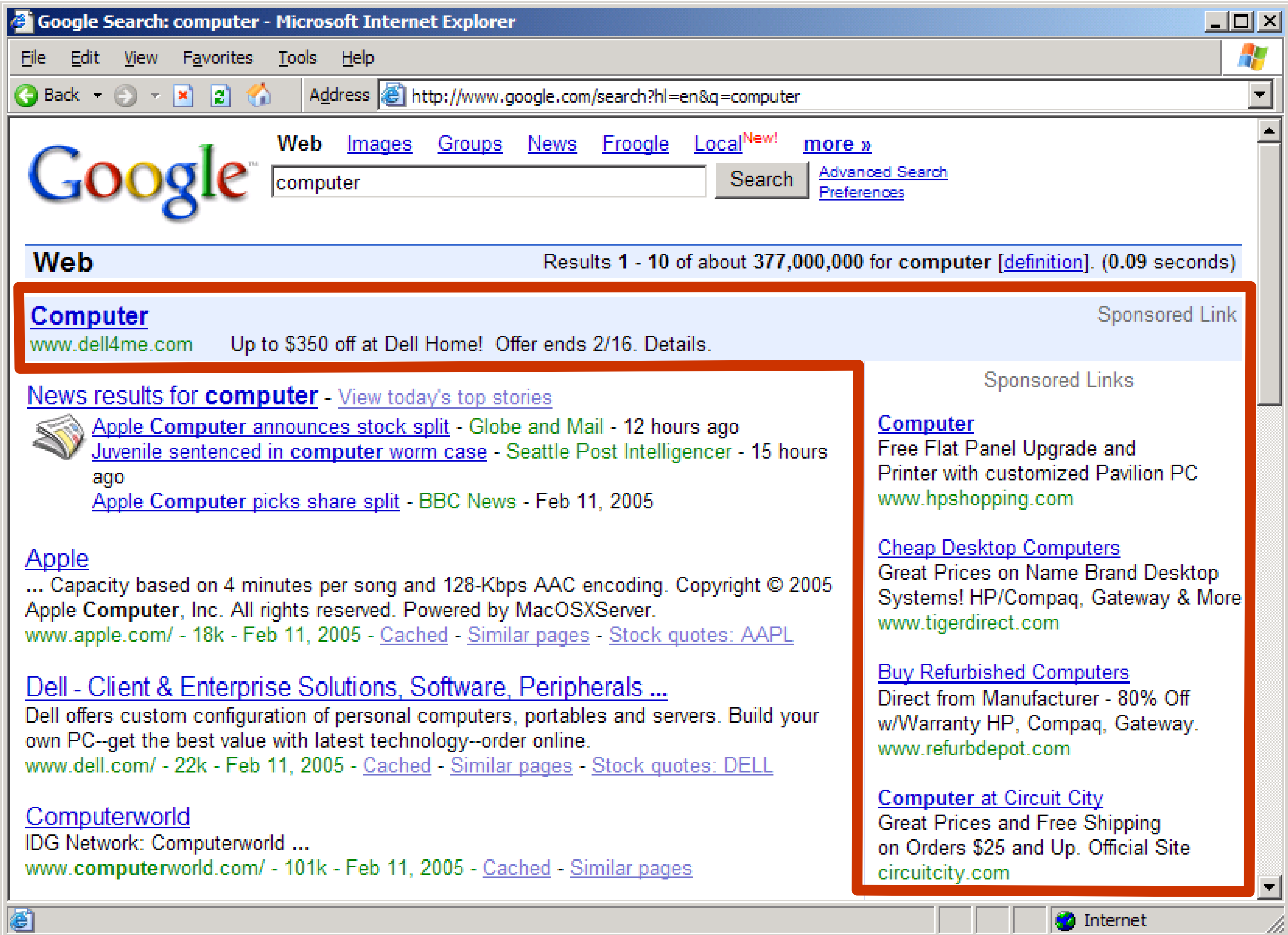
Bidding for Sponsored Link Advertisements at Internet Search Engines

Benjamin Edelman

Portions with Michael Ostrovsky and Michael Schwarz

Project status

- Two papers posted
  - "Strategic Bidder Behavior in Sponsored Search Auctions" (Edelman & Ostrovsky)
  - "Internet Advertising and the Generalized Second Price Auction: Selling Billions of Dollars Worth of Keywords" (Edelman, Ostrovsky & Schwarz)
- Further work in progress
  - Simulations
  - Testing bidding agents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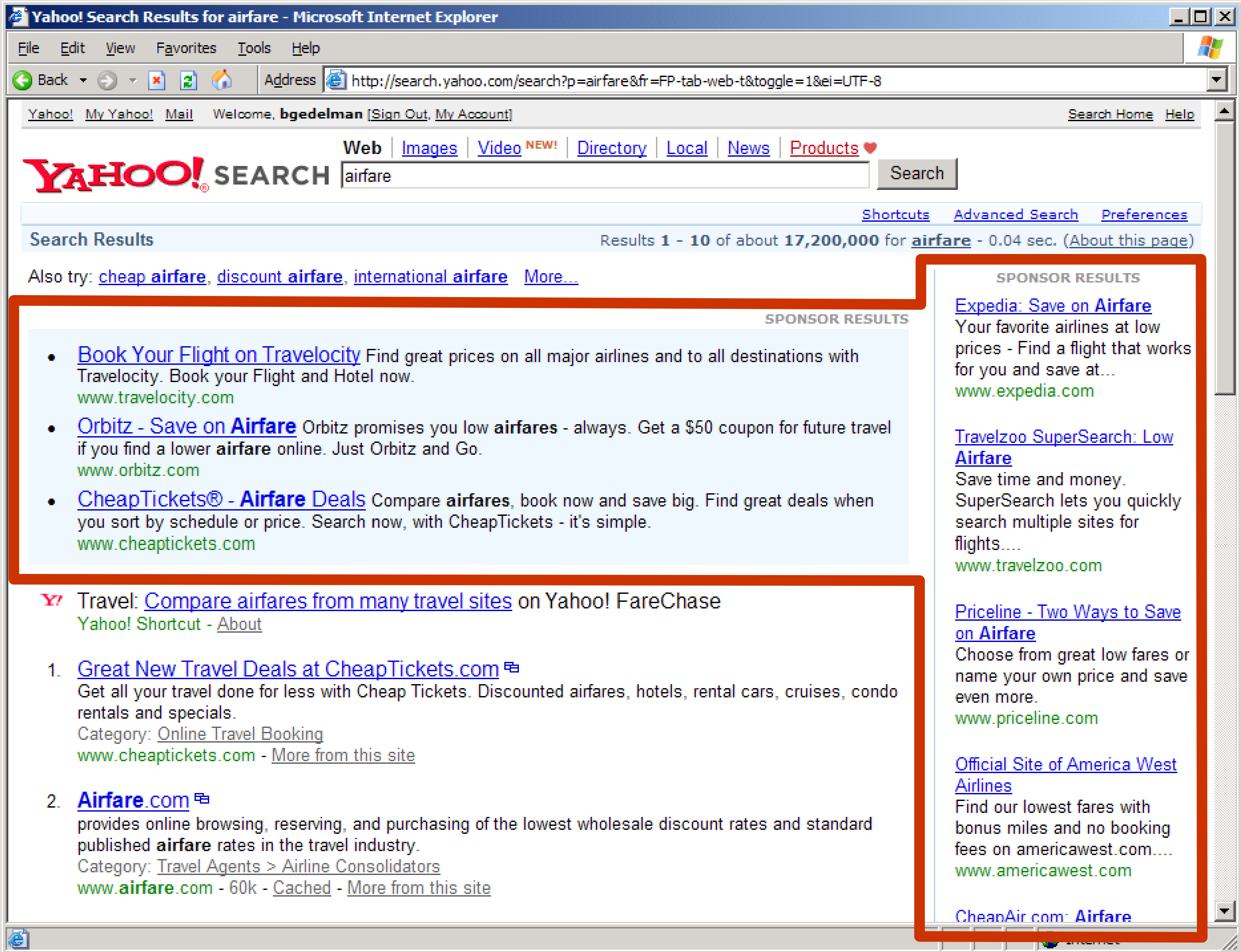
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Motivation

- Market inherently interesting
  - 98% of Google's and ~50% of Yahoo's revenues
  - "Future of advertising"
- Unusual auction rules
  - Multiple units, but only one bid. Continuous time.
- Structured market
  - Rules. Almost like a lab. Good data.
- Purely electronic market
  - No goods ever shipped anywhere.
- Flexibility to change auction rules from time to time

Market history & evolution

early banner ads (circa 1994)	Overture (1997)
per-impression pricing	per-click pricing
limited targeting	keyword targeting
person-to-person negotiations	automated acceptance of revised bids
	generalized first-price auction rules

Generalized first price auctions

Problem: Generalized first price auctions are unstable.

No pure strategy equilibrium, and bids can be adjusted dynamically. Bidders want to revise their bids as often as possible.

Initial empirical project: data

Yahoo data from June 15, 2002 to June 14, 2003

1000 top markets

10,475 bidders

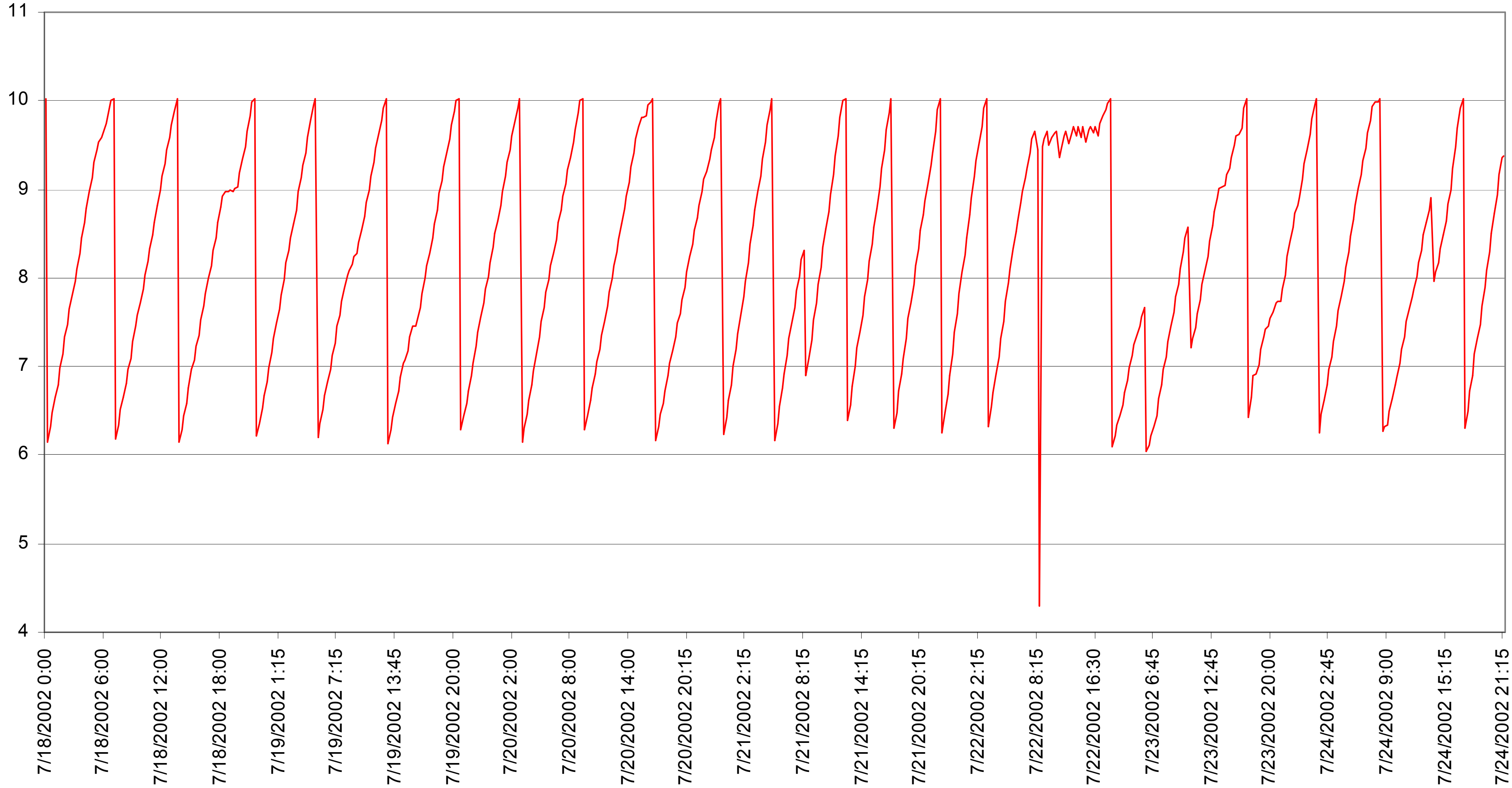
18,634,347 bids

Observe bids at the quarter-hour

Cycling

Time	Market	Bidder	Bid
6/17/2002 6:30 AM	24	810	$5.92
6/17/2002 6:30 AM	24	13	$5.91
6/17/2002 6:30 AM	24	14	$5.93
6/17/2002 6:30 AM	24	60	$5.95
6/17/2002 6:30 AM	24	13	$5.94
6/17/2002 6:30 AM	24	14	$5.96
6/17/2002 6:45 AM	24	810	$5.97
6/17/2002 6:45 AM	24	13	$5.97
…			
6/17/2002 11:30 PM	24	13	$9.98
6/17/2002 11:30 PM	24	14	$9.98
6/17/2002 11:45 PM	24	14	$10.00
6/17/2002 11:45 PM	24	60	$10.00
6/17/2002 11:45 PM	24	13	$10.00
6/17/2002 11:45 PM	24	810	$10.01
6/17/2002 11:45 PM	24	14	$10.02
6/17/2002 11:45 PM	24	13	$5.12
6/17/2002 11:45 PM	24	14	$5.13

Cycling



11
10
9
8
7
6
5
4
7/18/2002 0:00
7/18/2002 6:00
7/18/2002 12:00
7/18/2002 18:00
7/19/2002 1:15
7/19/2002 7:15
7/19/2002 13:45
7/19/2002 20:00
7/20/2002 2:00
7/20/2002 8:00
7/20/2002 14:00
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7/21/2002 14:15
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7/22/2002 8:15
7/22/2002 16:30
7/23/2002 6:45
7/23/2002 12:45
7/23/2002 20:00
7/24/2002 2:45
7/24/2002 9:00
7/24/2002 15:15
7/24/2002 21:15

Alternative mechanisms

- Generalized first-price
- Generalized second-price
  - Pay the bid of the next-highest bidder
  - First implemented by Google (2002), later adopted by Yahoo
- VCG

VCG/GFP revenue comparisons: strategy

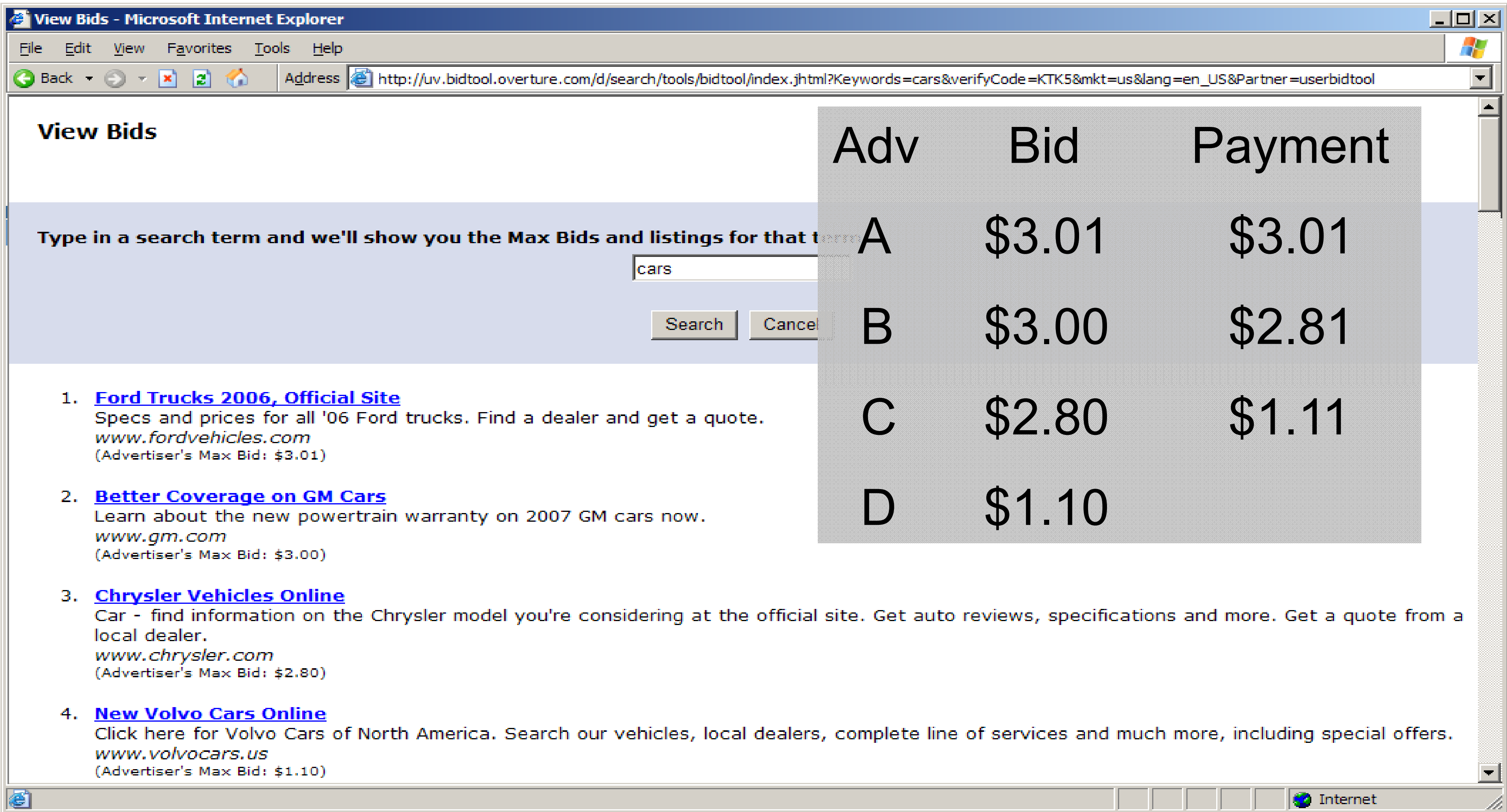
- Observe actual GFP bidder bids.
- Compute actual bidder payments under actual GFP mechanism.
- Compute (a lower bound of) each bidder's valuation using recently-observed GFP bids. These are VCG bids.
- Compute VCG payments.
- Iterate through entire data set (18 million bids).

VCG/GFP revenue comparisons: results

Distribution of ratios of VCG versus GFP revenues

Statistic	Value (all keywords)	Value (popular keywords)
10th percentile	0.36	0.95
25th percentile	0.52	1.02
Median	0.68	1.06
75th percentile	0.81	1.12
90th percentile	0.92	1.13
Avg ratio (by kw)	0.66	1.07
Avg ratio (by click)	0.76	1.09

GSP



Adv	Bid	Payment
A	\$3.01	\$3.01
B	\$3.00	\$2.81
C	\$2.80	\$1.11
D	\$1.10	

GSP versus Vickrey and VCG

"[Google's unique auction model uses Nobel Prize-winning economic theory to eliminate … that feeling that you've paid too much."

- Google marketing materials

- With only one slot, GSP is identical to standard second price auctions (Vickrey, VCG)
- With multiple slots, the mechanisms differ
  - GSP charges bidder *i* the **bid of bidder *i+1***
  - VCG charges bidder *i* for his **externality**

Truth-telling is not a dominant strategy under GSP

Intuition: Sometimes, bid below your true valuation.
You may get less traffic, but you'll earn greater profits.

Suppose there are 3 bidders but 2 positions.
Positions have click-through rates 100 and 80.

C's valuation: $10

bidder	bid
	← C bids $10, pays $8 → payoff ($10-$8)*100 =$200
A	$8
	← C bids $6, pays $5 → payoff ($10-$5)*80 =$400
B	$5

$400>$200. So C should place a bid below its valuation.

Notation and setup

$N \geq 2$ slots, $K=N+1$ advertisers

α_i is the expected number of clicks in position i, with $\alpha_1=1$.

s_k is the value per click to bidder k.

Payments are computed according to GSP rules.

Valuations are private information, drawn from commonly-known distributions.

GSP Equilibrium?

- Infinitely repeated game
- Folk theorem

Can we say anything
about likely outcomes?

GSP and the Generalized English Auction

A clock shows the current price (increasing).

An advertiser *i*'s bid b_i is the price p_i when he drops out, with k other bidders remaining.

An advertiser *i*'s strategy is a function $p_i(k, h, s_i)$ which depends on

- the advertiser's valuation, s_i
- the number of slots remaining, k
- history $h=(b_{k+1},\ldots b_K)$, the bids of bidders $K, K-1, \ldots k+1$.

GSP and the Generalized English Auction
(Theorem)

(i) In the unique perfect Bayesian equilibrium of the generalized English auction, an advertiser with value s_i drops out at price

$$p_i(k,h,s_i) = s_i - \frac{\alpha_k}{\alpha_{k-1}}(s_i - b_{k+1})$$

(ii) In this equilibrium, each advertiser’s position and payoff are the same as in the dominant strategy equilibrium in the game induced by VCG.

(iii) This equilibrium is ex post: Each bidder’s strategy is a best response to other bidders’ strategies, regardless of their realized values.

GSP* payments coincide with VCG

$b_{N+1} = s_{N+1}$, so bidder N pays is $\alpha_N \, s_{N+1}$. (Lowest bid)

$b_N = s_N - \frac{\alpha_N}{\alpha_{N-1}} (s_N - b_{N+1})$, so bidder $N-1$ pays

$$\alpha_{N-1} \, b_N = \alpha_{N-1} \, s_N - \alpha_N \, s_N + \alpha_N \, b_{N+1}$$

$$= s_N (\alpha_{N-1} - \alpha_N) + \alpha_N \, s_{N+1}$$

exactly the VCG payment

Repeat for b_{N-1}, b_{N-2}, etc.

The GSP* profile is an ex-post equilibrium

By construction, each bidder *i* is indifferent between its position *i* at b_{i+1} per click and position $i - 1$ at b_i. Notice:

$$b_i = s_i - \frac{\alpha_i}{\alpha_{i-1}}(s_i - b_{i+1})$$

$$\Updownarrow$$

$$\alpha_{i-1}(s_i - b_i) = \alpha_i(s_i - b_{i+1})$$

$s_{i-1} \geq s_i$, so bidder $i - 1$ prefers position $i - 1$ at price b_i to i at b_{i+1}. Bidder $i - 1$ likes position $i + 1$ at b_{i+1} even less. So no bidder wants to lower its bid.

By a similar argument, no bidder wants to raise its bid.

GSP* properties

- Unique equilibrium
- Explicit analytic formulas for bid functions
- Robust – does not depend on distributions of types or beliefs

Yet, the game is not dominant strategy solvable, and truth-telling is generally not an equilibrium.

Unusual combination of properties. Other examples?

Using the GSP* bid function

- We know bids as a function of valuations and alphas.
- Possibilities:
  - Given bids and alphas (e.g. from data), compute valuations.
  - Given valuations and alphas, compute bids and outcomes.

    → Simulations

Testing convergence

Testing convergence: setup

K bidders, K slots

Valuations $s_k \sim \mathbf{f}$ (predetermined)

Payments computed according to GSP rules.

Bidders all start with $b_k^{(0)}=\mu$ (minimum bid)

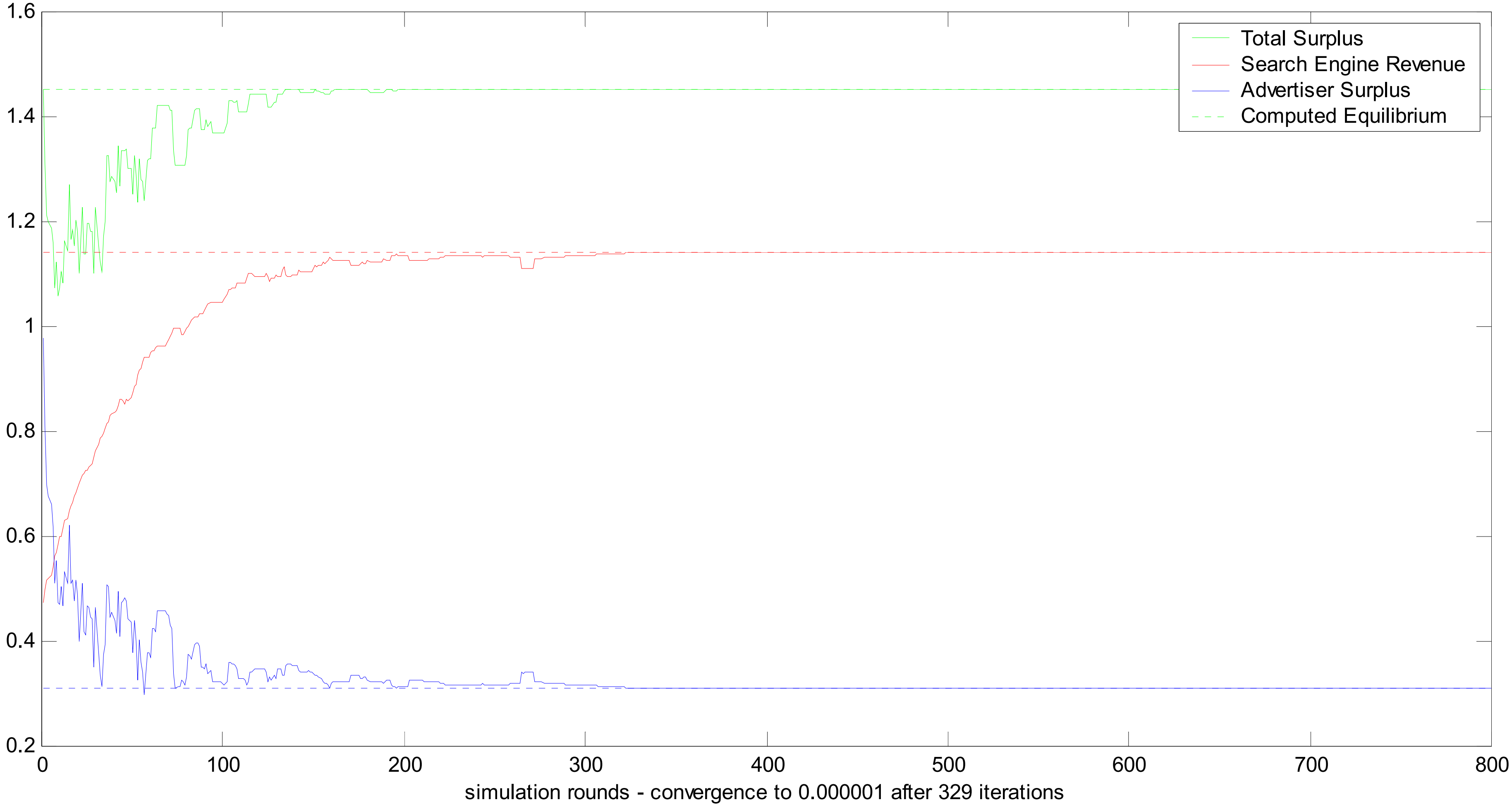
In each period, draw a bidder k, who can update his bid.

Compute payoff at each slot i, $\alpha_i (s_k - b_i)$. Find maximand i^*.

Use the GSP* bid function to select a b_k, so k is indifferent if bidder i^*-1 jams k.

Repeat until 1) convergence to equilibrium *or*
2) maximum periods have elapsed.

Convergence: simulation



Outcomes w/ ad hoc bidder strategies

Rules-Based Bidding for Pay-Per-Click Management - Microsoft Internet Explorer

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Rules-Based Bidding

+ How PPC Works
+ Managing Bids
+ Reporting
- Rules-Based Bidding
+ Conversion Tracking
+ Keyword MasterList
+ Summary of Benefits

If pay-per-click marketing is so strategic, how can it be automated? That's why we developed Rules-Based Bidding. Rules-Based Bidding allows you to apply the kind of rules you would use if you were managing your bids manually. For example, you might want to stay in third position unless first position is only three cents away. We have a rule that allows you to do just that. If you manage listings on a pay-per-click engine that automatically adjusts your cost per click (Overture and Google, for example), you are probably familiar with jamming. Jamming is when the person below you bids a penny below your bid, making sure you pay the most to stay in your position. Well, we have a rule to jam your competitors and we have a rule to defend against jamming.

The rules we offer include:

ROAS Bid Strategy
Changes a keyword bid based Return on Advertising Spend (ROAS) statistics from ProfitBuilder ROI.

CPA Bid Strategy
Adjusts a keyword bid based on Cost Per Acquisition (CPA) statistics from ProfitBuilder ROI.

Budget Manager
Lowers your keyword bid based on a set daily budget.

Max Bid Gap Jammer
Moves your keyword max bid to one cent below your competitor's keyword bid.

Don't Jam Me
Moves your keyword listing below a competitor that is jamming your bid.

First Gap
Moves your keyword listing to the first bid gap within a specified set of positions.

Largest Gap
Moves your keyword listing to the largest bid gap within a specified set of positions.

Daily-Bid Adjustment
Adjusts the keyword bid based on time of day.

Done Internet

Simulated best response analysis

- If the *K-1* other bidders play a given ad hoc strategy, what is bidder *K*'s best response?
  - ROI targeter
  - Jammer
  - "Kind" and "mean" best-responders
  - Reinforcement learning
  - Other ad hoc strategies

If others play GSP*

- Bidders *1,…,K-1* bid play GSP* according to the bid function.
- What is *K*'s best response?

bidder	bidder payoffs if bidder *K* plays	
	GSP*	ROI targeter
1		
…		
K-1		
K	0.1082	0.1009

If others play ROI targeter

- Bidders *1,…,K-1* bid according to the ROI targeting strategy.
- What is *K*'s best response?

bidder	bidder payoffs if bidder *K* plays	
	ROI targeting	GSP*
1		
…		
K-1		
K	0.0387	$\boxed{0.0457}$

If others jam

- Bidders *1,…,K-1* jam.
- What is *K*'s best response?

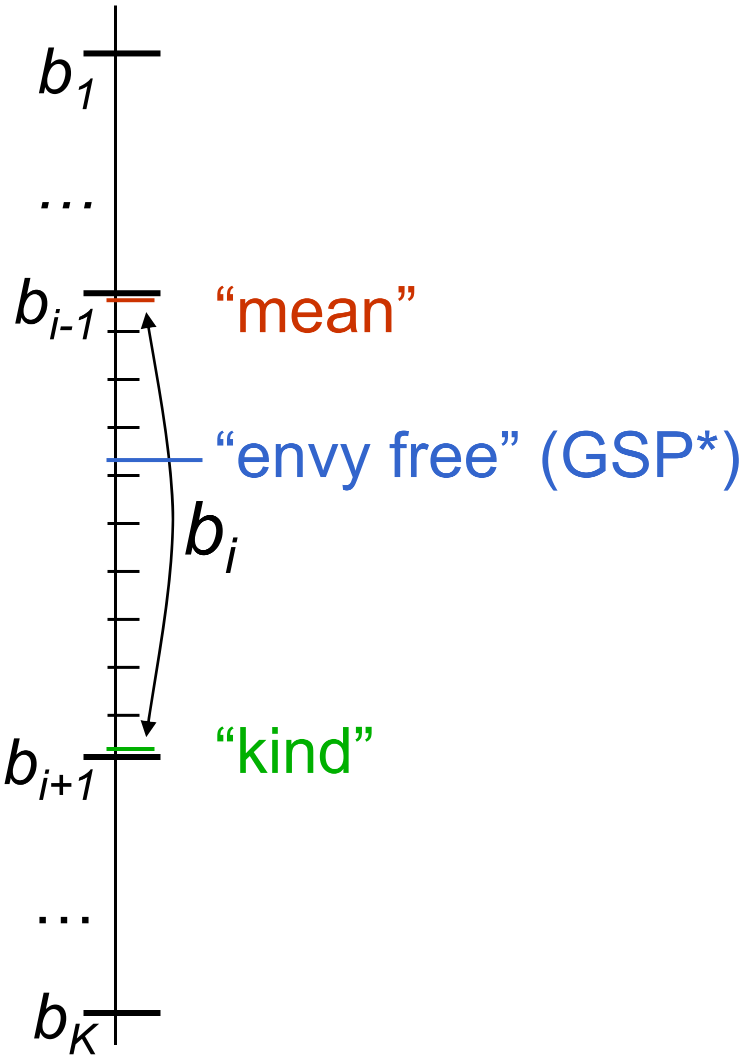
bidder	bidder payoffs if bidder *K* plays	
	jam	GSP*
1		
…		
K-1		
K	0.0680	0.1234

If others gap-surf

- Bidders *1,…,K-1* "gap-surf" (bidding at midpoint of biggest gap).
- What is *K*'s best response?

	bidder payoffs if bidder *K* plays	
bidder	gap surf	GSP*
1		
…		
K-1		
K	0.0825	0.0957

“Mean” and “Kind” Best Responders



Having chosen to bid between b_{i+1} and b_{i-1}, what specific bid should bidder i submit?

If others are mean best responders

- Bidders *1,…,K-1* play mean best response strategy.
- What is *K*'s best response?

bidder	bidder payoffs if bidder *K* plays	
	Mean BR	GSP*
1		
…		
K-1		
K	0.0673	$\boxed{0.0683}$

If others are kind best responders

- Bidders *1,…,K-1* play kind best response strategy.
- What is *K*'s best response?

bidder	bidder payoffs if bidder *K* plays	
	Kind BR	GSP*
1		
…		
K-1		
K	0.0810	0.0834

If others are midpoint best responders

- Bidders *1,…,K-1* play the midpoint of their best response correspondence.
- What is *K*'s best response?

bidder	bidder payoffs if bidder *K* plays	
	Midpoint BR	GSP*
1		
…		
K-1		
K	0.0700	0.0706

If others use reinforcement learning

- Bidders *1,…,K-1* use reinforcement learning.
- What is *K*'s best response?

bidder	bidder payoffs if bidder *K* plays	
	RL	GSP*
1		
…		
K-1		
K	0.0983	0.1130

Dead weight loss from ad hoc strategies

Non-GSP* strategies generally lead to inefficient ordering of advertisers → less total surplus.

	total surplus (per click)	% GSP*-random spread lost
GSP*	1.340	0%
ROI targeter	1.336	1.5%
Reinf. learning	1.331	3.1%
Gap surf	1.280	21.0%
Jam	1.239	35.4%
Random ordering	1.053	100.0%

Learning & unsophisticated bidders

- Suppose a GSP* bidder does not consider all *K* positions. e.g. considers only
  - proportion β of positions
  - positions near his current position.
- Or, suppose a bidder makes some other kind of error? (e.g. trembling hand)
- Still reach convergence? What happens to payoffs? Efficiency?
- Other models of learning?

  Good data available. New bidders still arriving.

Policy & counterfactuals

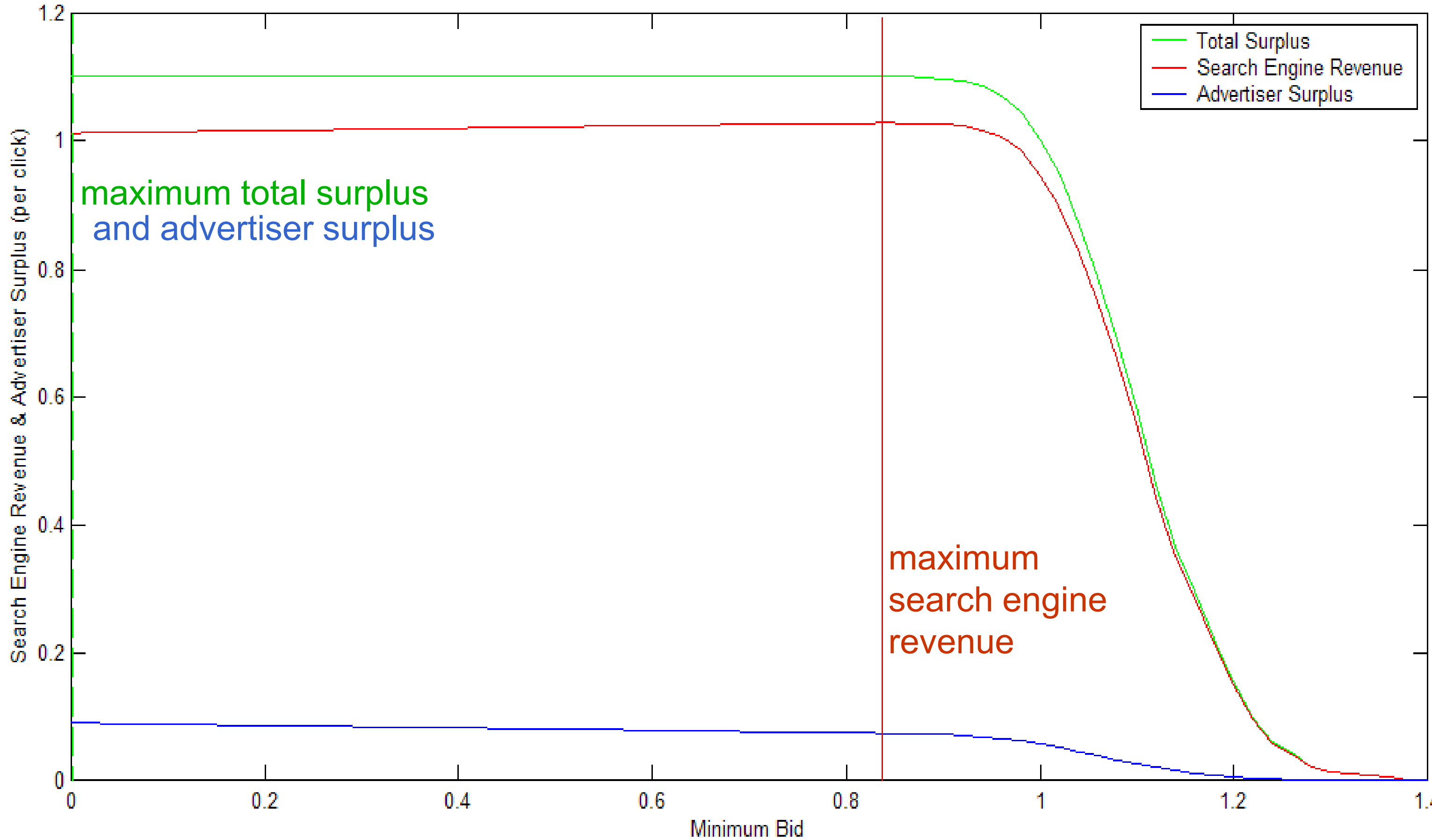
Optimal reserve prices

Optimal reserve prices

- What reserve price maximizes search engine revenue?
- How do outcomes differ from optimal reserve price? From the reserve price that maximizes advertiser surplus?

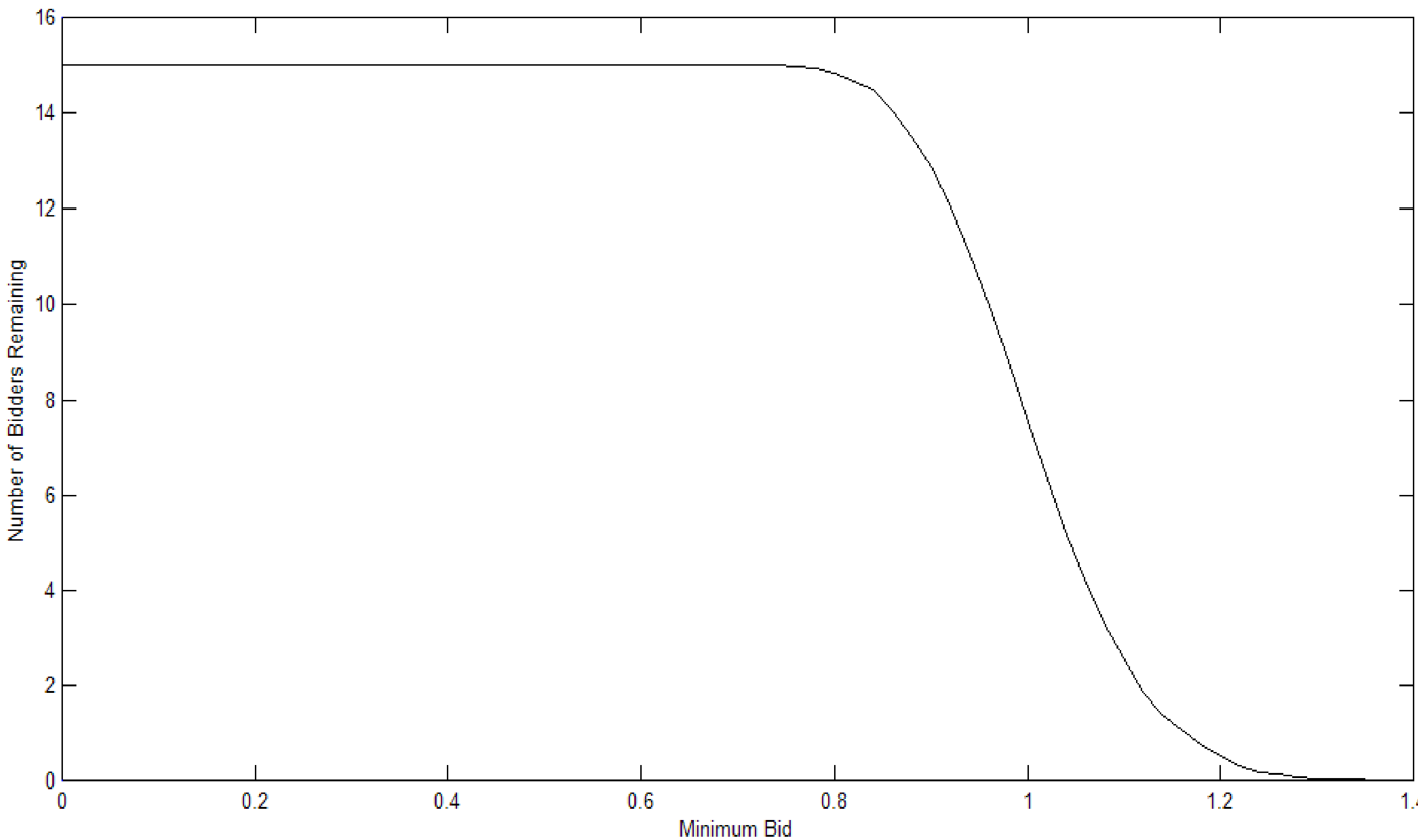
Method: Simulate a set of vectors of valuations. Use equilibrium bid formula to compute bids. Compute outcomes under each minimum bid rule.

SE Revenues and Adv Surplus

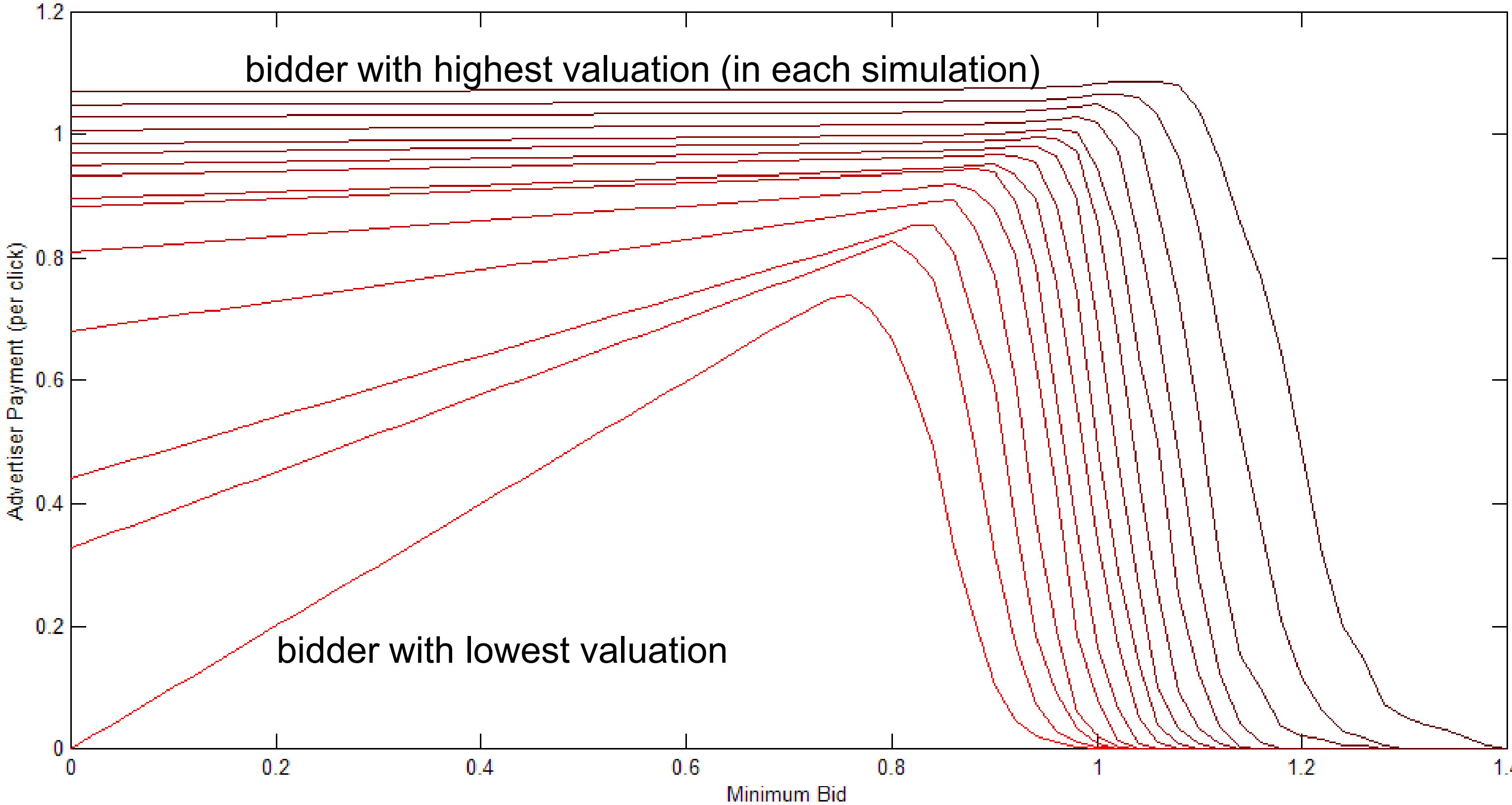


s_i ~ lognormal (1, 0.01)

Number of Bidders Remaining



Individual Bidders' Per-Click Payments

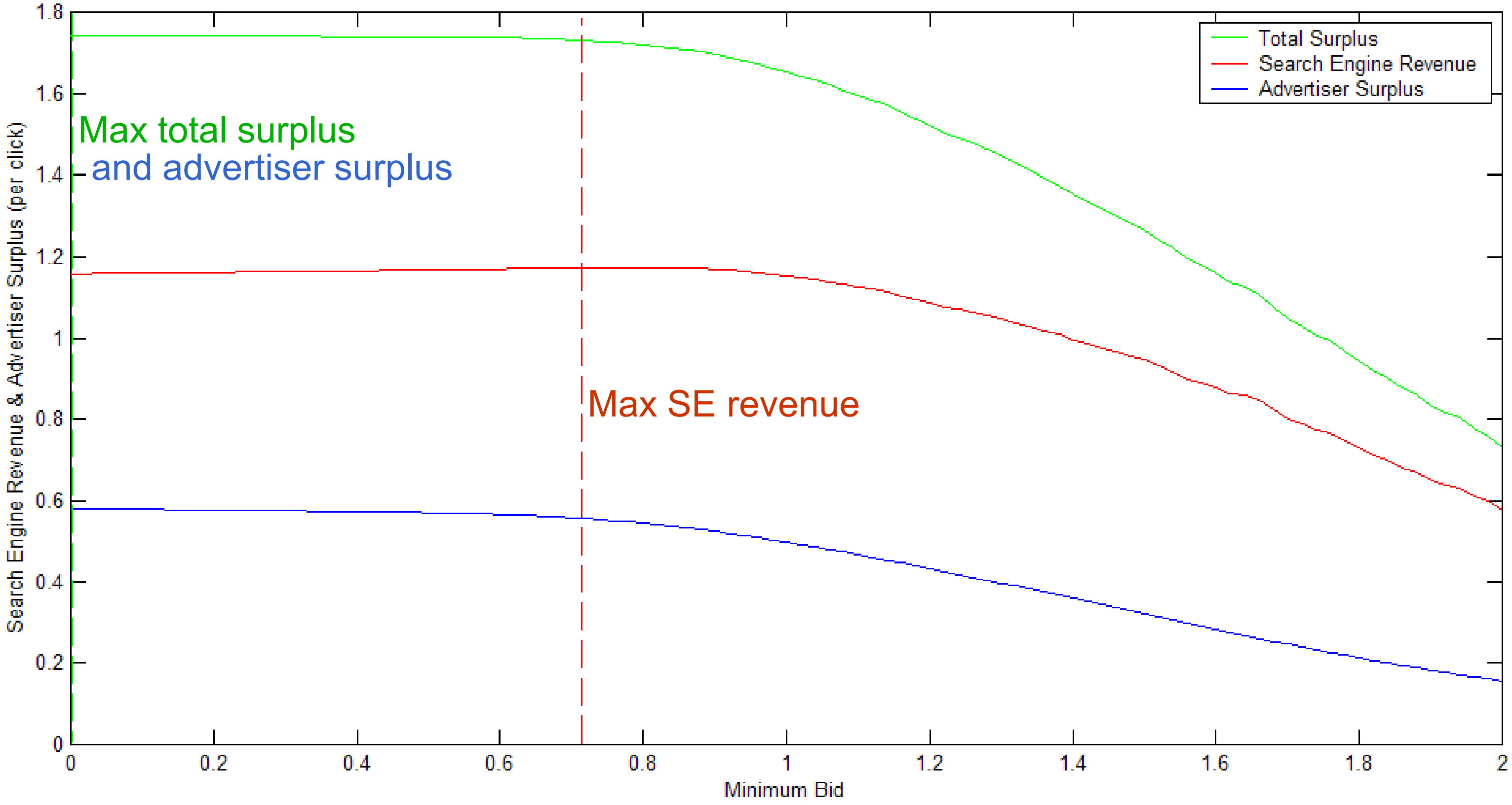


Optimal reserve prices: results

	set minimum bid to maximize		
	SE Rev	Adv & Ttl Surp	difference
Min Bid	0.840	0	0.840
SE Rev	1.029	1.013	0.016
Adv. Surplus	0.073	0.090	-0.017
Total Surplus	1.102	1.103	<0.001
p_1	1.075	1.070	0.005
p_K	0.840	0	0.840
$\alpha_1 p_1$	1.075	1.070	0.005
$\alpha_K p_K$	0.003	0	0.003

s_i ~ lognormal (1, 0.01)

With more variation in valuations



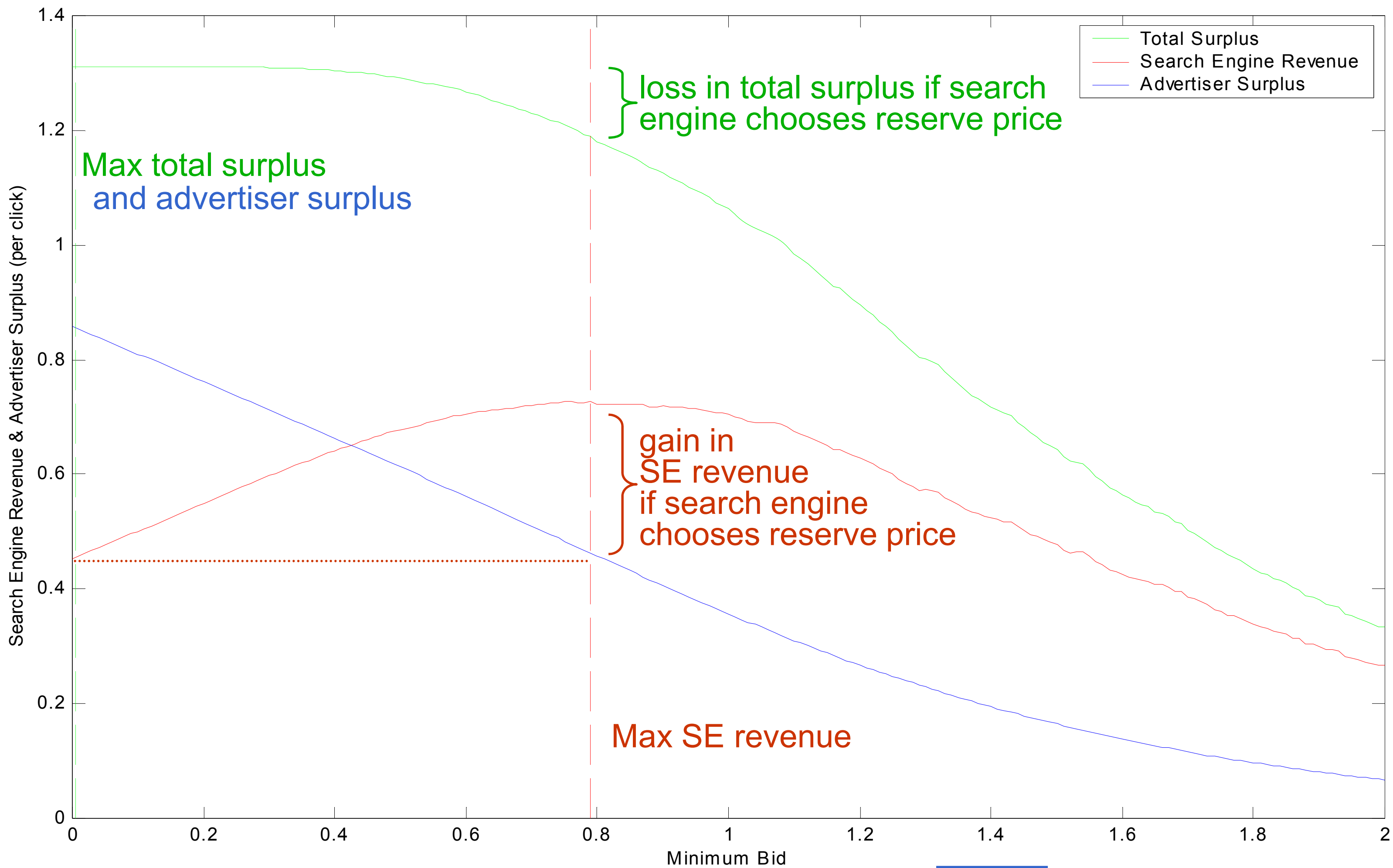
s_i ~ lognormal (1, **0.25**)

With more variation in valuations

	set minimum bid to maximize		
	SE Rev	Adv & Ttl Surp	difference
Min Bid	0.740	0.000	0.740
SE Rev	1.174	1.159	0.015
Adv. Surplus	0.554	0.581	-0.027
Total Surplus	1.728	1.740	-0.012

s_i ~ lognormal (1, **0.25**)

With fewer bidders

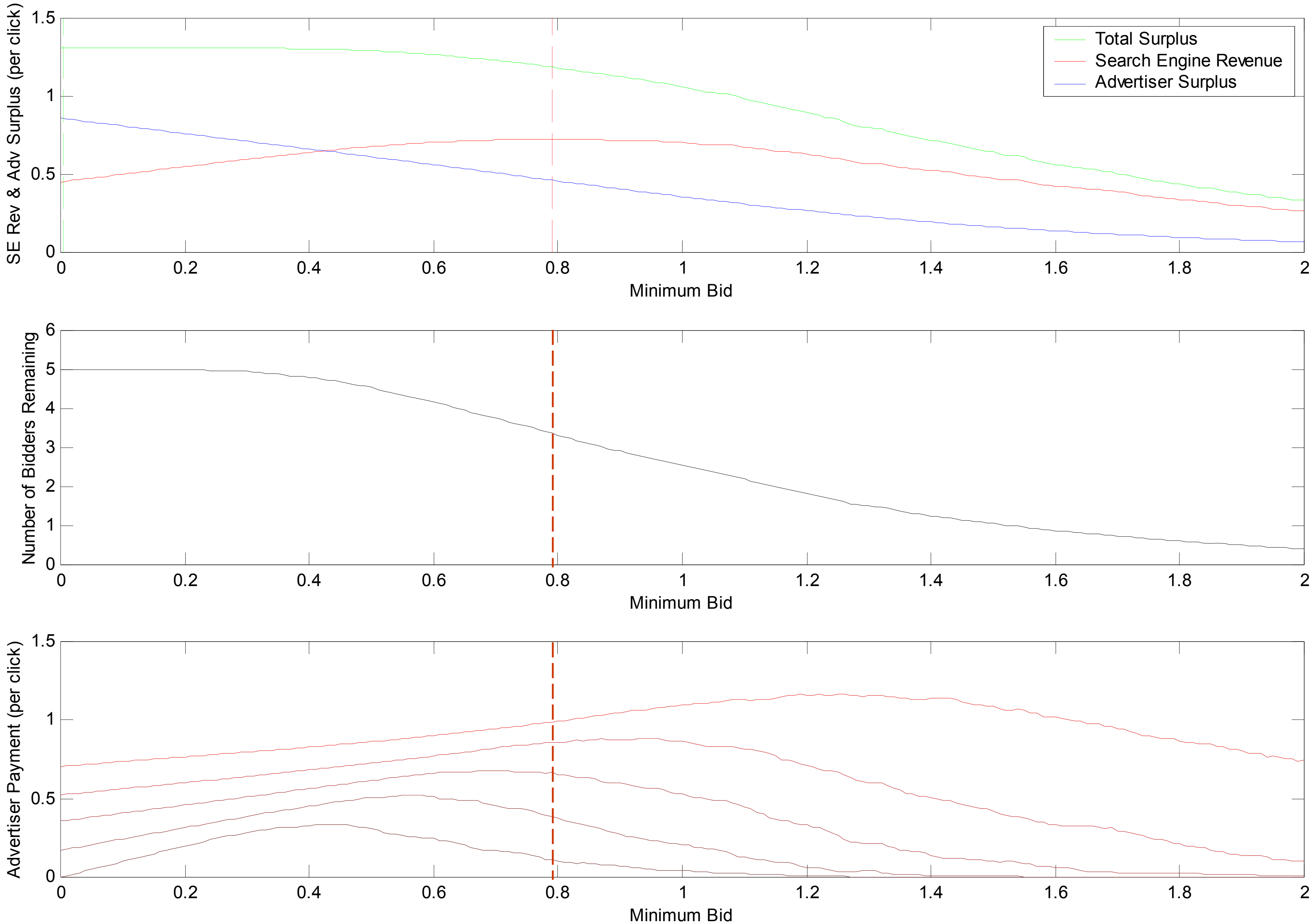


K=5 $s_i \sim$ lognormal (1, **0.25**)

With fewer bidders

	set minimum bid to maximize		
	SE Rev	Adv & Ttl Surp	difference
Min Bid	0.790	0.000	0.790
SE Rev	0.728	0.452	0.276
Adv. Surplus	0.463	0.859	-0.396
Total Surplus	1.190	1.311	-0.121

K=**5** s_i ~ lognormal (1, **0.25**)

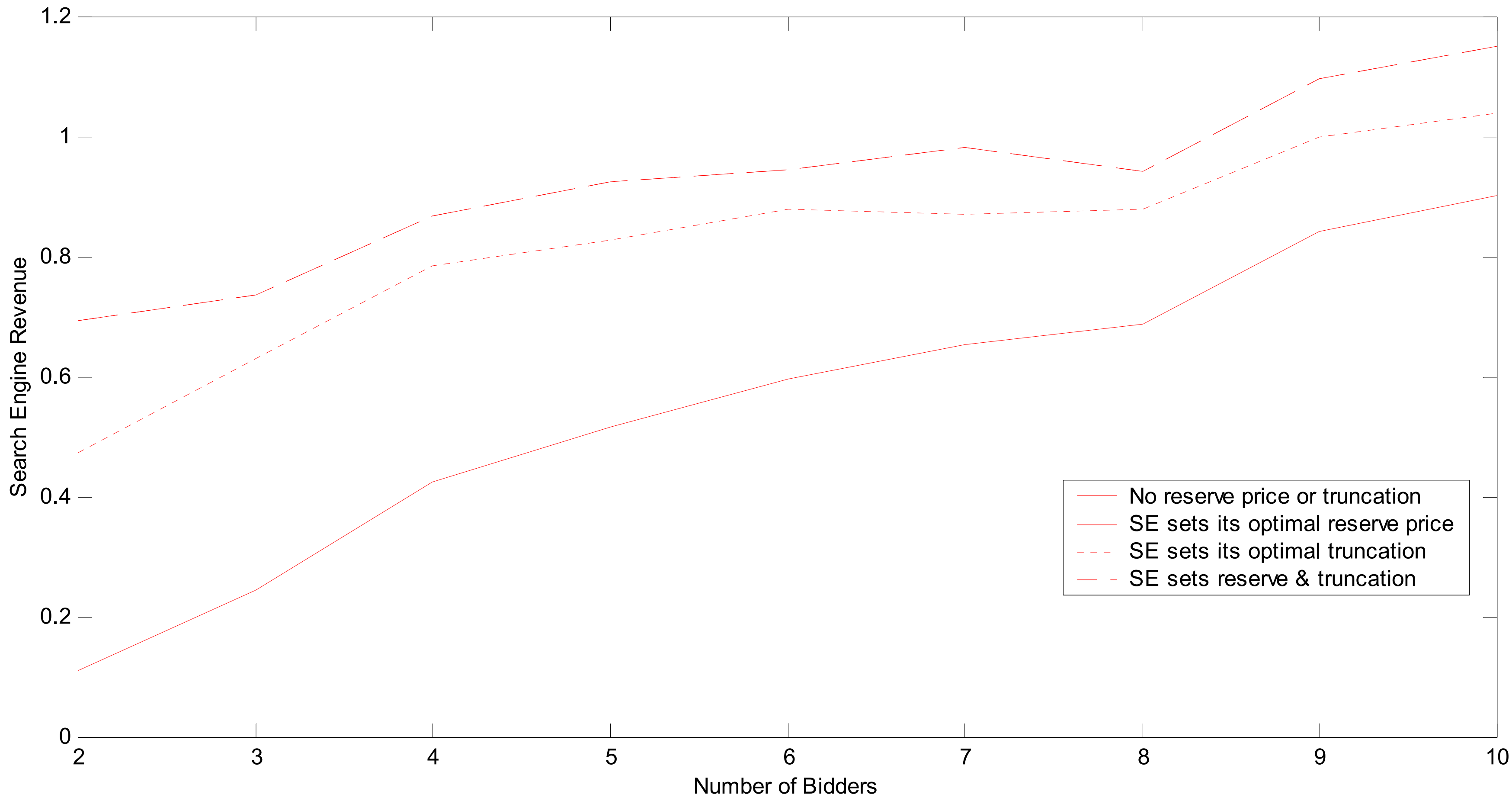


SE Rev & Adv Surplus (per click)
0
0.5
1
1.5
Total Surplus
Search Engine Revenue
Advertiser Surplus
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Minimum Bid
Number of Bidders Remaining
0
1
2
3
4
5
6
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Minimum Bid
Advertiser Payment (per click)
0
0.5
1
1.5
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Minimum Bid

The “holding back” alternative

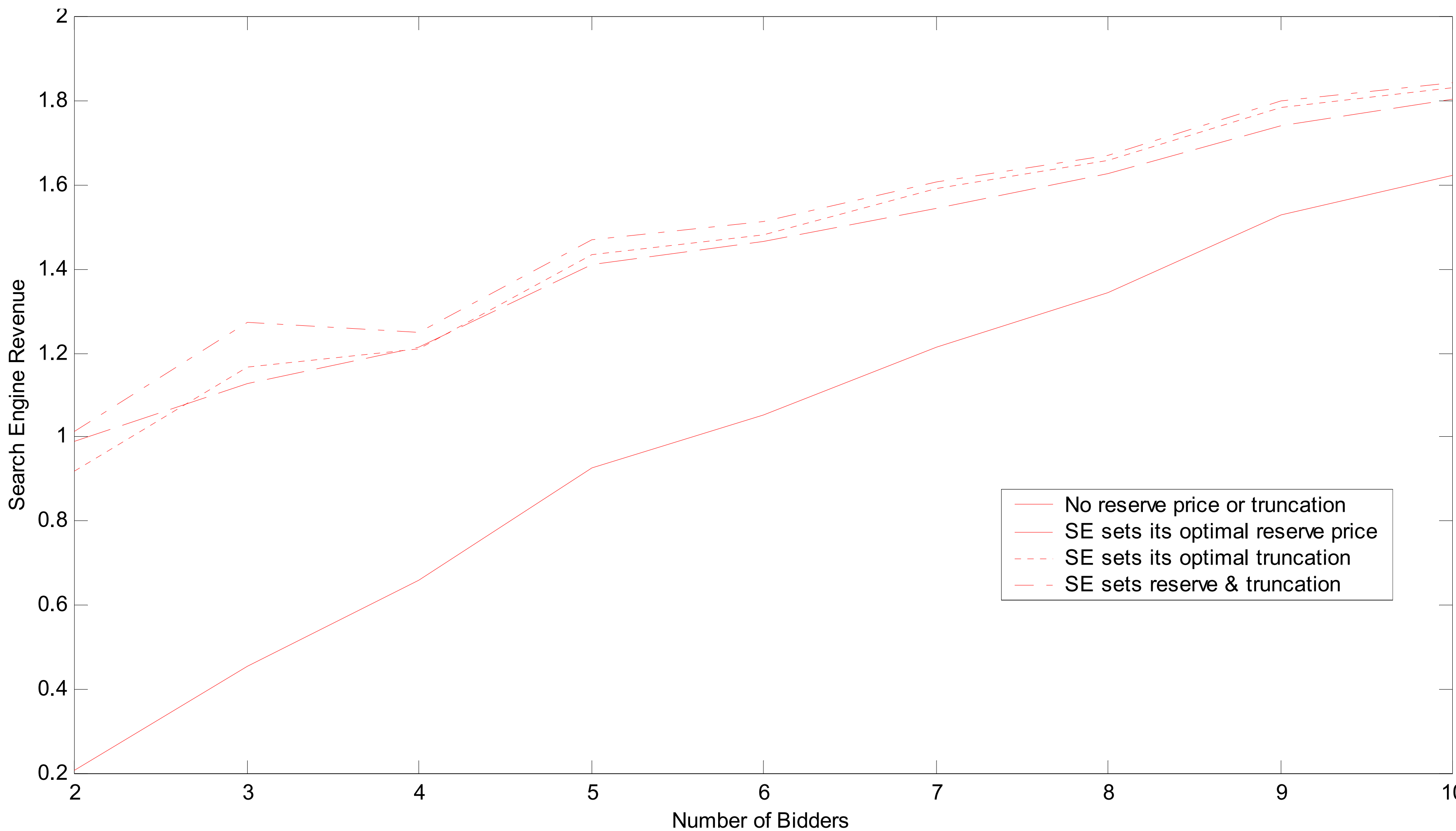
- Offering fewer units to increase the selling price

“Holding back” simulations



lognormal valuations

With structured variation in valuations



keyword markets with two different mean valuations (1 and 3)

Other simulation questions

- If bidders are misinformed about the rules, but bid rationally based on what they know, what result?
  - Useful in litigation, policy-making.
- What policy changes to achieve a particular split of the surplus between advertisers and search engine?
- …?

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Benjamin Edelman
Portions with Michael Ostrovsky and Michael Schwarz