

# Auction Econometrics

## Empirical Industrial Organization

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- Structural approach: we want to estimate primitives of the auction model, i.e. valuations
- From the observation of the bids  $b_1, \dots, b_n$  (and the auction rules) we want to recover the valuations  $v_1, \dots, v_n$  or equivalently the distribution  $F(v)$ .
- We can use observations of repeated auctions (assumption of the same bidders)
- When  $F$  is estimated, then the following questions can be addressed:
  - Market power of bidders: margin  $v - p$
  - Optimal auction format (maximize revenue)
  - Optimal reserve price

# Refresher Theory

- Assume there are  $I$  bidders
- bidder  $i$  has valuation  $U_i$
- $U_i$ s are i.i.d. draws from a distribution  $F$  with density  $f$
- in a second price auction, the equilibrium bid of bidder  $i$  is  $b_i = U_i$
- in a first-price auction, the equilibrium bid of bidder  $i$  is given by

$$\beta(U_i) = E[U_{-i} | U_{-i} < U_i]$$

where  $U_{-i} = \max_{j \neq i} U_j$  is the highest bid by a competitor

- the bid in a first-price auction can also be written as

$$\beta(U_1) = U_1 - \int_0^{U_1} \left( \frac{F(x)}{F(U_1)} \right)^{I-1} dx$$

# Refresher Theory

- There is a revenue equivalence between first-price auctions and second-price auctions: both generate the same expected revenue
- Revenue equivalence also holds when there is a reserve price
- The optimal reserve price is given by

$$r - \frac{1 - F(r)}{f(r)} = c$$

where  $c$  are the (opportunity) costs of the seller

# Estimation of First-Price auction

Distinct empirical approaches to infer distribution  $F$ :

- 1 Laffont, Ossard and Vuong (Econometrica 1995):  
“Econometrics of First-Price Auctions”
  - Use revenue equivalence theorem (“elegant”)
- 2 Donald and Paarsch (1993):
  - “Brute-force” approach: computationally intensive
- 3 Guerre, Perrigne and Vuong (Econometrica 2000): Indirect inference approach
  - Very influential methodology, straightforward and relatively simple

# Estimation of First-Price auction

Laffont, Ossard and Vuong (1995)

- Observe winning bids only
- Dutch auction (bidders with lower bids never have a chance to bid)
- Idea: revenue equivalence
- By revenue equivalence:

$$E[\textit{Winning Bid}] = E[\textit{2nd Highest Valuation}]$$

Can infer directly the distribution of second highest valuation (second order statistic).

- Need parametric assumption on the distribution of valuation:  $f(v|\theta)$ ,  $F(\cdot)$

# Estimation of First-Price auction

Laffont, Ossard and Vuong (1995)

- Simulation estimator in practice: for a value of parameter  $\theta$  and each auction  $l$ 
  - Prepare  $S$  simulations  $s = 1 : \dots, S$
  - Draw  $v_1^s, \dots, v_N^s$ , vector of simulated valuations for auction  $l$
  - Sort the draws in ascending order
  - Set  $b_l = v_{(2)}$  (2nd highest valuation)
  - Approximate  $E(b_l; \theta) = \frac{1}{S} \sum b_l^s$
  - Estimate  $\theta$  by simulated non linear least squares:

$$\min_{\theta} \frac{1}{L} \sum_l (b_l^w - E(b_l^w; \theta))^2$$

- Caveat:
  - Revenue equivalence assumes symmetric bidders (does not work for bidder heterogeneity)
  - Requires a parametric assumption on the distribution function

# Estimation of First-Price auction

## Direct inference approach

- Donald and Paarsch (1993), and others
- Idea: need to specify the density of observed data (which are bids) to write down likelihood.
- Find inverse bid function:

$$v = b^{-1}(b, \theta)$$

where  $\theta$  are parameters of density.

- Plug into distribution

$$F(b^{-1}(b, \theta), \theta)$$

Distribution of bids:

$$H(b, \theta) = F(b^{-1}(b, \theta), \theta)$$

with density

$$h(b, \theta) = f(b^{-1}(b, \theta), \theta) \cdot \frac{\partial b^{-1}(b, \theta)}{\partial b}$$



# Estimation of First-Price auction

## Direct inference approach

- Notice that:

$$\frac{\partial b^{-1}(b, \theta)}{\partial b} = \frac{1}{\frac{\partial b(v)}{\partial v}}$$

which has a simple analytic form for some distributions  $F$ .

- Example: Uniform distribution with  $N$  bidders:  $v \sim U[0, \theta]$

$$b(v) = \frac{n-1}{n} v$$

$$b'(v) = \frac{n-1}{n}$$

- Likelihood:

$$L(\theta) = \prod_{t=1}^T \prod_{i=1}^N f(b^{-1}(b_i^t, \theta), \theta) \cdot \frac{\partial b^{-1}(b_i^t, \theta)}{\partial b}$$

# Estimation of First-Price auction

## Direct inference approach

- Caveat: regularity condition of Maximum Likelihood is violated, support of bids depends on  $\theta$
- Donald and Paarsch (1993) derive asymptotic distribution of ML estimator.
- Asymmetric bidders, bidder heterogeneity  $\implies$  Need to numerically solve for the equilibrium (no analytic expression is known).
- Computationally very intensive.

# Estimation of First-Price auction

## Indirect Inference

- Guerre, Perrigne and Vuong (Econometrica, 2000)
- Idea: Use best response vis-a-vis the empirical distribution of opponents' bids.
- Observe bids, and thus observe density and distribution of bids.
- Bidder  $i$ 's problem: win if  $b_i \geq b_j$  for all  $j \neq i$  Probability of winning is  $H(b)^{N-1}$
- A risk neutral bidder will choose a bid that solves

$$\max_b [v - b] H(b)^{N-1}$$

# Estimation of First-Price auction

## Indirect Inference

- FOC:

$$-H(b)^{N-1} + [v - b](N - 1)H(b)^{N-2}H'(b) = 0$$

or

$$v = b + \frac{H(b)}{(N - 1)H'(b)}$$

- We need first to estimate the distribution (and density) of bids  $H(b)$

# Estimation of First-Price auction

## Indirect Inference

- Can estimate  $\hat{H}$  consistently using the empirical distribution function

$$\hat{H}(b) = \frac{1}{TN} \sum_t \sum_i \mathbf{1}(b_i^t \leq b)$$

and Kernel estimator for  $\hat{H}'(b)$

$$\hat{H}'(b) = \frac{1}{TN} \sum_t \sum_i \frac{1}{h_g} \kappa\left(\frac{b - b_i^t}{h_g}\right)$$

where  $\kappa(\cdot)$  is a kernel function (e.g. normal pdf).

# Estimation of First-Price auction

## Indirect Inference

- $h_g$  is bandwidth parameter (goes to zero as  $T$  goes to infinity)
- We can find optimal bandwidth
- Rule of thumb:  $h = \text{std}(\text{bids}) \times (\# \text{observations})^{-1/5}$
- If  $h_g$  is zero we get empirical cdf
- Kernel:
  - Epanechnikov:  $\kappa(u) = 0.01(1 - u^2)(|u| \leq 1)$
  - Normal:  $\kappa(u) = \frac{1}{\sqrt{2\pi}} \exp(-\frac{u^2}{2})$
  - Uniform:  $\kappa(u) = \frac{1}{2}|u| \leq 1$
  - Triangular:  $\kappa(u) = (1 - |u|)(|u| \leq 1)$

# Estimation of First-Price auction

## Indirect Inference

- To estimate distribution of  $v$ , generate *pseudo-values*  $\hat{v}$ :

$$\hat{v}_{it} = b_{it} + \frac{\hat{H}(b_{it})}{(N-1)\hat{H}'(b_{it})}$$

and then estimate distribution function

$$\hat{F}(v) = \frac{1}{TN} \sum_t \sum_i \mathbf{1}(\hat{v}_{it} \leq v)$$

and pdf

$$\hat{f}(v) = \frac{1}{TN} \sum_t \sum_i \frac{1}{h_f} \kappa \left( \frac{\hat{v}_{it} - v}{h_f} \right)$$

# Estimation of First-Price auction

## Indirect Inference

- With  $\hat{F}$  in hand we can:
  - design optimal auction,
  - find optimal reserve price,
  - market design.
- Indirect inference approach extends to:
  - asymmetric bidders,
  - common values,
  - other auction rules.



# Estimation of First-Price auction

## Identification

When is the distribution of private information identified?

- Distribution is identified if for any  $F_1, F_2$  consistent with data it must be that  $F_1 = F_2$ .
- Problem illustration: Suppose we have many data points (bids) Question: When is true distribution  $F$  uniquely determined from the data?
- Note that non-identification may arise in pooling equilibria  $\implies$  need a separating equilibrium (single crossing).
- Ideally: Examine identification problem prior to estimation.

# Estimation of First-Price auction

## Identification

- From earlier result we know that the inverse bid function

$$v = b + \frac{H(b)}{(N-1)H'(b)}$$

is strictly monotone.

- Guerre, Perrigne and Vuong (Econometrica, 2000):  
*Proposition: Distribution  $F$  is identified if and only if  $\frac{H(b)}{H'(b)}$  is strictly monotone.*
- Does identification result extend to bidder asymmetry in first-price auctions?
- Yes, because the bid function remains strict monotone.
- FOC characterizes  $v$  as a residual vis-a-vis the distribution of opponents' bids.

# Estimation of a Second-Price Auction

## Second-price auction

- Consider the dominant strategy equilibrium  $b(v) = v$
- Distribution of bids is identical to the distribution of private values.
- Hence: Distribution  $F$  is identified.

# Estimation of a Second-Price Auction

- Assumption: Data,  $\left( (b_i^t)_{i=1}^N \right)_{t=1}^T$  on a cross section of auctions,  $t = 1, \dots, T$ , is available, each auction with
  - 1 an identical object
  - 2 fixed number of bidders  $N$
  - 3 independent observations
- Assumption: bids are generated from the dominant strategy equilibrium in which

$$b_i(v_i) = v_i \quad \text{for all } i$$

- Estimate distribution function  $F$  using frequency estimator

$$\hat{F}(v) = \frac{1}{TN} \sum_t \sum_i \mathbf{1}(b_i^t \leq v)$$

- What if bids are not generated from dominant strategy equilibrium?

# Estimation of a Second-Price Auction

- When strategic equivalence applies then the earlier results from second-price auction extend.
- Note: English auctions used in practice may not share this strategic equivalence.
- English auction may feature:
  - 1 Discrete price increases sometimes step-size in the increment is chosen by bidder
  - 2 Open access: bidders may re-enter later-on, the number of remaining bidders may not be known
  - 3 Bidding costs bid preparation costs, costs to participating in the auction, etc.
- Ebay: late bidding (e.g. Bajari and Hortacsu, Rand (2003)).
- Haile and Tamer (2003) Incomplete model of an English auction.

- Auction is effective price discovery mechanism **under competition**
- Auction very sensitive to collusion
  - Small number of bidders, easily identifiable
  - Often repeated auctions
  - Collusion among bidders can benefit participants at the expense of the seller
- Collusion here is explicit, involves direct communication and side payments

# Collusion

## Collusive mechanisms

- Second price auction with IPV: ex post efficient collusion by any subset of bidders is possible
  - Implementation with a pre-sale knockout auction
- First price auction with IPV: efficient collusion possible if the ring includes all the bidders
  - E.g. territorial division of bidding privileges
  - Submits many identical bids at the reserve price

# Collusion

## Detection of collusion

- Main difficulty: bidders can submit artificially low bids to hide collusion
- Test for collusion (Porter & Zona 1993):
  - New-York state highway paving jobs
  - They know which bidders were part of the ring
  - Compare the distribution of bids within the two groups
  - Specifically the order of the bids (not the value/magnitude)
  - Exploit the theoretical relation between the order of the bid and cost measures
  - One should expect high cost bidders to place higher bids
  - Cost variables: firm capacity, distance, utilization rate
  - Bids from the cartel do not pass the test while bids outside the cartel pass the test



- Test for collusion (Porter & Zona 1999):
  - School milk procurement process
  - They know which bidders were part of the ring
  - Compare the magnitude of bids near the firm's plant and beyond their local territories.
  - Find that bids further away were not higher than bids for local territory
  - Suggests that bids in the local territory not competitive
  - Consistent with territory allocation
  - Key element here: distance as a cost shifter