El desafío de la implementación de los mecanismos para la internalización de los “costos no convexos“

Capítulo 2: La visión económica

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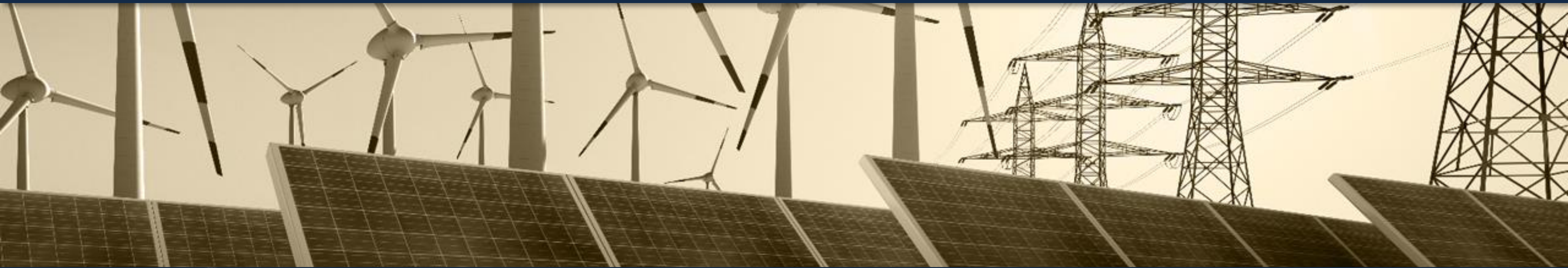
Preparado para Generadoras de Chile



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When is Price = MC Efficient?

- For an electricity supply industry with each generation unit having a constant marginal cost of production and no start-up or no load costs, a market-clearing price that meets the following three criteria exists
  - Provides the efficient economic signal to load
  - Enforces dispatch instructions issued by system/market operator
  - Recovers the total operating cost of each generation unit
- Example: 5 firms each of which owns 100 MW of capacity with marginal costs of $10/MWh, $20/MWh, $30/MWh, $40/MWh and $50/MWh and demand is 450 MWh
  - Market-clearing price is, $50/MWh marginal cost of highest cost unit necessary to meet demand
  - Equivalently, $50/MWh is increase in minimum cost of meeting demand of associated with serving one more 1 MWh of demand
    - Shadow price on constraint that total generation equals total demand

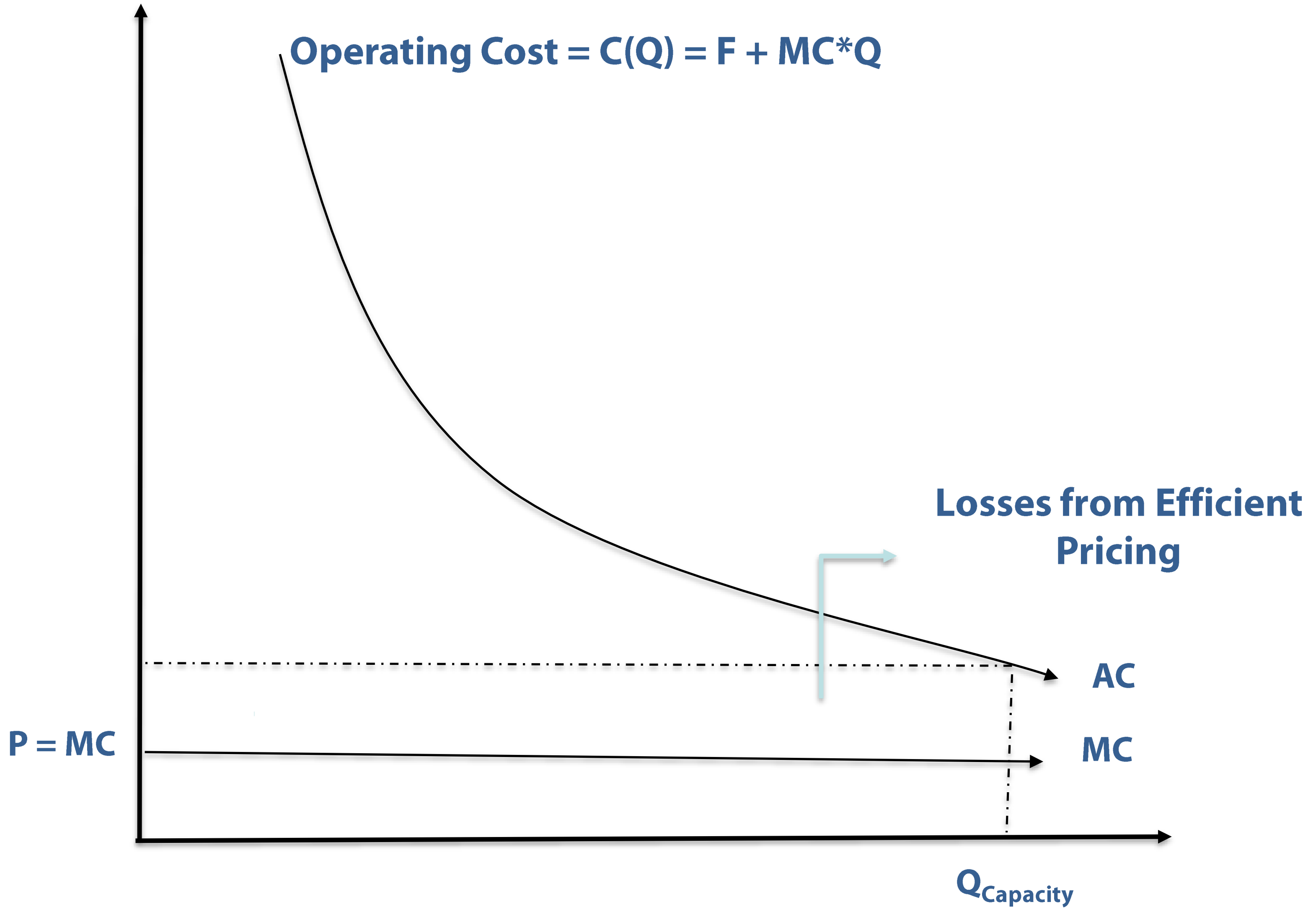
When is Price = MC Efficient?

- Price provides the efficient economic signal to load because the consumer does not purchase an additional MWh if his willingness to pay is less than the cost of supplying that additional MWh
- This price is enforces the dispatch instructions issued by the system/market operator
  - Suppliers 1 to 4 want to produce at full output given that the price is above their marginal cost
  - Supplier 5 has no incentive to deviate from 50 MWh, because the price is equal to its marginal cost of $50/MWh
- All suppliers earn sufficient revenues to cover their total operating costs
  - Suppliers 1 to 4 earn revenues in excess of their total operating costs
  - Supplier 5 earn revenues equal to its total operating costs

Fixed Costs and Non-Convexities

- Besides marginal cost of producing energy, thermal generation units have
  - Fixed costs of operating—start-up, no-load costs
  - Potential non-convexities in operation
    - Minimum up-time and down-time for unit
    - Block loading of unit (can only produce at discrete output levels)
  - Operating cost function for thermal generation unit takes the form $C(q) = F + cq$, where F is fixed costs and c is marginal cost of producing energy
- Under these conditions, a market-clearing price that meets following three criteria no longer exists
  - Provides the efficient economic signal to load
  - Enforces dispatch instruction issued by system/market operator
  - Recovers total operating cost of generation units producing energy
- Marginal cost pricing fails recover operating cost of some generation units

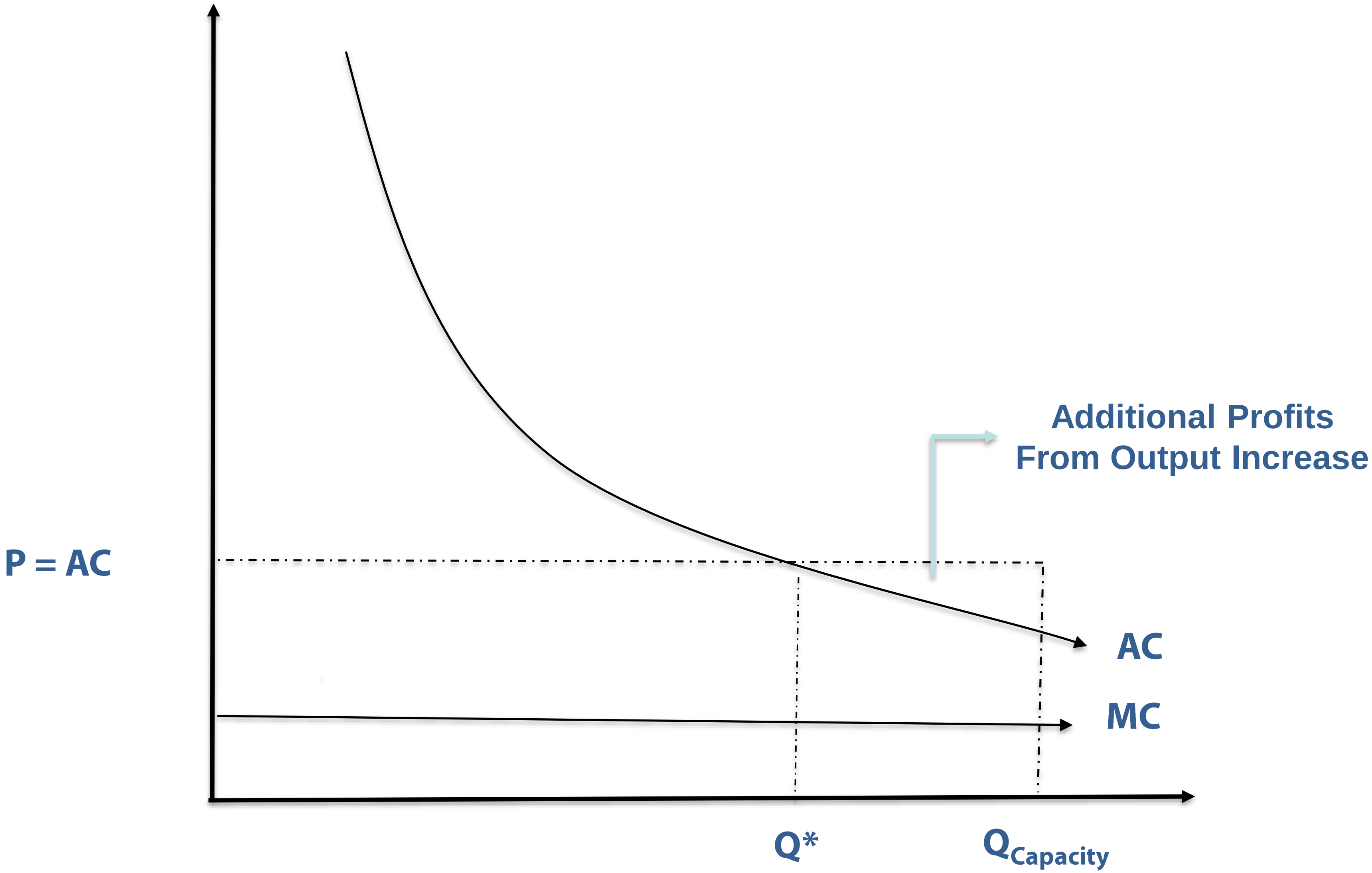
Losses from Efficient Pricing



What is the Problem?

- Setting price equal to average cost recovers the unit's operating costs but fails to meet other two criteria
  - Sends inefficient economic signal to load by curtailing demand that is willing to pay marginal cost of supplying an additional MWh
  - Provides an incentive for generation unit owner to produce more than amount dispatched by system/market operator
    - Unit with a marginal cost of $50/MWh would like to produce more than 50 MWh assigned by system/market operator because this increases its variable profits

Incentive to Deviate with P = AC



What is the Problem?

- Conclusion—With fixed costs of operating and/or non-convexities in operation, it is impossible to find a set of prices that satisfies all of the above three goals

What is the Solution?

- Market designer must decide which of three criteria will be compromised
- Currently there are two popular approaches in the US
  - Make-Whole-Payments (MWPs)—Set price equal to increase in minimized cost of serving one more 1 MWh of demand and then compensate individual generation units for their revenue shortfalls
    - Recover total MWPs from load on a $/MWh basis
  - Convex Hull pricing—Make aggregate minimum cost curve for serving demand convex and set price equal to slope of convex cost curve at market demand and use MWPs to recover remaining revenue shortfall
    - Set energy prices to minimize total MWP
- All US markets use MWP approach to achieving revenue recovery, although one has also implemented a limited version of convex hull pricing

How Do Make-Whole Payments Work?

- Make-whole payment guarantees recovery of start-up and no-load costs and as-offered energy costs for units accepted to start-up and produce energy
  - Example—Suppose a unit has $1000 start-up and no-load cost and an energy offer at $20/MWh and is accepted to supply 100 MWh.
    - If market price is $20/MWh, supplier with receive $1000 MWP payment
    - If market price is $30/MWh, supplier will not receive an MWP payment
    - If market price is $25/MWh, supplier receives a $500 MWP payment
- Make whole payments are specific to each generation unit that incurs a start-up and no-load cost or has non-convexities in operation
  - Provides positive difference between each generation unit's total operating costs (start-up, no load, and energy costs) and total market revenues

Advantage of Make-Whole Payments

- Make whole payment approach can be applied to virtually any market design
  - Single zone pricing, multi-zone pricing, and locational marginal pricing
  - Single settlement market and two-settlement (day-ahead and real-time) market design
- If total market revenues do not cover total operating costs of a generation unit, a make-whole payment will make up the difference for that generation unit
- Total make whole payments across all generation units can then be recovered as a \$/MWh charge (typically called uplift in the US) on all load consumed in market

Problems with Make-Whole Payments

- Magnitude of MWP payments has been growing in most US markets
  - Because costs are recovered as $/MWh charge to load, dulls incentive for market participants to limit magnitude of make whole payments
    - Different from locational price, where actions of generation unit or load at that location impacts that locational price
- Particularly in markets with significant amounts of intermittent renewable generation sources, make-whole payments are likely to increase further
  - Thermal generation units start-up and shutdown to meet renewable energy shortfalls and surges
  - Thermal generation units operate at minimum operating level to able to respond to rapid ramp down to solar resources at end of day
    - Locational marginal prices less than marginal cost of unit

Convexify to Limit Size of MWPs

- Different ISOs have attempted to limit size of MWPs by convexifying dispatch and pricing problem
- Consider example of two generation units

Unit	Capacity	Variable Cost	Pmin	Pmax	Start-Up Cost	Demand
G1	100 MW	$20/MWh	10 MW	100 MW	0	120 MWh
G2	80 MW	$100/MWh	50 MW	80 MW	$800	

- Two sources of non-convexities
  - Limited range of output for G1 and G2 (Pmin > 0)
  - Start-up cost for G2
- Set prices and compute MWP under four pricing scenarios using efficient dispatch
  - No convexification and pricing at efficient solution
  - Relax Pmin in pricing, and pay lost opportunity cost
  - Allocate start-up cost based on capacity of unit into unit's variable cost in pricing run
  - Allocate start-up cost based on efficient dispatch into unit's variable cost in pricing run

Convexify to Limit Size of MWPs

Item		Make whole payment		Make whole payment +Relajación restricción generación mímina+ Costos de oportunidad		Make whole payment +Relajación restricción generación mímina+ Costos de oportunidad +ΔCosto variable (pot máxima)[1]		Make whole payment +Relajación restricción generación mímina+ Costos de oportunidad +ΔCosto variable (despacho)[2]	
		G1	G2	G1	G2	G1	G2	G1	G2
Capacidad	MW	100	80	100	80	100	80	100	80
Restricción operación mímina	MW		50		50		50		50
Despacho	MWh	70	50	70	50	70	50	70	50
Potencia excedente	MWh	30	30	30	30	30	30	30	30
Costo variable	$/MWh	20	100	20	100	20	100	20	100
Precio energía	$/MWh	20	20	100	100	110	110	116	116
Costo oportunidad unitario	$/MWh	0	0	80	0	90	0	96	0
Ingresos	$	1400	1000	7000	5000	7700	5500	8120	5800
Costo de partida	$		800		800		800		800
Costo total	$	1400	5800	1400	5800	1400	5800	1400	5800
Costo de oportunidad	$	0	0	2400	0	2700	0	2880	0
Make whole payment	$	0	4800	2400	800	2700	300	2880	0
G1+G2 Make whole payment	$		4800		3200		3000		2880
Notas									

[1] Costo de partida incluido en costos variables a prorrata de la potencia máxima de la central

[2] Costo de partida incluido en costos variables a prorrata de la potencia óptima de despacho que resulta del unit commitment.

Note: Total make-whole payment is sum of lost opportunity cost (lost profits at price set in pricing run) and market revenue shortfall relative to cost (also a lost opportunity cost).

Magnitude of Make-Whole Payments

Uplift and Energy Make-Whole Payments in 2018			Bid Cost Recovery (BCR)	Annual Load	Average Cost BCR
			$ Millions	Millions of MWh	$/MWh
California ISO--Bid Cost Recovery			153.00	223.705	$0.68
ISO New England--Net Commitment Period Compensation			70.00	123.305	$0.57
New York ISO--Bid Production Cost Guarantee			77.00	161.184	$0.48
PJM--Energy Uplift			199.00	791.089	$0.25
MISO--Revenue Sufficiency Guarantee			36.94	700.8	$0.05
ERCOT--RUC Make Whole			0.60	376.4	$0.00

- On dollar per annual MWh of energy delivered to load, the magnitude of total side payments is modest for all US ISOs
  - For some days make-whole payments can be large because many units were committed and ran at Pmin
- Difficult to compare numbers across ISOs because of differences in what goes into these numbers
  - Make-whole payment is one component of all these figures
- ERCOT has different approach to start-up and no load cost recovery from ISOs that are FERC jurisdictional

Problems with Make-Whole Payments

- Concern over potential for growing magnitude of MWP payments has led one market in US to consider convex hull pricing
  - Midcontinent Independent System Operator (MISO) has implemented what it calls extended LMP (ELMP) for some fast start units
  - Similar to last two scenarios in two-generator example
- Convex hull pricing minimizes total Lost Opportunity Cost payments (LOCs)
  - LOC payment is the amount the ensure resources receives it maximum possible profit given prices and its bid-in operating constraints
  - A make whole payment is an LOC payment where the maximum as-bid profit is equal to zero
- Convex hull pricing convexifies minimum total cost curve and charge price at each level of demand equal to slope of this convex cost curve
  - Makes LOC payments to enforce system/market operator's dispatch instructions

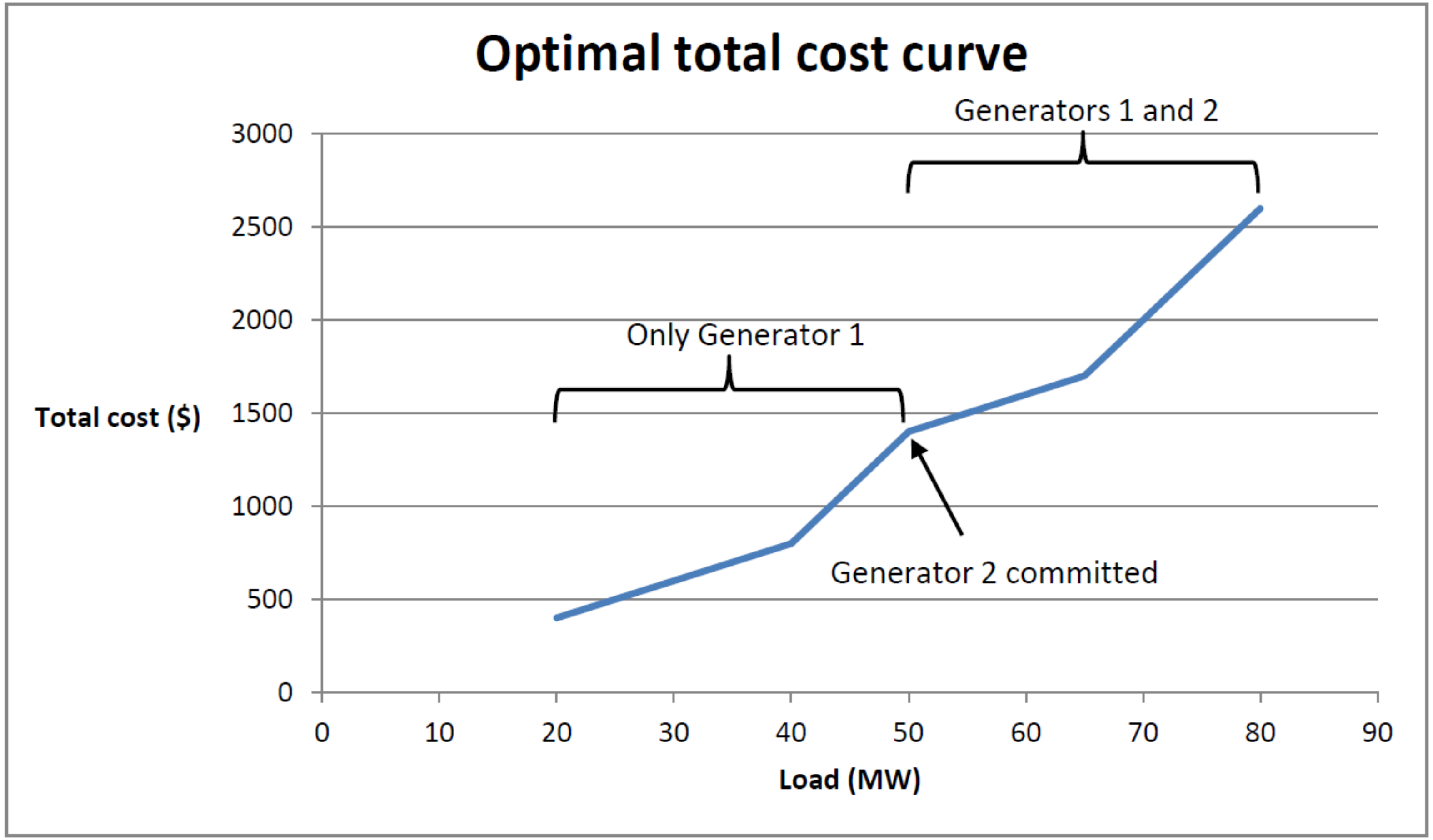
Convex Hull Pricing Example

- Two generator market from with Generator 1 online and incapable of shutting down and Generator 2 offline by available to start
- Both generators have minimum and maximum output levels
- Bids and offers given in following table

	Generator 1	Generator 2
Economic minimum (MW)	20	25
Economic maximum (MW)	55	25
Bid block 1 (MW range, $/MWh)	0 – 40, 20	-
Bid block 2 (MW range, $/MWh)	40 – 55, 60	-
No-load cost ($/hr)	-	900

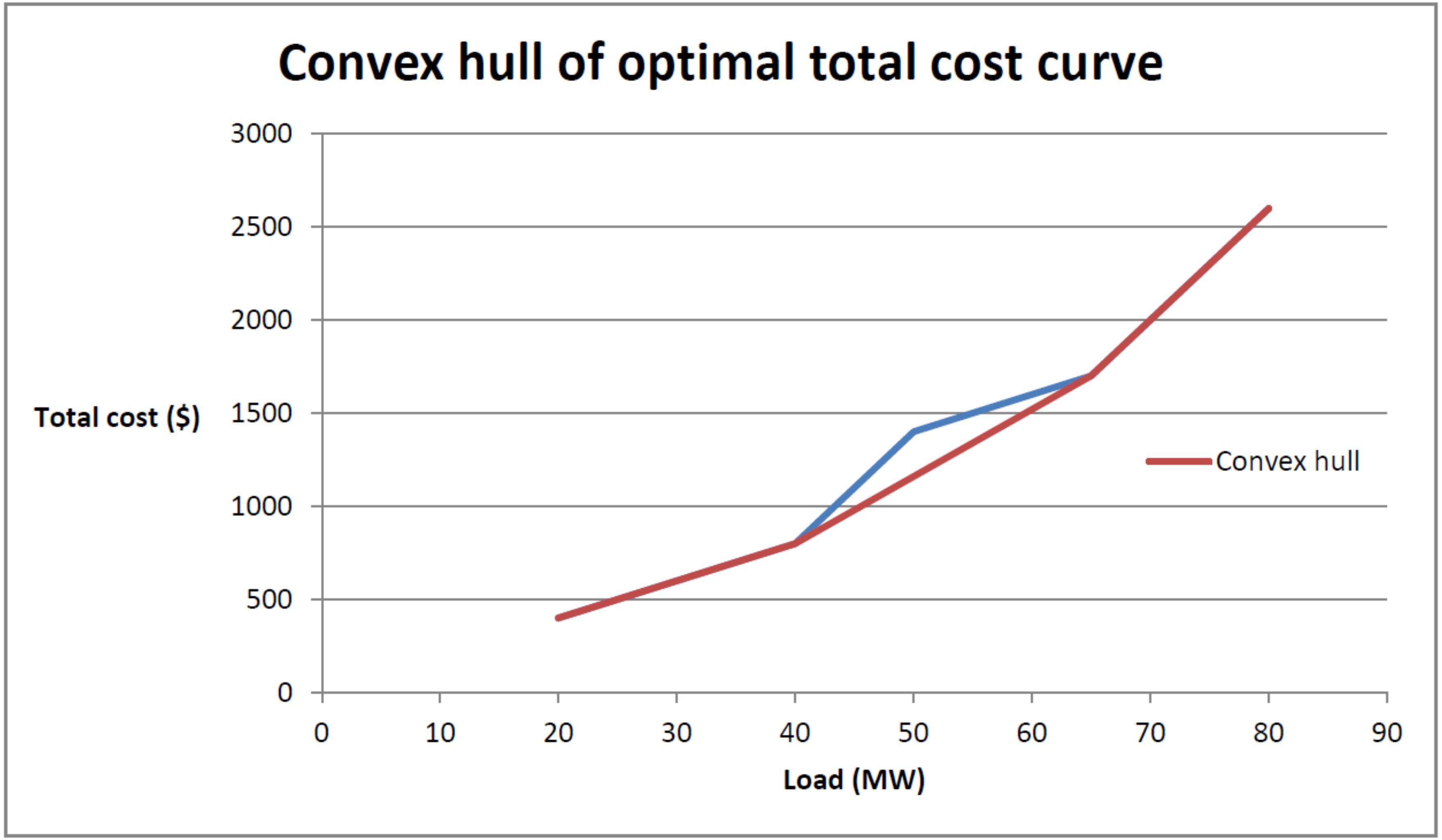
Source: "Convex Hull Pricing in Electricity Markets: Formulation, Analysis, and Implementation Challenges," Dane A. Schiro, Tongxin Zheng, Feng Zhao, and Eugene Litvinov, 2015.

Convex Hull Pricing Example



For loads of 20 – 50MW, the least cost solution is to produce from Generator 1 only.
Above 50MW, the least cost solution is to commit Generator 2 and produce from both generators.
The decrease in marginal total cost at the 50MW load level is caused by the 25MW block-loading of Generator 2 decreasing Generator 1's dispatch to 25MW.

Convex Hull Pricing Example



Find greatest convex function that is bounded above by the optimal total cost curve
Convex hull price is slope of convex hull at actual load level.

Convex Hull Pricing Example

Load level (MW)	Dispatch price ($/MWh)	Convex hull price ($/MWh)
30	20	20
45	60	36
55	20	36
70	60	60

Minimum cost marginal price, which is slope of minimum cost curve, need not be non-decreasing in demand level

Convex hull price is non-decreasing in level of demand and minimizes side-payments:

$$\sum_i (\text{Maximum possible as-bid profit} - \text{As-bid cleared quantity profit})_i$$

Properties of Convex Hull Pricing

- Identifies uniform energy and ancillary services prices that minimize LOC payments
- Nonbinding constraints on transmission network and reserves can receive positive prices from convex hull pricing
  - For this reason convex hull pricing best suited to nodal pricing markets
- In less spatially granular pricing markets, convex hull pricing can increase price paid to a significant amount of generation capacity
  - Raise total energy and ancillary services costs to consumers much more than make-whole payment approach

MISO's Experience

- MISO has been working on the development of extended LMP, a limited version convex hull pricing, for fast start resources (FSRs) for almost ten years before implementing
  - ELMP Phase I in March 1, 2015
  - ELMP Phase II in May 1, 2017
- This was only done after years study, market simulations, stakeholder discussions, and interactions with academic researchers
- "Considering the computational challenges and existing market structure, MISO implemented ELMP in staged approach" MISO, January (2019)
- Implementation has led to small (less than $2/MWh) annual average price increases, but potential for larger price increases during stressed system conditions
  - MISO is currently considering ELMP Phase III implementation with beyond simply pricing commitment of FSRs

Concluding Comments

- Many properties of convex hull pricing still not well understood
  - Highly dependent of specific market design
- Only in operation in limited form in one US wholesale market at the moment--MISO
- Make whole payment approach is much less risky approach for consumers to ensure generation unit owners operating cost recovery
- Annual $/MWh cost to recover make whole payment is less than $1/MWh for all US markets
  - No reason to expect this would not be case for Chile
- Convex hull pricing approach clearly worthy of further study given Chile intermittent renewable energy goals