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Empirical relevance of ambiguity in first-price auctions ☆

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ABSTRACT

We study the identification and estimation of first-price auctions with independent private values if bidders face ambiguity about the valuation distribution and have maxmin expected utility. Using variation in the number of bidders we nonparametrically identify the true valuation distribution and the lower envelope of the set of prior beliefs. We also allow for CRRA and unobserved auction heterogeneity, and propose a Bayesian estimation method based on Bernstein polynomials. Monte Carlo experiments show that our estimator performs well, and incorrectly ignoring ambiguity induces bias and loss of revenue. We find evidence of ambiguity in timber auctions in the Pacific Northwest.

1. Introduction

There are large theoretical and experimental literatures on ambiguity aversion, starting with Knight (1921) and Keynes (1921), and the famous thought experiment of Ellsberg (1961), which suggests that decision makers prefer lotteries with known distributions to lotteries with unknown distributions. Ellsberg's thought experiment led to the development of models of decision making under ambiguity that generalize expected utility models (henceforth, EU); see Gilboa (2009). Numerous laboratory studies confirmed Ellsberg's conjecture and found evidence of ambiguity aversion; see, for example, Camerer and Karjalainen (1994), Fox and Tversky (1995), Salo and Weber (1995) and Halevy (2007). Despite these large literatures, very little is known about the empirical importance of ambiguity in real world markets.

In this paper we contribute to the literature on ambiguity aversion by showing how to identify and estimate the effect of ambiguity aversion in a real-world first-price auction market where bidders are symmetric and have independent private values. Bidding behavior in a first-price auction depends on the bidders' beliefs about the distribution of valuations. The empirical literature on first-price auctions generally assumes that bidders know the true valuation distribution. However, bidders may face ambiguity about the valuation distribution, especially if they have limited information. Therefore, any empirical strategy that ignores ambiguity and resulting policy recommendations will no longer be valid.

Determining the effect of ambiguity aversion on bidding is important for policy recommendations. Under ambiguity aversion the revenue equivalence principle fails (Lo, 1998). However, whether ambiguity aversion leads to more or less aggressive bidding than an ambiguity-neutral bidder in first-price auctions is theoretically not determined (Bodoh-Creed, 2012) and therefore is an empirical question. Furthermore, under ambiguity aversion the first-price auction is generally not optimal, and the optimal reserve price depends on ambiguity aversion; see Bose et al. (2006), Bose and Renou (2014) and Bodoh-Creed (2012).

☆ This paper combines and supersedes "Identification of First-Price Auctions With Biased Beliefs," by S. Grundl and Y. Zhu, and "Empirical Relevance of Ambiguity in First Price Auction Models," by G. Aryal and D.-H. Kim. We thank Stéphane Bonhomme, Francesco Decarolis, Amit Gandhi, Emmanuel Guerre, Ken Hendricks, Brent Hickman, Keisuke Hirano, Ali Hortaçsu, Doug McDonald, Jack Porter, Ricardo Serrano-Padial, Dan Quint, and audiences at various seminars and conferences. We also thank Bekah Richards for outstanding editing work. The analysis and conclusions set forth are those of the authors and do not indicate concurrence by the members of the staff, by either the Board of Governors, or by the Federal Reserve Banks, or the Bank of Canada.
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To model ambiguity we rely on the maxmin expected utility model (henceforth, MEU), which was axiomatized by Gilboa and Schmeidler (1989). They show that if the preferences satisfy certain axioms, the decision maker behaves as if she is maximizing her minimum expected utility, where the minimum is taken over a unique and convex set of priors Γ.[1] To use MEU in a strategic setting we assume that Γ is common knowledge among bidders, which is analogous to the common prior assumption of Harsanyi (1967).

In our context Γ is a set of valuation distributions, and the bidding strategy is determined by the lower envelope of Γ. Therefore, the bid distribution depends on the true valuation distribution and the lower envelope of Γ. As we cannot identify two unknown distributions from a single bid distribution, additional restrictions are necessary for point identification. We impose the exclusion restriction that neither Γ nor the true distribution of valuations depends on the number of bidders.[2] We show that the true valuation distribution and the lower envelope of Γ are point-identified under this assumption, by exploiting variation in the number of bidders.[3]

We extend the identification result to allow for constant relative risk aversion and for unobserved auction heterogeneity.[4] An extension to risk aversion is important because it can have a similar effect on bidding as ambiguity aversion. Allowing for unobserved auction heterogeneity is important because in most applications, the researcher cannot observe all relevant characteristics. We allow the unobserved auction heterogeneity to be correlated with the number of bidders, which means that bidders can select into auctions based on unobservable auction characteristics.

For estimation we propose a direct Bayesian method based on Bernstein polynomials. Bayesian methods were introduced in the empirical auction literature by Bajari (1997) and have subsequently been used by Sareen (1999, 2003), Li and Zheng (2009, 2012), Kumbhakar et al. (2012), Aryal and Kim (2013), Kim (2013) and Kim (2015). To model the lower envelope, we introduce a quantile–quantile function (henceforth, the D-function) that maps the true valuation distribution to the lower envelope of Γ. We then specify the valuation density and the D-function using Bernstein polynomials, and use the Bayesian decision rule to choose the reserve price.

We evaluate the performance of our estimation method in a series of Monte Carlo exercises. Initially, we consider two cases. In the first case the bid data are generated from a model with ambiguity, and in the second case without ambiguity. In both cases, the method precisely estimates the D-function, the true valuation distribution, and the CRRA parameter. It also chooses reserve prices that generate nearly maximal revenue. We then consider an additional scenario in which the bidders face ambiguity but the econometrician incorrectly uses the EU model. The effect of ambiguity on bidding is partly (and incorrectly) captured by the CRRA parameter, leading to overestimation of the CRRA coefficient. Even though this overestimation moves the reserve price in the right direction, model misspecification still results in a revenue loss.[5,6]

In our empirical application we study the U.S. Forest Service timber auctions between 1976 and 1978 that are set aside for small firms (most of whom were loggers) in the Pacific Northwest. We choose this time period because after the National Forest Management Act of 1976, the Forest Service switched from ascending auctions to first-price auctions as the main selling method in this region. As less than 2% of the sales before the end of 1976 were first-price auctions, the period after the policy change provides a suitable environment to study ambiguity. We find evidence of ambiguity among bidders — the posterior probability of the EU model is less than 5%. Our estimates imply that the seller has no incentive to eliminate ambiguity among the bidders because it leads to aggressive bidding. We also conduct counterfactuals where we "shut down" ambiguity and risk aversion to isolate their effects on the bids and the seller's revenue.

We also estimate the model using data from California, which borders the Pacific Northwest. However, unlike in the Pacific Northwest, in California the first-price auction was common before 1976. We find that the effect of ambiguity on bidding is very small in California.

In the remainder of the paper we proceed as follows. We discuss the model and identification in Section 2, the estimation methodology in Section 3, the Monte Carlo study in Section 4, and the empirical application in Section 5. Section 6 concludes.

2. Model and identification

An indivisible object is allocated to one of $n \geq 2$ bidders in a first-price auction without a binding reserve price. Each bidder $i \in \{1, \ldots, n\}$ observes her own value v_i and the number of bidders n, and then bids b_i. The values $v_1, \ldots, v_n$ are independent and identically distributed draws from $F_0(\cdot|n)$, with density $f_0(\cdot|n)$, which is strictly positive on the support $[\underline{v}(n), \overline{v}(n)]$. Bidders, however, *do not* know $F_0(\cdot|n)$. To model their bidding behavior, we make the following assumption.

Assumption 1. Bidders' preferences have the MEU representation.

MEU was axiomatized by Gilboa and Schmeidler (1989), and it generalizes the EU paradigm. If preferences have the MEU representation, then bidders have a set of priors Γ_n, rather than a single prior. We make the following assumptions about Γ_n.

Assumption 2.

(1) $F_0(\cdot|n) \in \Gamma_n$.
(2) The prior set Γ_n is common knowledge among the bidders.

The first part of this assumption ensures that the bidders do not rule out the true valuation distribution. The second part of this assumption allows us to use the MEU model in a strategic environment, in the spirit of Harsanyi (1967).

The bidders maximize their expected utility under the most pessimistic scenario that is consistent with Γ_n. Let $\beta_n(\cdot)$ be the equilibrium bid function. If all $(n-1)$ opponents use $\beta_n(\cdot)$, then a risk-neutral bidder with valuation v solves

$$\max_{y \in \mathbb{R}_+} \inf_{F \in \Gamma_n} \left\{ [v - \beta_n(y)]\, F(y|n)^{n-1} \right\} = \max_{y \in \mathbb{R}_+} \left\{ [v - \beta_n(y)]\, F^*(y|n)^{n-1} \right\}$$

[1] There are models of decision under ambiguity that distinguish between the decision maker's attitude toward ambiguity and ambiguity. The MEU model, however, does not make such distinction; see Machina and Siniscalchi (2014). Therefore, we use both terms interchangeably throughout the paper.

[2] Examples of papers using this restriction include Haile et al. (2006), Guerre et al. (2009) and Aradillas-Lopez et al. (2013). We discuss the assumption in more detail in Section 2.

[3] The set Γ cannot be identified because the bid function depends only on the lower envelope of Γ. As the bid function depends only on the lower envelope of Γ, the MEU first-price auction model is similar to a model with a single prior distribution, which is allowed to differ from the true valuation distribution and takes the role of the lower envelope in the MEU model. We discuss the similarities and differences between both models in Appendix C.

[4] See, for example, Athey and Levin (2001) and Krasnokutskaya (2011).

[5] Unlike risk aversion, ambiguity aversion can lead to more or to less aggressive bidding. Risk aversion can only capture some of the effects of ambiguity aversion on bidding, and thereby move the reserve price in the right direction, if ambiguity aversion leads to more aggressive bidding.

[6] Monte Carlo experiments comparing our method with an indirect frequentist estimation method can be found in Aryal et al. (2017).

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