A <u>Brief</u> History of **Combined Value** Auction Mechanisms: *theory and practice*

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Sketch

- Structure
  - The Early Days (pre-FCC)
  - Since the FCC auctions
  - The New Things: (Up to new FCC contract)
- Content
  - Theory, experiments, practice, computation
  - Will try to differentiate between what we know and what we believe

What is a Combined Value problem?

The environment

- K items to sell (X_k units of each, X=1 here)
- N buyers [W = U-t where U(x) = maximum willingness to pay for the bundle of goods, x, and t is the payment for that bundle.]
  - Assume that if buyer i receives multiple bundles, then W = U(" x) - " t.
- Can be generalized to handle multiple units and differential information.

What is a CV problem?

Choosing x and t

- Want efficiency, or revenue, or whatever.
- Answer depends on the particular values of U(•) for all buyers
- So there is a standard
  - {U} ➜ {X}
  - For example, the <u>efficient allocation standard</u> is (a) choose x^1, … x^N to Max " $U^i(x^i)$ subject to feasibility <u>and</u> (b) " $t^i = 0$.

Early (pre FCC) Examples:
where combined value was recognized

- Airport slot allocations
  - Grether, Isaac, Plott (79)
- Course registration at U of Chicago (81)
  - Graves, et.al. (93)
- Resource allocation-NASA space station (88)
- New Zealand forest cutting rights (90, Smith) (?)
- Sears Transportation Acquisition Auction 93/94
      - Ledyard et.al. 2000
- New Zealand fishing rights (“a few years ago”) (Rothkopf)(?)

Other obvious examples:

combined value was not necessarily recognized

- Auctions
  - Procurement/provision of transport services
  - Procurement of land development parcels
  - Sale of geographically located assets
- Markets
  - Portfolio re-balancing in security markets
  - Emission permit markets with multiple permits
  - Secondary markets in advertising time

Solving the CV Problem

- Choose the “best” mechanism subject to
  - Incentive compatibility (what behavior?)
  - Individual voluntary participation
  - Information processing constraints (bidders)
  - Computational constraints (mechanism)
  - No-collusion constraints
- Question: Does best mean “expected value” or best in each different environment?

Mechanisms for a CV problem?

- Method 1: <u>direct mechanisms</u>
  - Ask buyers for information about $U^i(x^i)$
  - To achieve maximum efficiency or revenue
    - choose x^* to Max " $U^i(x^i)$ subject to feasibility
  - To max revenue
    - Charge each i, $t^{*i} = U^i(x^{*i})$ (voluntary participation)
  - Problem: <u>computationally hard</u>
    - need computer scientists
  - Problem: <u>incentive compatibility</u>
    - Need economists

Theory

Pre FCC (Groves 79)

- There exists a dominant strategy mechanism that produces the efficient x (but not the efficient t)
  - Each buyer reports $U^{*i}(x^{i})$ for all x
  - The mechanism chooses x* to max " $U^{*i}(x^{i})$
  - Each i pays
    - $t^{*i} = [\text{"}_{j/i} U^{*i}(x^{*j})] - [\max \text{"}_{j/i} U^{*i}(x^{j})]$
- Does solve the incentive problem, BUT

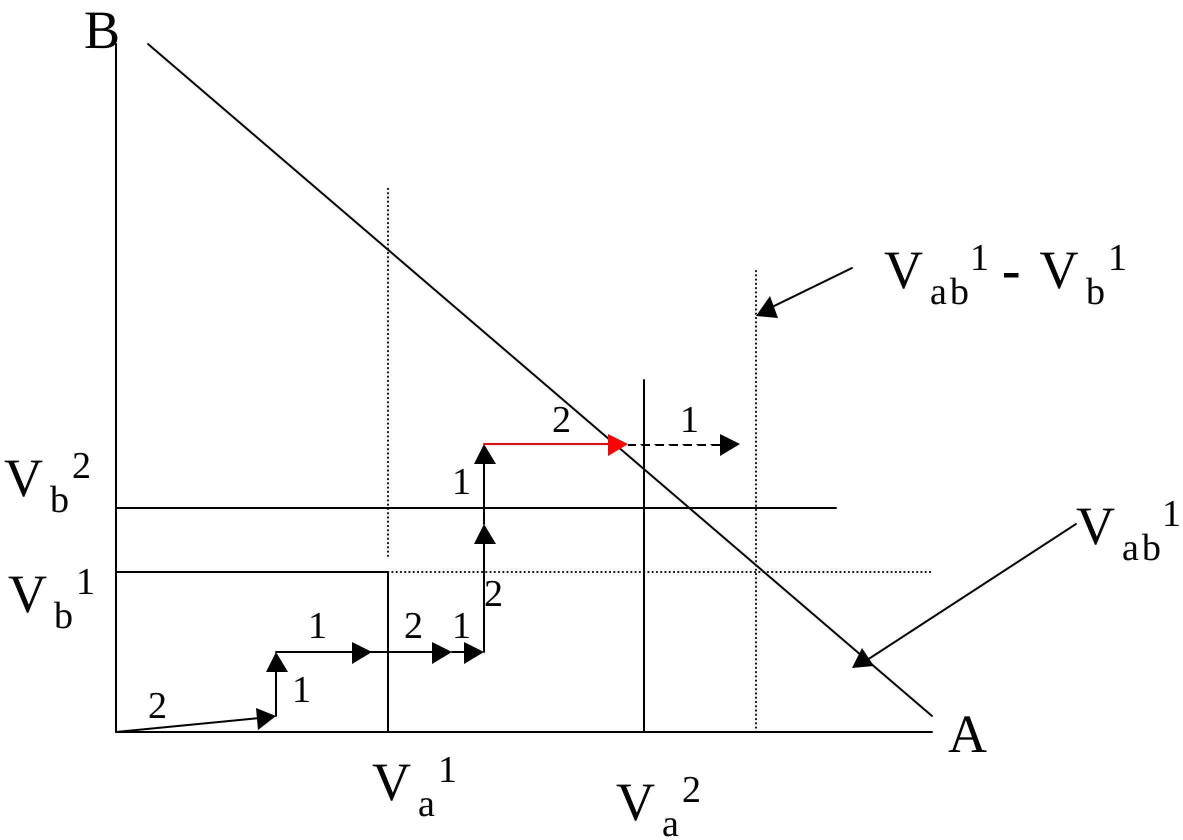
Problems with Groves

- Problem: may violate voluntary participation
  - Solve by eliminating second brackets in tax
- New Problem: may not even collect a positive amount
  - Vickrey rejected his auction for treasury bills on this basis
- Problem: computability constraints
  - combinatoric problems (Hard)
- Problem: information processing constraints
  - requires 2^K numbers from each buyer
  - (can lose IC with less)

Possible Answer?

- Method 2: <u>indirect mechanisms</u>
  - Run parallel sealed-bid auctions
  - Run parallel English auctions
- Theory: virtually none in pre-fcc days
  - Auction theory focused on single item auctions
  - General equilibrium allowed re-contracting and used a “bounded rationality” assumption
  - Mechanism design provided guidance about information and incentives but not computation

A possible problem: exposure



Combined value implications for parallel auctions

- Potential losses are a problem as long as items are sold or priced separately
  - Either bidders make losses (and default) or
  - They don't bid aggressively
  - In either case, the market is thinner, the auction is slimmer
- The answer - **Combined Value Bids**
  - I am willing to accept (at least) $95 iff I can buy both A and B.

Combined Value Auctions: How do they work?

- Allow CV bids
  - I will pay (up to) $50 iff I get both A and B.
- Can also allow other contingencies-(might as well)
  - XOR: Either (pay $40 for A) or (pay $32 for B)
- A bid is $(b,x) \in R \times R^k$
- Simple contingencies are M:
  - where, e.g., Mx" 1.

Combined Value Auctions: How do they work?

- <u>Select</u> a feasible collection of <u>winning bids</u> that <u>maximizes total revenue</u>
- Max " b•δ (revealed surplus)
  - Subject to " x•δ = w (demand = supply)
  - and δ ∈ {0,1} (AON - this makes it hard)
  - and M•δ = 1 (OR - also makes it hard)
- Design problem: what if it only solves to 85%?

Combined Value Auctions: How do they work?

- <u>Winners pay</u> (designer gets a choice here)
  - What they bid? (easy)
  - 2nd prices? What are they?
  - Item prices? What if separating prices don't exist?
  - What if only solve for 85% of optimum?
  - Issues
    - Revenue recovery - (no longer get equivalence)
    - Price discovery - aids coordination and computation

Combined Value Auctions: How do they work?

- The simplest example
  - a continuous version (update on new bid)
  - Pay what you bid

<u>6 items for sale: A,…,F</u>

Current high bids: 50 for AB, 60 for CDE, 40 for F

i wants BD - bids 115 (to beat 50+60)

Current high bids: 115 for BD, 40 for F

j wants A - bids 10 for A ……

A possible problem threshold

- Six items for sale
- One bidder, Big, wants all 6 for up to 100 or none.
- Six bidders, Little i, each want a different item for 25 and nothing else
- Suppose the current winning bid is held by Big at 75. The last bid of each of the Little i was 10. Little 6 is a game theorist who continues to bid 10 each time. The others see this and bid no more than 15 each - hoping the others will raise their bids. The total bid by the 6 Littles is 85. Big goes to 90 and wins, unless the Littles can overcome the threshold problem. (coordination problem - not free rider)

Combined Value Auctions: Design Choices

- Batch, continuous, iterative?
- CV bids, other contingencies?
- Pay what you bid, other?
- Queues, resubmit winners, withdrawal?
- Stopping rule - auctioneer, activity, at T?
- Reveal all bids, reveal only winners?
  - Exogenous or endogenous?

Early Design Attempts

- Out of Grether, Isaac, Plott
  - Forsythe & Isaac 82
    - Testing Vickrey (on multiple homogeneous (?)units)
  - Rasenti,Smith, & Bulfin, 82
    - allowed package bids, did not require all packages be bid on
    - 1-shot, sealed bid, 2nd best 2nd prices
    - Gave it the name “Combinatorial Auction”
      - My comment: in retrospect, a bad marketing choice

Early Design Attempts

- The beginning - Rasenti, Smith, Bulfin
  - *Bell Journal of Economics* 1982
  - Problem: airline deregulation (slots)
  - Included an after-market(am)
  - Experimental results:(vs. GIP-uniform price & am)
    - Efficiency (experienced subjects)

	easy	hard
GIP	88	75
RSB	98	99

- Result: Political issues - distribution - so only AM
- Used in New Zealand for forest cutting rights?

Early Design Attempts

- Out of NASA
  - Banks, Ledyard, Porter 89
    - Iterative Vickrey-Groves
      - Iterative, Groves taxes computed on current bids
      - Did well once - rest of time it cycled.
    - AUSM
      - Continuous, pay what you bid, (like english auction?)
      - Allowed package bids
      - Another kind of combinatoric auction
  - Plott, Porter 96
    - scaled it way up

Early Design Attempts

- Banks, Ledyard,Porter
  - AUSM - *Rand Journal* 1989
  - Problem: Commercial use of Space Station, DSN
  - Experimental results:
    - Efficiency: ausm 78%, admin 63%, markets 66%
    - Revenue: ausm 404
    - Threshold problem (Nash not efficient), need “coalitions”
    - Redesign & add Queue: ausmq: effic 81%, rev 476
- Result: not used for STS, would replace schedulers

The FCC Auction

- NTIA conference 1/94 at Caltech
  - Sequential or simultaneous
    - Simultaneous
  - Combinatoric or parallel
    - Parallel (no extant applications to build confidence)
  - Paper or electronic
    - Electronic
  - Etc………

New things

- Applications
  - Sears Logistics Services
- Theory
  - Bayes equilibrium analysis
  - Competitive equilibrium analysis
  - Myopic improvers
  - Single-minded bidders

New things

- Computation
  - Rothkopf, Pecec, Harstad (limited bundles)
  - Computer scientists.....
- Experiments and design
  - Vickrey mechanisms
  - Price guided mechanisms

New things: applications
Sears Logistics Auction

- Problem: SLS logistics (854 lanes)
  - Separate contracts on each
  - Cost = (about) $190 Million
- Proposal: Auction them off
- Problem: Auction form?
  - Recognized combined value benefits to bidders
  - wanted to share in these benefits (lower costs)
  - Recognized parallel auctions would not do that

Sears Logistics Auction what they did

- A slow version of AUSM (pre-fcc design)
- Iterative, pay what you bid, no queue
  - Dispersed agents in space and time eliminated continuous option given extant technology
  - Visicalc, mail, local server, own algorithm
- Provided information after each round
  - Winning bids but not bidders names
  - # bids covering each lane

The first SLS Auction results

93-94: 14 firms

	Round 1	Round 2	Round 3	Round 4	Round 5
# of bids submitted	3,383	4,409	4,595	3,691	4,589
# of packages submitted	2,374	1,698	2,273	1,803	1,721
# of packages in the winning allocation	65	63	57	59	57
acquisition cost ($000) of auction supported	$18,749	$17,988	$17,244	$16,837	$16,531
% drop from previous		4.5	4.1	2.4	1.8

Interesting observations

- Stopping rule was “auctioneers choice”
  - Created a political problem
    - Lobbying by current winners
    - Some were not serious early on
- Time to compute winners was 20 min to one hour
  - Now it would be 8- 30 sec.on a 300MHz and good algorithm
- Creative use of “dummy” bids to create OR bids

The next 5 SLS auctions

95-96

Auction	# carriers	# lanes	Acquisition cost	Savings estimate	Savings %
A	12	17	$1,200,000	$80,000	6.7
B	12	35	$15,000,000	$3,000,000	20.0
C	24	135	$40,000,000	$5,000,000	10.0
D	16	199	$10,000,000	$2,500,000	25.0
E	16	159	$27,000,000	$2,000,000	7.5

536 lanes were acquired for about $102 million

Total savings to SLS were about 13% or about $13.3 million

SLS- summary

Over a three-year period, SLS saved more than $84 million by running six combined value auctions.

Truckload transportation services were acquired for 1390 lanes for a total cost of $587 million. **(SO SAVINGS WERE 14%)**

This became the accepted methodology of transportation services procurement for SLS.

A 30 - 100 lane version was produced for their internal use.

The concept remains in use to this day; it has the full support of management

New Things: Practice

- Plott (in Wired) 99(?)
- ACE market (LA) 94-
- Bond Connect 00
- Others???

New things: theory

- Attempts at Bayesian Mechanism Design
  - No full theory yet (multi-dimensional types)
    - Armstrong - limited 2 type model
    - Williams - best ex-post efficient mechanism is Groves
    - Ledyard/Palfrey - if single minded bidders then best ex-ante mechanism is not ex-post efficient
  - Leaves open: what is best ex-ante Bayes mechanism for the CV environment

New things: theory

- Attempts at competitive equilibrium theory
  - Multiple-simultaneous (non-tatonnement)
  - Problem: CE does not always exist in CV environments (non-convexities)
- Try to identify when equilibrium exist and when it can be reached monotonically
  - Gul - Stacchetti
  - Bikhchandani - Ostroy
  - Bykowsky, Cull, Ledyard

New things: theory

- Myopic improvers -
  - Parkes iBundle mechanism
    - Converges monotonically to optimum
- Single minded bidders
  - Shoham et al.
    - Approximate Groves is not incentive-compatible in general but is if bidders are single minded.

New things: theory summary

- There still is no unambiguous theoretical answer to the question: what is the “best” mechanism subject to all design constraints.
- Don’t even have agreement on what the “right” behavioral model is.
- Don’t have a mathematically tractable way to model computation and information constraints

New Things:Designs

Have I got one for you!

- Ausubel
- Bali
- Isaac?
- Kelly and Steinberg
- Ledyard - RAD
- Milgrom?
- Parkes
- Plott
- Rothkopf
- Smith?

New Things:Designs

Have I got one for you!

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- Rothkopf
- Smith?

How do we decide which to choose?
Data? Test-bedding?

New things: experimental results

- Testing Vickrey
    - Brenner & Morgan 97
    - Isaac & James 97
  - Seem to get positive results for small numbers of items
  - Problem seems to be scalability

New things: experimental results

- Price guided mechanisms
  - Question: Can one improve on the rudimentary performance of earlier CV mechanisms by adding a new feature - per item prices that "guide" the choices of the bidders
  - Question: can one take parallel mechanisms, add package bids, provide per unit prices from the bids and do better?

New things: experiments

(sorry but I had to get this in sometime)

- New design: RAD (Demartini et al. 99)
  - Goal: speed up and improve simultaneous English auctions using same general structure (iterative, stopping rule)
  - Added package bidding (no "OR" but could do)
  - "Second best" 1st prices, no queue
    - price discovery suggests where "coalitions" might be found

New things: experiments

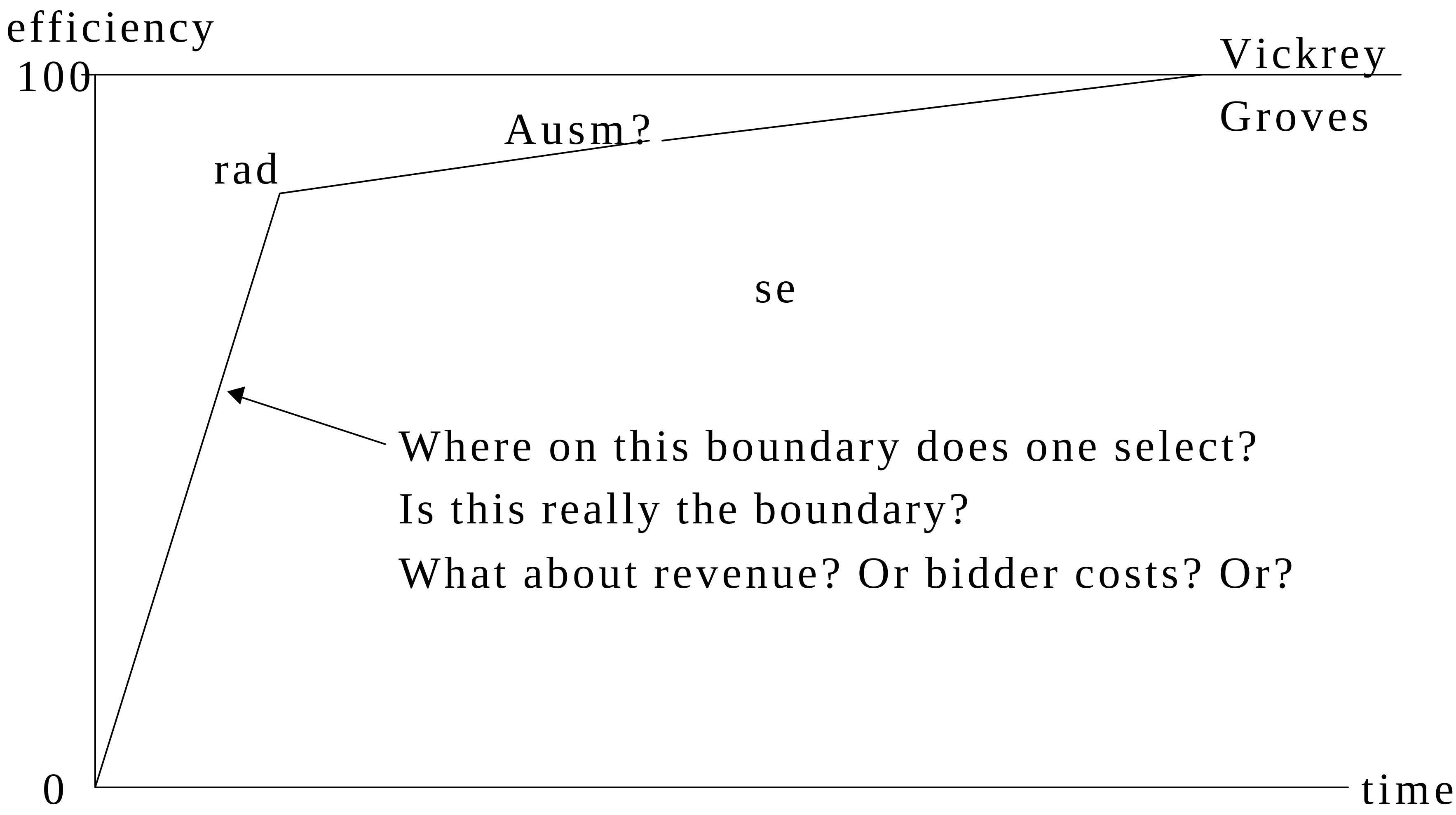
- General structure
  - Submit package bids
    - Must be x% as much as value of package at current prices
  - Provisional optimal revenue computed
  - “supporting” prices that add up to winning bids are computed
  - Prices and winning packages reported
  - Used FCC-like stopping rule (activity based)

Experiments

RAD Vs Simul. English

- 42 experimental auctions in 15 sessions with 5 parameter sets and 2 auctions
  - Report here the results from "tough environment"
- Efficiency: rad 90%, se 67%, ausm 94%
- Revenue: rad 80%, se 96%, ausm 71%
- Bidder profits: rad $4.23, se -$7.73
- Auction length: rad 3.32, se 16.2

Time efficiency trade-off



Open issues

- Partially complete computation
  - Actually this approach can handle that and, eventually, # bids reduced so it is manageable
- Orphans
  - Bids that cannot meet the price requirement but which belong in the efficient allocation
  - Best-and-final (raises the computation burden)
  - Ignore them (doesn’t generally lower eff. much

Open issues

- Are these the best prices?
  - This seems to be an empirical question that depends on how bidders process information, among other things.
- What about collusion?
  - A problem for most proposed mechanisms

New Things: Computation

- Sandholm
- Parkes 99
- Wurman 99
- deVries & Vohra 00 (in progress)

Summary to here

- Combined values create potential problems for standard auctions and markets
- CVA's work
  - SLS
  - Lab results (do they scale up?)
- Details matter
  - Stopping rules, payment schemes, ….
  - Incentives, cognitive aids,….
- Laboratory measurements are invaluable, But

What is best feasible combinatorial mechanism?

- There is none!
- Depends on your goals
- We don’t have the right model of the buyer
- It becomes an empirical question until better theory comes along - test bedding helps provide information

What about CV markets?

- They also work.
- They have been successfully applied
- NASA JPL project management
  - CRE 90 (internet, pre-web)
- Emission permit trading SCAQMC (LA)
  - ACE (1st trade 4/95), quarterly, $20M/year
- Bond trading - State Street Bank

Combined Value Markets: How do they work?

- Allow CV bids (e.g. swaps)
  - I will pay (up to) $50 iff I buy 50 A and sell 40 B.
- Can also allow other contingencies-(might as well)
  - I want 10,000 of at least AA bonds for no more than $300,000 with no less than 100 of each type
- A bid is $(b,x) \in R \times R^k$
- Complicated contingencies
- Lots or {0,1}

Combined Value Markets: How do they work?

- Select a feasible collection of winning bids that maximizes total revenue
- Max " b•δ (revealed surplus)
  - Subject to " x•δ = w (demand = supply)
  - and δ ∈ {0,1} (AON - this makes it hard)
  - and M•δ = 1 (OR - also makes it hard)
  - Etc.

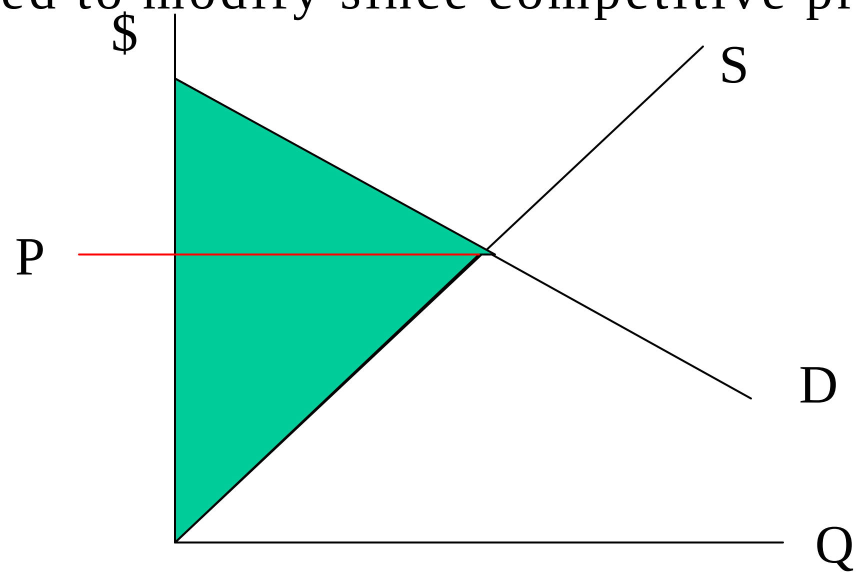
Combined Value Markets: How does pricing work?

Pay your bid doesn't seem to work very well

(fitting in multi-lateral negotiations)

Use economics: double-auction, modified uniform price

[need to modify since competitive prices may not exist]



A CVM
ACE (1st trade in 4/95)

- Emissions trading for SCAQMD (RECLAIM)
- Privately developed iterative CVM
  - by Net Exchange
- Results
  - Running quarterly since 1995
  - Volume last quarter = $6,000,000

A CVM
BondConnect

- NetExchange, StateStreetBank, BridgeInfoSys
- Bond trading in thin markets
- 1st trade this summer
- Designed to allow easy re-balancing of portfolios - a CV problem

Re-balance a portfolio

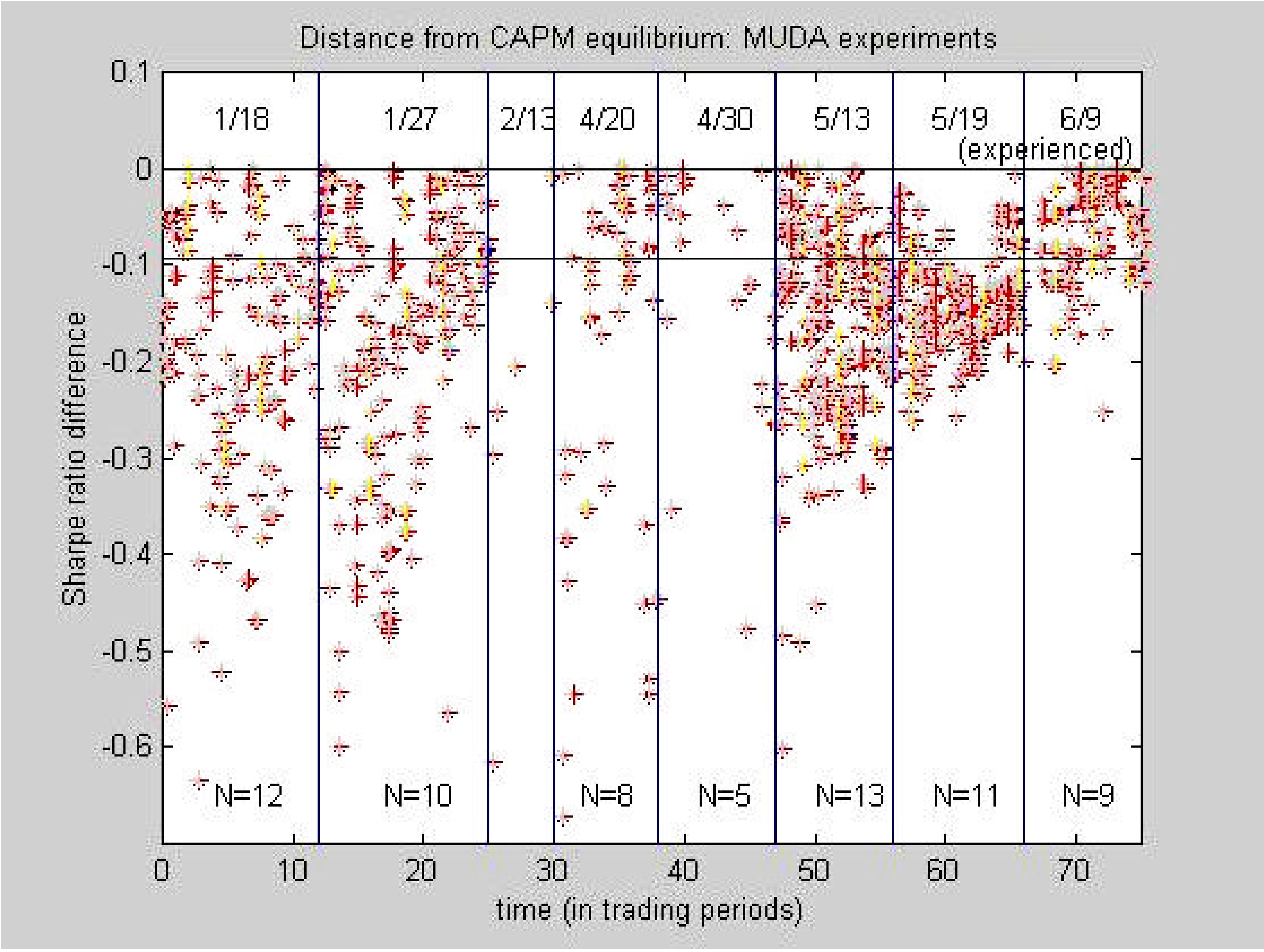
- I currently hold $200,000 treasuries (3%,'05), $500,000 Ford Motor (4.5%,'09), and $5M in mortgage backed securities. I want to lengthen the duration by at least 5% and I want to reduce convexity by 2%.
- In what sequence should I buy and sell securities to accomplish my goals

  if markets are not thick?
- What should I be willing to pay or accept?

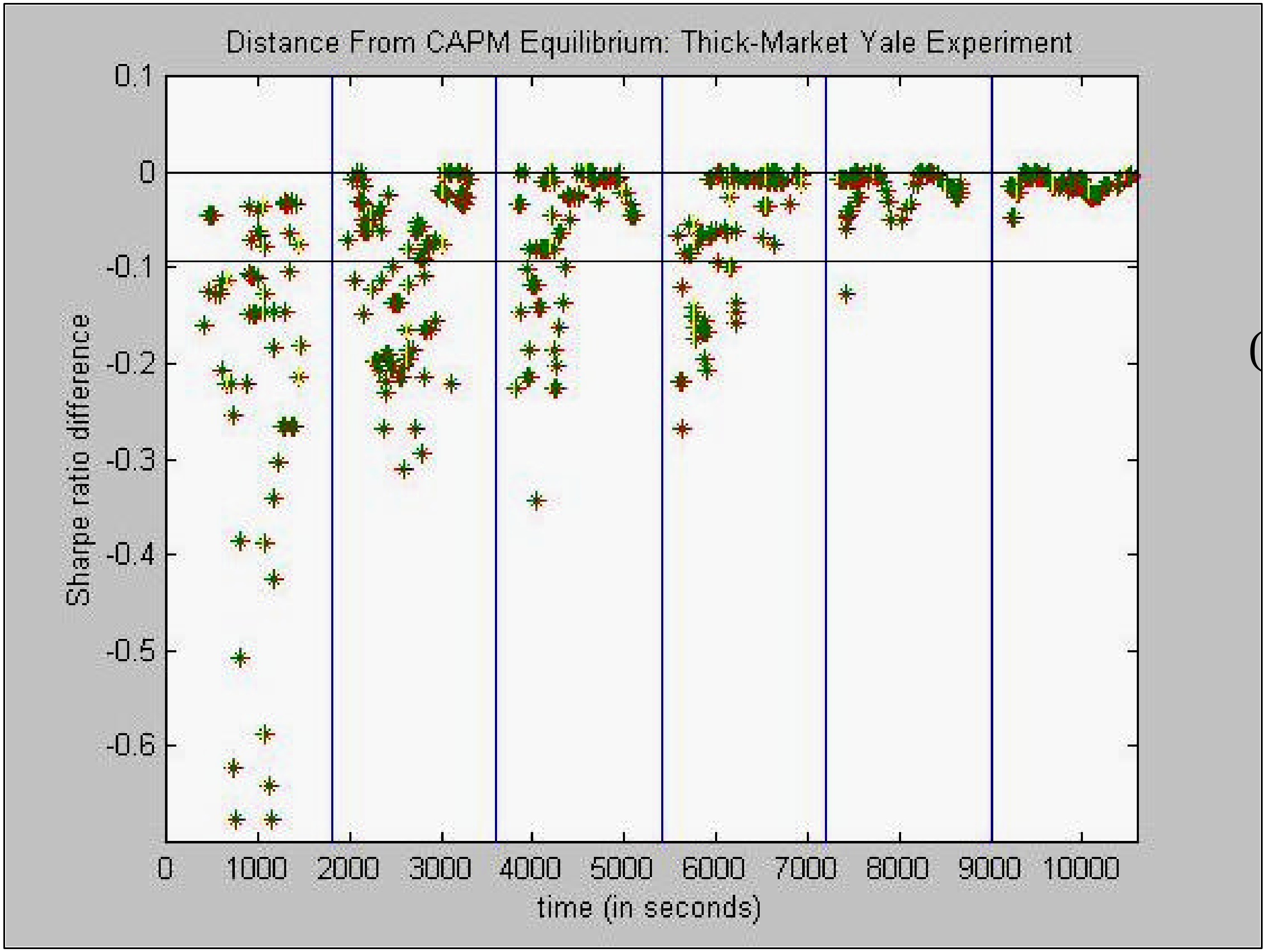
Is this a real problem? Bossaerts & Plott

- Finance mythology - it's easy: markets in instantaneous equilibrium - CAPM
- Is this right? Create asset markets in the lab
  - 3 assets (2 risky, 1 certain)
    - A:170,370,150
    - B:160,190,250
    - C:100,100,100
  - Let them trade, then draw state, then pay $, then restart

Converging slowly when thin



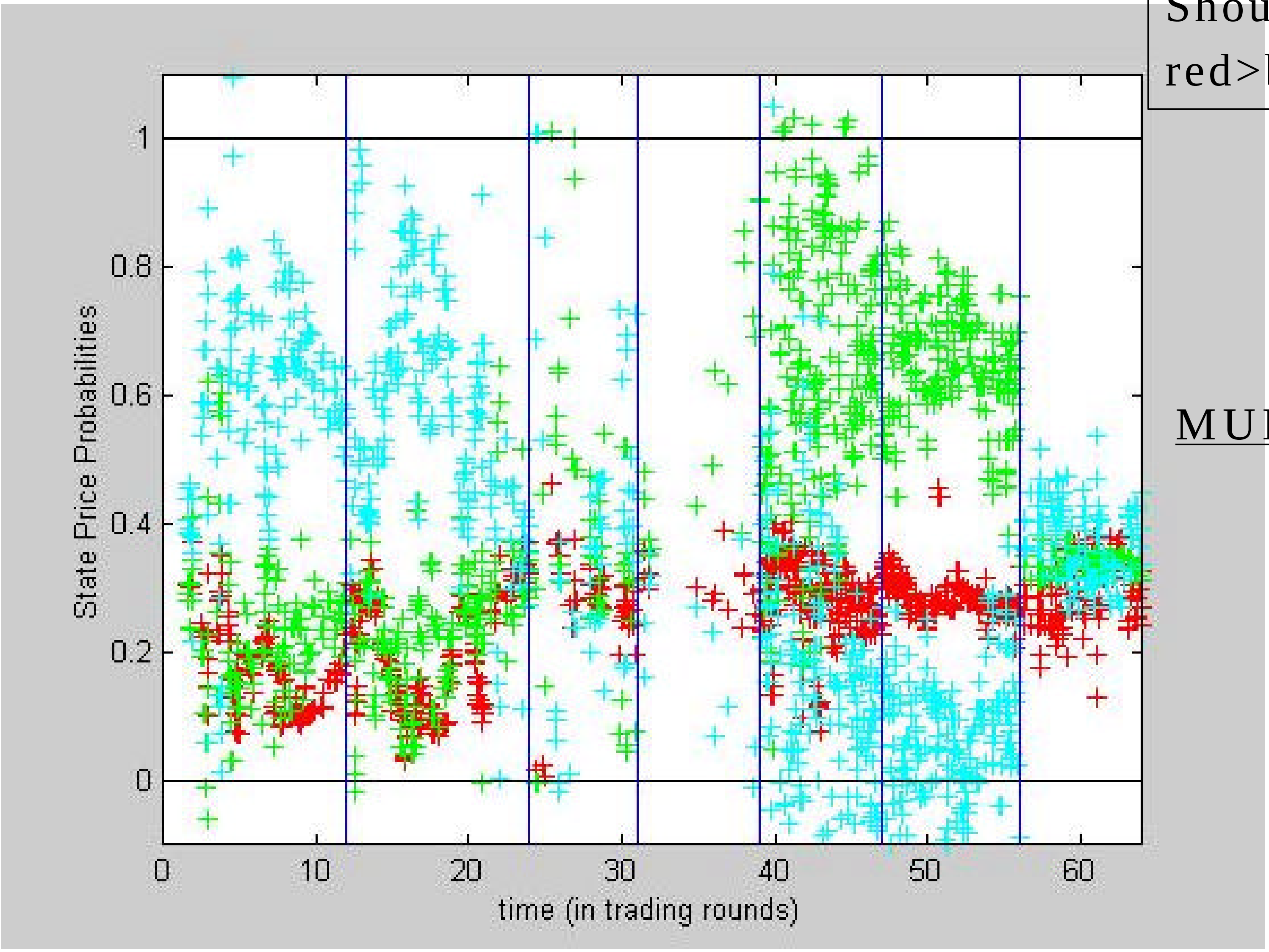
A little faster when much thicker



(N=40)

Thin markets imply hard (state) price discovery

Backward
Should be
red>bl>gr

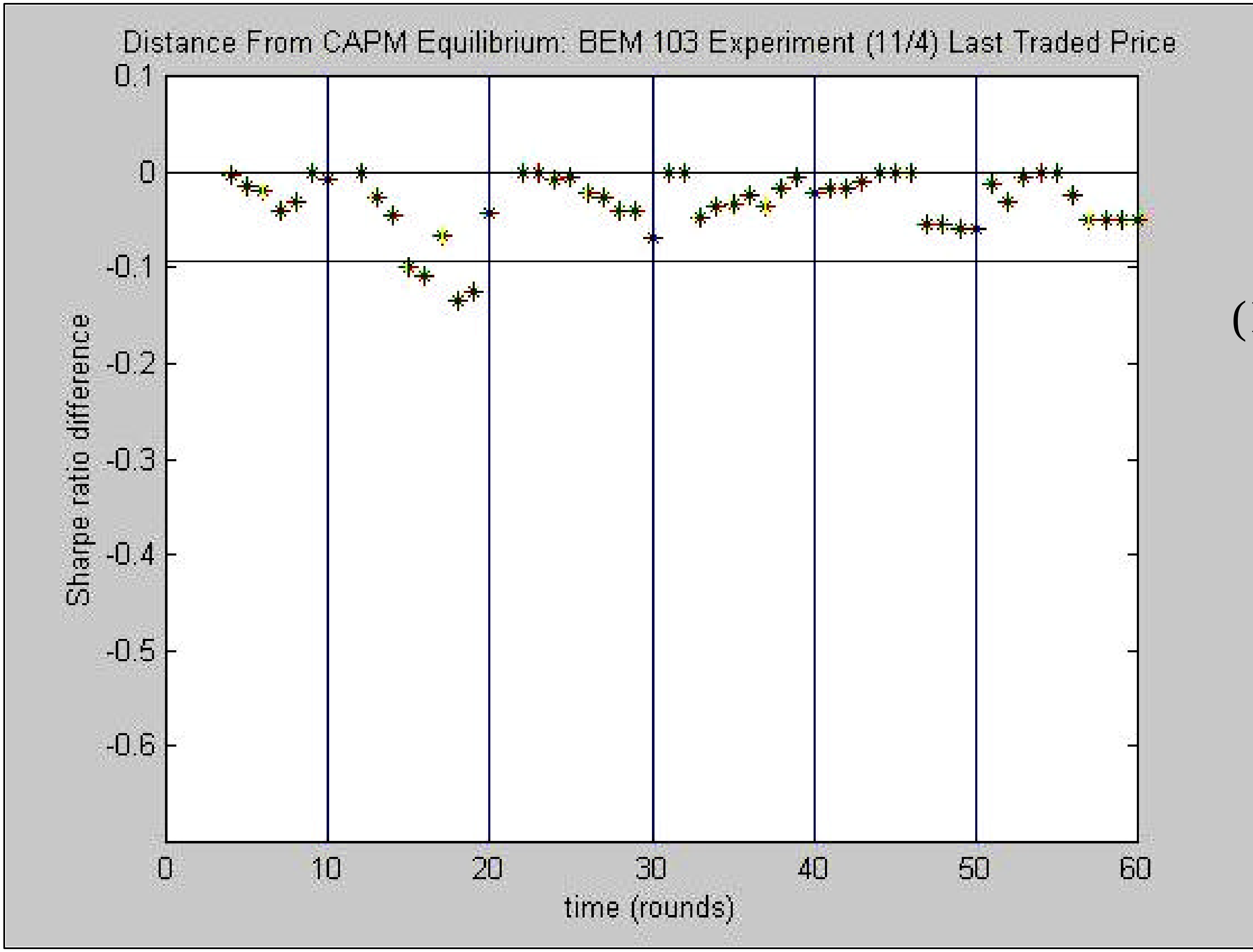


MUDA

What about a CVM?

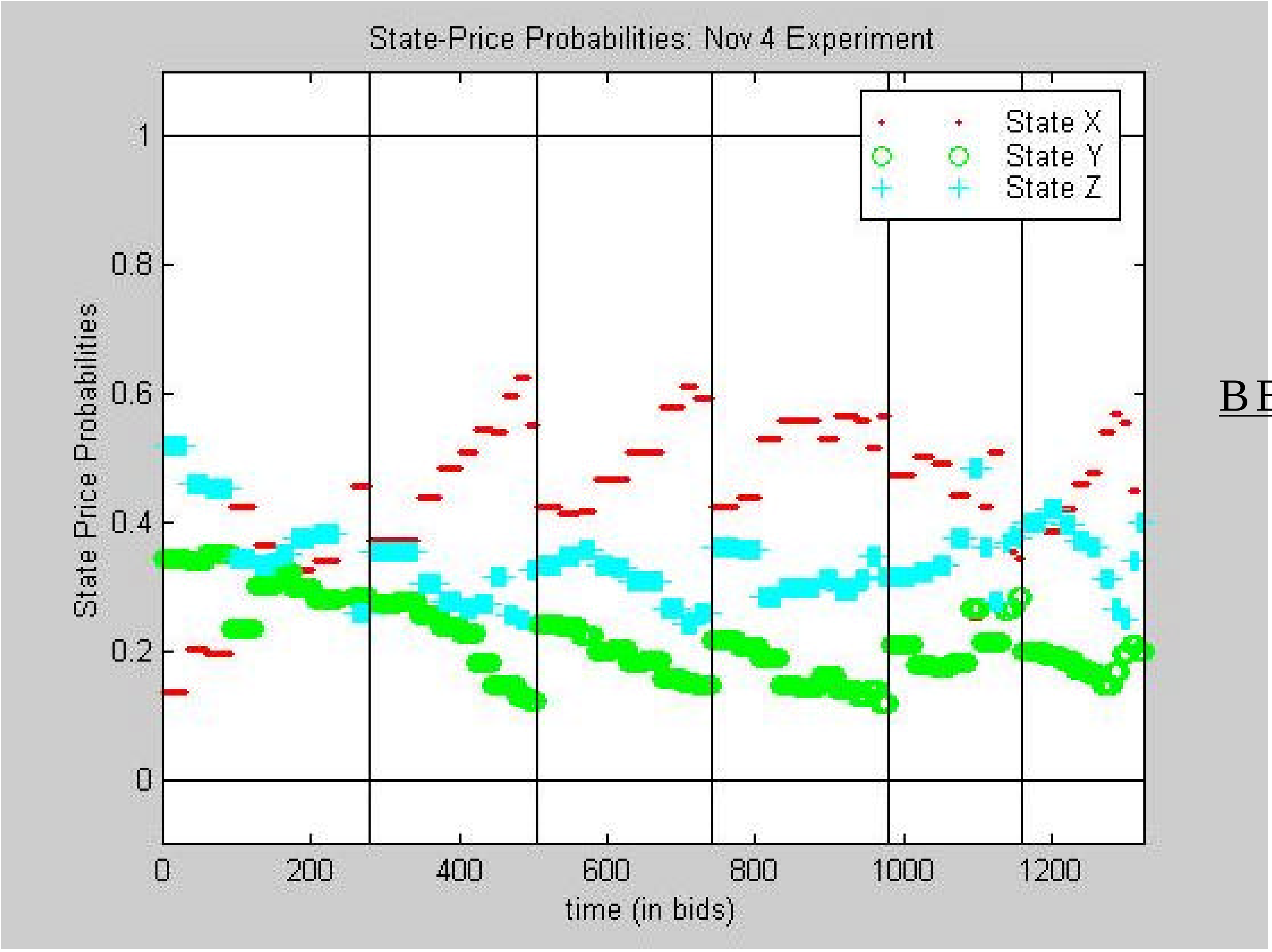
- Bossaerts, Fine, Ledyard
- Same environment as Bossaerts, Plott
  - A real advantage of experimental economics

What a CVM can do to a thin market!



(N=12)

CVM: This is what should happen!



BBC

The application - BondConnect

- Size and difficulty of the real problem
  - 200,000 variables, 300,000 constraints
    - 2,000 bonds
    - 50,000 bids (many contingencies allowed = {0,1})
  - Relaxed algorithm (LP) takes 20 minutes
  - Need a solution in 7 minutes
  - Get 85% of best known bound 90% of the time

Open questions
computers&people

- Computation - Better, faster algorithms
- Communication- run remote continuous?
- User - cognition & information processing
  - Customized problem solving interfaces (bot's?)
  - Easy to understand GUI (for inexperienced users)
  - Guides to "coalition" formation (threshold problem)
- Mechanism design for partial optimization