PROGRAM ON ENERGY AND SUSTAINABLE DEVELOPMENT

Long-Term Resource Adequacy in a Low Carbon Electricity Supply Industry

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Goal of Industry Restructuring

Lower retail prices for consumers and the same or a superior level of reliability of supply relative to vertically-integrated monopoly regime

- Difficult to rationalize restructuring if it raises retail prices or reduces reliability relative to former regime

At least in North America, price-regulated, vertically-integrated monopoly regime was effective at controlling incurred costs

Important Point: To pay more revenues to generation unit owners, consumers must pay higher average prices

Future Electricity Supply Industry

Electricity supply industry in a low-carbon world will have a significant amount of intermittent renewables

- Intermittent renewable energy shares in excess of 50 percent
- Significant amount of distributed solar generation capacity

Large intermittent renewables share will require

- Investments in both grid-scale and distributed storage
- Active demand-side participation by customers with interval meters using dynamic retail electricity prices
- Automated distribution network monitoring and on-site load-shifting technologies

Policy Question: What long-term resource adequacy mechanism will facilitate a least-cost transition to this future electricity supply industry?

- Capacity payment mechanism--Increasingly expensive approach to long-term resource adequacy, particularly for regions with a large share of intermittent renewables
- Long-term energy contracting--Least cost approach to long-term resource adequacy for future electricity supply industry

Why a Long-Term Resource Adequacy Mechanism Is Necessary

- A long-term resource adequacy mechanism is necessary because of *Reliability Externality*
  - Unwillingness of regulator to commit to allow uncapped real-time price of energy to clear short-term market under all possible future system conditions
  - Lack of interval meters often used to justify this unwillingness
- *Reliability Externality* is due to two factors
  - Offer cap on short-term market implies that consumers will not procure energy in forward market at an average price greater than offer/price cap
  - All consumers know that random curtailment—rolling blackouts--will occur if aggregate supply is less than aggregate demand
    - All customers of same size face same probability of curtailment, regardless of forward market purchases of energy

  Conclusion: Externality arises because no customer faces full expected cost of failing to procure adequate energy in forward market
- Because of "reliability externality," in markets with a finite offer cap regulator must have a long-term resource adequacy mechanism, or face periodic supply shortfalls
  - Ensures *adequate supply of energy* under all possible future system conditions and allowed short-term prices

Historical Long-Term Resource Adequacy Challenge
(Why Capacity Markets Came About in US)

- Initial Conditions: Electricity supply industry with *dispatchable thermal generation resources, mechanical meters, and offer cap on short-term wholesale market*
- Major concern: Sufficient installed capacity to meet system demand peak
- Mechanical meters: Only allow measurement of total electricity consumption between consecutive meter reads
  - Typically done on monthly or bi-monthly basis
  - Precludes use of dynamic prices to reduce system peaks
- Offer cap on short-term market: Can prevent units that run infrequently to recover their total cost
- History of Tight Power Pools: In former vertically-integrated monopoly regime, cost-based dispatch of generation units in power pool paid variable cost to units producing energy, but not capital cost

Capacity Payments: Historical Solution to Problem

- All retailers and large loads must purchase and hold firm capacity equal to a multiple of their annual peak demand
  - Typically between 1.10 and 1.15 times peak demand
- Regulator/Market Operator assigns to each generation unit a firm capacity quantity equal to amount of energy it can produce under *extreme system conditions*
  - Nameplate capacity times the availability factor for thermal generation units
- For hydroelectric units this is an extremely challenging task
  - Typically based on historically worst hydrological conditions
    - For example from Colombia, see McRae and Wolak (2016) "Diagnosing the Causes of the Recent El Nino Event and Recommendations," available from web-site
    - For example from Chile see Galetovic, Munoz, and Wolak (2015) "Capacity Payments in a Cost-Based Wholesale Electricity Market: The Case of Chile," available from web-site
- For solar and wind resources, it is even more difficult to determine firm capacity of these generation units

Capacity Approach to Resource Adequacy

Historic "Rationale" for capacity payment mechanism in US

- Offer caps on energy market were necessitated by inelastic real-time demand for electricity due to fixed retail prices that do not vary with hourly system demand and mechanical meters
- Capped energy market creates so called "missing money" problem because of argument that prices cannot rise to level that allows all generation units to earn sufficient revenues to recover costs
- "Conclusion"--Capacity payment necessary for provide missing money

Bid-based capacity payment mechanism with bid-based energy prices exists primarily in US (but they are spreading to rest of the world)

- Pay market-clearing prices for both energy and capacity

Paying two market-clearing prices *implies infra-marginal rents for capacity sales and energy sales*

- Two revenue streams--capacity and energy—paid by consumers
- Paying two market-clearing prices Increases likelihood that consumers are paying more than they would under former vertically-integrated monopoly regime—Contrary to the goal electricity industry restructuring

Capacity Approach to Resource Adequacy

- Problems with logic underlying standard rationale for capacity payment mechanism
  - In a world with interval meters, customers can be charged retail price that varies with hourly system conditions
    - For all system conditions, real-time hourly price can be set to equate hourly supply and demand, which eliminates missing money problem
  - Regulator setting aggregate firm capacity requirement can create “missing money” problem
    - Strong incentive for regulator, system operator, and generation unit owners, and incumbent retailers to set a high reserve margin that consumers pay for
    - By setting a high capacity requirement relative to peak demand, there is excess generation capacity relative to demand, which depresses energy prices, which creates need for capacity payment mechanism

Capacity Approach to Resource Adequacy

- Resource adequacy capacity requirement in US based on long-standing 1-in-10-year standard
  - No more than one outage due to generation shortage every 10 years
- Firm capacity standard established for a system dominated by dispatchable, primarily thermal, generation units, and no interval meters
- Assumes final demand is completely inelastic with respect real-time price
- Conclusion: The 1-in-10-year standard likely to be excessive in an industry with interval meters, dynamic retail pricing, distributed generation and storage, and automated demand-response technologies

Capacity Approach to Resource Adequacy

Short-term capacity markets are extremely susceptible to the exercise of unilateral market power

- Vertical supply (installed capacity) meets vertical demand
- Can create extremely volatile short-term capacity prices, which is contrary to capacity price providing signal for new generation investment

Market power concerns with capacity market has led to use of regulator-determined capacity “Dee-mand curve” and only new units being allowed to submit an offer price (existing units are price-takers) in most US markets

- Capacity market transformed into an inefficient regulatory price-setting process

Benefits and Costs of Capacity-Based Approach

- Unless capacity is purchased far enough in advance of delivery to allow new entrants to discipline market power of large generation unit owners, an administrative or regulatory pricing mechanism is necessary
  - Even with adequate generation capacity, high-level of fixed-price forward contracts for energy is still necessary to limit incentive of large suppliers to exercise unilateral market power in energy market
  - Conclusion--Capacity payment mechanisms do not have short-term market efficiency enhancing benefits that fixed-price energy contracting approach does
- Suppliers get two independent opportunities to exercise unilateral market power: (1) selling capacity and (2) selling energy and ancillary services in short-term market

Summary Comments on Capacity Mechanisms

Capacity payments are an expensive mechanism for attempting to achieve long-term resources adequacy

- Do not address primary reliability challenge in wholesale markets, particularly in renewable dominated markets
  - Energy shortfalls
- No guarantee that adequate capacity will be built
  - Depends on level of capacity payment
- Little success with capacity payments in international markets outside of Latin America countries with cost-based energy markets, e.g., Chile
- Market-based pricing of capacity extremely challenging, particularly locationally
- No evidence that markets with capacity payments in the US have achieved higher levels of short-term or long-term reliability of supply

Resource Adequacy with Intermittent Renewables

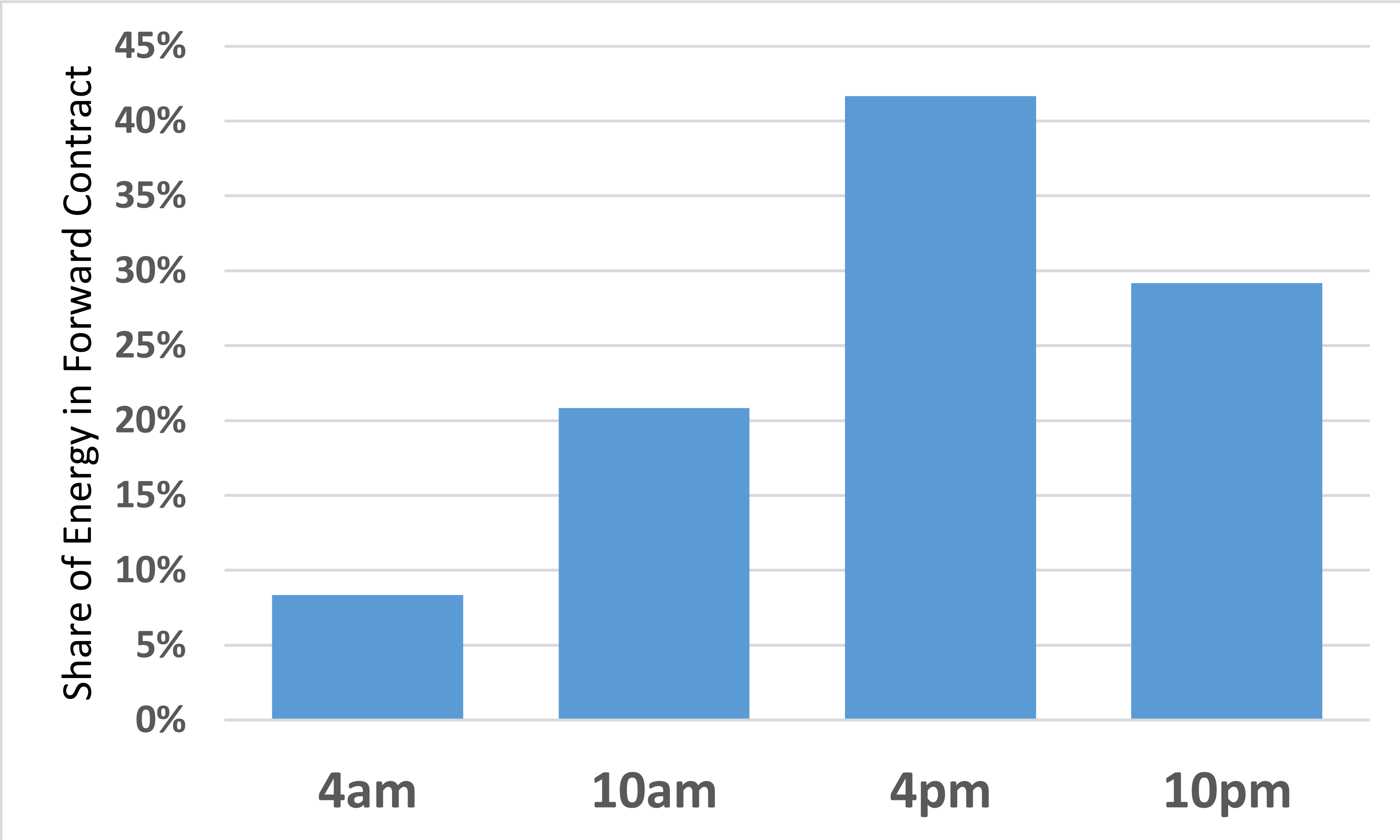
- Capacity payment mechanism difficult to rationalize in world with significant intermittent renewable capacity
- Firm capacity of an intermittent unit is very difficult to define politically
  - Intermittent resources typically are able to supply a very small fraction of their installed capacity during stressed system conditions
    - With more intermittent renewable capacity this statement is even more true
    - California's experience with capacity value of solar PV capacity
  - Politics more that economics or engineering determines "firm capacity" of intermittent renewable units
- Why pay all generation units a capacity payment to obtain a service is needed only from few units each day and can be provided by decreasing fraction of units in the control area?
  - How valuable is firm capacity from an intermittent resource?
- Why embark on a resource adequacy process that will to make storage and active demand-side participation in wholesale market much less economic?
  - Increases average annual cost of wholesale energy to consumers

Energy-Contracting Approach to Long-Term Resource Adequacy

Forward Contract Approach to Resource Adequacy

- Regulator mandates that retailers and large loads purchase and hold to delivery standardized forward contracts for energy for fractions of their annual demand at various horizons to delivery
  - 100% of demand one year in advance
  - 90% of demand two years in advance
  - 85% of demand three years in advance
  - 80% of demand four years in advance
- Standardized contracts are shaped to hourly system demand
  - Are long-term resource adequacy products just like firm capacity
  - Ensures that aggregate hourly demands throughout year have been purchased in forward market
  - Counterparties to contracts have strong incentive to ensure that system demand is met at least cost each hour of year

System Load-Shaped Forward Contract



Forward Contract Approach to Resource Adequacy

- Resource adequacy mechanism ensures that aggregate demand will met one year in advance
  - Aggregate demand for year has been purchased at a fixed price through standardized forward contract market
  - Product could be purchased through standardized auctions run by California ISO or CPUC and allocated to individual retailers and large loads like current capacity product
- California ISO or some other entity could run a clearinghouse to manage counterparty risk associated with contracts
  - – Ensures that all contracts clear against hourly short-term price
    - No buyers or sellers default on their contractual obligation
  - – If default occurs this is borne by all members of clearinghouse, not California ISO or other entity
    - Provides strong incentive for all parties to fulfill contractual obligations

Forward Contract Approach to Resource Adequacy

- Contracting mandates are regulator's security blanket to ensure adequate supply of energy
  - Can increase mandated percentages of demand in more distant years if worried about there being adequate energy to meet demand in future
  - Allows offers caps on short-term energy market to be raised, which will support storage and load-shifting investments
  - System operation should communicate concerns to regulator and market participants it believes demand in future cannot be met with existing and planned resources
- No installed capacity requirement
  - Lets suppliers figure out least cost mix of resources to meet hourly demands annually
  - Creates level playing field for demand-side and supply-side solutions

Forward Contract Approach to Resource Adequacy

- Standardized energy contracting requirements on retailers and large loads does not preclude other bilateral contracts being held or sold by generation unit owners or retailers and large loads
  - Can engage in additional hedging to manage their own quantity risk
- There is no requirement that seller of standardized RA contract must actually produce electricity sold in contract
  - In intermittent renewable dominated market, intermittent resource that sells standardized forward contract may need to purchase price spike insurance from thermal resource owner
  - Renewable resource must have an incentive to purchase *explicit or implicit insurance* against high short-term prices from thermal resource owner
    - Explicit insurance--Pay up-front fee to thermal resource and receive max(0,P(spot)-P(strike))Q(contract) from thermal resource owner
- Price spike insurance provides revenue stream to help recover fixed costs of thermal resource that rarely runs because of large amount energy from renewable resources

Forward Contract Approach to Resource Adequacy

- How would thermal and intermittent resources earn revenues under this resource adequacy mechanism? Example: 50 MW thermal resource and 110 MW intermittent resource
  - Intermittent resource can produce 100 MWh under normal conditions 60 MWh low supply conditions
  - Thermal resource can produce up to 50 MWh on demand but has variable cost of $50/MWh
- Without cross-hedging and with risk aversion on part of renewable supplier (implicit insurance)
  - Renewable resourse would sell 60 MWh of standardized product
  - Thermal resource would sell 40 MWh of standardized product
- Standardized auction price clears to serve demand of 100 MWh for 8760 hours per year at $40/MWh

Forward Contract Approach to Resource Adequacy

- During normal renewable conditions
  - Renewable resource serves demand of 100 MWh and receives $40 MWh forward price for 60 MWh and short-term price of $30/MWh for 40 MWh
  - Thermal resource buys 40 MWh from short term market at $30/MWh and sells at $40 MWh forward price and receives $10/MWh x 40 MWh hourly payment to recover its fixed costs
- During low supply conditions
  - Intermittent resource produces 60 MWh and receives $40/MWh
  - Thermal resource owner produces 40 MWh and receives $40/MWh
- Under both sets of system conditions consumers purchase 100 MWh demand at $40/MWh
  - They are completely protected from short-term prices
  - Thermal and renewable resource owners have strong incentive to ensure demand is served through least cost use their resources

Forward Contract Approach to Resource Adequacy

- Long-term resource adequacy mechanism provides zero baseline level short-term price exposure to final consumers
  - Retailers and large loads can take on short-term price risk by signing bilateral arrangements to expose themselves to some price risk
- Superior approach to high short-term price risk baseline under current market design
  - Retailers only have spot price certainly for prices below the offer cap unless then sign long-term contract for energy, which they have limited incentive to do
- Mechanism provides strong incentive for thermal resources to offer into short-term market at their marginal cost each hour of the year
  - Maintain unit in top working order to be ready to produce if price rises above their variable cost of production

Forward Contract Approach to Resource Adequacy

- Note that thermal generation unit owner sells more energy in standardized forward contract than it expects to produce under typical conditions
- Two ways to meet a forward sale of energy
    - Produce energy from own generation unit (make)
    - Purchase energy from short-term market (buy)
- As example shows, renewable rich market, it will often be cheaper to buy energy from the short-term market instead of produce energy because a substantial amount of energy is being produced and sold at a price less than variable cost of thermal unit
    - Generation unit owner ensures “efficient make versus buy decision” by submitting bid into short-term market at unit’s marginal cost

Forward Contract Approach to Resource Adequacy

- If is concerned that price of standardized forward contracts will be two low for thermal suppliers to win in auction could limit quantity each supplier could offer into standard forward contract auction
  - Suppliers can only offer in firm energy quantity determined by California ISO
  - Both intermittent renewable and thermal suppliers could only offer their firm energy quantity into auctions
- This would produce auction outcome described above
  - Intermittent unit sells 60 MWh and unit produces 100 MWh under normal conditions
  - Thermal unit sells 40 MWh and buys 40 MWh from short-term market under normal conditions
  - Would not preclude cross-hedging arrangement between market participants to manage intermittent renewable quantity risk
    - Additional revenue stream for thermal resources

Forward Contract Approach to Resource Adequacy

- Focuses on primary reliability problem in markets with significant amounts of renewables—*adequate energy to serve demand under all possible future system conditions*
- Provides strong incentive for thermal resources to offer into short-term market
  - Make efficient make versus buy decision to meet forward contracts
  - Sell additional energy in short-term market when price spikes occur
- There has never been a shortage of generation capacity in California and other high renewables industries in wholesale market regime
  - All market power problems in renewable dominated industries in California, New Zealand, and Colombia caused inadequate commitment to supply energy
- For more details see following papers on web-site
  - McRae and Wolak (2019) "Market Power and Incentive-Based Capacity Payment Mechanisms"
  - Wolak (2019) "The benefits of purely financial participants for wholesale and retail market performance: Lessons for long-term resource adequacy mechanism design"

Thank You

Questions/Comments

The Energy Market Game

(www.energymarketgame.org)

Mark Thurber and Frank Wolak

Game Implementation by Trevor Davis

Program on Energy and Sustainable Development Stanford University

Summary of Game

Basic Game--Bid-based wholesale electricity market
- Pay-as-bid auction
- Uniform price auction
- Transmission constraints (two-zone market)
- Can allow Zonal and Nodal pricing markets

Adding electricity retailers
- Financial contracts for energy: gencos-retailers
- Critical-peak pricing rebates

Adding carbon market
- Emissions allowance auctions and trading

Adding renewables
- Ability to build and operate wind and solar units
- Satisfies renewable portfolio standard (RPS) on retailers

Offering In Generation Capacity

Energy Trading Game

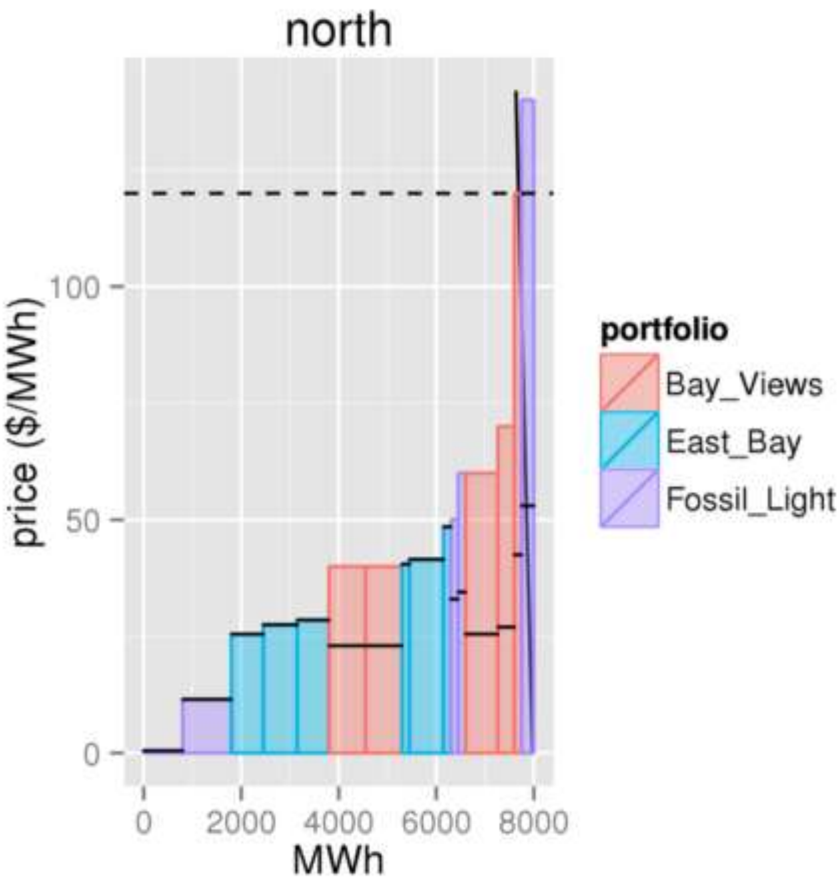
1) Click on blue tab for desired hour of the day
(Period 1, 2, 3, or 4 for Day 1 / Period 5, 6, 7, or 8 for Day 2)

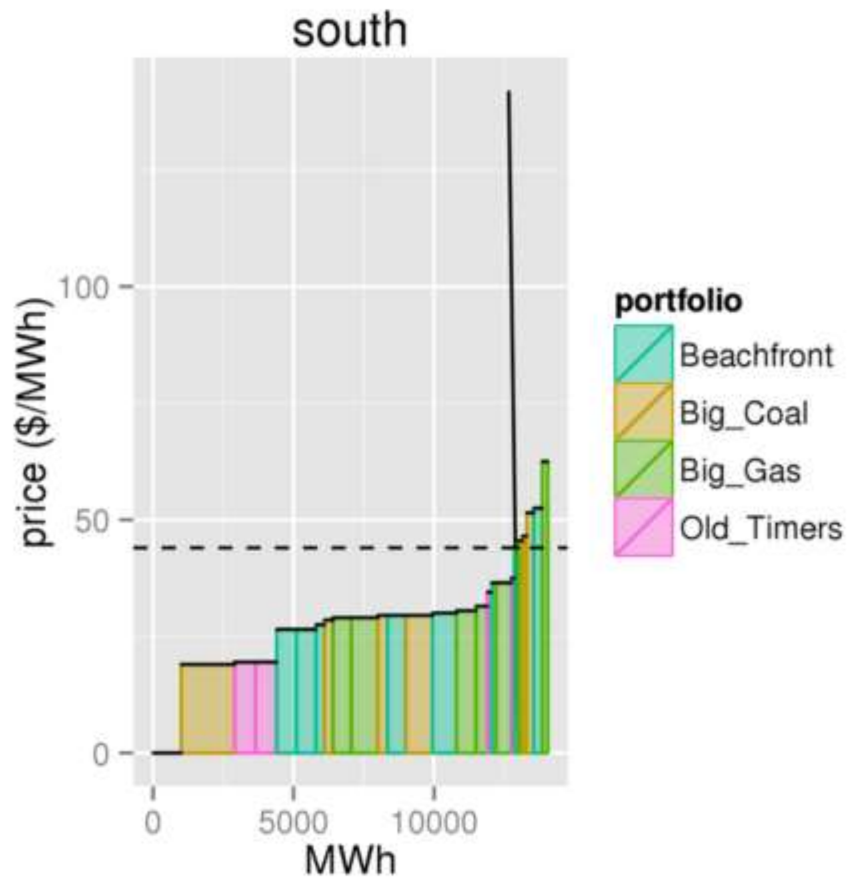
PLANT	CAPACITY (MW)	PRICE	$000/ton	$100/ton	$200/ton	$300/ton	$400/ton	$500/ton
FOUR_CORNERS	1,900	19.0	$19.00	$74.00	$129.00	$184.00	$239.00	$294.00
HUNTINGTON_BEACH_1-2	300	28.5	$28.50	$60.50	$92.50	$124.50	$156.50	$188.50
REDONDO_7-8	950	29.5	$29.50	$62.50	$95.50	$128.50	$161.50	$194.50
REDONDO_5-6	350	29.5	$29.50	$62.50	$95.50	$128.50	$161.50	$194.50
HUNTINGTON_BEACH_5	150	46.5	$46.50	$99.50	$152.50	$205.50	$258.50	$311.50
ALAMITOS_7	250	51.5	$51.50	$110.50	$169.50	$228.50	$287.50	$346.50

2) Enter price offers for each of your generation units (<u>marginal cost is the default</u>)
3) Press the Update button. (<u>If you fail to do this, offers will not register!</u>)
4) Repeat for all four hours of the day

Viewing Market Results (Chart)

"Equilibrium results" tab: png files show supply and demand for each period.





- Height of bar represents bid price for a given unit
- Width of bar represents capacity for a given unit
- Horizontal black line shows marginal cost for a given unit

- Sloping, near-vertical black line is demand curve
- Dotted line shows market-clearing price

Lessons from Game

Two papers (both available on web-site) summarize features of game

- "Carbon in the Classroom: Lessons from a Simulation of California's Electricity Market Under a Stringent Cap and Trade System"
- "Simulating the Interaction of a Renewable Portfolio Standard with Electricity and Carbon Markets"

Game has been used to teach

- Stanford Graduate School of Business Students for past 8 years
- Executive education courses to regulators, policymakers, and market participants from Ghana, Nigeria, Brazil, Western US States

Application to Long-Term Resource Adequacy

Run capacity market versus energy contracting market experiment with Western US States regulators and members of staff of ANEEL, Brazilian Electricity Regulator (separately)

In each game players face identical demand and renewable energy realizations

- Only difference in games is long-term resource adequacy process

Capacity Market—Players compete to sell firm capacity equal to 110 percent of peak demand in a uniform price auction

Players given table of firm capacity, fixed cost, variable for each possible technology they can build

Players must construct at least the amount of firm capacity they won in capacity auction

Players required to meet 33% renewables portfolio standard

Players then compete to sell electricity in offer-based short term market

Energy Contracting Market—Players compete to sell long-term energy contracts tailored to daily load shape equal to 100 percent of expected demand in game

Players given same table of fixed cost and variable cost for each technology

Players were free to construct any mix of generation units to meet their forward contract obligations

Players required to meet 33% renewables portfolio standard

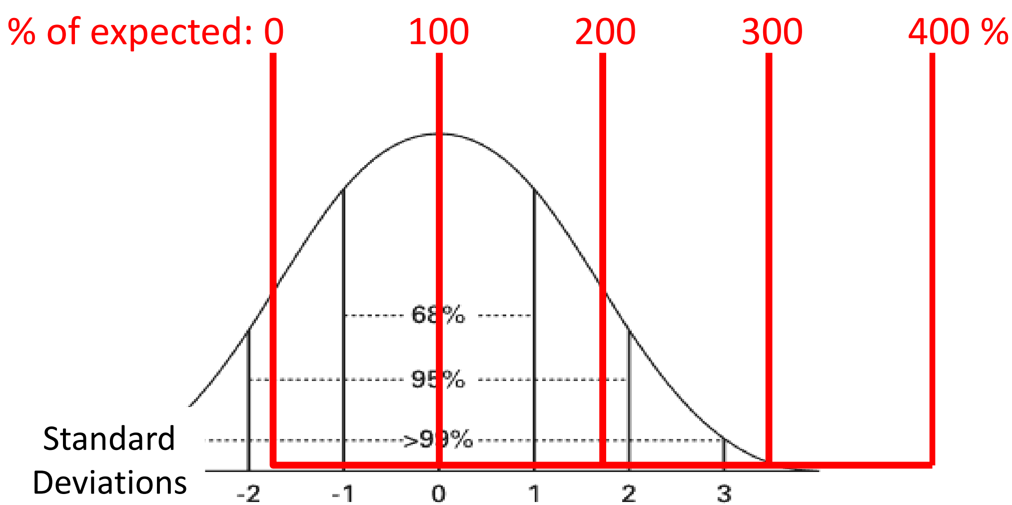
Players then compete to sell electricity in offer-based short-term market

Variable Energy Resources

- Intermittent renewable generation units produce throughout day in similar pattern to actual pattern of production in California

Type	Expected Generation (Normalized to Overall Average)				Variable Cost ($/MWh)
	4am	10am	4pm	10pm	
Wind	1.3	0.7	0.7	1.3	$0
Solar PV	0	2.0	2.0	0	$0

Variability



Renewable generation will fall between 40% and 160% of its “expected” value 68% of the time

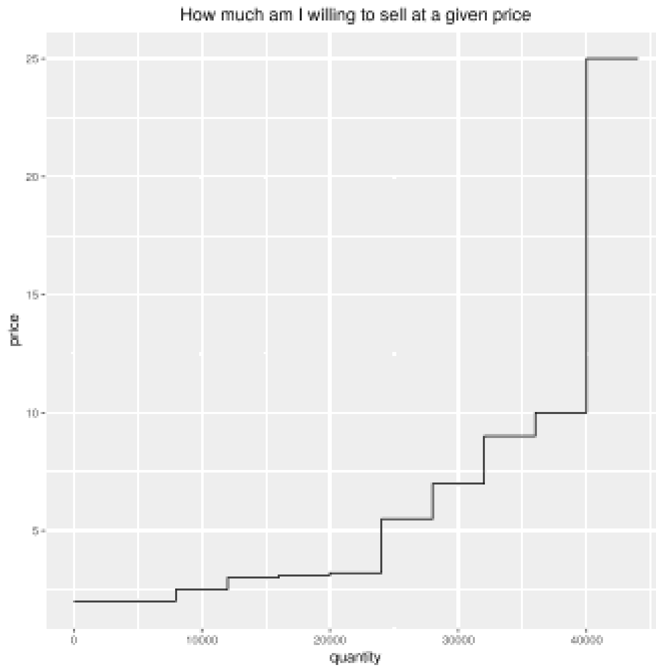
Capacity Market game mechanics

1) Submit auction bids ($/MW-hr) for available capacity

price	quantity
$2.00	8,000
$2.50	12,000
$3.00	16,000
$3.10	20,000
$3.20	24,000
$5.50	28,000
$7.00	32,000
$9.00	36,000
$10.00	40,000
$25.00	44,000

Enter new bids

bids submitted



- Minimum bid is $2/MW-hr (2/3 of fixed cost of Peak unit)
- Maximum bid is $25/MW-hr (full fixed cost of Base unit)
- Renewables counted at expected 4pm output
- Your existing capacity is bid in at minimum

2) Buy/decommission units to meet capacity contracts you won (*required*)

Plant Type	Capacity (MW)	Var Cost ($/MWh)	Fixed cost ($/hr)	Fixed cost ($/MW-hr)	LCOE ($/MWh) -- by portion of hours running: 10%	25%	50%	75%	100%
Base	2000/1000	20	100,000/25,000	25	270	120	70	53	45
Intermediate	1000	45	10,000	10	145	85	65	58	55
Peak	1000	90	3,000	3	120	102	96	94	93

3) Bid in all thermal units to maximize returns

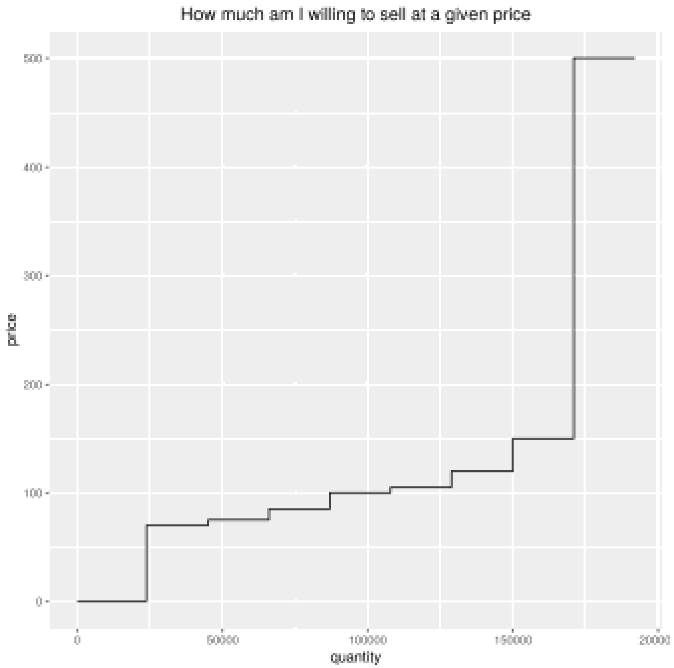
Forward Energy Contracting game mechanics

1) Submit auction bids ($/MWh) for available forward contracts (~100% of demand)

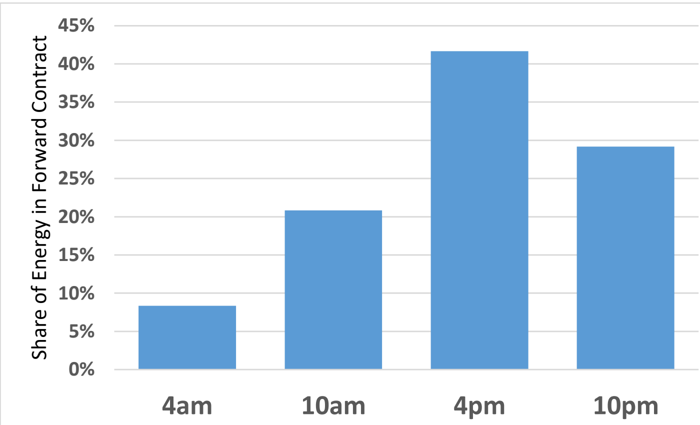
price	quantity
$0.00	24,000
$70.00	45,000
$75.00	66,000
$85.00	87,000
$100.00	108,000
$105.00	129,000
$120.00	150,000
$150.00	171,000
$500.00	192,000

Enter new bids

bids submitted



- Forward contracts have fixed load shape expected to meet demand



2) Buy/decommission units to physically hedge forward contracts you won

Plant Type	Capacity (MW)	Var Cost ($/MWh)	Fixed cost ($/hr)	Fixed cost ($/MW-hr)	LCOE ($/MWh) -- by portion of hours running 10%	25%	50%	75%	100%
Base	2000/1000	20	100,000/25,000	25	270	120	70	53	45
Intermediate	1000	45	10,000	10	145	85	65	58	55
Peak	1000	90	3,000	3	120	102	96	94	93

- Renewables are not firm! (Can hedge if desired with more extra thermal capacity)

3) Bid in all thermal units to maximize returns. (Remember incentives w/contracts!)

Summary of Experiment Results

- For both games and both set of players—Western US regulators and ANEEL staff--computed average revenues paid by load and average cost to serve demand for game
- Capacity payment mechanism
  - Capacity payments, energy contracting and short-term energy market revenues divided by total demand served ($/MWh)
  - Total cost of serving demand divided by total demand ($/MWh)
- Energy contracting market
  - Energy contracting and short-term energy market revenues divided by total demand served ($/MWh)
  - Total cost of serving demand divided by total demand ($/MWh)
- For both Western US regulators and ANEEL staff average wholesale revenues per MWh from capacity mechanism was close to double that for energy contracting approach
  - Average cost to serve demand slightly lower for energy contracting approach

Concluding Comments

- Hard to find empirical evidence anywhere in the world of a well-performing capacity market
  - Even capacity market based on peak energy rent refunds in Colombia appears to reduce rather that improve market efficiency
- Standardized forward financial contracting approach appears to come closest to achieving market design goals in Singapore
  - Buy necessary energy far enough in advance of delivery to allow maximum flexibility of suppliers to meet these obligations at least cost and limit market power in spot market
  - Regulator must set portfolio standards for adequate hedging if maintain price and bid caps or shield final demand from short-term prices
- Head-to-head comparison of capacity market approach to energy contracting approach for two diverse groups—Western US regulators and staff of ANEEL yields same conclusions
  - Energy contracting is lower average cost per MWh, for consumers, approach
  - Lower average cost of production approach
- Contract adequacy approach can allow significant demand-side involvement as part of retailer's hedging strategy
  - With symmetric treatment of load and generation, individual loads can choose level of exposure to short-term price risk
  - Retailers can offer short-term price risk and mean price profiles and consumers choose which combination they prefer
  - Forward contracting is then tailored to hedge remaining fixed price retail obligations

Benefits and Costs of Capacity-Based Approach

- Capacity-based resource adequacy process does not address primary resource adequacy problem in intermittent resource-dominated world
  - Sufficient energy available to meet system demand for all states of the world
- Capacity shortfall highly unlikely to occur in markets with significant intermittent renewable resources
  - McRae and Wolak (2019) "Market Power and Incentive-Based Capacity Payment Mechanisms" on available on web-site
- Inadequate energy to meet demand far more likely
  - Fixed price forward contracts for energy insure against this risk
- Having sufficient installed capacity provides little guarantee that generation capacity owners will sell energy
  - During June 2000 to June 2001 in California, all rolling blackouts occurred during time period with peak demands less than 34,000 MW
  - Peak demands above 44,000 MW occurred during summers of 2000 and 2001 without rolling blackouts
  - Lack of fixed-price forward contract coverage of final demand increased incentive of suppliers to exercise unilateral market power during "crisis" period
    - See Wolak (2003) "Diagnosing the California Electricity Crisis," available on web-site

Thank you
Questions/Comments