An Analysis of Risk in Nuclear Power

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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
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%

\[
\frac{dx}{x} = \mu \, dt + \sigma \, dz
\]
Factor 1: Load Growth

Sample Path of Load, 200 months
Factor 1: Load Growth

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
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.
Factor 1: Load Growth

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%
Factor 1: Load Growth

Equilibrium Price, low cost technology
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
Factor 1: Load Growth

Equilibrium Price, high cost technology

![Graph showing equilibrium price trends over time for nuclear and gas technologies with and without transmission upgrades. The graph includes lines for Price - Nuclear - No TTB, Price - Gas - No TTB, Average Price - Nuclear - No TTB, and Average Price - Gas - No TTB.]
Factor 1: Load Growth

Installed Capacity, low & high cost technologies

[Graph showing installed capacity for nuclear and gas technologies over time]
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
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 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%**

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**Factor 1: Load Growth**
Factor 1: Load Growth

Capacity Installed with Time-to-Build
Factor 1: Load Growth

**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
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!
Factor 1: Load Growth

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
Factor 1: Load Growth

Capacity for Two Technologies