

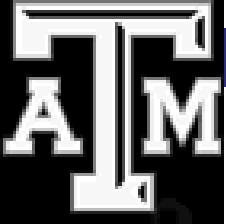


PSERC

Tools For Assessment of Bidding into Electricity Auctions

PSERC Publication 8-24

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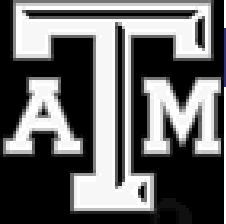


Outline

- Motivation to better analyze electricity auctions:
 - Efficiency of dispatch, and
 - Improve market participation by small generating firms,
- Simplified example & basic intuition:
 - Why an automated tool is useful.
- ERCOT example,
- Transmission constraints,
- Tool design,
- Transmission-constrained ERCOT example.

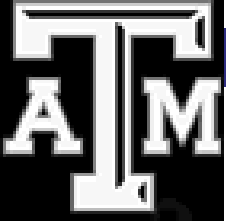
Why Study Electricity Auctions?

- Consider an offer- (or bid-) based electricity auction market:
 - Generators offer to generate or offer/bid to deviate from day-ahead scheduled generation,
 - Uniform price for energy equal to clearing price.
- For example:
 - Day-ahead and real-time markets in NE, NY, PJM, MISO, and future markets in CA and ERCOT, and
 - The ERCOT balancing market.
- How do we understand the performance of such a market?



Use of Offer Tools.

- Market monitor:
 - Allows market monitor to analyze offers and develop quantitative metrics:
 - Assess *potential* to exercise market power and *actual* exercise of market power.
 - Measure effect of specific offer/bid behavior on dispatch costs.
 - Separate scarcity rents from market power.
- Small generators:
 - Develop offer/bid strategies in the face of strategic complexity.
 - More fully participate in the market and improve efficiency.

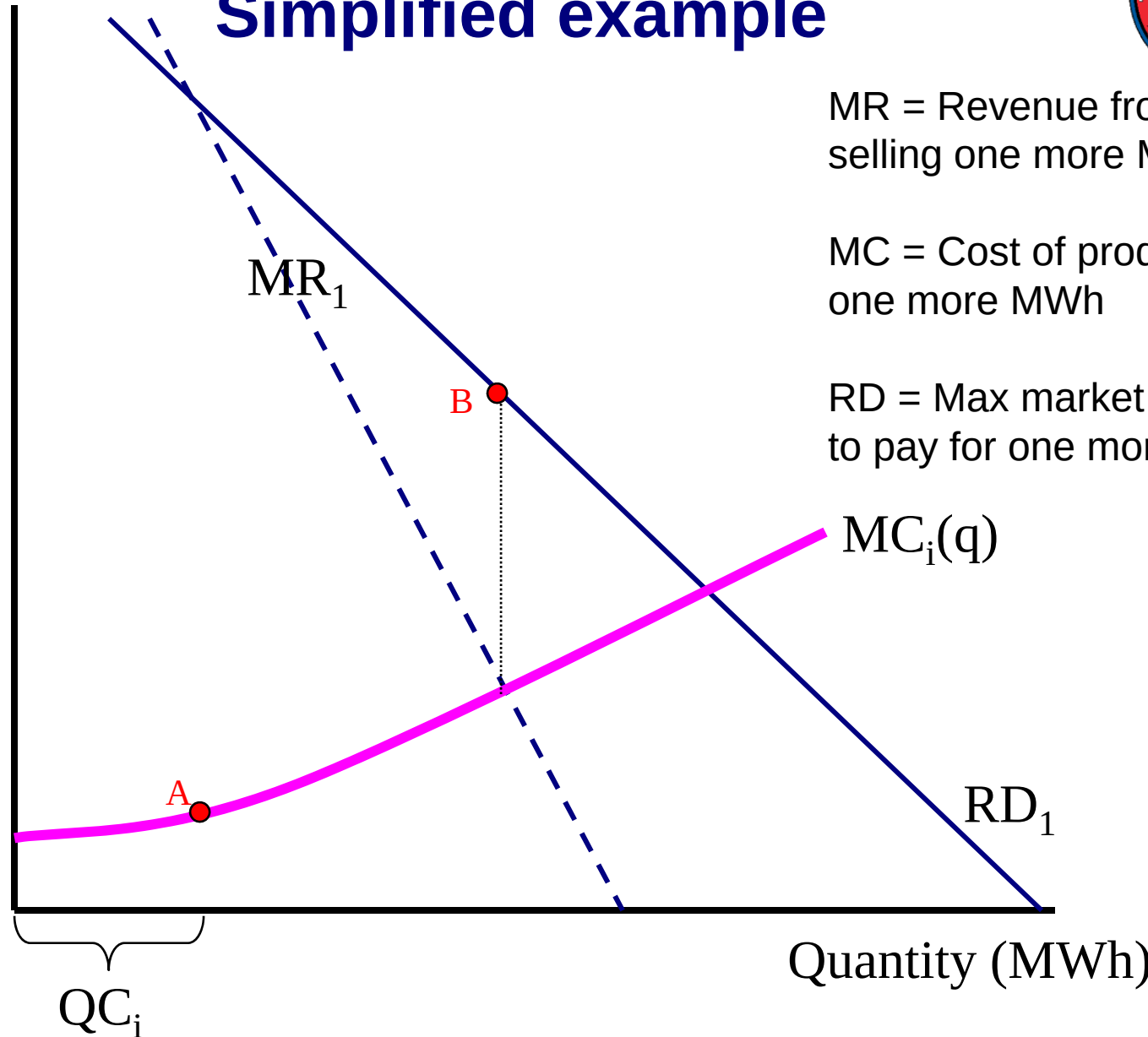


How Do We Expect Firms to Offer/Bid?

- Basic economic model assumes that each firm chooses bids and offers to maximize profits.
- Profits depend on price, quantity sold, and costs.
- Relationship between price and quantity sold depends on the relationship between the demand and the offers of other firms.
- “Residual demand” is the demand minus the supply of the other firms.

Simplified example

Price



MR = Revenue from selling one more MWh

MC = Cost of producing one more MWh

RD = Max market willing to pay for one more MWh

$MC_i(q)$

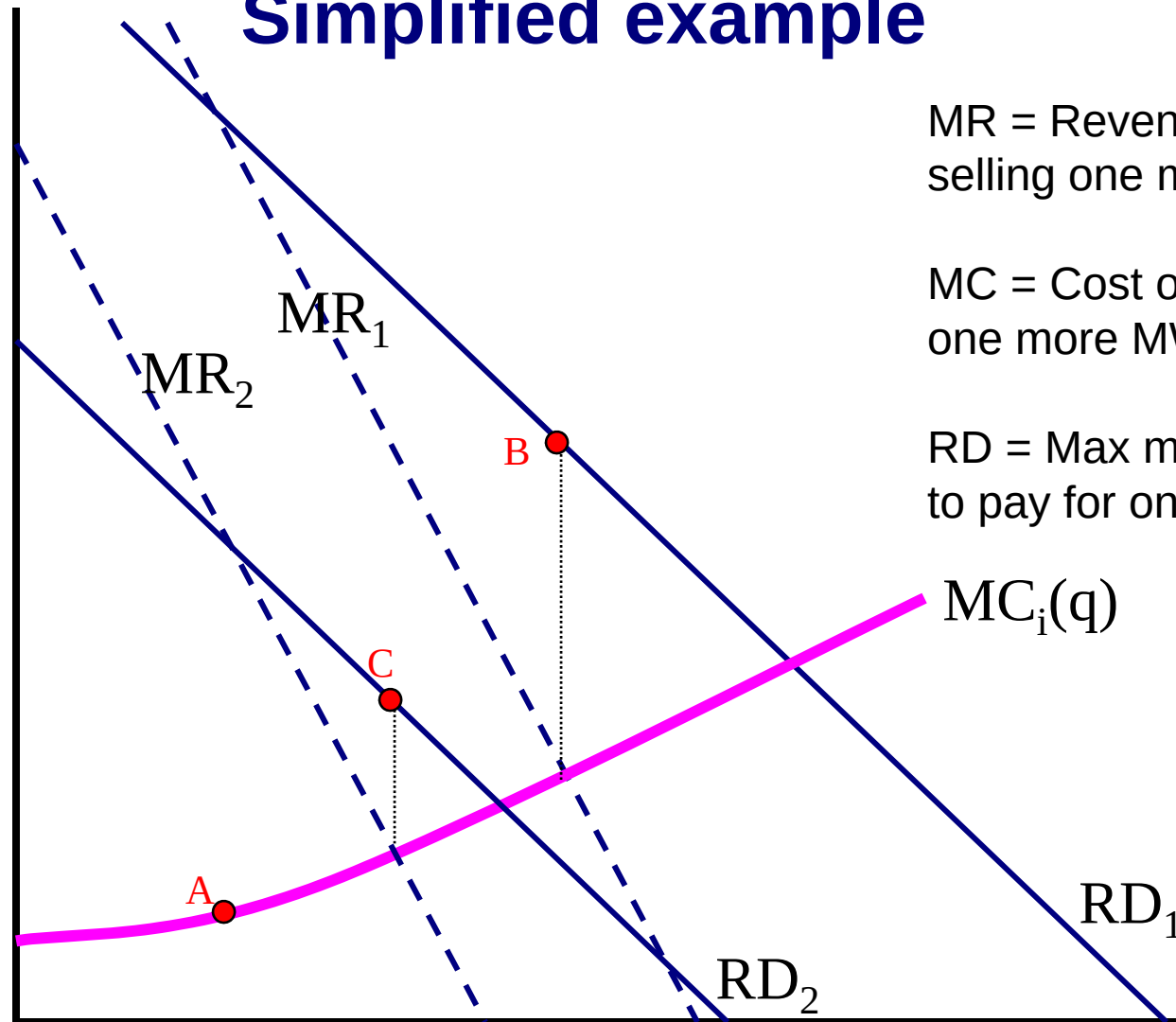
RD_1

Quantity (MWh)

QC_i

Simplified example

Price



MR = Revenue from selling one more MWh

MC = Cost of producing one more MWh

RD = Max market willing to pay for one more MWh

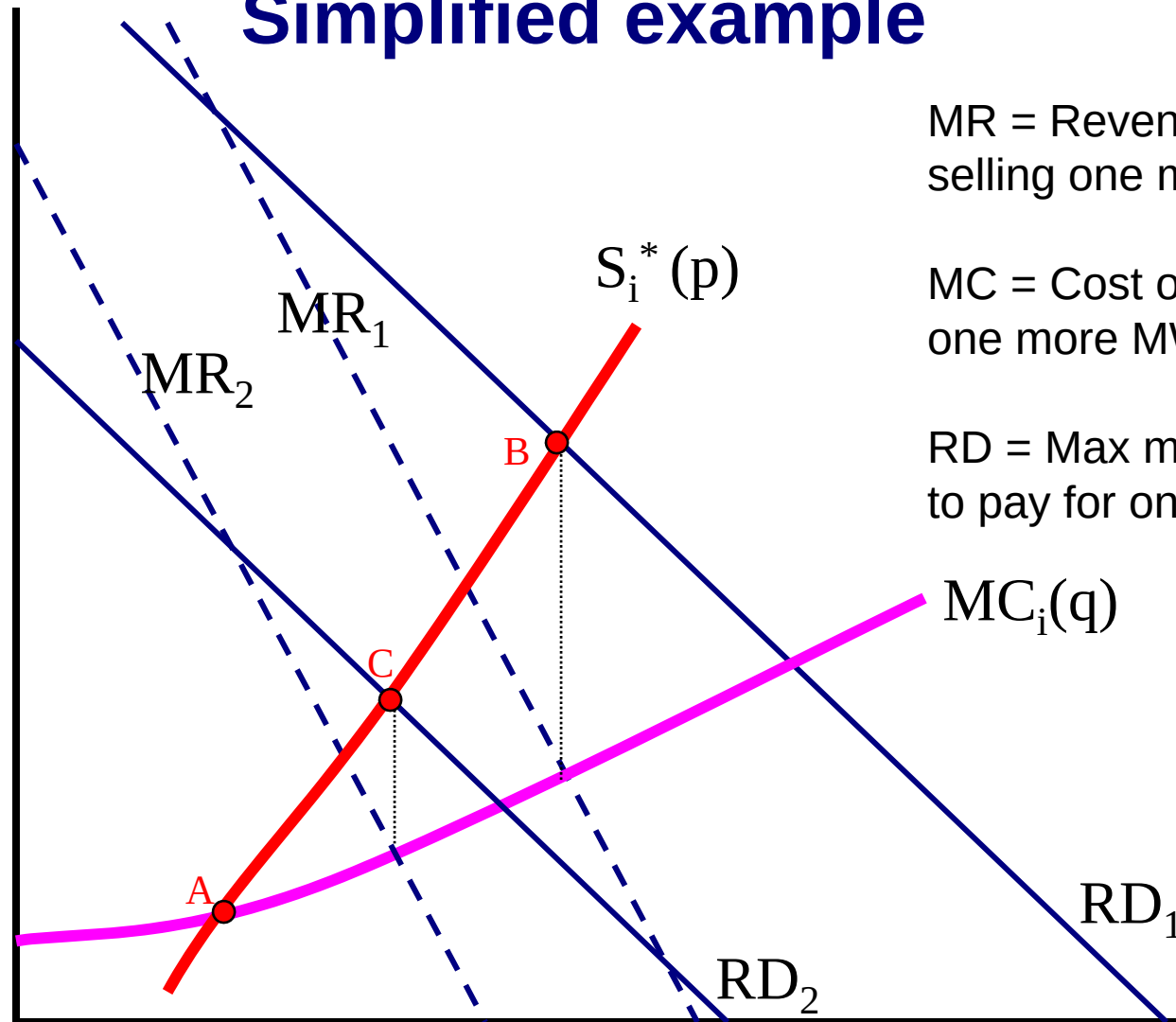
$MC_i(q)$

Quantity (MWh)

QC_i

Simplified example

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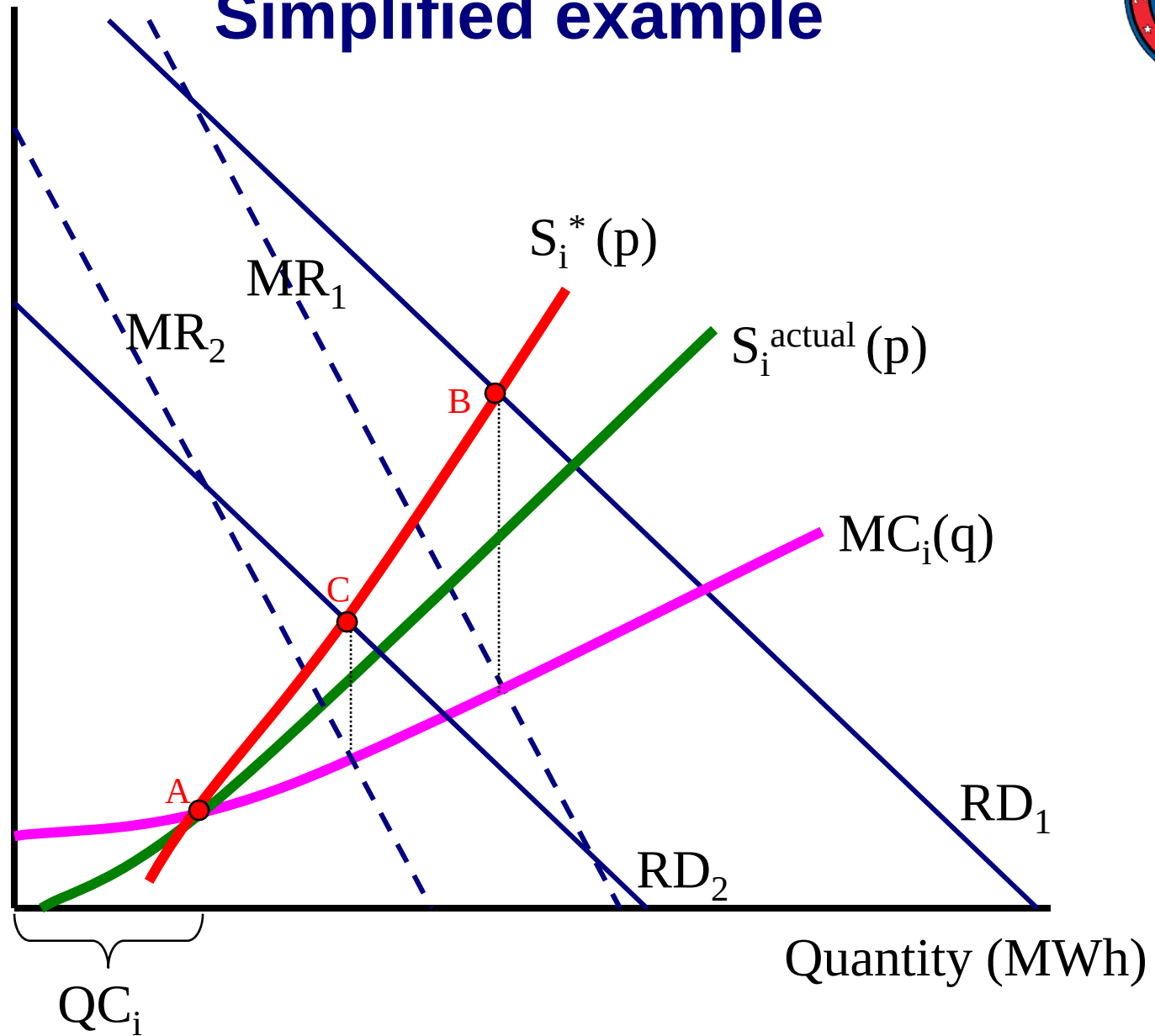
MC_i(q)

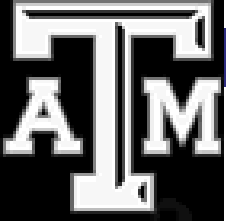
Quantity (MWh)

QC_i

Simplified example

Price

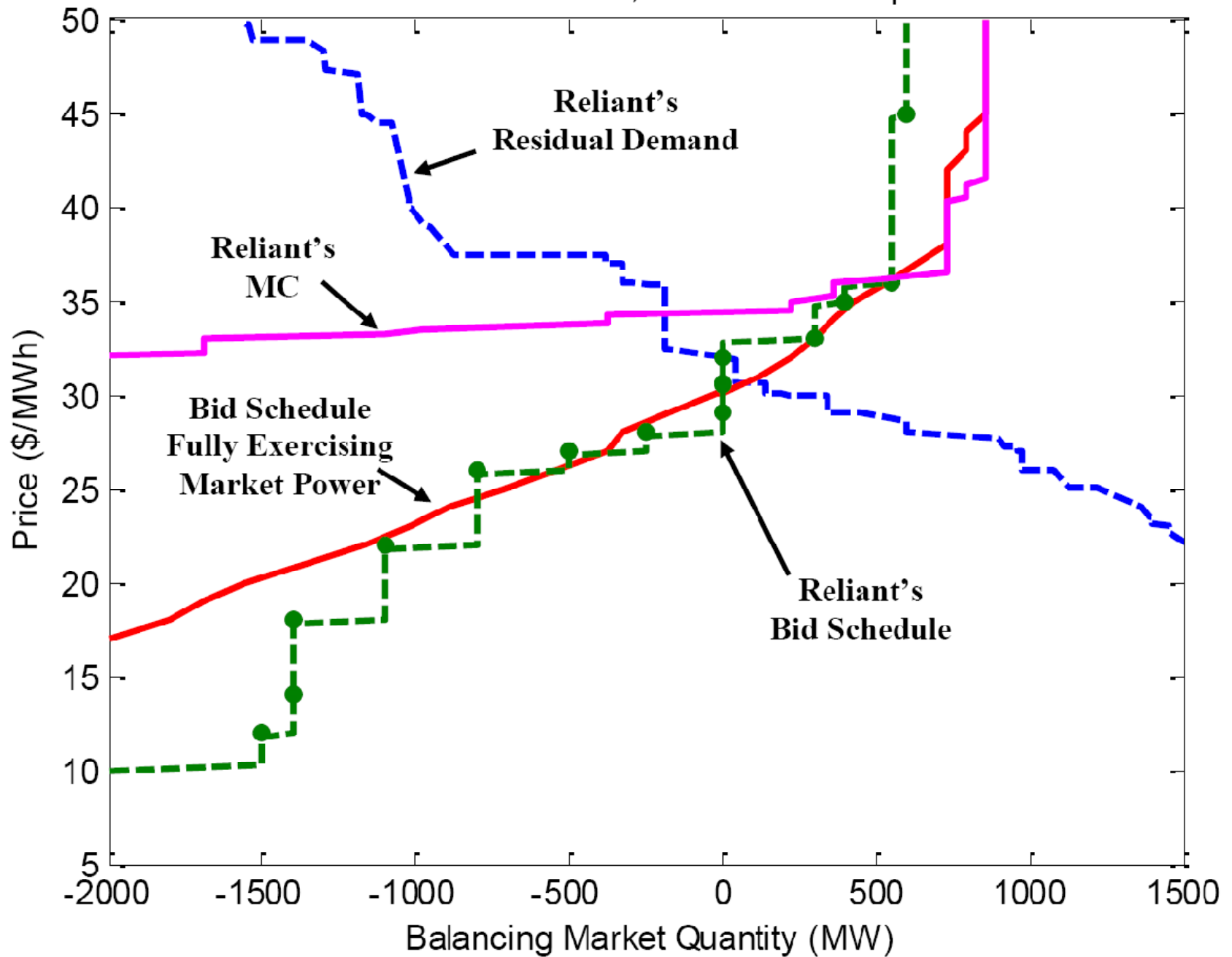




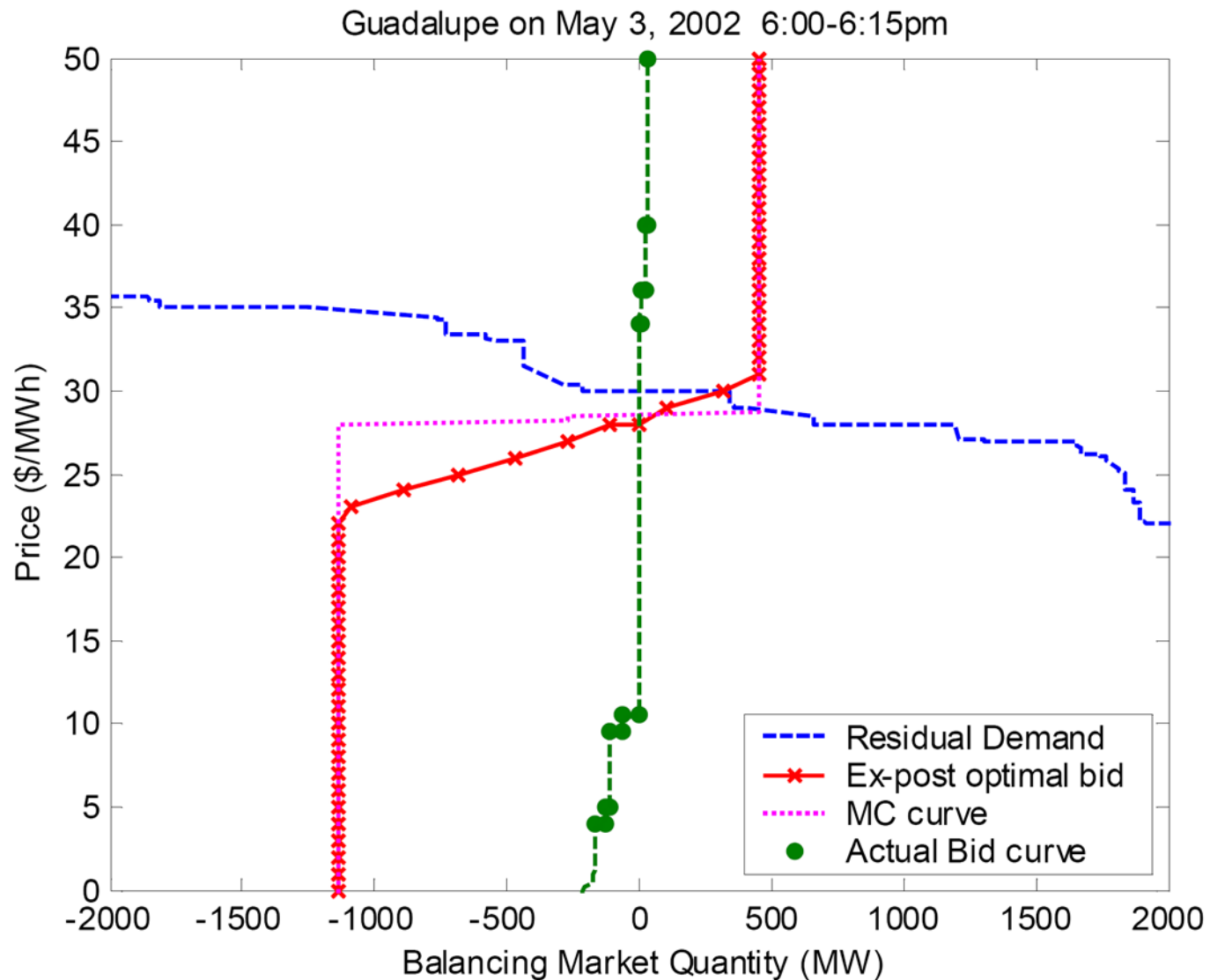
Example 1

- ERCOT Balancing Market:
 - Actual historical market data from 2002, but
 - No binding transmission constraints.
- Compare actual offer and ex post optimal offer (fully exercising market power) of several firms:
 - Illustrate large and small seller.

Reliant on June 4, 2002 6:00-6:15pm



Guadalupe (small seller) Example



Implications for Cost of Dispatch.

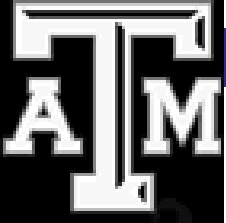
- Which source of inefficiency is larger:
 - Exercise of market power by large firms?
 - Bidding “to avoid market” by “unsophisticated” firms?

Bidding Counterfactual

Average Production Cost

Actual Bids for all firms	\$29,874
“Strategic” firms Bid MC, Others Bid Actual	\$28,671
All Firms Bid MC (Vickrey auction)	\$23,571
Total Efficiency Losses	\$6,303
“Strategic Bidders”	\$1,203
“Non-Strategic Bidders”	\$5,100

-
- Total efficiency loss = 27%.
 - Fraction “strategic” = 19%.
 - Fraction “unsophisticated” = 81%!!

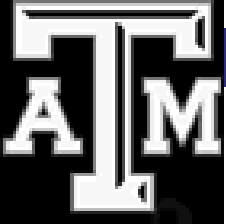


Transmission Constraints.

- Example 1 uses data from hours when transmission constraints not binding in ERCOT:
 - However, transmission constraints bind for many hours in ERCOT and in most restructured markets.
- For the transmission constrained case, we need to recognize four issues:
 - Residual demand (and its derivative) varies zonally or nodally.
 - Residual demand will be less “elastic” when transmission constraints bind.
 - Marginal cost of portfolio must be dis-aggregated zonally or nodally.
 - Ex post optimal offer/bid for a firm with multiple generators will consist of offer/bids for each zone or for each node.

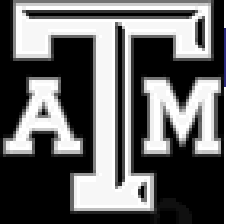
Residual demand derivative calculation assumptions.

- Nodal (or zonal) prices determined by *DC* optimal power flow (OPF).
- Suppose we are interested in calculating the residual demand derivative at a particular bus (or zone).
- Choose this bus (or zone) to be the reference bus, bus n .
- For notational simplicity, combine the supply function with the demand curve at each node by treating demand as negative supply.



Optimal power flow (OPF) formulation.

- Assume supply offers at each bus have been translated into “offer costs:”
 - Offer cost is the integral of offer.
- Assume transmission constraints have been written in terms of shift factors and transmission limits.
- For notational simplicity, neglect generation capacity constraints:
 - Implementation considers these constraints.



Optimal power flow (OPF) formulation.

$$\min_{\mathbf{q}} \sum_{i=1}^n O_i(q_i)$$

$$\text{s.t. } \bar{\mathbf{H}} \bar{\mathbf{q}} \leq \mathbf{Z},$$

$$q_n = -\sum_{i=1}^{n-1} q_i$$

O_i , $i = 1, \dots, n$, are the offer costs,

q_i , $i = 1, \dots, n$, are the production quantities,

n is the reference bus,

$\mathbf{q}$ is the vector of productions
at buses $1, \dots, n$,

$\bar{\mathbf{q}}$ is the vector of productions
at buses $1, \dots, n-1$,

$\mathbf{H}$ is the shift factor matrix,

$\bar{\mathbf{H}}$ is the shift factor matrix
with reference bus n deleted,

$\mathbf{Z}$ is the vector of transmission limits.

Optimal power flow (OPF) and its first-order necessary conditions (FONCs).

- Only show binding constraints, denoted by b :

OPF

$$\begin{aligned} \min_{\mathbf{q}} \quad & \sum_{i=1}^n O_i(q_i) \\ \text{s.t.} \quad & \bar{\mathbf{H}}_b \bar{\mathbf{q}} = \mathbf{Z}_b, \\ & q_n = -\sum_{i=1}^{n-1} q_i. \end{aligned}$$

FONCs

$$O'_i(q_i) = \lambda + \boldsymbol{\mu}_b^T \bar{\mathbf{H}}_{bi}, \quad i = 1, \dots, n-1, \quad (1)$$

$$O'_n(q_n) = \lambda, \quad (2)$$

$$\bar{\mathbf{H}}_b \bar{\mathbf{q}} = \mathbf{Z}_b, \quad (3)$$

$$q_n = -\sum_{i=1}^{n-1} q_i. \quad (4)$$

- Consider FONCs (1) & (3) parameterized by λ .

Sensitivity analysis.

- Assume $[\tilde{q}_1 \dots \tilde{q}_{n-1} \tilde{\mu}_1 \dots \tilde{\mu}_m]^T(\lambda)$ solves (1) & (3).
- Sensitivity analysis evaluated at $\lambda = \hat{\lambda}$:

$$\begin{bmatrix} O_1''(\tilde{q}_1) & \dots & \mathbf{0} \\ \vdots & \ddots & \vdots \\ \mathbf{0} & \dots & O_{n-1}''(\tilde{q}_{n-1}) \end{bmatrix}(\hat{\lambda}) \frac{d\tilde{\mathbf{q}}}{d\lambda}(\hat{\lambda}) - \bar{\mathbf{H}}_b^T \frac{d\tilde{\boldsymbol{\mu}}}{d\lambda}(\hat{\lambda}) = \bar{\mathbf{1}},$$

$$\bar{\mathbf{H}}_b \frac{d\tilde{\mathbf{q}}}{d\lambda}(\hat{\lambda}) = \mathbf{0}.$$

- Solution:

$$\frac{d\tilde{\boldsymbol{\mu}}}{d\lambda}(\hat{\lambda}) = -(\bar{\mathbf{H}}_b \boldsymbol{\Lambda} \bar{\mathbf{H}}_b^T)^{-1} \bar{\mathbf{H}}_b \boldsymbol{\Lambda} \bar{\mathbf{1}},$$

$$\frac{d\tilde{\mathbf{q}}}{d\lambda}(\hat{\lambda}) = \left(\boldsymbol{\Lambda} - \boldsymbol{\Lambda} \bar{\mathbf{H}}_b^T (\bar{\mathbf{H}}_b \boldsymbol{\Lambda} \bar{\mathbf{H}}_b^T)^{-1} \bar{\mathbf{H}}_b \boldsymbol{\Lambda} \right) \bar{\mathbf{1}}.$$

$$\boldsymbol{\Lambda} = \begin{bmatrix} O_1''(\hat{q}_1) & \dots & \mathbf{0} \\ \vdots & \ddots & \vdots \\ \mathbf{0} & \dots & O_{n-1}''(\hat{q}_{n-1}) \end{bmatrix}^{-1}.$$

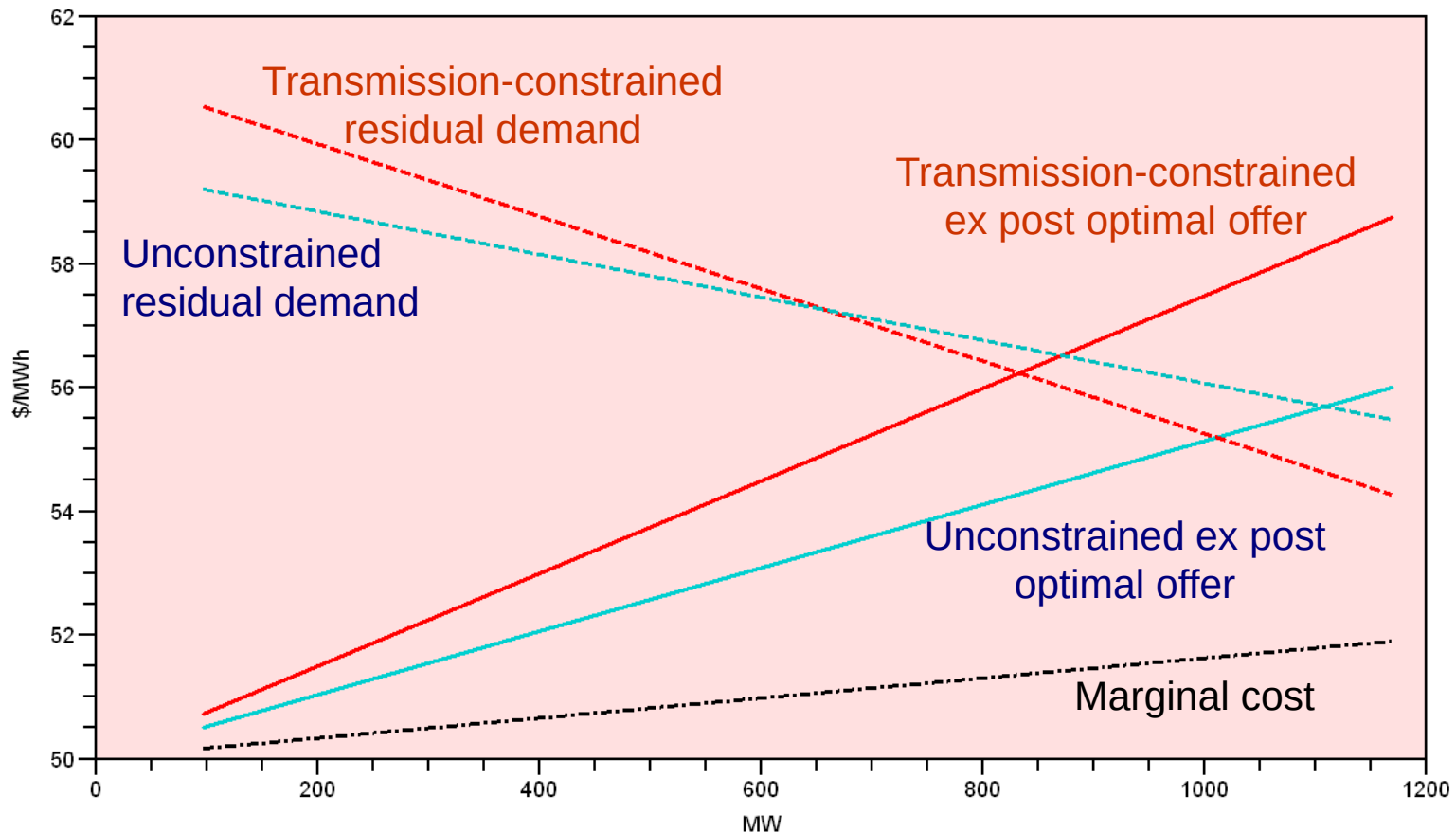
Transmission-constrained residual demand derivative (RDD).

- By energy balance, (4), the residual demand derivative is:

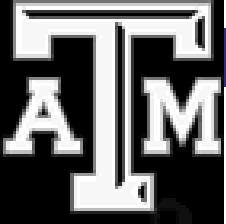
$$\begin{aligned} \frac{d\tilde{R}_n}{d\lambda}(\hat{\lambda}) &= -\bar{\mathbf{1}}^T \frac{d\tilde{\mathbf{q}}}{d\lambda}(\hat{\lambda}), \\ &= -\bar{\mathbf{1}}^T \Lambda \bar{\mathbf{1}} + \bar{\mathbf{1}}^T \Lambda \bar{\mathbf{H}}_b^T \left(\bar{\mathbf{H}}_b \Lambda \bar{\mathbf{H}}_b^T \right)^{-1} \bar{\mathbf{H}}_b \Lambda \bar{\mathbf{1}}. \end{aligned}$$

- Inverse residual demand is “steeper” when transmission constraints bind.
- These results are reported in:
 - Lin Xu and Ross Baldick, “Transmission-constrained residual demand derivative in electricity markets,” *IEEE Transactions On Power Systems*, vol. 22(4), pp. 1563-1573, Nov. 2007.

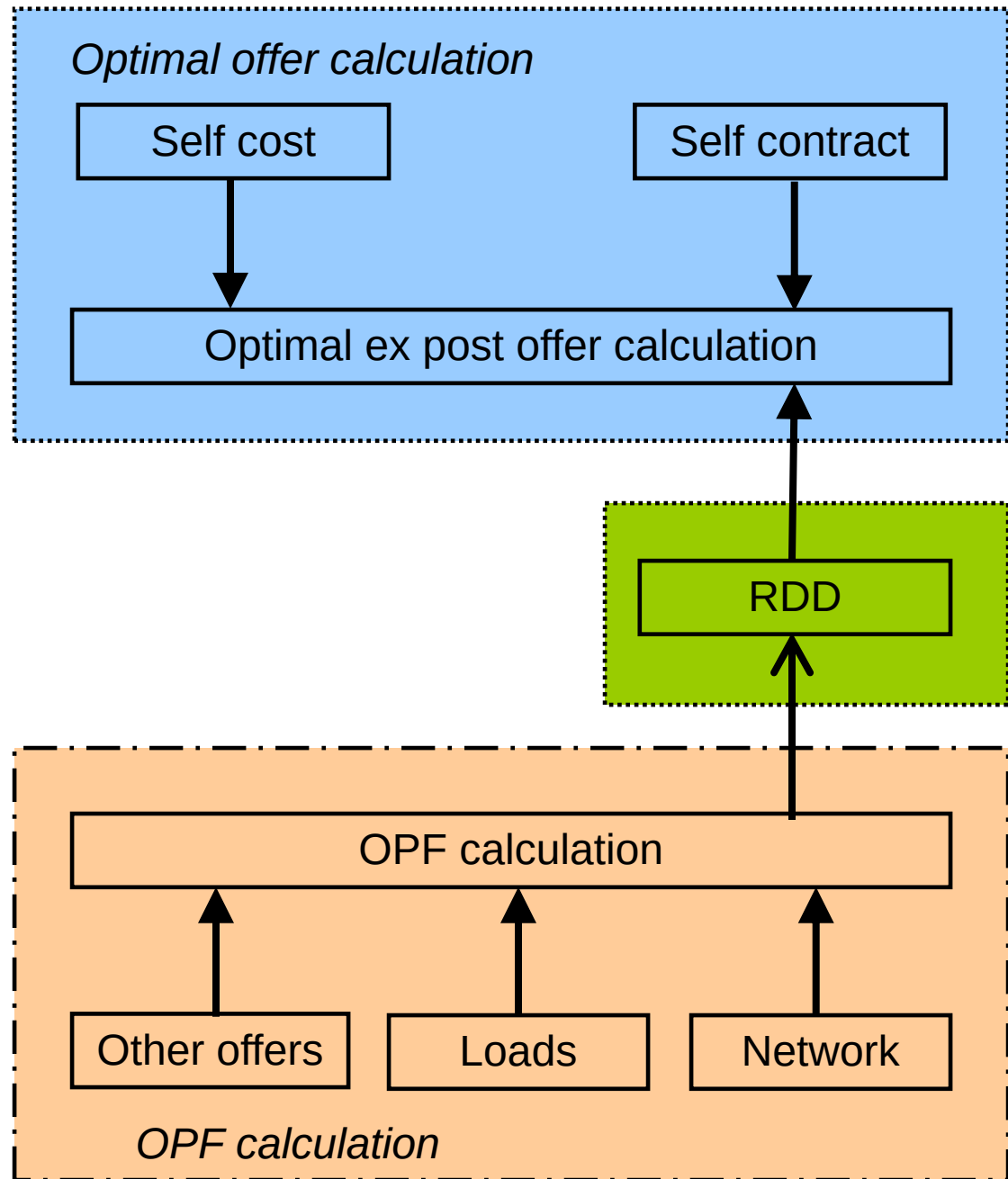
Ex post optimal response for a generating firm in a particular zone.



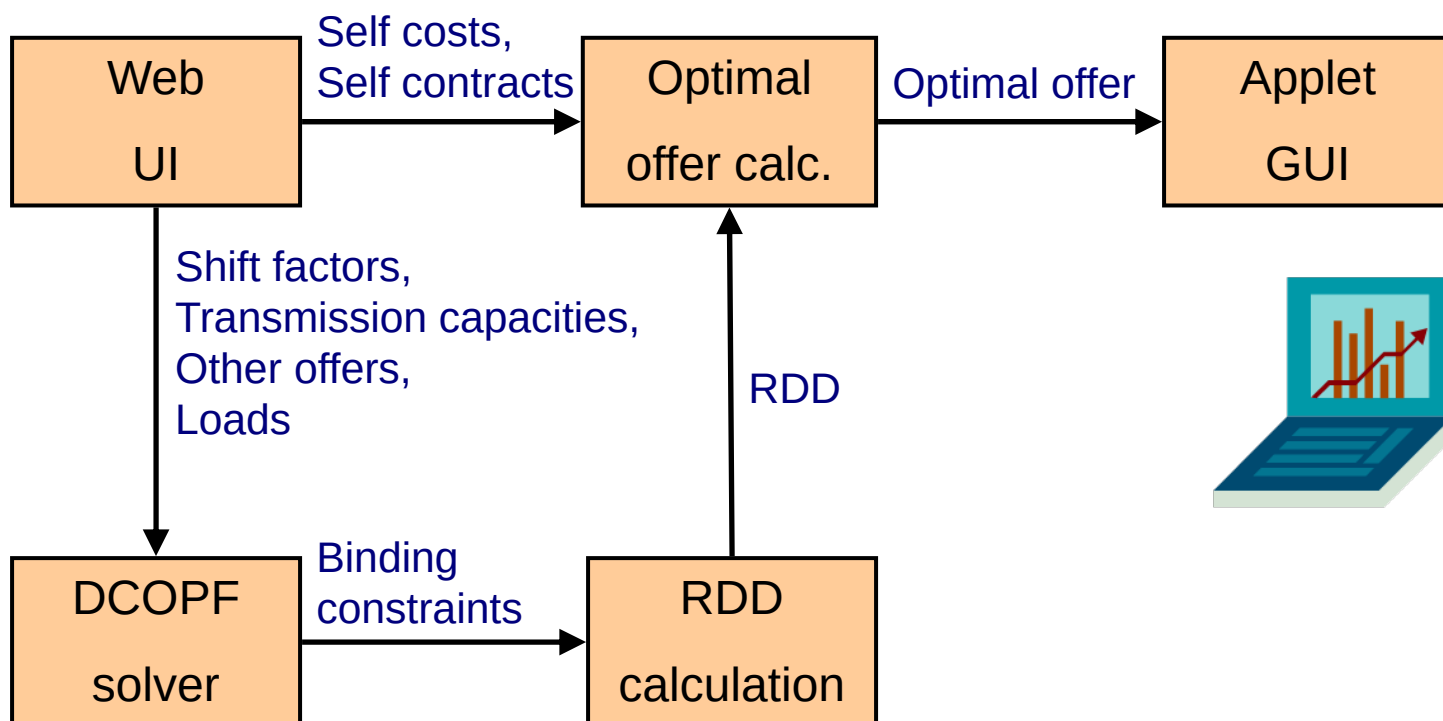
- When transmission constraints bind:
 - Ex post optimal offer becomes “steeper,” and
 - Mark-up above marginal cost increases.

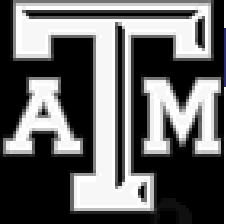


Offer Tool Conceptual Design



Offer tool design overview.

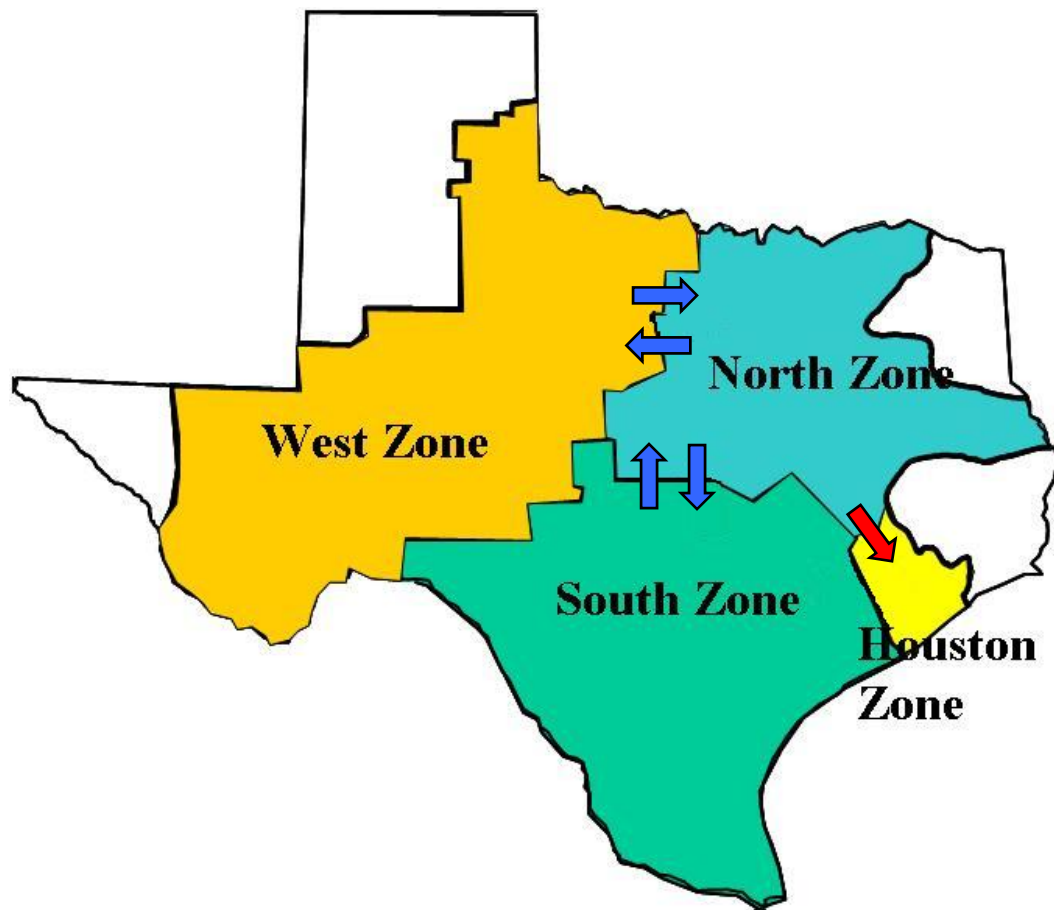




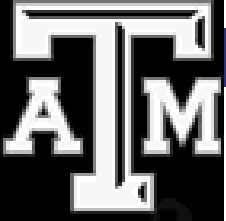
Example 2

- ERCOT Balancing Market:
 - Market data from 2008,
 - Binding transmission constraint.
- Calculate ex post optimal offer of hypothetical firm.

Example 2



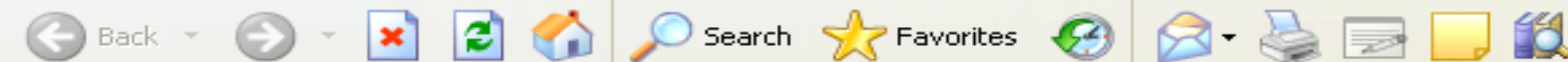
- Data set:
 - April 2, 2008
4:00pm
- Transmission:
 - North-Houston congested
- Forward contract positions in balancing market considered.



Example 2 Data: Shift factors

Commercially Significant Constraints - Microsoft Internet Explorer

File Edit View Favorites Tools Help



Address http://mospublic.ercot.com/ercot/jsp/commercially_significant_constraints.jsp

COMMERCIALLY SIGNIFICANT CONSTRAINTS

Market Date: 09-SEP-2008

Hour: 1000

Interval: 0915

Capability	N08H08	N08S08	N08W08	S08N08	W08N08
OC0	9999	9999	9999	9999	9999
OC1	9999	9999	9999	9999	9999

CM Zone	N08H08		N08S08		N08W08		S08N08		W08N08	
	Shift Factor	MW Scheduled Impact	Shift Factor	MW Scheduled Impact	Shift Factor	MW Scheduled Impact	Shift Factor	MW Scheduled Impact	Shift Factor	MW Scheduled Impact
HOUSTON2008	-33.92%	133	-21.73%	85	-1.31%	5	21.73%	-85	1.31%	-5
NORTH2008	-0.19%	-3	-0.16%	-3	-1.29%	-23	0.16%	3	1.29%	23
SOUTH2008	-22.95%	185	37.79%	304	-2.43%	20	37.79%	-304	2.43%	-20
WEST2008	-1.84%	10	-2.13%	12	38.05%	211	2.13%	-12	38.05%	-211
Total Scheduled Impact		325		398		213		-398		-213
Shadow Price	\$0.0		\$0.0		\$0.0		\$0.0		\$0.0	

CSC/CRE Data

Help



Example 2: Transmission capacities

CSC/CRE Data - Microsoft Internet Explorer

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Address http://mospublic.ercot.com/ercot/jsp/csc_cre.jsp Go

CSC/CRE DATA Data queried at: 09/09/2008 09:49

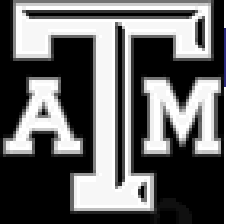
CSC	MW	MVAR	MVA	MW LIMIT	Contingency	Overloaded Element	Calc Time
NORTH-HOUSTN	2025	150	2031	3234	DCKT King-Kuykendahl-Roans Prairie & Jewet To Tomball Tb 345KV	Gibbons Creek - Obrien - 345 KV	09/09/2008 08:4
NORTH-SOUTH	9	92	92	617	DCKT Temple Pecan Crk - Tradinghouse Ses & Temple Sw - Lake Crk Ses 345KV	Evant - Goldthwaite - 138 KV	09/09/2008 08:4
NORTH-WEST	-384	11	384	648	SCKT Comanche Sw-Comanche Peak Ses 345KV	Murray Tu - Paint Creek - 138 KV	09/09/2008 08:4
SOUTH-NORTH	-9	-92	92	1133	SCKT Sandow Switch - Temple Switch 138KV	Sandow Switch - Temple Switch - 345 KV	09/09/2008 08:4
WEST-NORTH	384	-11	384	940	SCKT Fisher Rd Sw-Oklaunion & Bowman 345KV	Long Creek Switching Station - Abilene Mulberry Creek - 345 KV	09/09/2008 08:4

CSC LINE DATA

CSC	LINE	MW	MVAR	NORMAL MVA RATING
NORTH-HOUSTN	Gibbons Creek - Obrien	465	-50	11
NORTH-HOUSTN	Jewet - TH Wharton	478	-43	11
SOUTH-NORTH	Sandow Switch - Temple 1	-9	-92	12
SOUTH-NORTH	Sandow Switch - Temple 2	0	0	12
WEST-NORTH	Graham - Benbrook	190	-5	10
WEST-NORTH	Graham - Parker	194	-6	9

CRE LINE DATA

RELATED CSC	LINE	MW	MVAR	MVA	NORMAL MVA RATING
NORTH-HOUSTN	Kuykendahl - King # 1	15	-8	17	17
NORTH-HOUSTN	Kuykendahl - King # 2	-529	37	530	17



Example 2 Data: Other offers

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AGGREGATED BID CURVES FOR BALANCING ENERGY SERVICES

Find historical data on the aggregated bid curves for the balancing energy market. View the bid curves by hour and zone, as well as the break-out of the bids for balancing energy up and balancing energy down.

[Aggregated Bid Curves - February](#)

[Aggregated Bid Curves - January](#)

Archives

[2008 Aggregated Bid Curves](#)

[2007 Aggregated Bid Curves](#)

[2006 Aggregated Bid Curves](#)

[2005 Aggregated Bid Curves](#)

[2004 Aggregated Bid Curves](#)

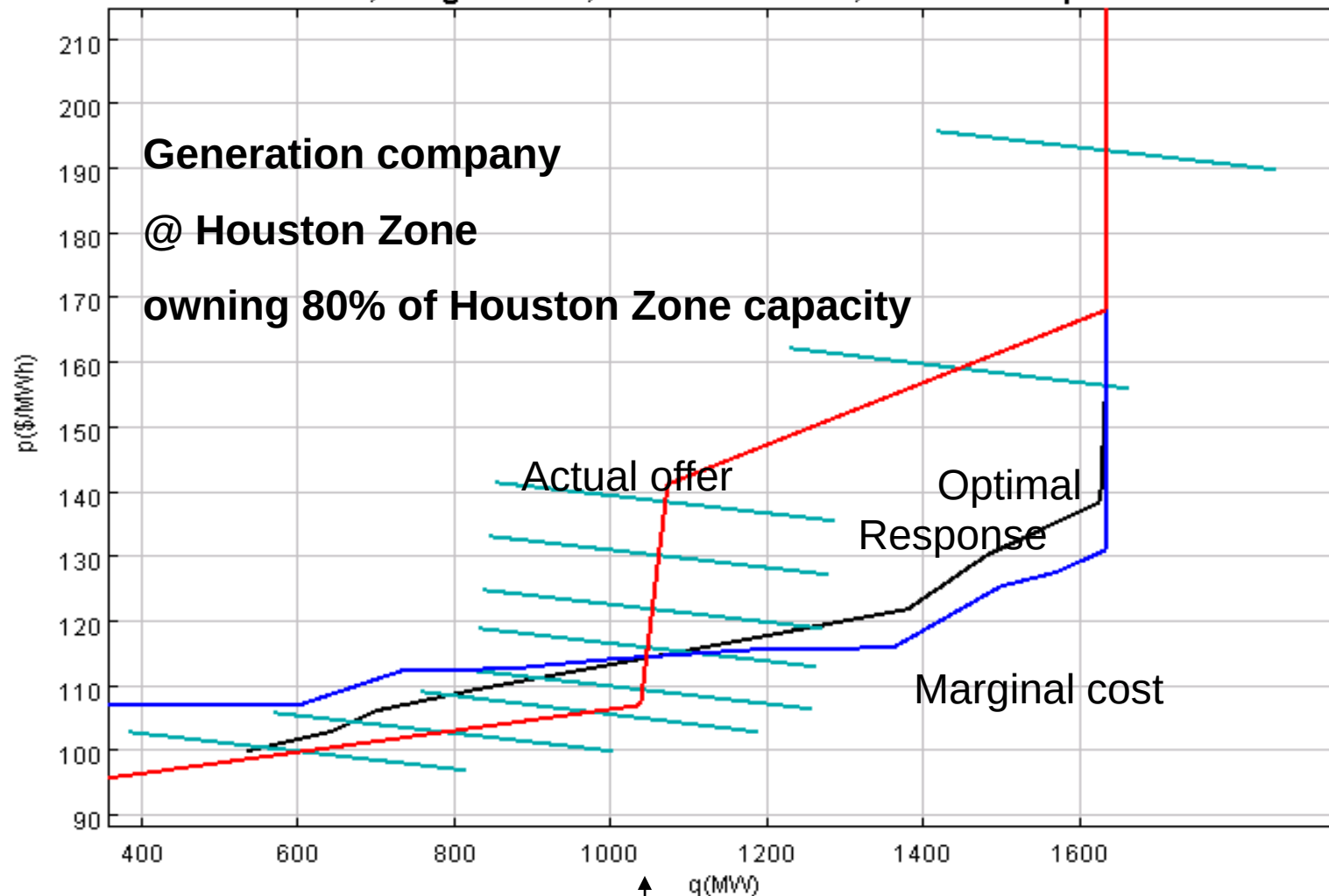
[2003 Aggregated Bid Curves](#)

[2002 Aggregated Bid Curves](#)

Example 2: Results



Offer, Marginal Cost, Residual demand, and Best Response



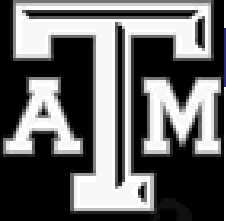
SelfOfferData
SelfMCDData
ResidualDemandData
BestResponseData

**Generation company
@ Houston Zone
owning 80% of Houston Zone capacity**

Forward contract quantity

Conclusion and future work.

- A Java tool for calculating the ex-post optimal offer has been developed.
- Transmission-constrained residual demand calculation has been integrated into the tool.
- Allows market monitor to analyze offers and develop quantitative metrics in transmission-constrained case, avoiding *ad hoc* measures of market power.
- Helps small generators to develop offer strategies in transmission-constrained case to more fully participate in market.
- Next steps include issues related to nodal pricing.



Thanks to industry sponsors!

- Mark Sanford (GE Energy),
 - Mario DePillis (ISO-NE),
 - Robert de Mello (Siemens).
-
- Offer tool available from:
http://users.ece.utexas.edu/~baldick/offer_tool/offer_tool.html