Identification of Time and Risk Preferences in Buy Price Auctions

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Introduction

Goal: Identification of structural parameters in auctions with buy price

- Buy Price (BP): option to purchase a good at a fixed price
- eBay "buy-it-now," GMAC fleet auctions, etc.
- BP option appeals to bidders who are risk averse and/or impatient
- Conjecture: BP format can be used to identify risk aversion and impatience
- In ordinary auctions, very difficult to recover risk aversion from observe bidder actions

Approach

- Set up a model for BP auctions
  Stylized, but captures key dynamic structure and does not impose functional forms on structural parameters
- Characterize equilibria
- Show nonparametric identification of structural parameters under suitable exogenous variation
- Extensions to limited variation in auction features, and alternative auction mechanisms (including eBay)

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Background

- **Theory:** Budish & Takeyama (2001), Mathews (2004), Mathews & Katzman (2006), Hidvégi, Wang, & Whinston (2006), Gallien & Gupta (2007), Wang, Montgomery, & Srinivasan (2008), Reynolds & Wooders (2009).
- **Identification in Auctions:** Guerre, Perrigne, and Vuong (2000), Li, Perrigne, and Vuong (2002), Athey and Haile (2002), Haile and Tamer (2003).
- **ID of Risk Aversion in Auctions:** Campo, Guerre, Perrigne, and Vuong (2002), Bajari and Hortacsu (2005), Campo (2006), Athey and Haile (2007), Lu and Perrigne (2008), Guerre, Perrigne, and Vuong (2009).

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Basic Model

IPV buy price auction with fixed length bidding phase

Auction parameters:

- r: reserve price (minimum bid)
- $p \geqslant r$: buy price
- $\tau > 0$: fixed length of bidding phase

Continuous time: $t \geqslant 0$.

Potential bidders arrive according to an inhomogeneous Poisson process with arrival rate $\lambda(t)$.

After a potential bidder arrives:

- Can wait
- If BP option available, can choose to accept it (paying p), ending the auction
- If BP option available, can instead initiate bidding phase, eliminating BP option
- If in bidding phase, can submit a sealed bid $b \geqslant r$.

Valuations of bidders: $v_i \overset{\text{iid}}{\sim} F_V$.

Bidder utility function: if bidder who arrives at time t_i wins the good at time t and pays p, she obtains utility

$$\delta(t - t_i)U(v_i - p).$$

Allow for impatience ($\delta' < 0$) and risk aversion ($U'' \leqslant 0$).

Normalizations: $U(0) = 0, U'(0) = 1, \delta(0) = 1$.

Structural parameters:

$$\lambda(\cdot), F_V(\cdot), \delta(\cdot), U(\cdot).$$

We can think of these as conditional on auction-level covariates.

Our goal is to identify structural parameters from observable data on bidding behavior.

Assumption: Bidders do not play weakly dominated strategies.

Proposition: Any symmetric, pure strategy, perfect Bayesian-Nash equilibrium (BNE) of this auction game has the following properties:

1. Potential bidders with $v < r$ never take any action.
2. Potential bidders with $v > r$ who arrive during the buy price phase act *immediately* (accept or reject BP)
3. Potential bidders with $v > r$ who arrive during the bidding phase place a sealed bid equal to v at some point before the end of the auction.

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Accepting vs. Rejecting the BP

Consider such a bidder with valuation v who arrives at time t when BP option still available.

If the bidder accepts the BP option immediately, she will obtain payoff

$$U^A(v,p) := U(v-p).$$

($\delta(0)$ normalized to 1.)

If instead bidder places a sealed bid, she will compete with a random number of other bidders who arrive in $[t, t+\tau]$.

$$U^R(v, r, \tau, t) := \delta(\tau) \cdot \Big\{ e^{-\gamma} U(v - r) + \sum_{n=1}^{\infty} \frac{\gamma^n e^{-\gamma}}{n!} F_V^n(v) E_n \left[U(v - \max\{r, Y\}) | Y \leqslant v \right] \Big\},$$

where $F_V^n(v) = [F_V(v)]^n$, E_n is expectation under F^n, and

$$\gamma = \int_t^{t+\tau} \lambda(s) ds,$$

Simplification:

$$U^R(v,r,\tau,t) = \delta(\tau)\left[\alpha(r,\tau,t)U(v-r) + \int_r^v U(v-y)h(y,\tau,t)dy\right],$$

where

$$\alpha(r,\tau,t) = \exp(\gamma F_V(r) - \gamma),$$
$$h(y,\tau,t) = \exp(\gamma F_V(y) - \gamma)\gamma f_V(y),$$

Cutoff Rule

Under some conditions on the structural parameters, a bidder arriving at time t with valuation v:

- Accepts the BP if $v > c(p, r, \tau, t)$
- Rejects the BP if $v < c(p, r, \tau, t)$
- Is indifferent if $v = c(p, r, \tau, t)$.

What conditions guarantee cutoff rule? $U''' \leqslant 0$ is sufficient for any $\lambda(\cdot), F_V(\cdot), \delta(\cdot)$, but weaker conditions possible.

Certainty Equivalent of Rejecting the BP

$$M(v) = U^{-1}\left(\delta(\tau)\left[\alpha(r,\tau,t)U(v-r) + \int_r^v U(v-y)h(y,\tau,t)dy\right]\right).$$

Sufficient condition for cutoff rule is that $M'(v) < 1 - \epsilon$.

(Necessary: $M'(v) \leqslant 1$.)

Properties of $c(p,r,\tau,t)$

Under these conditions, the cutoff function satisfies:

$$U(c(p,r,\tau,t)-p)=\delta(t)\Big[\alpha(r,\tau,t)U(c(p,r,\tau,t)-r) + \int_r^{c(p,r,\tau,t)} U(c(p,r,\tau,t)-y)h(y,\tau,t)dy\Big].$$

and

$$c_p(p,r,\tau,t)>0$$
$$c_r(p,r,\tau,t)<0$$
$$c_\tau(p,r,\tau,t)\leqslant 0$$

Inverse Cutoff Function

By strict monotonicity, there is an inverse cutoff function $p(c, r, \tau, t)$ satisfying:

$$U(c - p(c, r, \tau, t)) = \delta(t) \left[\alpha(r, \tau, t) U(c - t) + \int_r^c U(c - y) h(y, \tau, t) dy \right].$$

This will be useful in identification arguments.

Identification: Setup

Heuristically: many independent realizations of auctions, with

- same $\lambda(\cdot), F_V(\cdot), \delta(\cdot), U(\cdot)$;
- variation in r, p, τ
- (after conditioning on auction-level covariates).

Formally:

- $(R, P, \Upsilon) \sim F_{r,p,\tau}$.
- Conditional on $R = r, P = p, \Upsilon = \tau$, the auction model above generates a distribution over observed bidder actions.

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Observational Model

We observe R, P, Υ and

- T_1: time of first action (either accept or reject BP)
- $B = 0$ if reject BP, $B = 1$ if accept BP
- optional: final price

So

$$\{F_{r,p,\tau}, \lambda, F_V, U, \delta\} \to F(R, P, \Upsilon, T_1, B).$$

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Support conditions

Identification will rely on variation in auction design parameters.

Initially, assume a large support:

$$\begin{aligned} supp(R) &= [0, \infty) \\ supp(P|R = r) &= [r, \infty) \\ supp(\Upsilon|R = r, P = p) &= [0, \infty) \end{aligned}$$

We will consider weaker conditions below.

Identification of λ and F_V

$\lambda(t)$: consider $r = 0$

- Since $r = 0$, the first bidder who arrives will take some action.
- So hazard rate of T_1 given $R = 0$ is same as $\lambda(t)$ ✓

F_V: consider $r > 0$

- Hazard rate of T_1 :

$$\lambda(t)(1 - F_V(r)).$$

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- Testable restrictions: can consider different t

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Identification of $c(p, r, \tau, t)$

Fix p, r, τ, and suppose $T_1 = t_1$.

At T_1, there is a bidder who draws valuation $V \sim F_V$.

Probability of accepting BP option:

$$Pr(B = 1|p, r, \tau, t_1) = Pr(V > c(p, r, \tau, t_1)|V > r) = \frac{1 - F_V(c(p, r, \tau, t_1))}{1 - F_V(r)}.$$

Since F_V identified, we can recover $c(p, r, \tau, t_1)$ and hence $p(c, r, \tau, t_1)$. ✓

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Identification of U

We have identified λ, F_V, c, p, hence α and h.

Indifference condition:

$$U(c - p(c, r, \tau, t)) = \delta(t) \left[\alpha(r, \tau, t) U(c - r) + \int_r^c (c - y) h(y, \tau, t) dy \right].$$

Is there a unique U and δ that satisfies this integral equation?

Drop $\delta(t)$ for now, consider $r = 0$, fixed t, τ.

- We have an integral equation over c:

$$U(c - p(c)) = \alpha U(c) + \int_0^c U(c - y) h(y) dy.$$

- This is a Volterra equation.
- But nonstandard due to *delay* term $U(c - p(c))$.
- Identification if U is analytic, but this is undesirable.

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We can get rid of delay term by working in both r, c dimensions.

$(\star)$

$$U(c - p(c,r,\tau)) = \delta(\tau)\left[\alpha(r,\tau)U(c-r) + \int_r^c U(c-y)h(y,\tau)dy\right].$$

Differentiate $(\star)$ wrt c:

$$U'(c - p(c,r,\tau))(1 - p_c(c,r,\tau)) = \delta(\tau)\Big[\alpha(r,\tau)U'(c-r) + \int_r^c U'(c-y)h(y,\tau)dy\Big].$$

Differentiate ($\star$) wrt r:

$$-U'(c - p(c, r, \tau))p_r(c, r, \tau) = -\delta(\tau)\alpha(r, \tau)U'(c - r).$$

Take ratio of two derivatives:

- Eliminates delay term
- Eliminates δ

Differentiating the ratio wrt r gives an ODE

$$U''(c - r) = \Psi(c, r, \tau)U'(c - r).$$

where Ψ is identified.

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Set $r = 0$:

$$\frac{U''(c)}{U'(c)} = \Psi(c, 0, \tau).$$

Identification: using the normalization $U'(0) = 1$ as an initial condition, there is a unique solution in C^2 given by

$$U'(c) = \exp\left(\int_0^c \Psi(c, 0, \tau)\right).$$

✓

Identification of δ

From indifference condition:

$$\delta(\tau) = \frac{\alpha(r,\tau,t)U(c-r) + \int_r^c U(c-y)h(y,\tau,t)dy}{U(c-p(c,r,\tau,t))}.$$

RHS is identified, so $\delta(\tau)$ is identified. ✓

Some (limited) intuition

- Start with some $r, p, c = c(r, p, \tau, t)$.
- $r \to r + 1$.
- There is some $\Delta > 0$ s.t.

$$c - p(c, r) = c + \Delta - p(c + \Delta, r + 1)$$

  (we are raising price such that new cutoff minus new price is same.)
- So

$$U(c - p(c, r)) = U(c + \Delta - p(c + \Delta, r + 1))$$

- Hence

$$\delta(\tau)\left[\alpha(r)U(c-r)+\int_r^c U(c-y)h(y)dy\right]$$

$$=\delta(\tau)\left[\alpha(r+1)U(c+\Delta-r-1)+\int_{r+1}^{c+\Delta} U(c+\Delta-y)h(y)dy.\right].$$

- We have constructed distinct lotteries that give same expected utility.

Working with limited support

- Basic ID uses $r \in [0, \infty)$, $p \in [r, \infty)$, $\tau \in (0, \infty)$.
- If $\tau = \tau_0$ wp1, we identify $\lambda(\cdot), F_V(\cdot), U(\cdot)$, and $\delta(\tau_0)$.
- If $r \in [r^l, r^u]$, we can only identify composite arrival $\lambda(t)(1 - F_V(v))$.
  U is identified on $[0, r^u - r^l]$.
- If $p \in (p_0 - \epsilon, p_0 + \epsilon)$, can recover Arrow-Pratt measure U''/U' at one point.
- Other variations possible

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eBay's "Buy-it-Now"

- In eBay BP auctions, the total length of the auction is fixed.
- Differs from our model where bidding phase has fixed length.
- In eBay BP auction, arriving bidders who want to reject BP do not have a strict incentive to so immediately.
- If these bidders wait, can't use variation in r to recover λ and F_V.

- Gallien and Gupta (2007) use a trembling-hand argument to rule out equilibria where these bidders wait.
- Other possibilities to rule out these equilibria, but may require different identification arguments.
- Could use stronger support conditions (e.g. $p = r$) to identify λ.

- In addition, with eBay style auctions it may be hard to estimate $\lambda(t)$ for t near end of auction.
- However, to recover U and δ we only really need α and h in

$$U(c - p(c,r,T,t)) = \delta(T-t)\Big[\alpha(r,T,t)U(c-r) + \int_r^c U(c-y)h(y,T,t)dy\Big]$$

where T is length of auction.

- α can be recovered from observed probability that BP rejector wins at reserve price.
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- Even without risk aversion and impatience, it is not easy to identify F_V in ordinary eBay auctions.
- Number of (potential) bidders is unknown.
- See Bajari and Hortacsu (2003), Song (2004), Canals-Cerda and Pearcy (2008).
- BP format helps by creating incentive to act immediately.

Estimation

- Due to overidentification, may not want to use ID results directly for estimation.
- Specify structural components parametrically or with sieves, then derive moment conditions or partial likelihood.
- Expressions for α and h simplify things, but require computation of cutoff functions and a few low-dimensional integrals.
- Parametric version with eBay data: Ackerberg, Shahriar, Hirano (in progress).

Conclusion

- Structure of BP auctions (plus some strong assumptions) generates rich identification.
- We can recover arrival rate, utility function, etc., nonparametrically.
- We identify U by viewing the BP format as generating different *lotteries* for the rejector.
- A lot of overidentifying restrictions.
- Connections to general identification/elicitation of utility functions that can be explored.