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Online double auction mechanism for perishable goods ☆

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ABSTRACT

One-sided auctions are used for market clearing in the spot markets for perishable goods because production cost in spot markets is already "sunk." Moreover, the promptness and simplicity of one-sided auctions are beneficial for trading in perishable goods. However, sellers cannot participate in the price-making process in these auctions. A standard double auction market collects bids from traders and matches the higher bids of buyers and lower bids of sellers to find the most efficient allocation, assuming that the value of unsold items remains unchanged. Nevertheless, in the market for perishable goods, sellers suffer a loss when they fail to sell their goods, because their salvage values are lost when the goods perish. To solve this problem, we investigate the suitable design of an online double auction for perishable goods, where bids arrive dynamically with their time limits. Our market mechanism aims at improving the profitability of traders by reducing trade failures in the face of uncertainty of incoming/departing bids. We develop a heuristic market mechanism with an allocation policy that prioritizes bids of traders based on their time-criticality, and evaluate its performance experimentally using multi-agent simulation. We find out that our market mechanism realizes efficient and fair allocations among traders with approximately truthful behavior in different market situations.

1. Introduction

Most *perishable goods* such as fish and vegetables are traded mainly in the spot market because their yield and quality are unsteady and unpredictable by nature. In the spot markets, which by definition occur after production, the variable production costs of the goods are typically *sunk costs* and these costs are *irretrievable* for perishable goods when the goods remain unsold and the value of the perishable goods evaporates.[1] Therefore, sellers of perishable goods may suffer large losses if the trade fails in the markets (Bastian et al. 2000; Wang and Webster 2009).

To prevent sellers' goods from perishing without being traded, the markets need to bring together a large enough number of potential buyers and process a large amount of transactions as quickly as possible. Electronic commerce (a.k.a., e-commerce) is a suitable candidate for the markets of the perishable goods because advanced information technologies improve communication, search, monitoring and information sorting capabilities and thus succeed in reducing transaction costs. The reduced transaction costs stimulate the market (Ribbers et al. 2002). Therefore, several agricultural products have been traded in the e-commerce markets for various types of transactions, raging from retail in B2C (business-to-consumer) markets to wholesale in B2B (business-to-business) markets (Bogaardt et al. 2001).

In those B2B e-commerce markets as well as in traditional wholesale markets for perishable goods, one-sided auctions such as a *Dutch auction* are widely used (Ribbers et al. 2002; Krott 2003) because of their simplicity and promptness, vital for smoothly dealing with large volume transactions of perishable goods with many participating buyers (Krishna 2010). In the one-sided auction, a seller can influence price-making only indirectly in the following ways:

(i) By declaring a *reserve price*, below which the goods are not to be sold, in advance of the transactions (Myerson 1981).
(ii) By limiting the quantity of goods to be traded.

Nevertheless, sellers cannot always maximize their profit by selling the optimum amount of goods at the best price because finding the optimal price and quantity is difficult for sellers in real auctions where precise demands are unknown to them.

Fig. 1 shows the effects of sellers' actions in the one-sided auction: the left figure shows the case where a seller sets a reserve price, and the right figure shows the case where a seller adjusts

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[1] In other words, their salvage value reduces to zero.

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1567-4223/

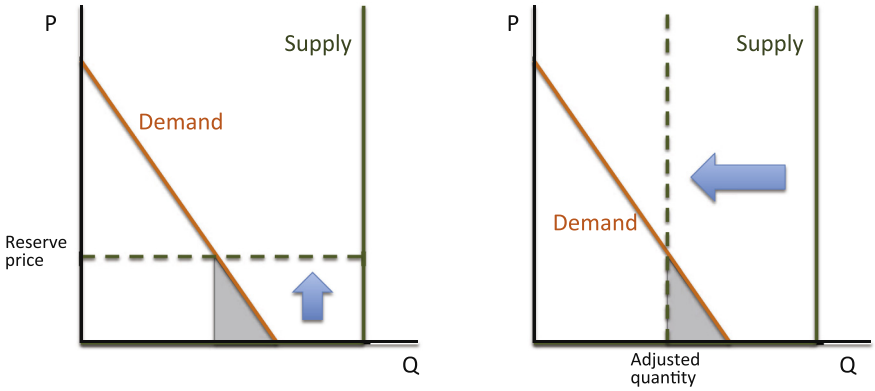

Fig. 1. Possible effects of sellers' manipulation in the one-sided auction.

quantity. As shown in Fig. 1, these manipulations by sellers not only raise the *competitive equilibrium price* of the market, but also cause *deadweight loss* (which is represented as gray triangles in the figures) and thus reduce the efficiency of the market.

Consequently, traditional markets of perishable goods have the following problems:

(i) Sellers suffer loss in the trade when
  (a) their goods are sold at a price below the production cost, or
  (b) their goods perish without being sold (because salvage value of perished goods is zero).
(ii) The markets lose *social surplus* when sellers try to avoid the above losses and make profits by manipulating prices and quantities of goods to be traded.

We develop a prototypical market for the perishable goods, which adopts online *double auction* (DA) as a market mechanism (Friedman and Rust 1993) to solve the problems by realizing fair price-making among traders while reducing allocation failures. In the online DA, multiple buyers and sellers arrive dynamically over time with their time limits. Both buyers and sellers tender their bids for trading commodities. The bid expresses a trader's offer for valuation and quantity of the commodity to be traded. The arrival time, time limit, and bid for a trade are all private information to a trader. Therefore, the online DA is uncertain about future trade. It collects bids over a specified time interval, and clears the market on expiration of the bidding interval by applying pre-determined rules.

In the market for durable goods, sellers never lose their utility on failing to sell the commodity. Therefore, in the DA market for durable goods, the utility of the traders can be maximized by using a price-based mechanism that matches the highest buyer's bid and the lowest seller's bid iteratively until no matchable bid remains. However, in the online DA market for perishable commodities, the market mechanism should decide the bids with different prices and time limits that should be matched to increase the utility of traders and reduce trade failures in the face of uncertainty about future trade. The online market also presents the tradeoff for clearing all possible matches as they arise versus waiting for additional buy/sell bids before matching. Although waiting could engender better matching, it can also hurt matching opportunities because the time limit of some existing bids might expire.

Double auction mechanisms in the spot market have been investigated in the fields of agricultural economics (Krogmeier et al. 1997) and experimental economics (Mestelman 2008). These studies observed the behavior of human subjects in the experimental periodic market and found that their decisions are influenced by the inability to carry unsold goods from one trading period to the next period.

Until recently, not much work had addressed online double auction mechanisms (Blum et al. 2006; Bredin et al. 2007; Zhao et al. 2011; Chang et al. 2011; Gerding et al. 2013). These studies examine several important aspects of the problem: design of matching algorithms with good worst-case performance within the framework of competitive analysis (Blum et al. 2006), construction of a general framework that facilitates truthful dynamic double auctions by extending static double auction rules (Bredin et al. 2007), and development of computationally efficient matching algorithms using weighted bipartite matching in graph theory (Zhao et al. 2011). Chang et al. (2011) developed the online double auction mechanism for the TAC Market Design Tournament and showed their adaptive market strategies achieved stable and efficient performance. Gerding et al. (2013) applied the online double auction mechanism to an imaginary market for advance reservation of electric vehicle charging facilities. Although their research results are theoretically significant, we cannot straightforwardly apply their mechanisms to our online DA problem because all of their models incorporate the assumption that trade failures never cause a loss to traders, which is not true in our spot market for perishable goods.

In the field of revenue management (Talluri and van Ryzin 2004), several methodologies have been studied to increase the revenue of sellers in services industries such as airlines and accommodation, which provide perishable services to customers. Their objective is maximizing seller revenues since in the industries where revenue management is typically practiced, the capacity cost is sunk and the variable production cost is negligible (Vulcano et al. 2002). These techniques are difficult to apply to "non-service" markets, where the variable production cost of perishable goods has a large influence on the profit of sellers.

In this paper, we advocate a heuristic online DA mechanism for the spot markets of perishable goods, which improves revenue of the traders by reducing allocation failures in the market. And as a preliminary step of developing the real field application, we study computational simulations of the designed DA mechanism in an imaginary market.

The remainder of the paper is organized as follows: Section 2 introduces our market model and presents desiderata and objectives of the market. Section 3 proposes the allocation policy to prevent trading failures in the online DA market. Section 4 explains the settings of multi-agent simulations used to evaluate the developed market mechanism. Section 5 experimentally studies the effectiveness of our allocation policy in two types of markets using multi-agent simulations. Section 6 analyzes the performance of various types of agents in the markets and investigates the market