Re-structuring the Japanese Electricity Supply Industry in the Aftermath of Fukushima

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Outline of Talk

- Pathways to improving the efficiency of the Japanese electricity supply industry
- INPO and its role in increasing safety, efficiency, and transparency in the Japanese nuclear power sector
- Dynamic Pricing to manage supply shortfalls
- Unconventional natural gas and Japan's role in the global LNG market
- Unbundling to create a short-term wholesale electricity market
  - Cost-based versus bid-based markets
- The role of fixed-price forward contracts in ensuring competitive short-term market outcomes
- Concluding comments

Increasing safety, efficiency, and transparency in the Japanese nuclear power sector

US Nuclear Regulation Post TMI

- Post-Three Mile Island (TMI) nuclear safety regulation recognized need for ongoing monitoring for compliance with rules and procedures
  - Process of continuous improvement
    - Learning from experience of other plants in industry
  - Human factors analysis of nuclear power plant performance
  - Provide objective input to NRC to shutdown unsafe reactors
  - Longer re-fuelling outages of nuclear power plants
- Institute of Nuclear Power Operations (INPO) formed by US nuclear power industry after TMI
  - Industry self-regulator
    - "We are all in this together"
    - *Hostages of Each Other: The Transformation of Nuclear Safety Since Three Mile Island*, Joseph V. Rees, 2nd Edition, 1996.

Impact of INPO

- INPO activities focus on improving safety and performance at nuclear facilities
  - Human Performance Evaluation System (HPES)
    - Designed to improve human reliability in nuclear power plant operations
  - Developed performance indices for nuclear power plant operations
    - Track indices over time by facility and compare across facilities
  - Monitoring teams visit power plants to monitor and grade operating procedures that are in place
    - INPO rating of plant operations shared with plant operator
    - Provide recommendations for “best practice” procedures
  - Annual meetings with CEOs of all nuclear power plant owning companies discuss performance ratings of facilities publicly
    - Peer pressure to improve safety and operating efficiency at all facilities

Performance Improvement

- Significant increase in power plant safety and performance since TMI
  - Fleet-wide average capacity factor increased steadily from less than 50 percent in 1970s to more than 90 percent currently
  - Large portion of low capacity factors during early stages of nuclear industry due to proliferation of different nuclear technologies
    - EDF (France) with single technology had much faster gains in plant performance and safety
  - INPO safety indices increased steadily since plant-level measurement and monitoring began

Performance Improvement

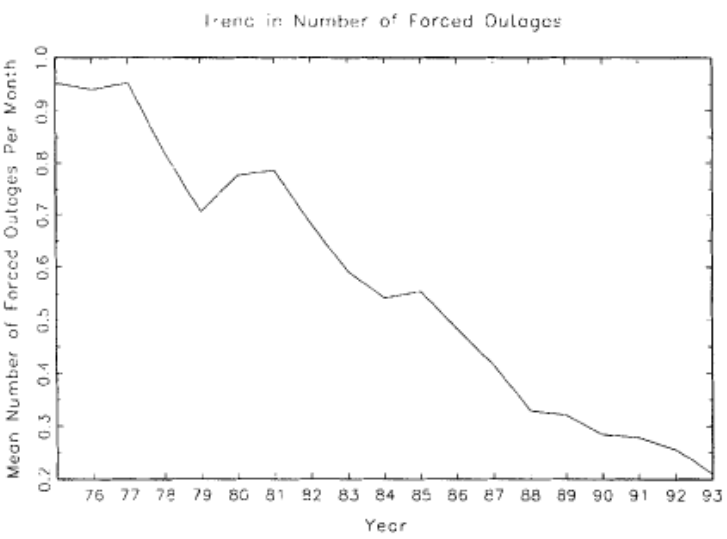


Figure 3. Trend in mean number of forced outages per reactor-month

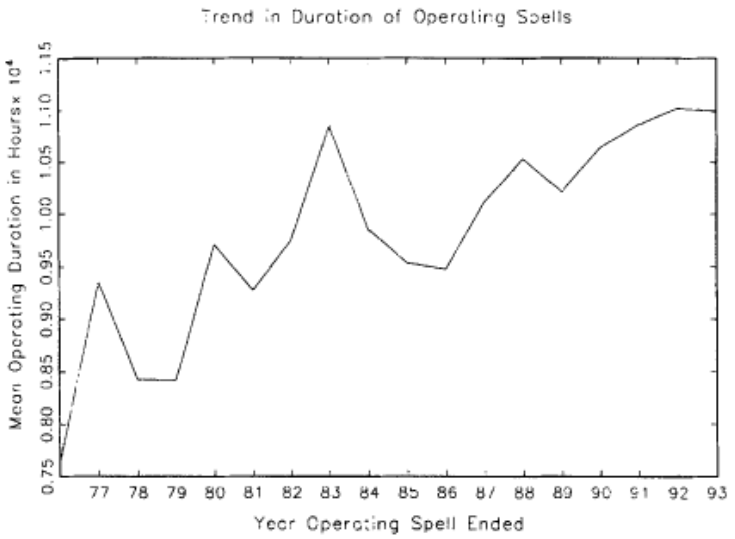
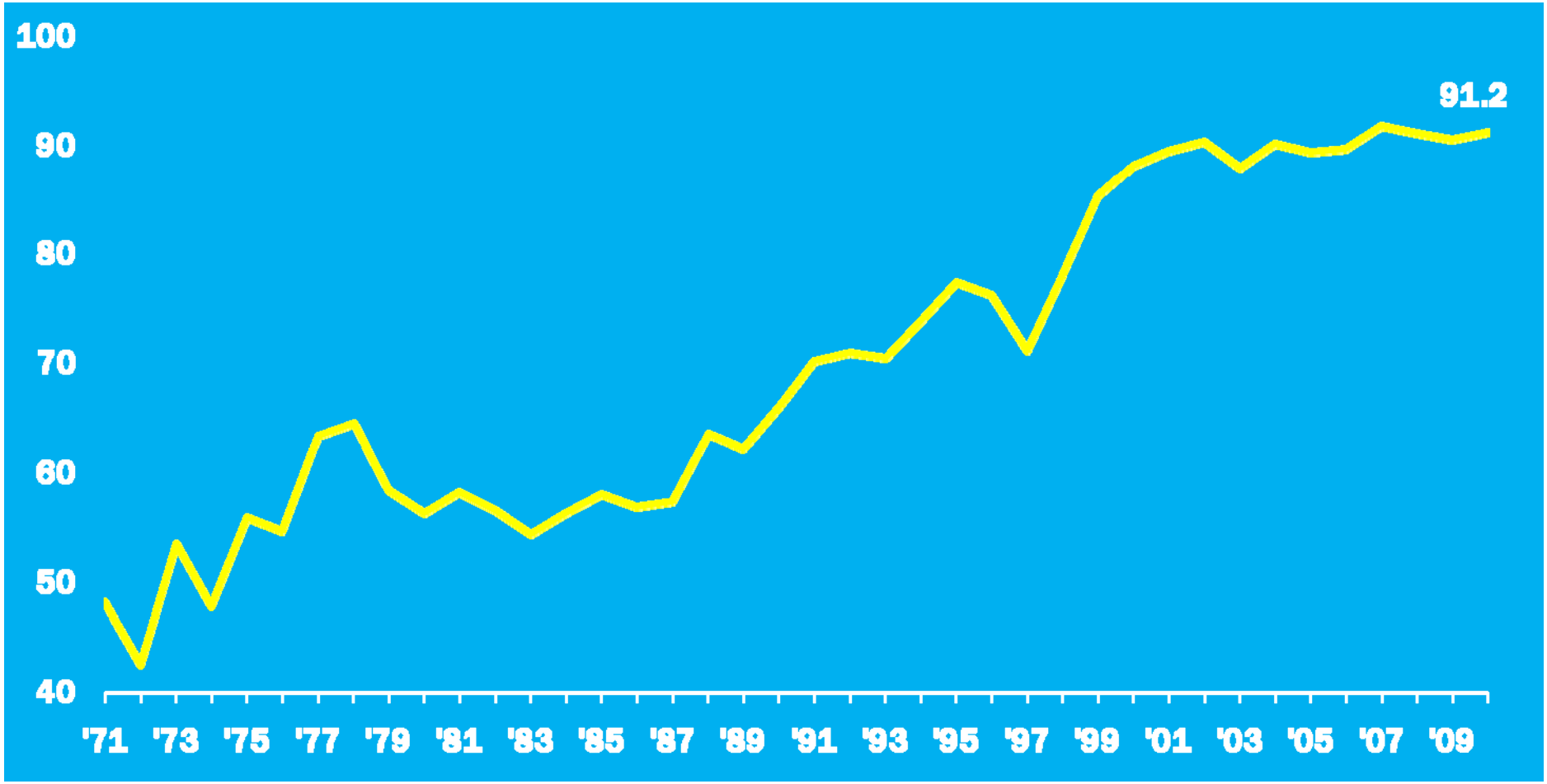


Figure 5. Trend in mean durations of refuelling and operating spells

Source: Rust and Rothwell (1995) "Optimal Response to a Shift in Regulatory Regime: The Case of the US Nuclear Power Industry," Journal of Applied Econometrics, S75-S118.

U.S. Nuclear Industry Capacity Factors

1971 – 2010, Percent



Source: Energy Information Administration

Updated: 4/11

Improving Perception of Japanese Nuclear Power Sector

- Japanese nuclear power plant owners could become members of INPO and subject themselves to industry oversight
  - Increase transparency and credibility of safety and reliability of nuclear fleet
  - Demonstrate willingness to implement international best practices
- Increase effectiveness of safety and maintenance operations through participation in INPO functions
- Implement incentive regulation plans for Japanese nuclear facilities
  - Rather than simply reimbursing “prudently incurred costs” of operating facility, incentive regulation rewards improved performance
  - Diablo Canyon Performance-Based Pricing
    - Plant removed from rate base and replaced with fixed price paid to Pacific Gas and Electric (PG&E) for every MWh produced by Diablo Canyon facility
    - Significant increase in average capacity factor at Diablo Canyon
      - In 1991, Diablo Canyon broke world record for longest continuous operation of nuclear reactor

Using Dynamic Pricing to Maintain Demand-Supply Balance with Supply Shortfalls

Maintaining Demand-Supply Balance

- Reliable system operation requires demand to equal supply at every instant in time at all locations in transmission network
  - Imbalances can be managed by either
    - Reducing demand to meet supply
    - Increasing supply to meet demand
- Historically system balance achieved by increasing supply
  - Requires holding significant excess generation capacity relative to demand during most hours of the year in order to meet high demand during a small number of hours of the year
  - Current approach is increasingly expensive because
    - Excess capacity must be fully paid for, if even it is rarely used
- Combination of interval metering technology and dynamic pricing allows demand to play a key role in achieving balance
  - Can reduce the annual cost of electricity to final consumers
  - Manage supply-demand balance at least cost

Maintaining Demand-Supply Balance

- Examples of temporary supply shortfalls
  - Less available baseload generation capacity due to tsunami in Japan
  - Reduction in amount generation units willing to make their capacity available to wholesale market in California during 2000 to 2001
- "California Electricity Crisis" was not due to a shortage of available generation capacity, but an unwillingness of suppliers to make generation capacity available to the wholesale market
  - More profitable for suppliers to withhold capacity in order to a earn higher price on energy that was supplied
  - Rolling blackouts in California occurred during trough of annual demand cycle during January and March of 2001
    - During hours with system demand less 34,000 MW
  - No rolling blackouts occurred during summers of 2000 and 2001 when peak demands were close to 44,000 MW
- For more complete discussion of causes and remedies for "California Electricity Crisis" see
  - Wolak, F.A. "Diagnosing the California Electricity Crisis" on web-site
  - Adequate fixed-price forward contract coverage of final demand eliminates possibility of California crisis occurring in Japan (more on this later).

Dynamic vs. Time-of-use pricing

- Dynamic pricing
  - Retail prices that vary with real-time system conditions
  - *Requires hourly meters to implement*
    - Must measure consumption on hourly basis to charge hourly prices
- Time-of-use pricing (TOU)
  - Retail prices that vary with time of day, regardless of system conditions
    - Low price from midnight to 12 pm and 6 pm to midnight
    - High price from noon to 6 pm
  - *Does not require hourly meter*
    - Only meter that records monthly consumption in two time periods during day

Dynamic vs. Time-of-use pricing

- Dynamic pricing
  - Customers have incentive to reduce demand during periods with high prices and stressed system conditions
    - Reduces wholesale price volatility and increases system reliability
    - Limits ability of suppliers to exercise unilateral market power
      - Retailers with dynamically priced customers can even use them to exercise monopsony power (more on this if there is time)
      - Downward sloping aggregate hourly demand for electricity with respect to hourly wholesale price
- Time-of-use pricing
  - Customers have no incentive to reduce demand during periods with high wholesale prices and stressed system conditions
    - Similar incentive to single fixed price tariff
      - Two fixed prices all days as opposed to one fixed price all days
  - Produces perfectly inelastic hourly demand for electricity with respect to hourly wholesale price

Dynamic Pricing for Japan

- Japan ideally-suited to benefit from dynamic pricing
  - Large peak demand relative to average demand
    - Load factor, ratio of average to peak demand, is very low, approximately 0.60
  - Large amount of pumped storage facilities to manage peaks
    - Almost 10,000 MW of pumped storage facilities
- Dynamic pricing can allow more efficient use of storage facilities and increase load factor
  - Automated response technologies produced in Japan and can be implemented in Japan

Dynamic Pricing for Japan

- Two major challenge to dynamic pricing in Japan
  - Deploy metering technology necessary to record hourly demand
  - Set hourly dynamic prices for retail electricity on day-ahead and real-time basis
- All dispatch centers schedule generation units for operation the following day
  - Typically, security-constrained unit commitment model is used to determine day-ahead schedules for each hour of following day
    - Uses start-up, no load, and variable costs of operating each generation unit
  - Hourly shadow prices associated with meeting demand at each location in the transmission network can be used as the day-ahead price
  - Experience with Critical Peak Pricing (CPP) and other dynamic pricing programs in US and UK are very encouraging
    - Patrick and Wolak (1997) “Estimating the Customer-Level Demand for Electricity Under Real-Time Market Prices,” available at http://www.stanford.edu/~wolak
    - Wolak (2006) “Residential Customer Response to Real-Time Pricing: The Anaheim Critical-Peak Pricing Experiment,” available at http://www.stanford.edu/~wolak
    - Wolak (2010) “An Experimental Comparison of Critical Peak and Hourly Pricing: The PowerCentsDC Program,” available at http://www.stanford.edu/~wolak

Dynamic Pricing for Japan

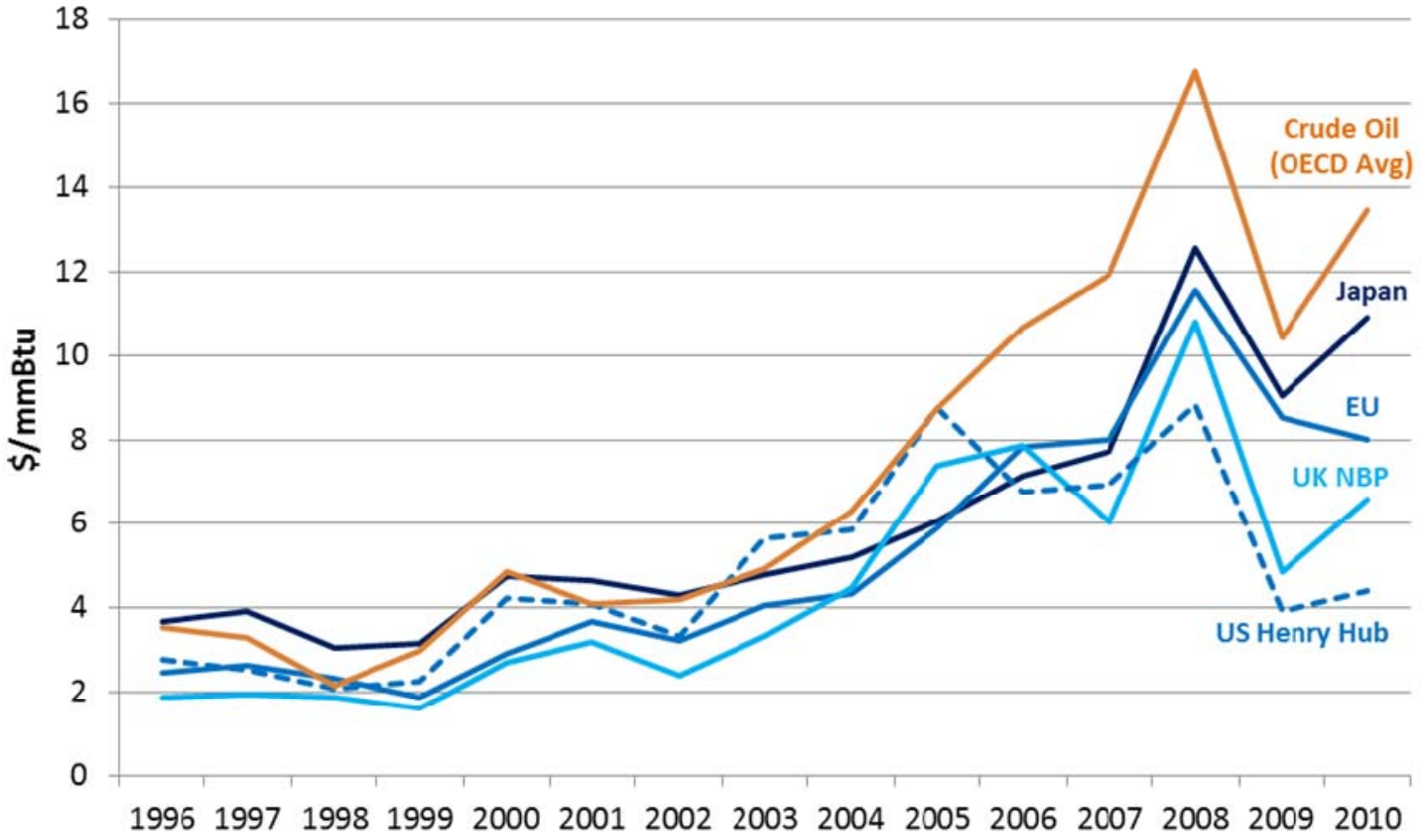
- Customers with interval meters charged for consumption during CPP event at price that is high enough for system operator to expect achieve scheduled demand reduction
  - Actual demand reduction may differ from that expected from CPP event
- Automated demand response ensures real-time system balance
  - Real-time prices at all location set using the similar procedure to day-ahead price-setting process
  - These prices can be used to trigger automated response technologies on customer's premises to reduce or increase demand

Japan’s Role in the Global Liquefied Natural Gas (LNG) Market

Unconventional Natural Gas and Japan

- Japan currently purchases virtually all of its liquefied natural gas (LNG) at prices indexed to crude oil prices
  - Crude oil is currently trading at a substantial premium on a dollar per million BTU ($/MMBTU) basis relative to oil
    - Oil at $120 per barrel this translates into more than $20/MMBTU
  - Current price of natural gas at Henry Hub (large natural gas trading hub in Gulf of Mexico) is $2.50/MMBTU
    - Explosion in US natural gas supply due to hydraulic fracturing technology
    - Other countries around the world are exploiting this technology
      - China is making major investments of unconventional natural gas exploration
- Massive BTU arbitrage possibility for Japan
  - Purchase LNG at prices indexed to Henry Hub
- Japan is world's larger buyer in global LNG market
  - South Korea is also a substantial buyer of LNG
- If Japan and South Korea buy at Henry Hub indexed prices can achieve enormous savings for Japanese electricity consumers

Price Differentials Between the Henry Hub and Japan Are Now Even Larger



Source: BP Statistical Review of World Energy 2011

Unbundling to Form a Short-Term Wholesale Market: Cost-Based versus Bid-Based Approaches

Forming a Short-Term Wholesale Market

- Forming a short-term wholesale electricity market in Japan to improve efficiency of dispatch of generation units
- Independent System Operator (ISO) where suppliers submit curves to supply energy each hour of day
  - Centralized unit commitment subject to all relevant operating and network constraints sets prices and dispatch levels for all generation units
  - Wolak (2011) “Measuring the Benefits of Greater Spatial Granularity in Short-Term Pricing in Wholesale Electricity Markets,” available on web-site
    - Annual operating cost savings from implementation of formal day-ahead market with security constrained unit commitment in California exceeded $100 million per year
- Transmission and distribution networks are operated on an open-access basis
  - Which suppliers are allowed to produce and which retailers purchase electricity depends on their offer and demand curves submitted and network and other relevant operating constraints

Bid-Based versus Cost-Based Dispatch

- In bid-based market suppliers submit their willingness to supply energy
  - Price is highest bid necessary to meet demand
- In cost-based market suppliers submit heat rates and other information about variable costs to ISO
  - Price is highest variable cost necessary to meet demand
- Under both regimes suppliers receive market price and loads pay the market price for deviations from their forward contract positions
- System/market operator creates opportunity cost of water for hydro units in cost-based market to manage water
  - Opportunity cost of water is hydro supplier's "variable cost"

Cost-Based Markets in LACs

- Several Latin American Countries (LACs) have a long history with electricity supply industry re-structuring using cost-based short-term market
  - Chile has had a wholesale market since mid-1980s
    - Almost 300% increase in capacity since 1990, all privately financed
  - Argentina has had a wholesale market since early 1990s
  - Brazil, Peru, Panama, and Guatemala also have significant experience with cost-based short-term markets
  - Colombia, El Salvador only LACs with bid-based short-term markets
- Experience of Chile is generally thought to be a success, as is the experience of Argentina
  - Cost-based markets in LACs have had success at attracting new investment
    - LACs focus on what is needed to attract new investment—active forward market
  - Unclear if bid-based short-term market, such as those operated in US, have benefited consumers, relative to cost-based short-term market
    - Risky market design given limited transmission capacity in US
      - Many opportunities for suppliers to exercise unilateral market power
      - Limited upside for consumers in terms of potential for lower prices

Cost-Based Dispatch Market

- Countervailing benefits of cost-based market
  - Limit number of ways suppliers can exercise market power
    - Can only bid higher if can “cost justify” higher bid
  - Limit amount and sophistication of technology needed to operate wholesale market
  - Reduce volatility of wholesale prices and congestion prices
    - Requires little demand-side involvement in market
    - Can still operate market with limited transmission upgrades
    - Both of which limit ability of suppliers to exercise market power in bid-based market
- Summary Trade-offs
  - Potential for increased incurred cost of real-time system operation
  - Limit risk of enormous market power in short-term market and reduce uncertainty associated with future spot prices

Pre-Condition for Cost-Based Market

- Mandated forward contracting levels for retailers enforced by regulator
  - Specify minimum hedging requirements at various time horizons to delivery, for example
    - 95% coverage 1-year in advance of delivery
    - 90% coverage 2-years in advance of delivery
    - 85% coverage 3-years in advance of delivery
- Desired contracting levels can be achieved through financial incentives to retailers
  - For example, allow pass-through of higher wholesale price the farther in advance power is purchased
- Mandated contracting needed because of cost-based short-term dispatch limits incentive of retailers to hedge short-term price risk

Limiting Exercise of Unilateral Market Power in Short-Term Markets

Forward Contracts and Spot Market Power

- Extent of final output covered by fixed-price forward contracts limits incentives for suppliers to exercise market power in short-term market
  - Wolak (2000) “An Empirical Analysis of the Impact of Hedge Contracts on Bidding Behavior in a Competitive Electricity Market” (on web-site)
- No incentive to raise spot price until produce at least forward contract quantity
  - Incentive to reduce price if sell less than fixed-price forward market quantity in short-term market
- In virtually all markets around the world, a very small amount of energy is sold at the short-term market price because of high levels fixed-price forward contracting
- With high levels of coverage of final demand with fixed-price forward contracts, consumers are protected from periods of high wholesale prices

Forward Contracts and Spot Market Power

- Forward contracts must be signed far enough in advance of delivery to obtain contestable market price
  - Must allow new entrants to compete with existing suppliers to provide long-term contract
    - Emphasizes importance of streamlined generation siting process
  - New Combined Cycle Gas Turbine (CCGT) can compete at 2-year delivery horizon in forward contract market
- Signing forward contracts 3-months, 6-months or even one-year in advance of delivery may not provide any short-term market power mitigation benefits of fixed-price forward contracts
  - May simply pay for expected market power in short-term market on installment plan in forward contract price
  - Short-term prices will subsequently reflect less unilateral market power, but consumers must still pay higher forward contract price

Concluding Comments

- Five suggested pathways to improving the efficiency of the Japanese electricity supply industry
- Japanese nuclear power plant owners join INPO
- Dynamic pricing to manage supply shortfalls
- Japan, Korea, Singapore and other Asian buyers coordinate global LNG market
- Unbundling to create a short-term wholesale electricity market
  - Start with cost-based market and transition to bid-based market
- Focus on development of forward market for energy to ensure competitive short-term market outcomes
  - Large fraction of final demand covered by fixed-price forward contracts signed with generation unit owners far in advance of delivery

Questions/Comments

For more information:

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