PESD STANFORD | PROGRAM ON ENERGY AND SUSTAINABLE DEVELOPMENT

Long-Term Resource Adequacy with Significant Intermittent Renewables

Frank A. Wolak

Director, Program on Energy and Sustainable Development

Professor, Department of Economics

Stanford University

Colombia

March 23, 2020

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

Market design should support business models that lead to adoption of these pricing policies and technologies

Future Electricity Supply Industry

Policy Question: What long-term resource adequacy mechanism will facilitate a least-cost transition to this future electricity supply industry with these pricing policies and technologies?

- Capacity payments mechanism--Increasingly expensive approach to long-term resource adequacy, particularly for regions with a large share of intermittent renewables
  - Limits economic benefits from dynamic pricing and storage and load flexibility investments
- Standardized long-term energy contracting--Least cost approach to long-term resource adequacy for future electricity supply industry
  - Supports dynamic pricing policies and storage and load flexibility investments

Need for Resource Adequacy Mechanism

In former vertically-integrated geographic monopoly regime, monopoly is responsible for ensuring there are sufficient resources to meet demand

- Regulator penalizes monopoly for supply shortfalls

In wholesale market regime no single entity is responsible for ensuring sufficient resources to meet demand

- Independent System Operator (XM) can only operate market with resources it has
- Generation unit owners can only supply energy from their generation units
- Retailers can only purchase the energy that generation unit owners supply to wholesale market

Conclusion—Unless regulator treats electricity like any other product (see next slide), wholesale market regime requires a long-term resource adequacy mechanism

Need for Resource Adequacy Mechanism

A long-term resource adequacy mechanism is necessary because of “reliability externality”

- Unwillingness of regulator to commit to use real-time price of energy to clear market under all possible system conditions creates “reliability externality”
- Lack of interval meters often used to justify this unwillingness of regulator “to treat electricity like any other product”

All consumers know that random curtailment will occur if aggregate supply is less than aggregate demand, so no customer faces full expected cost of failing to procure adequate energy in forward market

Because of existence of “reliability externality,” in markets with a finite offer cap regulator must mandate a long-term resource adequacy mechanism

- Ensure *adequate supply of energy* under all future system conditions and allowed short-term prices

Historical Long-Term Resource Adequacy Challenge

- 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

Capacity Payments: Historical Solution to Problem

- Assign all retailers firm capacity obligations equal to a multiple of their annual peak demand
  - Between 110 to 120 percent, depending on region
- All generation units assigned firm capacity quantity equal to amount of energy unit can produce under stressed system conditions
  - For thermal resource this is typically equal to nameplate capacity times the availability factor of the unit
  - For hydro units this is an extremely challenging task
    - Typically based on historically worst hydrological conditions
      - See McRae and Wolak (2016) "Diagnosing the Causes of the Recent El Nino Event and Recommendations" available from web-site.
  - For solar and wind resources, it is even more difficult to determine firm capacity of generation units
    - Firm capacity of a MW of wind or solar capacity declines with share of wind or solar energy in system demand

Summary Comments on Capacity Mechanisms

Capacity payments are a expensive mechanism for attempting to achieve long-term resources adequacy in regions with significant intermittent generation resources

- Does not address primary reliability challenge in intermittent-renewable-dominated wholesale 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
  - Capacity Payments in a Cost-Based Wholesale Electricity Market: The Case of Chile (available on web-site)
- 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

Long-Term Resource Adequacy for Markets Dominated by Intermittent Renewables

Question is not an energy-only market versus capacity market

- A long-term resource adequacy mechanism is necessary in any energy market with a finite offer cap because of the reliability externality
- Higher offer caps on short-term market only reduce magnitude of reliability externality, but do not eliminate it

How to maximize benefits of market mechanisms while still providing regulator with assurance that demand will equal supply under all possible future system conditions

- Design long-term resource adequacy mechanism to provide consumers with what they want
- Make consumers pay for what they want
  - Some long-term resource adequacy mechanisms involve many “small” charges that sum up to higher costs for consumers
- Allow market participants maximum flexibility to determine least cost way to provide consumers with what they want

Consumers want their demand for electricity to be met under all possible future system conditions

- Consumers would probably pay to have fewer, not more generation units

Energy-Contracting Resource Adequacy Process

Mandate standardized forward contract holdings by retailers for pre-specified fractions of system demand at various horizons to delivery

- 100% of demand one year in advance
- 97% of demand two years in advance
- 95% of demand three years in advance
- 92% of demand four years in advance
- Percentages are not set in stone, nor is length of contracting mandate

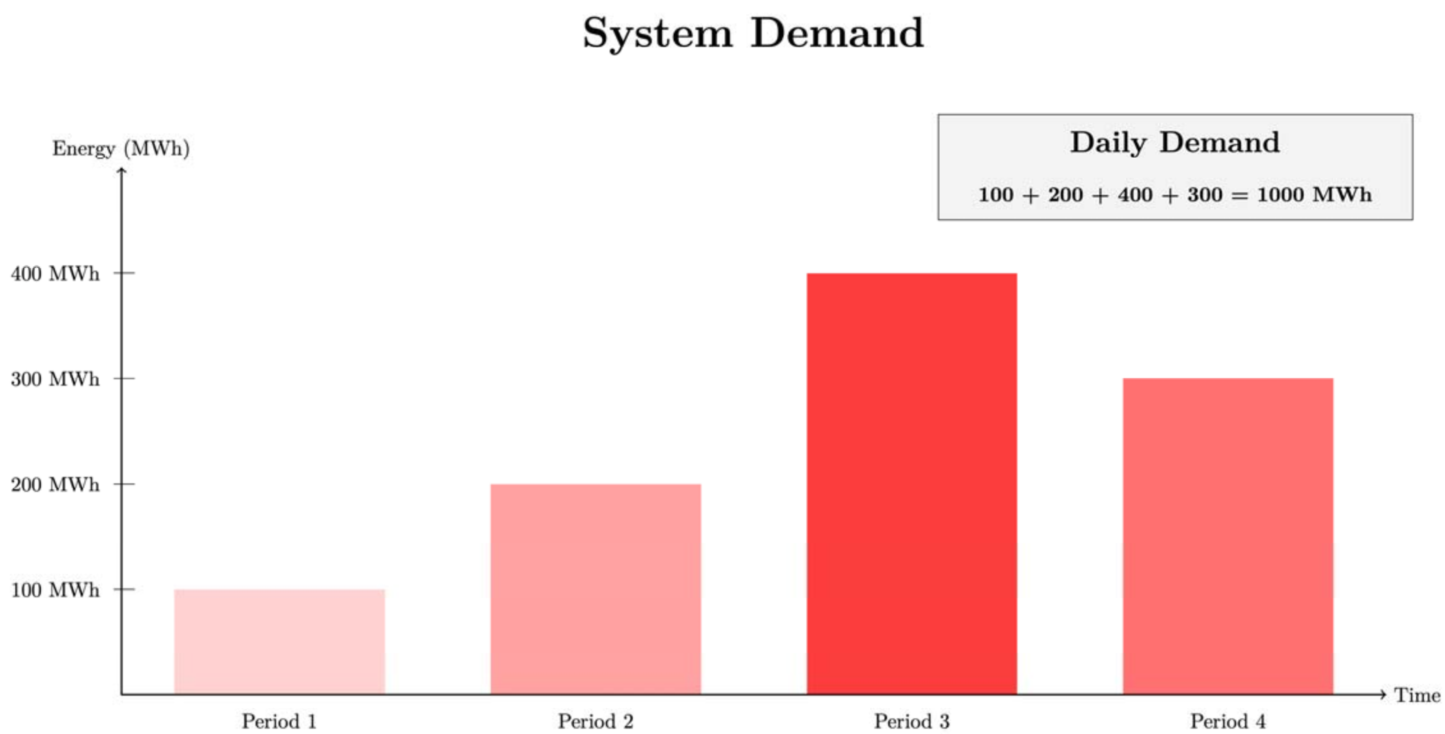
Contracts are shaped to hourly system demand within delivery period

- QD_h = actual system demand in hour h of delivery period of contract for h=1,2…,H
- QC_{total} = amount of energy sold in standardized contract at a fixed price
- $QC_h = \left(\frac{QD_h}{\sum_{h=1}^{H} QD_h}\right) QC_{total}$ for h=1,2,…H is forward contract obligation of seller of QC_{total} for each hour of delivery period

Energy shaped to realized pattern of system demand sold in standardized contract

- Sellers of contracts have ability to manage this quantity risk through use of own generation units or through hedging arrangements
- Sellers charge price for standardized contract that incorporates cost of managing quantity risk

Energy-Contracting Resource Adequacy Process



Realized Total System Demand ($\sum_{h=1}^{4} QD_h$) is equal 1,000 MWh and Has the Above Hourly Values, QD_h, h=1,2,3, and 4

Energy-Contracting Resource Adequacy Process

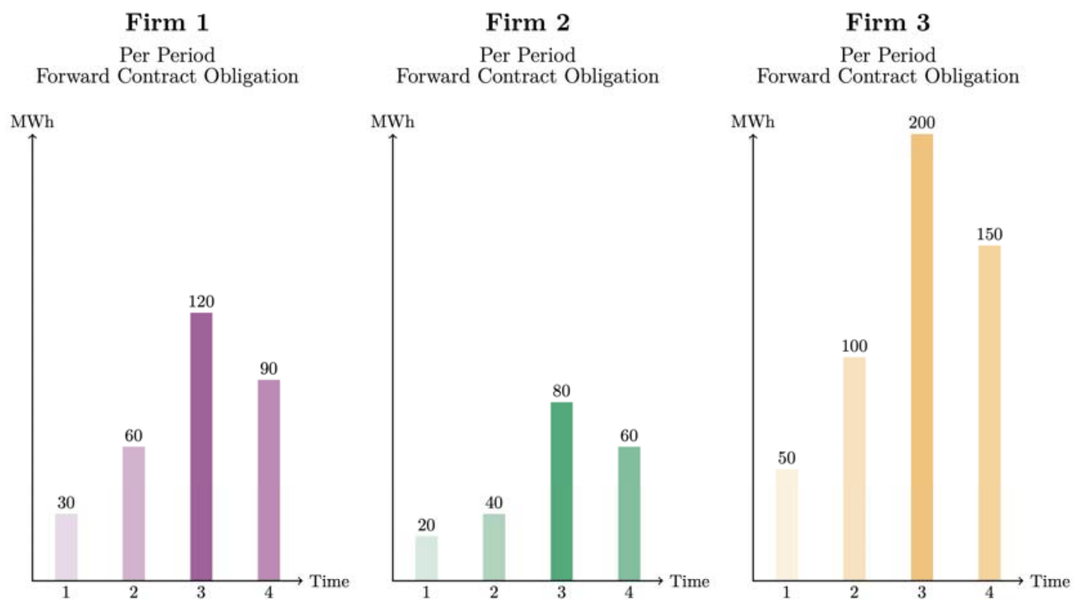
There are Three Firms:

Firm 1 sells 300 MWh

Firm 2 sells 200 MWh

Firm 3 sells 500 MWh

Total Amount Sold by Three Firms = 1000 MWh



Period-Level Values of QC_{hk} for Total Sales $Q_{total,k}$ of Each Firm k=1,2,3

$$\sum_{k=1}^{3} QC_{Total,k} = 1000 \text{ MWh} = \sum_{k=1}^{4} QD_h$$

Energy-Contracting Resource Adequacy Process

Standardized contracts can run for different delivery horizons

- Multi-year, single year, quarterly or monthly

Delivery on initial multi-year contracts should begin far enough in advance of delivery that new sources of supply can compete to provide energy

- At least three years between close of auction and delivery of energy

Contracts can be procured to meet actual system demand on behalf of retailers and large consumers through periodic standardized auctions

- Annually, Quarterly, Monthly

Simple auction mechanism can be used to procure energy because single product is being purchased—energy shaped to hourly system demand

Energy-Contracting Resource Adequacy Process

Contracting mandates (percentages) are regulator's security blanket to ensure adequate supply of energy under all possible system conditions in future

- Allows offers caps on short-term energy market
- Can increase offer caps over time because system demand is hedged

No capacity requirement

- Let suppliers figure out least cost way to meet system demand
- Creates level playing field for demand-side and supply-side solutions
- Focuses on primary reliability problem in markets with significant amounts of renewables—adequate energy to serve demand
  - There has never been a shortage of generation capacity in California and other high renewables regions--New Zealand, Colombia, Brazil, and Chile--in wholesale market regime

Energy-Contracting Resource Adequacy Process

Periodic standardized auctions run by XM overseen by CREG

- Purchases of standardized contracts are made and allocated to all loads based on their load share
- Can be allocated based on hourly, monthly or annual load share
- QD_k = system demand in MWh during interval k
- C_{ik} = consumption in MWh of retailer or large consumer i during interval k
- QC_{ik} = forward contract coverage of retailer or large customer i during interval k

If allocation interval is an hour, then retailers and large consumers have hourly value of QC_{ik} equal to their hourly share of system demand

- Can assign forward contract quantity to retailers and large consumers at higher degree of temporal aggregation than hourly
- Only have to ensure that aggregate hourly difference payments between buyers and sellers of standardized contracts balance

Energy Contract Allocation Process

There are Four Retailers:

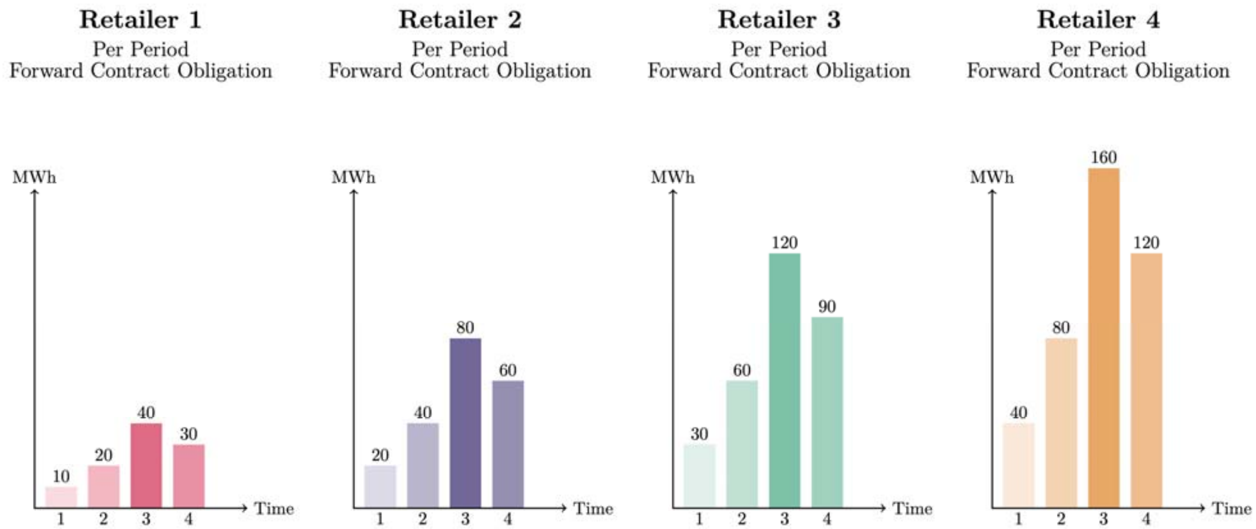
Retailer 1 sells 100 MWh

Retailer 2 sells 200 MWh

Retailer 3 sells 300 MWh

Retailer 4 sells 400 MWh

Total Amount Sold by Four Retailers = 1000 MWh



Sum of Hourly Forward Contract Obligations (QR_{hr}) Assigned to r=1,2,3,4 Retailers is equal to Hourly System Demand (QD_h) and Aggregate Forward Contract Obligations of Generation Unit Owners (QC_{hk})

$$\sum_{r=1}^{4} QR_{hr} = QD_h = \sum_{k=1}^{3} QC_{hk} \quad for\ h = 1,2,3,4$$

Energy-Contracting Resource Adequacy Process

Aggregate forward contract obligation for all suppliers should cover hourly system demand

- Interval level difference payments can be recovered from retailers and large loads over longer time interval

Contracts allocated to individual retailers and large consumers cannot be sold, they must be held to delivery

- This ensures that system demand is fully hedged
- Output of suppliers not fully hedged by their sales of this contract
- Aggregate, but not individual, consumption of retailers and large consumers fully hedged by this contract

Hourly clearing of contracts for retailers and large consumers

$$(P(retail) – P(spot))Q(retail)+(P(spot) - P(contract))Q(contract)$$

Hourly clearing of contracts for generation unit owners

$$P(spot)Q(spot) + (P(contract) – P(spot))Q(contract) – C(Q(spot))$$

Generation unit owner that produces no energy during hour earns

$$(P(contract) – P(spot))Q(contract)$$

Energy-Contracting Resource Adequacy Process

Contract sales by generators and purchases allocated to retailers do not preclude other bilateral contracts

- Standardized contracts for long-term resource adequacy mechanism

Standardized contracts are "nudge" to retailers and large consumers to ensure aggregate demand is fully hedged—long-term resource adequacy criteria met

Rather than base case of zero hedging of system demand

Start from base case of 100% hedging of system demand

Generators can hedge their remaining wholesale price and quantity risk associated with production of energy from their generation units through bilateral contracts

- Standardized contracts designed to jump-start active forward market for energy

Retailers can hedge their remaining wholesale price and quantity risk through bilateral contracts

- Difference between their load shape and system load shape

Energy-Contracting Resource Adequacy Process

There is no requirement that seller of contract must actually produce electricity sold in standardized forward contract

- Because producing electricity is only way to physically hedge this contract, some market participant will produce the electricity

This requirement addresses issue of futures contract sales by thermal generation unit owners

- These owners will often buy energy from short-term market instead of produce energy when there is a substantial amount of wind and solar energy is being produced

Encourages active demand-side participation in wholesale market (no need for low offers caps on short-term market)

- Consumers protected from high wholesale prices by financial contract coverage of final demand
- Consumers willing to manage short-term price risk can sell bilateral contract to expose themselves to this risk

Energy-Contracting Resource Adequacy Process

Standardized contracts of different durations could be purchased and sold in periodic auctions, for example

- Annual auction for multiple years in future starting delivery in 3 years
- Annual auction for single year in future starting delivery in 2 years
- Annual auction for single year in future starting delivery in 1 year
- Quarterly auction starting delivery in 3 quarters
- Quarterly auction starting delivery in 2 quarters
- Quarterly auction starting delivery in 1 quarter

All auctions sell the same hourly system-load-shaped product at a fixed price for duration of contract

XM and CREG could purchase standardized product on behalf of retailers and large loads and allocates contract obligations to these entities using interval load-share-weights described earlier

Retailers and large loads and generation unit owners can hedge their own remaining price and quantity risk through bilateral purchases and sales

- Entities that want to expose themselves to short-term prices can do so, but must find a willing counterparty and negotiate a price

Energy-Contracting Resource Adequacy Process

Making XM comfortable with transition to an energy-contracting based resource adequacy mechanism

- The firm energy construct from capacity mechanism should be used to limit the amount of a standardized contract of energy a unit owner can sell
- Do not want unit owners in the aggregate selling more standardized energy than they are able to provide under all possible future system conditions

Dispatchable (typically thermal) resources will typically produce less energy than they are capable of producing during extreme system conditions

Intermittent resources will typically produce more energy than they are capable of producing during extreme system conditions

Implication--Cross-hedging between dispatchable resources and intermittent resources required to insure demand is met under all possible future system conditions

- Intermittent units purchase quantity insurance from dispatchable resources for standardized energy contracts sold

Energy-Contracting Resource Adequacy Process

Ensuring cross-hedging between intermittent and dispatchable resources

- Allow existing resources only to sell up to their firm energy
  - Amount of energy units can produce under stressed system conditions
- Firm energy (FE) = ENFICC (Energía Firme para el Cargo por Confiabilidad) on annual basis

Each participant in standardized contract auction can only sell a total amount of annual energy than is less than or equal to annual firm energy value (FE)

Insures that total standardized contracts for energy sold can actually be delivered under all possible future system conditions

- Under typical conditions, most energy produced by intermittent resources and dispatchable (thermal) resources purchase this energy to meet standardized energy contract obligations
- Under scarcity conditions, most energy produced by dispatchable (thermal) resources and intermittent resources only provide their firm energy

Energy-Contracting Resource Adequacy Process

To make efficient "make versus buy" decision to meet standardized forward contract obligation, thermal suppliers will submit offer to supply energy at marginal cost

- If Price > MC, supplying from unit is cheapest way to meet forward contract obligation
- If Price < MC, buying from short-term market is cheapest way to meet obligation

Allocation of standardized contracts across thermal suppliers ensures that all are committed to the short-term market at marginal cost for at least the hourly value of QC

Allocation of standardized contracts across intermittent suppliers ensures that they have strong incentive to make arrangements to supply or purchase at least hourly value of QC

- Can purchase price spike insurance from thermal resources against hourly value of QC
- Provides additional revenue stream to fast start thermal resources

Energy-Contracting Resource Adequacy Process

How do new entrants compete in these auctions?

- New entrant sells energy to be delivered three years in the future must show reasonable progress towards having amount of FE sold in real-time
- If reasonable progress according to XM and CREG is not shown, then contract is liquidated and purchase must be made in upcoming standardized energy auction to meet this shortfall
- Reasonable progress showing can be done every six months through filing by new entrant and site review by XM and CREG staff
- Cost of forward energy purchased to replace energy not supplied by new entrant is allocated to all loads in proportion to load share as described earlier

Energy-Contracting Resource Adequacy Process

Managing local long-term resource adequacy

- Can run auctions for standardized contracts that clear against different pricing hubs
  - Different spatial aggregated prices for each retailer
- Need to determine service territory-level demands that sum to total system demand

Suppliers with fixed-price forward contract obligations that clear against service territory-level prices have a strong incentive to keep these short-term prices as low as possible until cover fixed price forward contract obligations

Suppliers have strong incentive to limit price dispersion across locations within the service territory

- Meet aggregate demand within service territory at lowest possible costs

Each supplier has a strong incentive to make the efficient "make versus buy" decision for its hourly forward contract quantity within in the service territory

Energy-Contracting Resource Adequacy Process

To the extent there are local long-term resource adequacy concerns can run auctions for more spatially granular standardized products

- Can run auctions for standardized contracts that clear against different more pricing locations
  - Local reliability area prices
- Need to determine service territory-level demands that sum to total system demand

Suppliers with fixed-price forward contract obligations that clear against these price have a strong incentive to keep these short-term prices as low as possible until cover fixed price forward contract obligations

Products must be purchased far enough in advance of delivery to allow new entrants to compete to supply products

Energy-Contracting Resource Adequacy Process

Transitioning to this approach to long-term resource adequacy requires significant advance notice

- First procurement of contracts should start delivery at least three years in advance

Retailers and generation owners need sufficient time to adapt to an energy-contracting resource adequacy process

Significantly more cross-hedging between resources to ensure system demand is met under all possible future system conditions

- Intermittent resources re-insurance with dispatchable resources
- Dispatchable resources earn premium for providing this insurance

Mechanism values a firm MWh more than a non-firm MWh

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

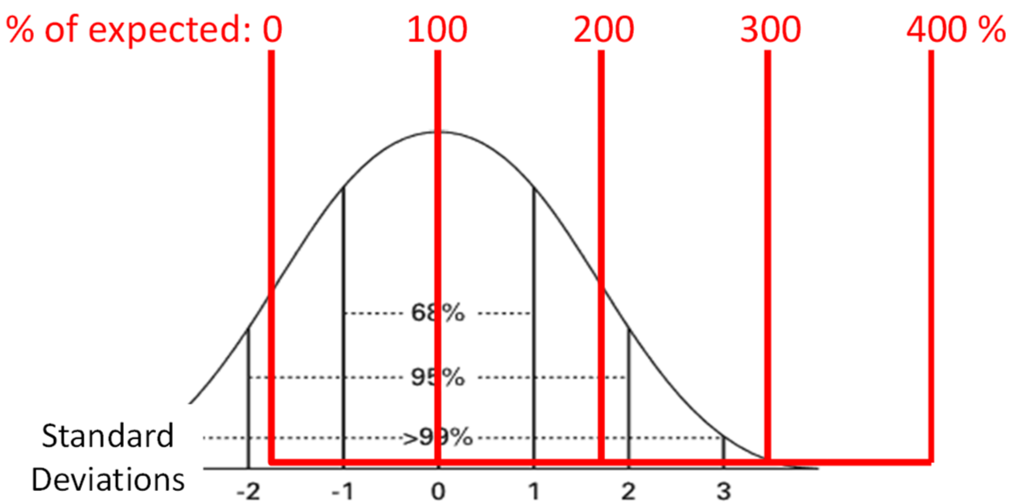
Players then compete to sell electricity in offer-based short-term market

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

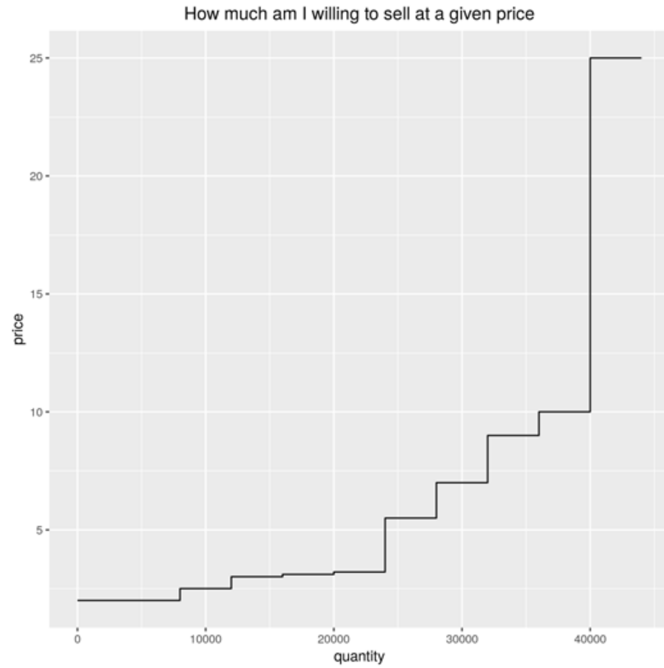
Capacity Market game mechanics

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

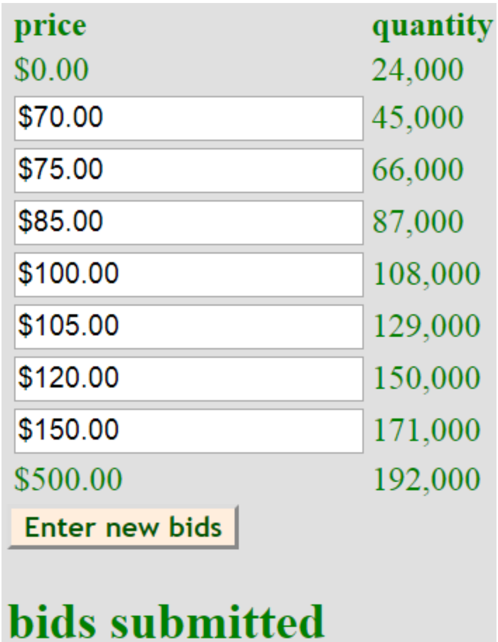
2) Buy/decommission units to meet capacity contracts you won (*required*)

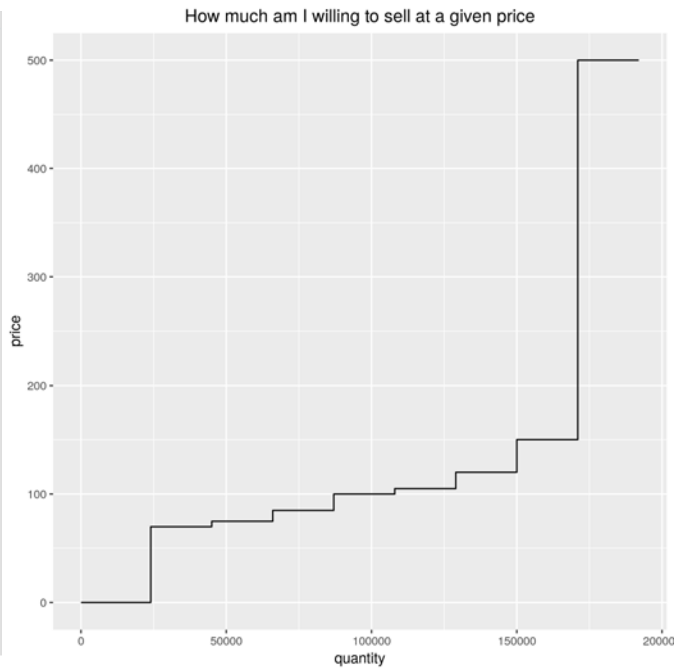
Plant Type	Capacity (MW)	Var Cost ($/MWh)	Fixed cost ($/hr)	Fixed cost ($/MW-hr)	LCOE ($/MWh) -- by portion of hours running: 10%	25%	50%	75%	100%
Base	2000/1000	20	100,000/25,000	25	270	120	70	53	45
Intermediate	1000	45	10,000	10	145	85	65	58	55
Peak	1000	90	3,000	3	120	102	96	94	93

3) Bid in all thermal units to maximize returns

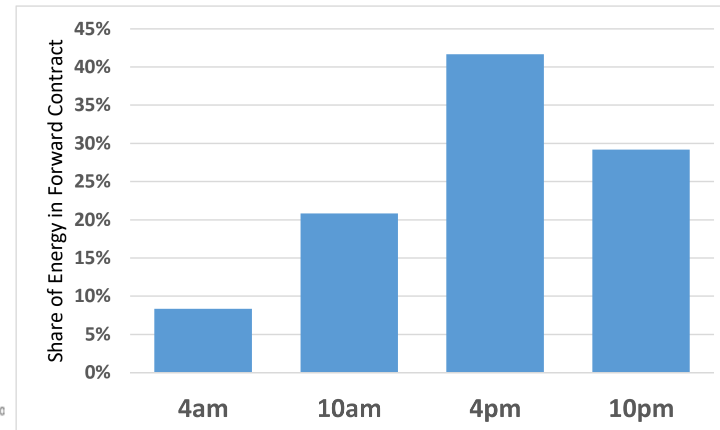
Forward Energy Contracting game mechanics

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





- 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

Concluding Thought

There is nothing more difficult to take in hand, more perilous to conduct, or more uncertain in its success, than to take the lead in the introduction of a new order of things. Because the innovator has for enemies all those who have done well under the old conditions, and lukewarm defenders in those who may do well under the new."

– Niccolo Machiavelli (The Prince)

Thank you

Questions/Comments

Common Misconceptions

- Claim—An energy-based resource adequacy mechanism requires energy and ancillary services markets with no bid cap
- If fixed-price forward contract coverage of final demand for energy and ancillary services is high enough, bid cap must only be above variable cost (properly computed) of highest variable cost unit on system
  - 100 percent coverage of final demand only need offer cap above variable cost of highest cost unit in system
- Can require higher level of coverage of forecast of final demand to account for unexpectedly high levels of actual demand relative to forecast
- Cost of purchasing last 5 to 10 percent of forward contract coverage of final demand can be very expensive relative to allowing short-term prices and active demand-side participation to clear these energy and ancillary services markets

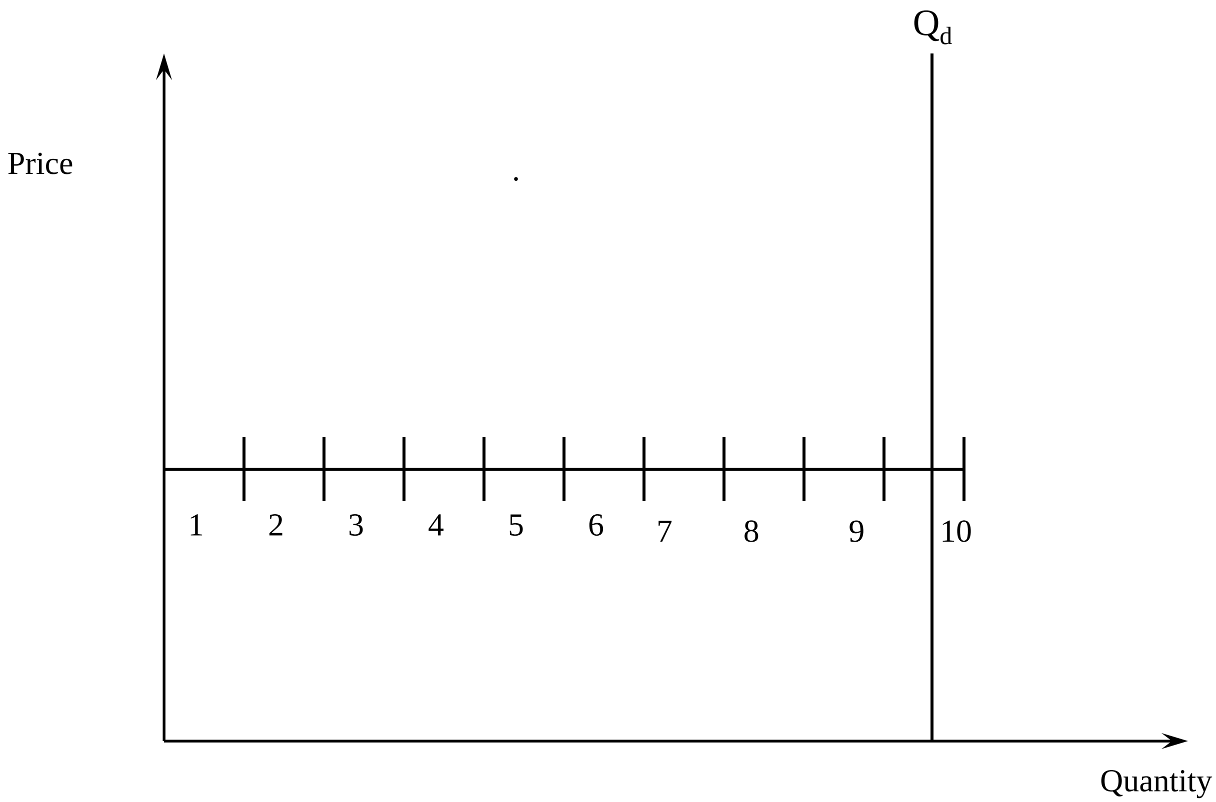
Capacity Approach to Resource Adequacy

- Historic “Rationale” for capacity payment mechanism in US
  - Historically, 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
  - 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 price 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

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 hourly price can be set to equate hourly supply and demand, which eliminates missing money problem
  - Regulator setting value of capacity margin likely to create missing money problem
    - Strong incentive for regulator, system operator, and generation unit owners, and 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 markets are extremely susceptible to exercise of unilateral market power
    - Vertical supply (installed capacity) meets vertical demand
    - Can create extremely volatile short-term capacity prices, which is contrary to claimed investment signal of capacity price

Capacity Auction--Pivotal Supplier Problem



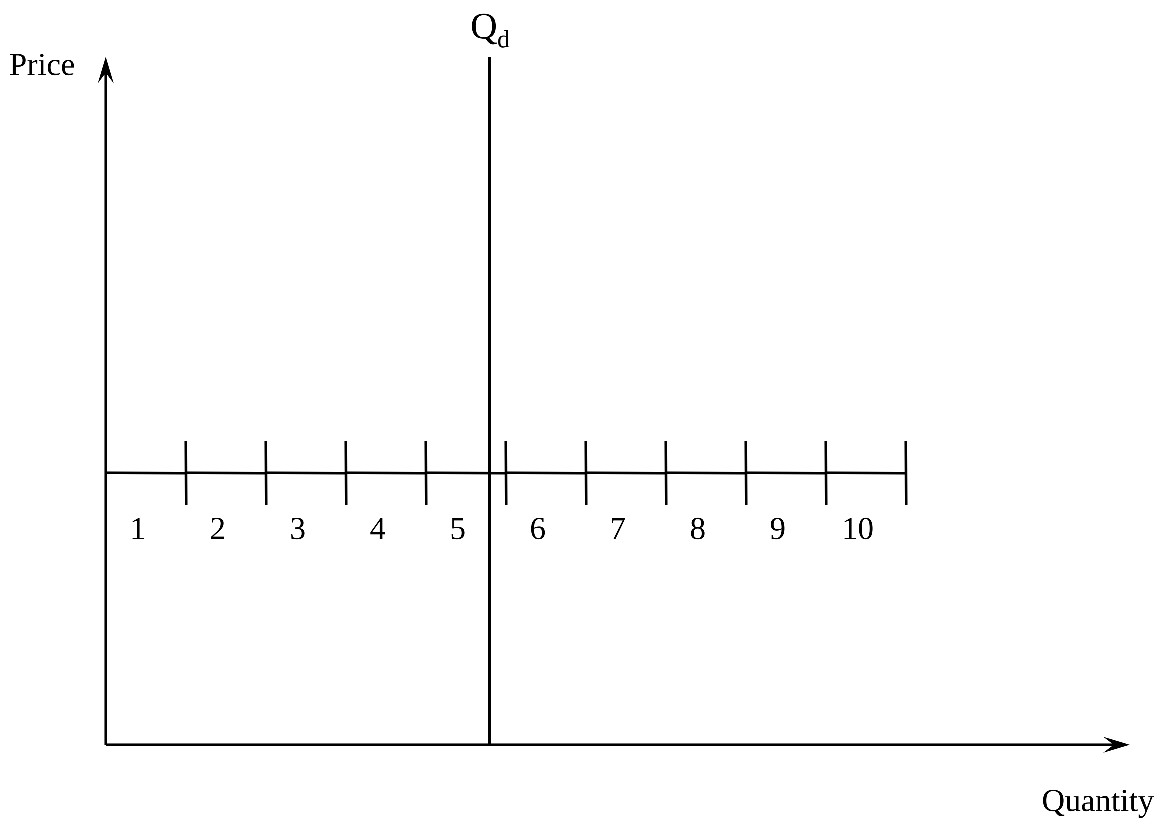
10 Firms--Each has 1 MW to sell, Market Demand is 9.5 MW

Marginal Cost = $0/MW, Price Cap of $10,000/MW

Auction Equilibrium

- 9 firms all bid $0/MW for one 1 MW
- 1 firm bids $10,000/MW for 1 MW
- Equilibrium price is $10,000/MW
- Each of 9 firms bidding $0/MW has no incentive to unilaterally change its bid
  - Earns highest possible profit given capacity
- 1 firm bidding $10,000/MW has no incentive to unilaterally change its bid
  - Cannot increase price
  - Decreasing price only reduces profit
  - Reductions in quantity can only reduce profit

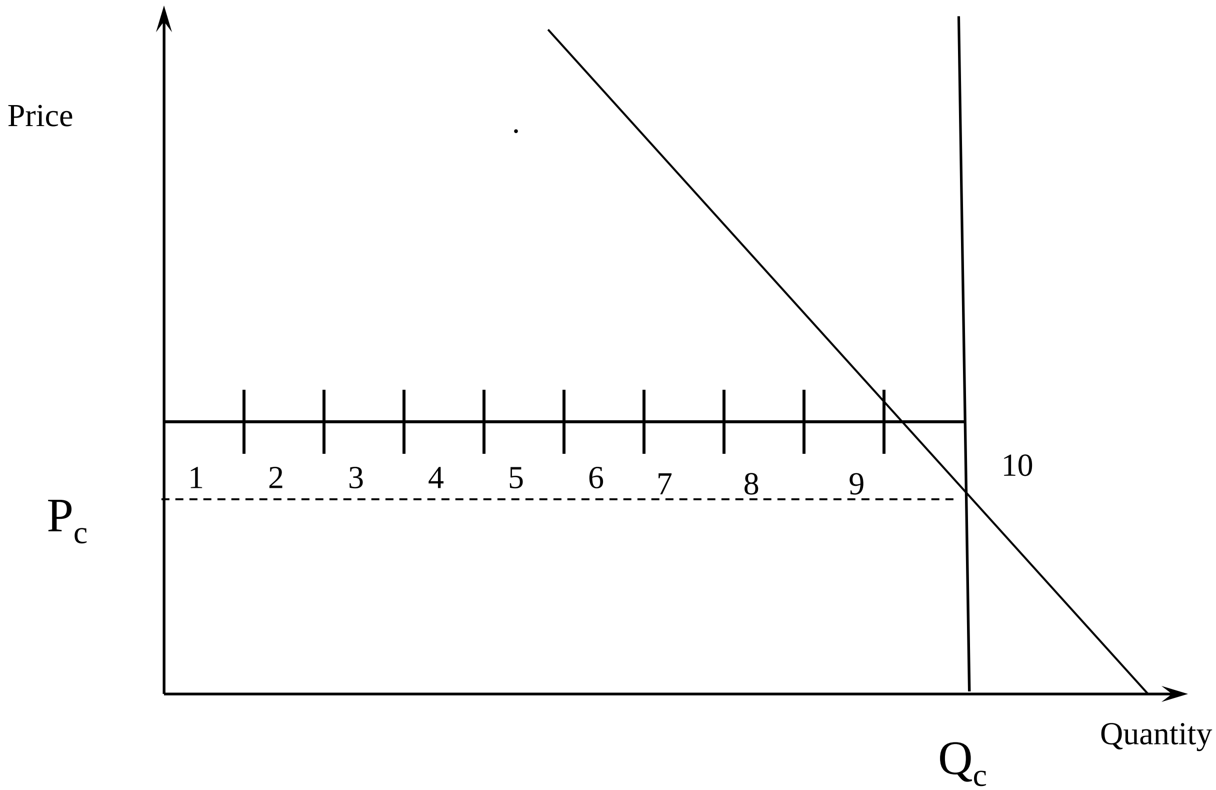
Capacity Auction—No Pivotal Supplier



A Nash equilibrium to this auction is that all firms bid zero and each sell $Q_d/10$

These two conditions imply extremely volatile short-term capacity market prices.

Solution: Capacity "Dee-mand Curve"



10 Firms--Each has 1 MW to sell, Market Demand is 9.5 MW

Marginal Cost = $0/MW, Price Cap of $10,000/MW

Benefits and Costs of Capacity-Based Approach

- Costs of capacity-based resource adequacy process falls primarily on final consumers
  - Consumers pay market price of capacity to all generation units receiving capacity payments
  - Unless capacity is purchased far enough in advance of delivery to allow new entrants to discipline market power of large incumbent generation unit owners, an administrative or regulatory pricing mechanism is necessary
    - Severe market power problems can arise even with “administrative dee-mand curve” approach used in eastern US
  - With bid-based short-term market and adequate generation capacity, high-levels of fixed-price forward contracting 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 energy contracting approach does
    - Suppliers get two independent opportunities to exercise unilateral market power: (1) selling capacity and (2) selling energy in short-term market