Self-confirming price-prediction strategies for simultaneous one-shot auctions

Michael P. Wellman a,⁎, Eric Sodomka b,1, Amy Greenwald c

a Computer Science & Engineering, University of Michigan, United States
b Facebook, United States
c Computer Science, Brown University, United States

A B S T R A C T

Bidding in simultaneous auctions is challenging because an agent’s value for a good in one auction may depend on the outcome of other auctions; that is, bidders face an exposure problem. Previous works have tackled the exposure problem with heuristic strategies that employ probabilistic price predictions—so-called price-prediction strategies. We introduce a concept of self-confirming prices, and show that within an independent private value model, Bayes–Nash equilibrium can be fully characterized as a profile of optimal price-prediction strategies with self-confirming prices. We operationalize this observation by exhibiting a practical procedure to compute near-self-confirming price predictions given a price-prediction strategy. An extensive empirical game-theoretic analysis demonstrates that bidding strategies that use such predictions are effective in simultaneous auctions with both complementary and substitutable preference structures. In particular, we produce one such strategy that finds near-optimal bids, thereby outperforming all previously studied bidding heuristics in these environments.

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1. Introduction

One of the most promising features of automated trading is the ability to monitor prices and trade in many markets simultaneously. Compared to human traders, automated traders can take in data from many more sources at much higher throughput rates. In principle, automated traders can also process massive quantities of information relevant to trading decisions in short time spans. In practice, however, dealing with multiple markets poses one of the greatest strategic challenges for automated trading. When markets interact, a strategy for trading in one market must consider the ramifications on others.

1.1. Problem addressed

Markets are interdependent when an agent’s preferences over outcomes in one depend on outcomes in others. For instance, an agent’s value for one good can increase by obtaining another (such goods are called complements). Complementary

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⁎ Corresponding author.

E-mail address: wellman@umich.edu (M.P. Wellman).

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preferences for goods in multiple markets gives rise to the classic exposure problem: before it can obtain a valuable bundle, an agent must risk obtaining only a strict subset of the goods it wants at the prevailing prices. Exposure is a potential issue for substitute goods as well, when the agent risks obtaining a strict superset of the goods it wants at the prevailing prices.

The pitfall of exposure is a primary motivation for combinatorial auctions (Cramton et al., 2005), where the mechanism takes on the responsibility of allocating goods respecting agents’ expressed interdependencies. Combinatorial auctions are often infeasible, however, due to nonexistence of an entity with the authority and capability to coordinate markets of independent origin. Consequently, interdependent markets are inevitable. Nonetheless, there is at present very little fundamental understanding of agent bidding strategies for these markets. Specifically, how should an agent address the exposure problem?

We address this question in one very basic form of interdependent markets—simultaneous one-shot sealed-bid (SimOSSB) auctions. Since these markets can be plagued by the exposure problem, they get at the essence of interdependent markets. Yet, despite their simplicity, there is little available guidance in the auction theory literature on the strategic problem of how to bid in these auctions. We aim to fill this gap by providing computationally feasible methods for constructing bidding strategies for SimOSSB auctions, which we justify with both theory and evidence gathered from extensive simulations.

1.2. Summary of results

Our theoretical and experimental findings point to two key ingredients for developing effective bidding strategies for simultaneous one-shot sealed-bid auctions, in the special case of independent private values.

The first is an algorithm for computing approximately optimal bid vectors given predicted market clearing prices. We call the method LocalBid, as it employs a local search approach (§5.4.2), cyclically iterating over the set of goods, on each cycle optimizing the bid for a single good given the current other-good bid vector and the input price prediction. We have found in computational experiments that LocalBid achieves a high fraction of optimality (Appendix D), and that this translates into superior performance in strategic SimOSSB simulations (§6).

The second ingredient is an approach to generating price predictions for input to a prediction-based bidding strategy. Specifically, we compute self-confirming price predictions: predictions that give rise to themselves when the given price-prediction bidding strategy is applied to them in a specified auction environment. We exhibit a simple iterative estimation procedure (§5.6), which we have found to be effective at finding price distributions that are approximately marginally self-confirming for a range of strategies and environments (Appendix C). We refer to the corresponding bidding strategies as self-confirming price-prediction strategies.

Our theoretical results say that if these ingredients were to accomplish their tasks perfectly (i.e., without any approximation error), they would produce a solution (i.e., a Bayes–Nash equilibrium, BNE) to the corresponding simultaneous auction game (§4). This conclusion follows from the fact that for typical single-good sealed-bid auctions, an agent’s own bid plus the highest other-agent bid is a sufficient statistic for describing an auction’s outcome. Given this fact, the logic behind our BNE characterization is mathematically straightforward, so its significance lies in its generality and that it enables a dramatic reduction in dimensionality for equilibrium reasoning. Specifically, rather than consider best responses to profiles of bidding strategies, it is sufficient to best-respond to distributions over prices. The two ingredients listed above comprise a computational recipe for exploiting this observation in general SimOSSB auction environments.

Of course, perfectly responding to exactly self-confirming price predictions is generally not practical. To somewhat mitigate this concern, we also show that the equilibrium solutions degrade gracefully, in that approximations to the ideal in these ingredients yield approximate game-theoretic solutions (Appendix B).

Our computational experiments indicate that following this approach produces results that are as good or better than any other general method proposed for bidding in simultaneous one-shot auctions. The evidence takes the form of a comprehensive simulation-based analysis, covering both complementary and substitutable valuation classes and a broad swath of heuristic strategies from the literature. Systematic simulation of hundreds or thousands of strategy combinations in each setting provides payoff estimates, which we use to construct an empirical normal-form game model. For each game we derive an equilibrium over the heuristic strategies. This analysis demonstrates the efficacy of self-confirming LocalBid compared to all competitors, across five evaluation environments covering qualitatively different valuation classes. A direct comparison of bid-optimization performance also favors LocalBid over other heuristics (Appendix D).

Overall, the investigation provides strong support for self-confirming price-prediction strategies as a general approach to bidding in SimOSSB games, and establishes LocalBid as a leading computationally feasible bidding strategy.

2. Related work

Theoretical results about bidding in general simultaneous auction games are few and far between. The leading auction theory textbook (Krisha, 2010) treats sequential but not simultaneous auctions, and the most influential comprehensive survey (Klemperer, 2004) addresses simultaneity only in the context of ascending or multi-unit auctions. Cai and Papadimitriou (2014) recently showed that finding Bayes–Nash equilibria for simultaneous second-price auctions is PP-hard and

2 This despite the fact that its author is responsible for some of the few results (Krisha and Rosenthal, 1996) in this area.
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