A Data-Driven Exploration of Bidder Strategies in Continuous Combinatorial Auctions

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Extended Abstract

Combinatorial auctions, in which bidders can bid on combinations of assets (commonly referred to as *bundles* or *packages*), represent an innovative yet complex market mechanism that can enhance the ability to allocate multiple assets efficiently when the values of the assets exhibit synergies (e.g., "I will pay $100 if I get both matching end tables but only $40 for either one separately"). Although combinatorial auctions have been gainfully employed for resource allocation in industrial settings (e.g., by Sears, Home Depot, and Compaq), they are relatively absent in business-to-consumer (B2C) and consumer-to-consumer (C2C) electronic commerce, primarily due to the absence of a *continuous* mechanism that allows asynchronous bidding. The computational complexity of determining winners (the problem is *NP-hard*) and the cognitive complexity of formulating efficient combinatorial bids (in an *n*-item auction, the number of biddable item bundles is 2^n-1) have acted as hurdles for the development of a continuous mechanism (Adomavicious and Gupta 2005; Kwasnica et al. 2005).

Extant research in combinatorial auctions has primarily focused on reducing complexity by creating rules and restrictions to allow several well-defined rounds of bidding, with the auctioneer declaring the intermediate results after each round. However, such discrete mechanisms that do not allow continuous bidding are difficult to implement in electronic marketplaces, where bidders can potentially join an ongoing auction at any time and expect to immediately find up-to-date information about the auction state (e.g., "how much do I need to bid to win bundle X?").

Our research focuses on the design of appropriate bidder-support infrastructure that can facilitate a *continuous* form of combinatorial auction that neither limits the scope to a specific application (e.g., FCC spectrum auctions) nor imposes restrictive bidding rules (e.g., discrete bidding rounds) on its participants. Using theoretical constructs developed by Adomavicius and Gupta (2005), we have designed novel feedback schemes that are intended to ease the cognitive burden on the bidders by making information available that matches the demands of their tasks. In this continuous environment bidders can join an auction at any time and place bids at any time (i.e., asynchronous bidding), without an auctioneer's intervention or an activity rule. In Adomavicius et al. (2007), we demonstrate that, with the aid of appropriate information feedback, continuous combinatorial auctions can generate high efficiency.

This recent development of a continuous environment provides us an opportunity to study how bidders behave in a complex continuous auction environment. While numerous studies have examined bidder behavior in various forms of single-item auctions (e.g., Bapna et al. 2003; Bapna et al. 2004; Ockenfels and Roth 2002; Shah et al. 2002), only a few have attempted to analyze bidder behavior in combinatorial auctions (e.g., An et al. 2005). Further, these studies are based on simulations of bidding agents, and also the goal of the study by An et al. (2005) in particular was to find "*a good bidding strategy*" (p. 1) in a complex combinatorial environment. In contrast, our goal in this paper is to adopt a data-driven approach towards uncovering the strategies pursued by bidders in such auctions. To study bidder behavior, we conduct a laboratory experiment where bidders are able to place asynchronous bids in hypothetical combinatorial auctions. We capture not only the bids but also the *click-stream* of the bidders with the goal to inductively discover the strategies that bidders pursue in formulating and placing bundle bids.

The study is motivated by the notion that, to design effective information systems, it is not only essential to evaluate the performance and the user acceptability of the systems but also the interactions of the users with the systems that lead to certain economic outcomes (Bapna et al. 2003, 2004). Bapna et al. (2004)

assert that "*users' preferences, behaviors, personalities, and ultimately their economic welfare are intricately linked to the design of information systems*" (p. 1). Thus, for the success of combinatorial auctions as an effective online mechanism, it is important to understand how bidders behave in such auctions, what strategies they pursue, and how variations in behavior lead to varying outcomes in terms of both the users' own economic surplus and the overall auction revenue.

We study the bidder behavior under three different treatment conditions that differ only in the nature of feedback provided to bidders. The feedback consists of information regarding provisional allocation (a non-trivial computational problem) and potential winning prices at every stage of the auction. Thus, in addition to exploring the bidder strategies in continuous auctions, we also study how different types of feedback affect the characteristics of bids, and hence the economic outcome of the auctions in terms of efficiency, seller's revenue, and bidder's surplus. Using cluster analysis of several bidding characteristics (e.g., number of bids, time of first bid, number of clicks), our study reveals that bidders employ three broad bidding strategies. We analyze the impact of these strategies on the bidders' own economic welfare as well as the profits and efficiency of the auctions.

The insights regarding bidder strategies under varying levels of feedback should be useful for simulating realistic continuous combinatorial bidding environments. Experimental approach provides a controlled environment to understand and isolate the impact of design choice on bidding strategies and resulting bidding dynamics, which has impact on auction outcomes and has implications for sustainability and acceptability of a mechanism.

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