Shmuel's Contribution to Behavioral Operations Management

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Shmuel's guidance

Real Problems

Interdisciplinary Approach

Go Beyond

W. J. Elmaghraby and N. Larson (2012), "Explaining Deviations from Equilibrium in Auctions with Avoidable Fixed Costs", *Games and Economic Behavior*, pp. 131-159

Design Questions are 'Real'

n

"We're at the home of Jim and Mindy Marks, who are about to discover that their utility bill has gone sky-high. Let's watch."

(Peter Cramton and Steven Stoft, Uniform-Price Auctions in Electricity Markets, *The Electricity Journal*, 20:1, 26-37, 2007)

Bid Structure

→

Ability to represent preferences

Auction Market

Prices, Quantity

→

Feedback on 'place' in market

"Simple Auction"

Single dimensional bid (avg price/MWh)

Auctioneer stacks bids to create (increasing) supply curve

Highest accepted price paid to all inframarginal (accepted) bids

Simplicity of design

Bidders cannot directly express presence of avoidable fixed costs

Must guess how long the unit will be asked to run
→ *Quantity risk.*

Inframarginal suppliers accrue 'rents'

Guessing Game may lead to volatile bidding and unstable prices.

Bid Structure

→

Ability to represent preferences

Auction Market

Prices, Quantity

→

Feedback on 'place' in market

"Expressive Auction"

Multi-part bidding
(bid at multiple MWh production levels)

Auctioneer solve MIP to get optimal allocation

Individualized (discriminatory) pricing possible

Bidders are able reveal their costs structure.

If market power exists, impact on strategic behavior not clear

Allocation and payments mechanism is opaque
→ *Multiple, individualized prices*
→ *extrapolation is difficult.*

Research Question

- How well/poorly do simple bidding, pricing and allocation rules align individual profit maximizing behavior with the buyer's goal of productive efficiency and/or minimizing total cost, when compared to expressive mechanisms?

- Outline:
  - Family of supplier cost structures that encompass both increasing, constant and decreasing average costs of production
  - Present simple family of auction formats that capture the 'simple' versus 'expressive' nature of auction debate
  - Present observed behavior in lab
  - Contrast with equilibrium predictions based on various preference structures
- Our 'eye' is on the *efficiency* and *total cost* of each auction format

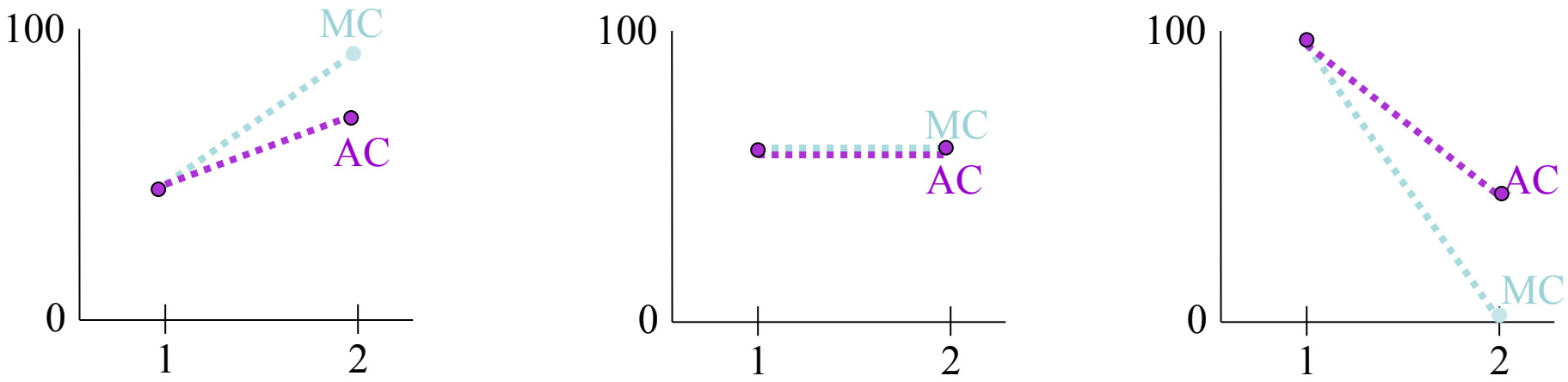
Model

- Buyer demands exactly 3 units of a homogeneous good.
- 3 suppliers
  - each supplier can produce either 0,1,or 2 units.

$$C(0) = 0 \qquad c_1 = 100 - \theta \qquad c_2 = \frac{100 + \theta}{2}$$

  - $\boldsymbol{\theta}$ is privately known and is i.i.d. from $\theta \sim U(0, \bar{\theta}),$ where $\bar{\theta} = 50.$
    - Decreasing average costs $\theta \in [0, \frac{100}{3})$
    - Increasing average costs $\theta > \frac{100}{3}$
    - Constant average costs $\theta = \frac{100}{3}.$

Experiments: Supplier Cost Types



Most efficient producer of 1 unit

Most efficient producer of 2 units

c_1	50	58	67	75	83	92	100
$c_2 = C(2)/2$	75	71	67	63	58	54	50

Model (cont.)

- Buyer demands exactly 3 units of a homogeneous good.
- 3 suppliers
  - each supplier can produce either 0,1,or 2 units.

Features:

→ Multi-sourcing: Capacity constraints and D > 2 imply that 2 or 3 suppliers will be selected.

→ *D* odd implies efficient production will require a mix from the two ends of the supplier types

→ Prominence of economies of scale: over 1/2 of suppliers produce more efficiently at full capacity.

→ N =3 captures possibility of no-production (competition)

Details of the Sessions

- Ran treatments in Behavioral Lab Fall 2005
- Each treatment had 10-16 *different* subjects
  - Undergraduates at UMD
  - Paid for participation : $10 show-up fee +earned profits (~ $20)
- 30 rounds/treatment
  - Subjects randomly matched with 2 other students in the lab in each round.
  - Each subject randomly assigned a new cost every 6 rounds

Auction Formats

- Bid Expressivity
  - **1**-part bid (single bid per bidder)
  - **2**-part bid (bid to produce one unit, bid to produce second unit)

- Payment Rule
  - **U**niform (all bidders paid the same price per unit produced)
  - **D**iscriminatory (bidders paid individualized prices)

Auction Formats…start simple
1U

- Bid Expressivity
  - 1-part bid
  - 2-part bid
- Payment Rule
  - Uniform
  - Discriminatory

1U

1. Buyer ranks all bids, low to high.
2. Procure 2 units from lowest bidder, final unit from next lowest bidder.
3. Price = marginal bid.
4. Bidders see own allocation and price

<u>Example 1U</u>

$b_1 = 77$ $b_2 = 85$ $b_2 = 80$

$Q_1 = 2$ $Q_2 = 0$ $Q_3 = 1$

Price = 80

Round

1 of 30

Time remaining: 36

Note that your costs remain the same for the next 6 rounds.

Your Costs

Your average cost if you supply one unit:	50
Your average cost if you supply two units:	75

Enter your bid.
(Your bid must be an integer between 0 and 100)

OK

Bid Confirmation Screen

Your bid has been entered.

Average cost for...	1 unit:	50
	2 units:	75
	Your bid:	70

Please wait for the other bidders to finish.

Round

1 of 30

Results Screen

Time remaining: 22

Price:	70
Your bid:	70
Quantity you supplied:	1
Your profit this period:	20
Your cumulative profits so far:	20
Remaining balance in your account:	520

…then change bid expressivity…
2U

- Bid Expressivity
  - One-part bid
  - Two-part bid
- Payment Rule
  - Uniform (U)
  - Discriminatory (D)

2U

1. Buyer ranks bids for 1 and 2 units, respectively, from low to high.
2. Procure from lowest bidder for Q=1 and 2 (when more than 2 bidders, compare against procuring 1 unit from 3 bidders)
3. Price = highest accepted bid.
4. Bidders see own allocation and price

Example 2U :

$(b_{11}, b_{12}) = (\underline{60},77)$ $\quad Q_1 = 1$

$(b_{21}\ b_{22}) = (70,67)$ $\quad Q_2 = 0$

$(b_{31}, b_{32}) = (100,\underline{55})$ $\quad Q_3 = 2$

Price = 60

…then the pricing rule...
2D

- Bid Expressivity
  - One-part bid
  - Two-part bid
- Payment Rule
  - Uniform (U)
  - Discriminatory (D) → **2D**

1. Buyer ranks bids for 1 and 2 units, respectively, from low to high.
2. Procure from lowest bidder for Q=1 and 2 (when more than 2 bidders, compare against procuring 1 unit from 3 bidders)
3. Priced = accepted bids.
4. Bidder see own allocation and price vector

Example 2D:

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$(b_{31}, b_{32}) = (100,\underline{55})$ $\quad Q_3 = 2$

Price = (55,55,60)

High Level Results

Table 1: Summary Statistics on Buyer's Cost and Suppliers' Cost under 1U, 2U and 2D.

	Treatment			
	Random	1U	2U	2D
% efficient	24%	33%	68%	77%
$\frac{(SC-SC_{eff})}{SC_{eff}}$	16.7%	10.1%	2.9%	1.9%
SC		186.7	173.7	170.1
BC		187.5	212.2	188.1
$\frac{(BC-SC)}{SC}$		0.4%	22.2%	10.6%

- Is this what we should expect?
  - What are equilibrium strategies for each auction?

How well does equilibrium theory explain observed behavior ?

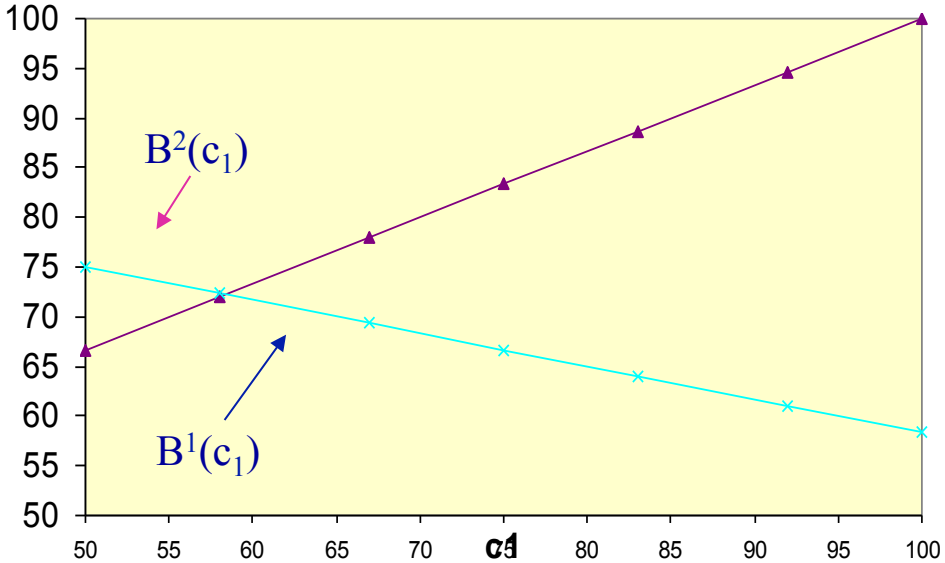
Table 2: Equilibrium Predictions versus Observed Behavior under 1U, 2U and 2D.

	Treatment		
	1U	2U	2D
% efficient	33%	68%	77%
% efficient$_{eqm}$	37%	41%	97%
BC	187.5	212.2	188.1
BC_{eqm}	193	289	200
$\frac{(BC-SC)}{SC}$	0.4%	22.2%	10.6%
$\frac{(BC_{eqm}-SC_{eqm})}{SC_{eqm}}$	5%	58%	17%

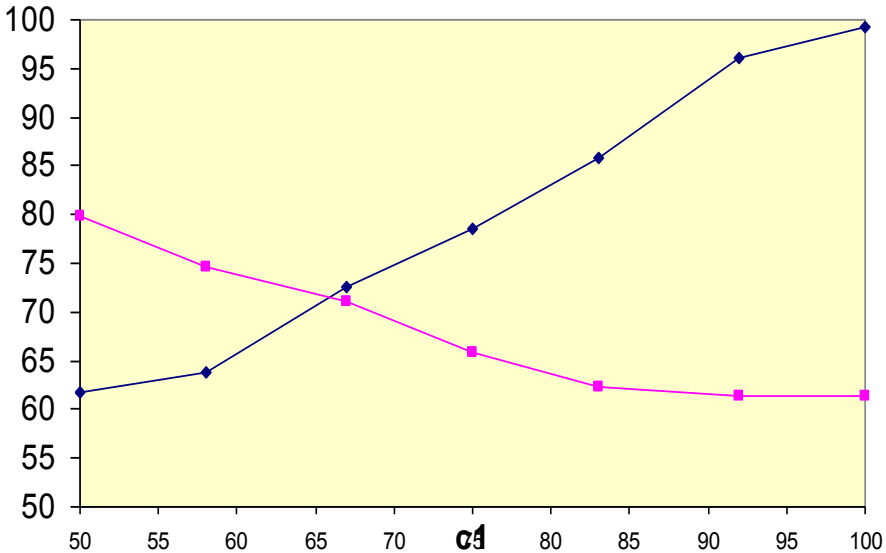
*Theory based on rational, risk-neutral profit maximizing behavior

Equilibrium in **2D**

Equilibrium Bids



Actual Bids (avg.)



- Equilibrium Prediction …subjects should bid for each package *independently*

$$
\begin{aligned}
b_1(c_1) &= \frac{100}{3} + \frac{2}{3}c_1 \\
b_2(c_1) &= \frac{11}{12}100 - \frac{1}{3}c_1 \\
&= 25 + \frac{2}{3}c_2
\end{aligned}
$$

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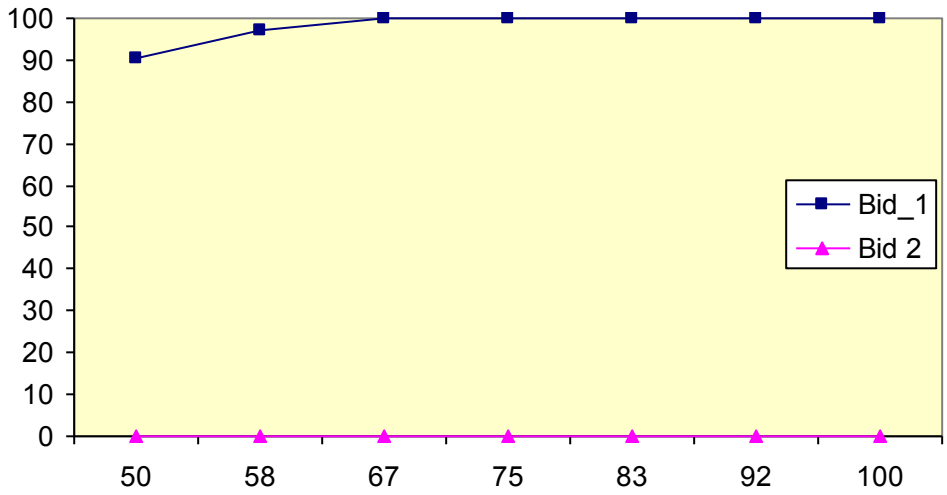
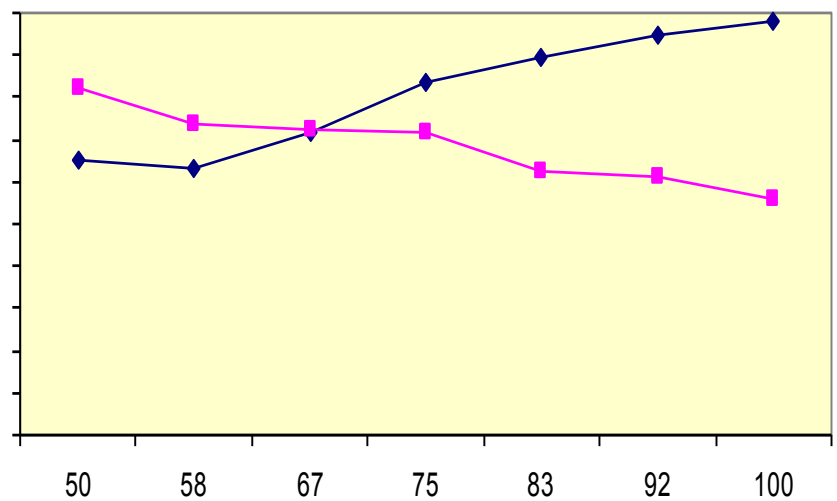
Equilibrium in **1U**

Equilibrium Bids



Actual Bids (avg.)



The symmetric equilibrium bids, as a function of one-unit cost c_1 are

$$b_1(c_1) = \begin{cases} 3c_1 + 100\ln(1 - c_1/100) + 100\ln 3 - 100 & \text{if } c_1 \leq \frac{200}{3} \approx 66.7 \\ 100 & \text{if } c_1 > \frac{200}{3} \end{cases}$$

$$b_2(c_1) = 0$$

In equilibrium, bidders should submit a 'low-ball' bid for the 2 units, and bid very high on for the single unit.

In actuality, bidders much closer to the setting of discriminatory pricing, i.e., treat each auction separately

How well does equilibrium theory explain observed behavior ?

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*Theory based on rational, risk-neutral profit maximizing behavior

Equilibrium in **1U**

- Characteristics of efficient equilibrium

  (50,75), (75,63), (100,50)

  - Efficient allocation – (50,75) & (100, 50)

  $\longrightarrow$ $b_{100} < b_{50} < b_{75}$

  (50,75), (58,71), (75,63)

  - Efficient allocation – (50,75) & (75,63)

  $\longrightarrow$ $b_{75} < b_{50} < b_{58}$ …contradiction!

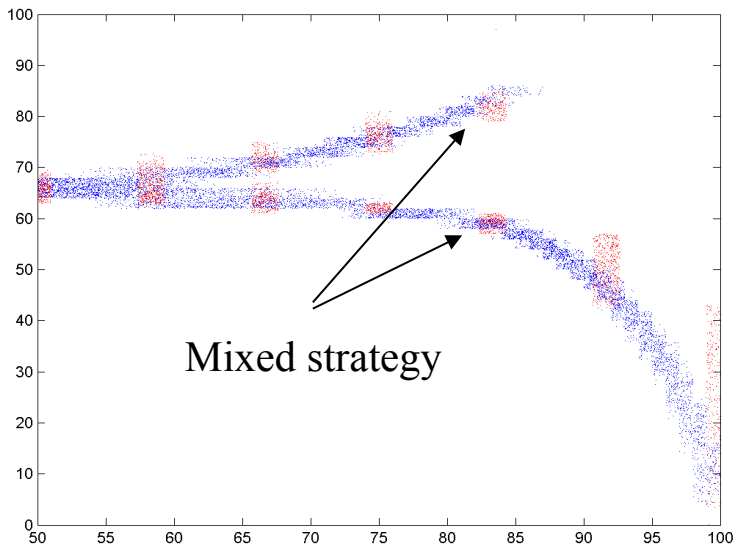
- There does not exist a deterministic bidding strategy that is monotonic in c_1(c_2) and always yields the efficient allocation.

- Analysis indicates that local incentives (incentive compatibility constraints) and global incentives (since expected payoffs may not be single-peaked) interact in a way to preclude the existence of *any* pure strategy equilibrium.

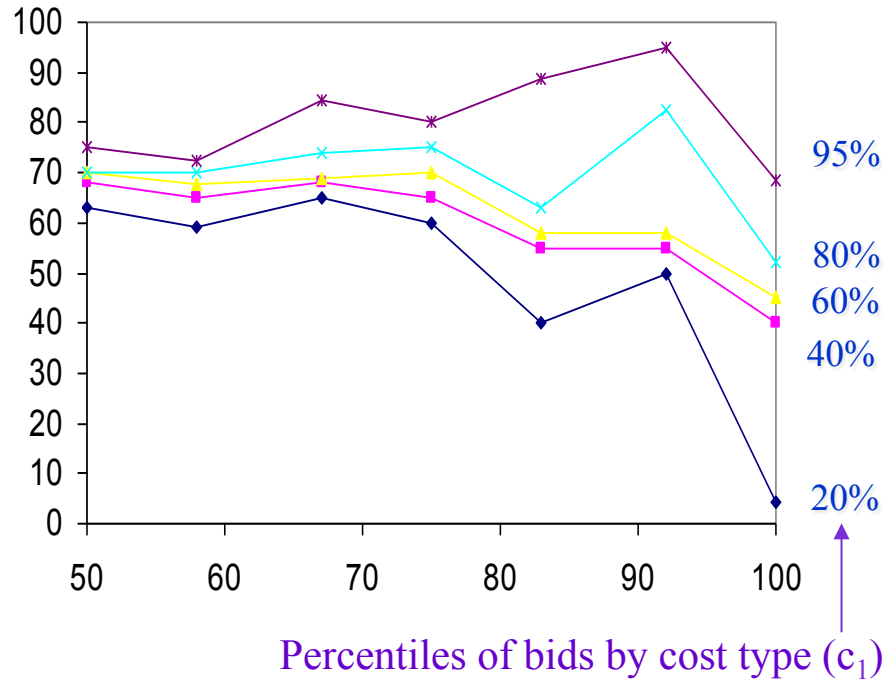
- Any equilibrium involves *mixing* by some cost types

Equilibrium in **1U**

Equilibrium Bids



Actual Bids



- Are subjects behaving as equilibrium would predict?
  - Tentative 'yes' for 1D, 'no' for 1U and '?' for 2U
- Not clear if we should expect equilibrium behavior.

Responding to profit making opportunities?

Table 3: Suppliers responses to profit making opportunities.

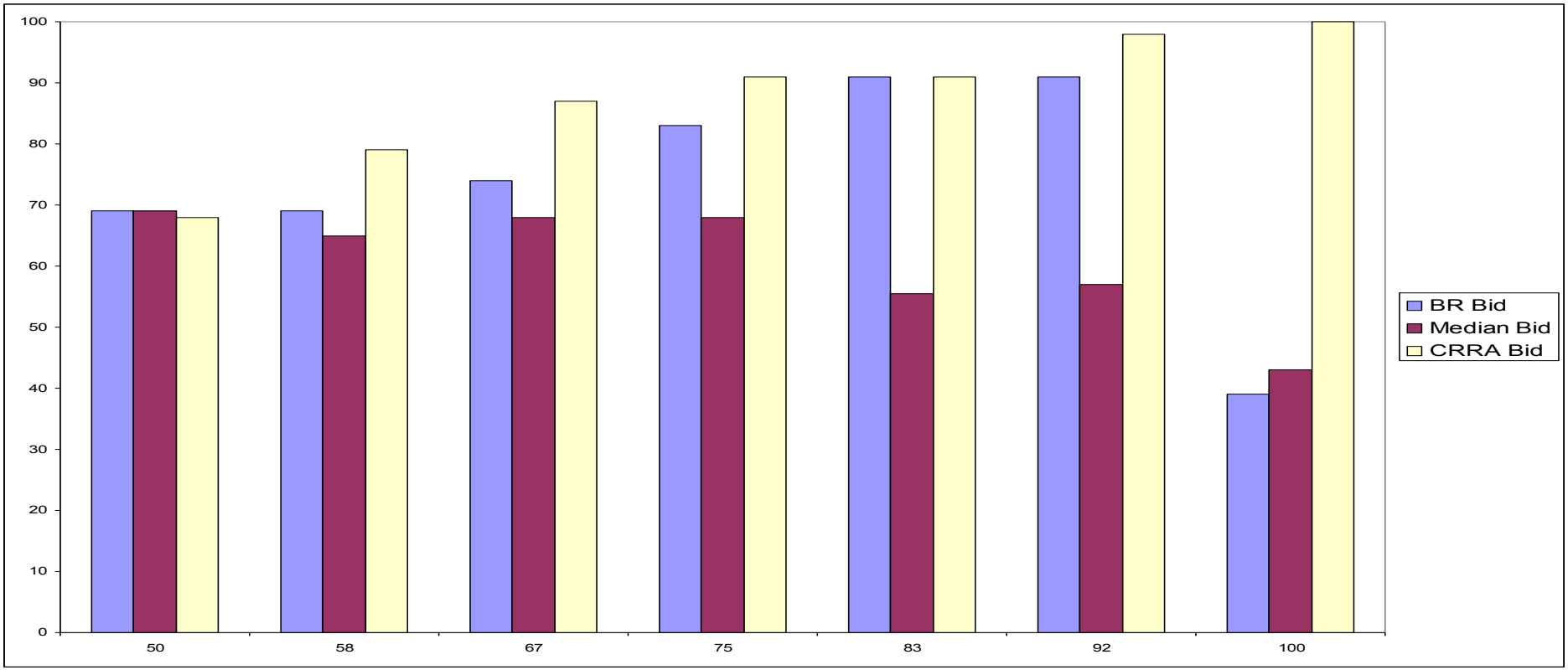
	1U	2U	2D
Actual Avg. π	0.26	13.02	5.99
Average potential π	3.45	25.53	9.07
% π left on table	92%	51%	33%
Shortfall	-3.3	-12.5	-3.1

- Subjects leave $ on the table in every case
  - Do particularly poorly (in absolute terms) under 2U and (in relatively terms) under 1U.

- Explore explanations based on alternative preferences and learning in hard optimization problems.

Alternative Preference Structure: Bidding under 1U with Risk Averse Preferences

- Hypothesis: Subjects are risk averse –hence bid more competitively, and leave more profits 'on the table'
- In our setting, risk aversion and overly competitive bids are not synonymous



Bids under 1U (CRRA 0.5)

Alternative Preference Structure: Loss Aversion

- Do not treat gains and losses symmetrically.
- If our subjects place some weight on avoiding losses per se, expect their bids to expose them to a smaller chance of losses than best response strategies
- Identify bids that *could* result in a loss for some realization of opponents' bids

2U: $b_1<c_1$ or $b_2<c_2$ **1U:** $b < max(c_1,c_2)$

Table 4: Suppliers' responses to profit making opportunities.

	1U	2U
% Loss Exposed under BR	16%	60%
% Loss Exposed (actual)	77%	12.5%

- Neither risk aversion nor loss aversion offer satisfactory explanation of deviations
- Leads us to question if subjects have a clear understanding of prospective payoffs, and if not, what features of the auction formats obscure learning.

Learning

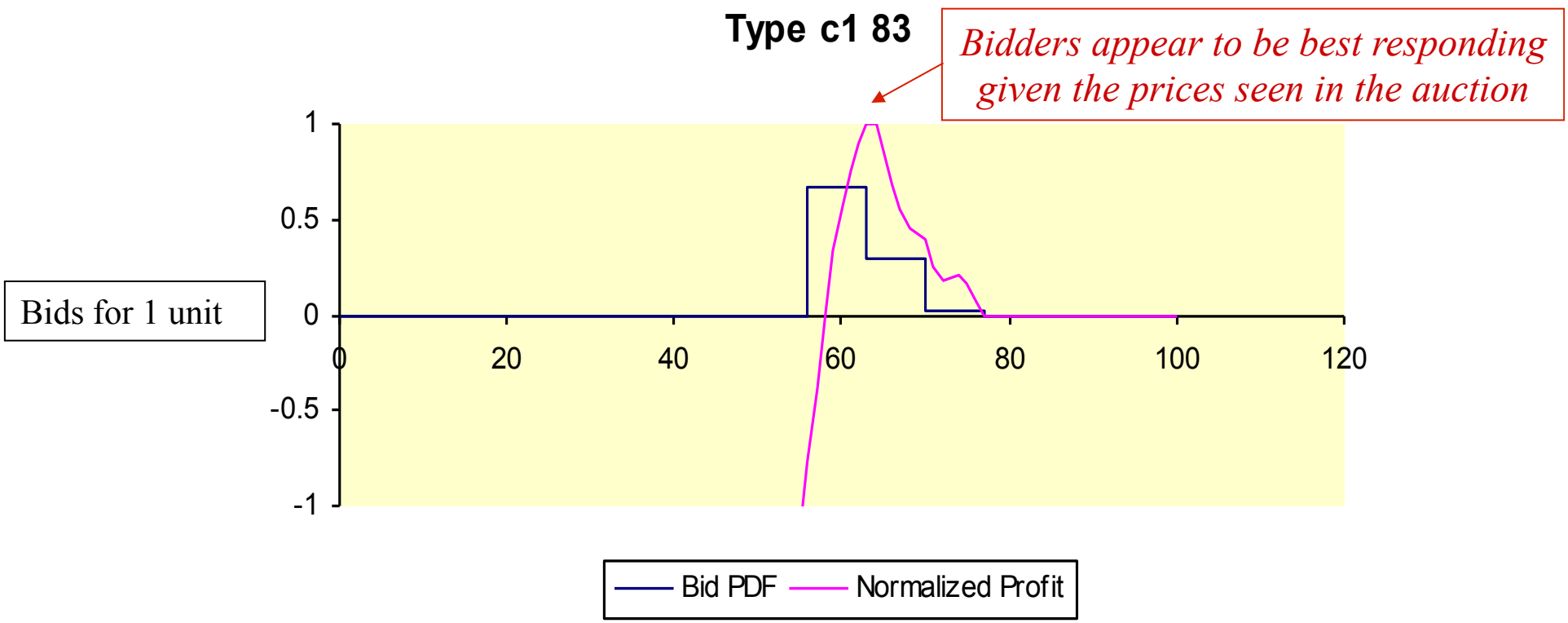
Table 5: Suppliers responses to profit making opportunities.

Treatment	1U3		2U		2D	
	1-3	4-6	1-3	4-6	1-3	4-6
π_{Actual}	0.2	0.5	10.8	12.3	5.1	6.7
π_{BR}	4.3	3.9	22.4	25.5	9.6	9.1
Shortfall: $\pi_{Actual} - \pi_{BR}$	−4.0	−3.4	−11.6	−13.2	−4.5	−2.4
% captured	5%	13%	48%	48%	53%	74%

- Conjecture: Interaction of cost structure with institutional and strategic features of 2U and 1U makes it difficult for otherwise rational, risk neutral subjects to be effective profit maximizers

Learning with 2D

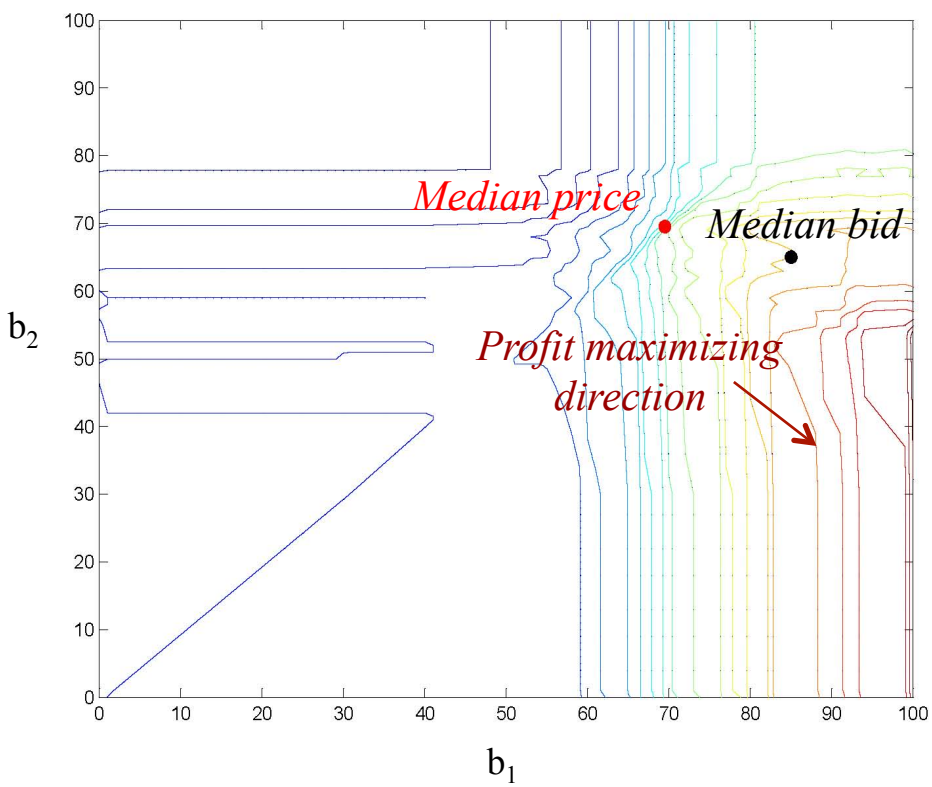
- Marginal and Modular Intuition for 2D
  - Bidders have effectively 2 'knobs'
  - Intuition at the 'margin' works
  - Since can effectively treat 2 auctions as separate (modular),



Partial Learning with 2U

- Marginal intuition does not work
- Modular intuition offers some guidance

Type c_1=83

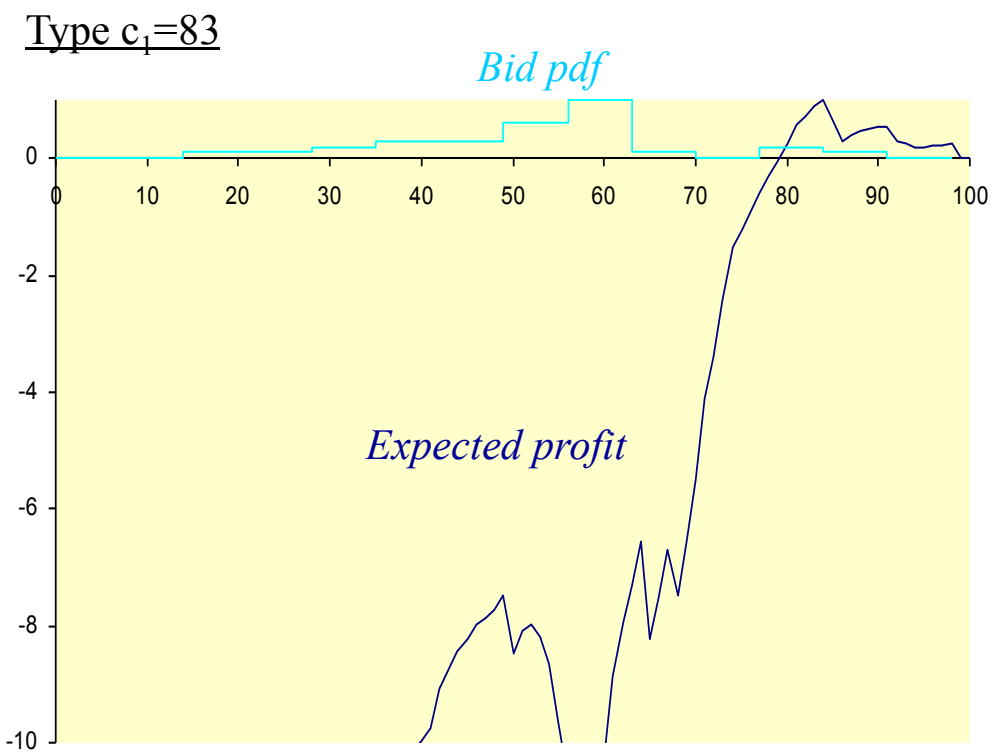


- Payoffs are not separable across markets
- Moving in π-max direction requires diagonal moves
- Suppliers avoiding bids below cost even when profitable

c_1	75	83	92	100
% times $b_2<c_2$	0	.028	.013	.019
E[Gain| $b_2<c_2$]	19.55	8.27	1.88	0.6

Difficulty in Learning with 1U

- Neither Marginal nor Modular Intuition are helpful under 1U



- Bidders have only 1 'knob' - trading off receiving high prices (bid high) and selling larger quantities (bid low).
- π function has multiple local max and max π is small.
- Suppliers bidding below cost even when unprofitable

c_1	75	83	92	100
% times $b<c_2$	0.26	0.58	0.32	0.7
$E[Loss\|b < c_2]$	3.88	7.18	2.8	6.33

Complexity and Auction Performance

Auction Format	2-part bid Discriminatory	2-part bid Uniform price	1-part bid Uniform price
% Efficient Allocation	77%	68%	51%
Inefficiency $(SC - SC_{eff})/SC_{eff}$	1.9%	2.9%	10.1%
Mark-up over cost (BC-SC)/SC	10.6%	22.2%	0.4%
Actual Avg. π	5.99	13.02	0.26
Preference Matching Observed Behavior	Profit Maximizing?	Cost Recovery?	???

Complexity of Supplier's Bidding Decision:

Simple **Moderate** **Hard**

What we’ve learned so far…what is next.

- Motivation: The presence of non-convexities in auctions
- Research Question: Does adding flexibility to bid expressivity and prices ‘help’ the buyer and/or suppliers?

- Use experiments to study the reasons that suppliers deviate from risk neutral best response bidding when avoidable fixed costs are present.

- Multi-part bids come a long way in reducing inefficiencies in market

- ‘Simple’ auction formats like 1U may pose an extremely difficult problem for bidders
  - Mixed strategy equilibrium
  - Small profit opportunity

What we've learned so far…what is next.

- When subjects presented with 'difficult' problem, equilibrium behavior may be a poor predictor of behavior.

- Our main finding in the paper (results not presented here) is that measures of optimization difficulty help to explain behavior across auction formats.
  - In contrast, preference-based explanations (such as risk or loss aversion) do not generalize well across auction formats.

- Auction designers should consider ease/difficulty of learning to bid in auction – has important implications for actual bidding behavior.