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Nonparametric estimation of first-price auctions with risk-averse bidders

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ABSTRACT

This paper proposes nonparametric estimators for the bidders' utility function and density of private values in a first-price sealed-bid auction model with independent valuations. I study a setting with risk-averse bidders and adopt a fully nonparametric approach by not placing any restrictions on the shape of the utility function beyond regularity conditions. I propose a population criterion function that has a unique minimizer, which characterizes the utility function and density of private values. The resulting estimators emerge after replacing the population quantities by sample analogues. These estimators are uniformly consistent and their convergence rates are established. I further suggest an estimator for the optimal reserve price. Monte Carlo experiments show that the proposed estimators perform well in finite samples.

1. Introduction

Risk aversion is essential to understanding economic decisions under uncertainty. In first-price sealed-bid auctions, risk aversion plays a fundamental role in explaining bidders' behavior. Although several families of utility functions have been employed to describe different attitudes toward risk, in practice, we do not know which one accurately explains bidders' behavior.

I consider a first-price sealed-bid auction with risk-averse bidders within the independent private values (IPV) paradigm. In this setting, each potential buyer has his own private value for the item being sold and makes a sealed bid. The bidder who makes the highest bid wins the item and pays the seller the amount of that bid. This model can be characterized by two objects: the bidders' utility function and the density of private values. No parametric restrictions are imposed on these objects beyond standard regularity conditions. Guerre et al. (2009) have shown that this model is nonparametrically identified from observed bids under certain exclusion restrictions. Their primary exclusion restriction is exogenous bidders' participation, which implies that the density of private values is independent of the number of participants.

The objective of this paper is to propose nonparametric estimators for the bidders' utility function and the density of private values based on Guerre et al. (2009)'s exogenous participation restriction. With this aim, first, I construct a population criterion function that has a unique minimizer, which characterizes these two objects. Second, this minimizer is estimated by minimizing the empirical counterpart of the criterion function over a finite-dimensional space of functions (sieve space). The empirical version of the criterion is estimated from observed bids and we consider the Bernstein polynomials as our sieve basis due to its shape-preserving property and computational tractability. Third, the estimators of the bidders' utility function and density of private values are constructed as nonlinear functionals of the estimated minimizer.

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The proposed estimators for these two objects are uniformly consistent and their convergence rates are established. Among other features, the estimator of the utility function is shape-preserving (i.e., strictly increasing and concave) regardless of the sample-size. The estimator of the private value density is developed by extending Guerre et al. (2000)'s approach to accommodate risk aversion without relying on a parametric specification of the bidders' utility function. I highlight that these estimators allow for the presence of exogenous covariates to account for heterogeneity in the auctioned object. To implement this feature, I extend Barron and Sheu (1991)'s exponential series density estimator to conditional densities.

The results obtained in this paper are useful for public policy recommendations. First-price sealed-bid auctions are used in many socio-economic contexts such as timber sales, outer continental shelf wildcat auctions (Li et al., 2003), and competitive sales of municipal bonds (Tang, 2011). The auctioneer usually faces the problem of finding the optimal reserve price (in terms of maximizing the expected revenue) to extract the largest profits from the auction. For this purpose, I provide an estimator of the optimal reserve price and study its performance via simulations. Monte Carlo experiments suggest that ignoring risk aversion leads to a downward bias in the estimator of the optimal reserve price and, consequently, a decrease in the expected revenue.

Related literature. Empirical and experimental evidence indicates that risk aversion is a fundamental component of bidders' behavior.[1] Hence, in the context of first-price sealed bid auctions, many articles have considered the problem of identifying and estimating bidders' utility function. Lu and Perrigne (2008) nonparametrically identified and estimated such a function by exploiting two auction designs, ascending and first-price sealed-bid auctions. Guerre et al. (2009) identified bidders' utility function by using the latter design only. As discussed above, they showed that the bidders' utility function is identified under exogenous participation and, exploiting this restriction, they developed a constructive identification strategy. Campo et al. (2011) adopted a semiparametric approach and proposed an estimator for the bidders' risk aversion parameter. Kim (2015) suggested a nonparametric estimator of the bidders' utility function based on a contraction mapping. My contribution to this literature is to develop a (uniformly) consistent nonparametric estimator of the bidders' utility function.

Many articles have developed nonparametric estimators for the latent density of private values assuming that bidders are risk-neutral. The pioneering work of Guerre et al. (2000) established the optimal rate of convergence for estimating this density and constructed an estimator that attains such a rate. Marmer and Shneyerov (2012) proposed a quantile-based estimator that is asymptotically normal. Bierens and Song (2012) used integrated simulated moments to propose an estimator and construct a test for the validity of the first-price auction model. Hickman and Hubbard (2015) suggested a boundary correction that improves the finite sample performance of Guerre et al. (2000)'s estimator. Ignoring the presence of risk aversion may undermine the asymptotic properties of the valuations density estimator and weaken the finite-sample performance. My contribution here is to develop a nonparametric estimator for density of private values that does not rely on a parametric specification of the bidders' utility function.

This paper is also related to a vast literature on empirical industrial organization. First, it relates to the literature on structural econometrics of auction data. This literature is extensive and has expanded at an extraordinary rate; for example, see the surveys of Hendricks and Paarsch (1995), Laffont (1997), Perrigne and Vuong (1999), Athey and Haile (2007) and Hendricks and Porter (2007), as well as the textbook of Paarsch et al. (2006). I remark that nonparametric approaches have become very popular as auction data has become more available. Second, this paper is also related to the literature on recovering risk preferences from observed behavior. Within this line of research, I highlight the working papers of Lu (2004) and Ackerberg et al. (2017). The former proposes a semiparametric method to estimate the risk aversion parameter, as well as the risk premium, in the context of a first-price sealed-bid auction with stochastic private values. The latter considers a buy price auction framework and nonparametrically identifies both time and risk preferences of the bidders.

The rest of the paper is organized as follows. The next section describes the auction model together with the data generating process and the assumptions. Section 3 develops a nonparametric estimator for the function (minimizer) that characterizes the bidders' utility function and the density of private values. Section 4 proposes estimators for these two objects, as well as, for the optimal reserve price. Section 5 provides an implementation guide. Section 6 reports the results of Monte Carlo experiments. Section 7 concludes with a discussion about possible extensions. Proofs of lemmas, propositions, and theorems are relegated to the Appendix.

2. Auction model and data generating process

This section is divided into two subsections. Section 2.1 describes briefly the benchmark model, which is standard in the auction literature: a first-price sealed-bid auction with risk-averse bidders, independent private values, and a non-binding reserve price.[2] Section 2.2 presents the data generating process together with its assumptions.

[1] Among others, Delgado (2008)'s findings are consistent with a role for risk aversion in the tendency to bid too high. See Guerre et al. (2009, pp. 1193–1194) for further references.

[2] For a detailed description of this auction model and additional results, see Guerre et al. (2009, sec. 2) and the references cited therein.

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