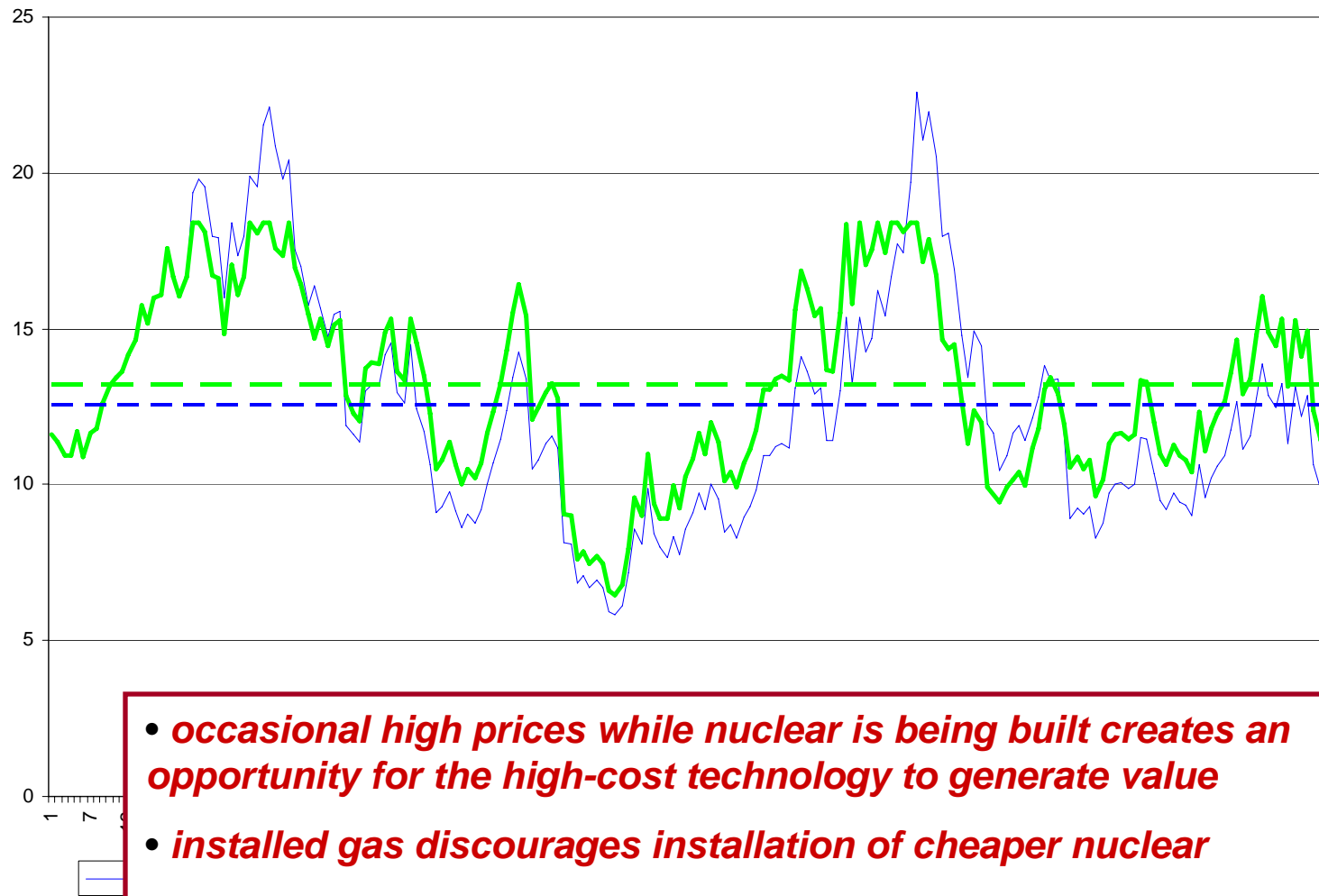
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Equilibrium Price with Two Technologies
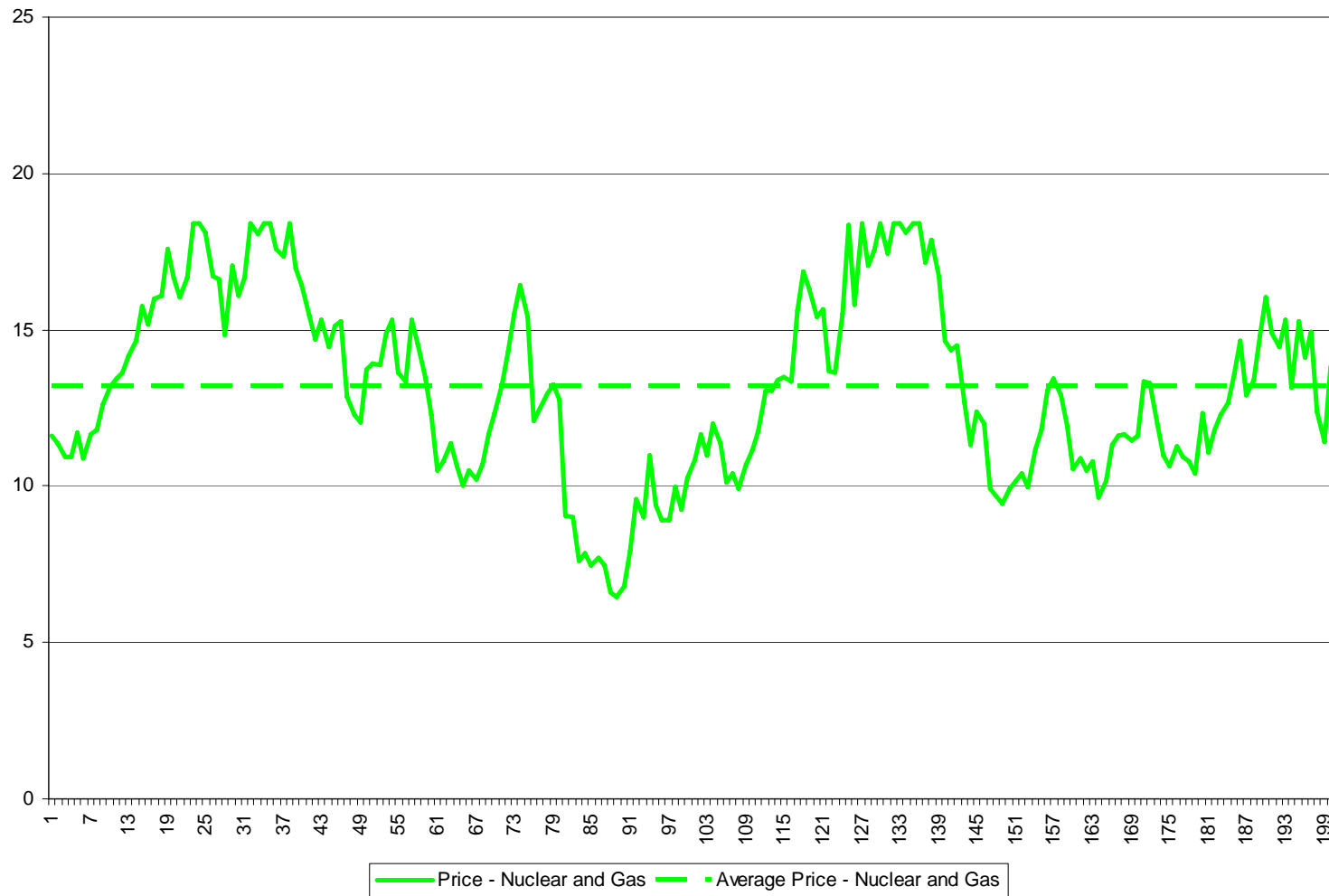
Price Compared to Single Technology Equil.

- *equilibrium volatility drops to 22%*

- *gas technology trigger effectively caps the price*

- *but average price increases…to $13.18 from $12.55!*

Legend: - TTB — Average Price - Nuclear and Gas

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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