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Design of Online Double Auction Mechanism for Aging Sensitive Commodity

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Abstract. Aging sensitive commodities are those who must be sold within a certain period of time or their value will have a decline, in other words, the value is changing over time. In order to maximize the profit of the aging sensitive commodity product operators, both the sellers and buyers should arrive dynamically and leave the market within their time limits, the traditional auction mechanism design method in static environment is not suitable for solving the problem in dynamic environment. This paper presents an online double auction mechanism DAPA (Double Auction Payment Allocation) for aging sensitive commodity under dynamic environment, and then proposes and implements the corresponding allocation and payment algorithm as well. We carry on a theoretical analysis on truthful and establish the simulation experiment to prove that our DAPA is superior in improving transaction success rate and realizing fair price-making between traders than traditional equilibrium matching in static environment.

Keywords: Aging sensitive commodity, online mechanism design, double auction payment allocation.

1. Introduction

Aging sensitive commodities are those who must be sold within a certain period of time or their value will have a decline, in other words, the valuation of the goods varies with time [15]. Fresh but perishable products, rapidly updated fashion commodities as well as cosmetics with limited shelf lives and all kinds of medications are included in it. Aging sensitive commodities are traditionally sold in spot markets where transaction happens after manufacturing, which means production costs will turn into sunk costs [21]. In that case, once the transaction breaks down, seller will inevitably suffer a great loss. To overcome the shortcomings of spot markets, auction mechanism has been introduced into the transaction process of aging sensitive goods, improving transactional efficiency and cutting the cost [20].

Currently, the auction mechanism of aging sensitive commodities is conducted mainly in a static environment, such as Dutch single-sided auction [9] [28]. In a static environment, buyers and sellers provide quote information respectively, after that, auction houses will auction the goods intensively in a certain time, and decide the successful bidder and the willing-to-pay price [5]. Although the fact that this kind of mechanism is simple to operate and quick to deal, the characteristics of aging sensitive commodity decide that only by selling these goods out within the sale duration, can we obtain a relatively high value or most of the value will be lost [17]. In order to maximize the profits of these production operators, buyers and sellers are supposed to participate dynamically and leave in any time during the period. Besides, payments as well as earnings of both sides should be clarified. Current auction mechanism in static environment is not capable of tackling this kind of problem while the design theoretical framework of dynamic auction mechanism fit for the nature of the problem [26]. The latter is, undoubtedly, an ideal way to solve the issue of aging sensitive commodities' auction [23].

In recent years, the auction mechanism design of dynamic environment has gained attention of researchers. However, nowadays, researchers mostly focused on one-side dynamic market, in which only one side, buyer or seller, is dynamic. In consideration of the features of aging sensitive commodities, in order to reduce failure rate of transaction as well as achieve fair trades for both sides, a dynamic bilateral mechanism design of auction comes up in this article, which means that both sellers and buyers in markets join and leave markets within blocking time dynamically [24]. In addition, the mechanism should make decisions on distribution and payment dynamically on an occasion when the information of potential traders remains unknown. At present, the researches on dynamic bilateral mechanism of auction have not gone in depth. What this article studies can be applied in electronic auction markets of aging sensitive goods based on Network circumstances, therefore, exerting profound impacts theoretically and realistically on the solutions to the price fluctuation of aging sensitive goods as well as on an increase in production operators income.

This paper is organized as follows. The related works were introduced in Section 2. In Section 3, the online double auction market towards aging sensitive commodity, and the general standard of the auction mechanism were presented. In Section 4, the online auction mechanism of the time sensitive commodity is designed, including the allocation and payment algorithm, and analysis theoretical the nature of the mechanism. The performance of the mechanism is verified by simulation experiments in Section 5. And the Section 6 is the summary of the whole paper.

2. Related works

Since Friedman published the first article on the auction theory in 1956, the auction theory has been greatly developed. The basis point model and the principle of income equivalent proposed by Vickrey in 1964 have become the cornerstone of the auction theory research. In the next 50 years, the research system of auction theory has been formed, and the research results are very rich [27]. Many scholars have made important contributions (McAfee, Gallien, Riley, and Jimnez-Martłnez etc) [13] [14] [18] [19]. The traditional auction mechanism design is a method to achieve the goal of the mechanism designer in the static environment. However, many problems in reality are dynamic, and the traders are dynamically arrived and left. The mechanism needs to make decisions immediately, so the traditional static auction mechanism design method is not suitable for solving the problem of dynamic environment.

In recent years, online auction mechanism design has attracted the attention of some researchers and then has become the frontier of mechanism design research. Lavi and Nisan firstly proposed the problem of online auction in dynamic environment [16]. After that Friedman and Parkes pointed out the key challenges of online mechanism design [10], Blum et al. proposed a general framework for online double auction [2]. After that, Bredin, Zhao, and Laurent etc., designed a variety of matching and payment algorithm for online double auction mechanism. So far, online auction mechanism has been preliminarily studied in many fields such as electric vehicle charging of the network background, wireless spectrum auction, cloud resource allocation and so on [3] [32] [33].

Until recently, not much work had addressed online double auction mechanisms. These studies examine several important aspects of the problem: design of matching algorithms with good worst-case performance within the framework of competitive analysis, construction of a general framework that facilitates truthful dynamic double auctions by extending static double auction rules, and development of computationally efficient matching algorithms using weighted bipartite matching in graph theory. Gerding studied electric vehicle charging problem and designed an online mechanism which could offer a trade-off between budget balance and stability [11]. Dong etc applied the online double auction mechanism to dynamic spectrum allocation [7]. Wang etc studied the online double auction problem of mobile cloud computing [29] [30]. Although their research results 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 sensitive commodities. In the field of revenue management, several methodologies have been studied to increase the revenue of sellers in services industries such as airlines and accommodation, which provide the aging sensitive 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. These techniques are difficult to apply to non-service markets where the variable production cost of the aging sensitive commodities has a large influence on the profit of sellers [8].

In summary, online auction mechanism theory is the hot spot and frontier in the current research of auction mechanism, but the application of the theory of the double online auction mechanism in the field of aging sensitive commodity has not yet been involved [12] [22]. This paper proposed an online double auction mechanism DAPA which is suitable for aging sensitive commodity, and the mechanism can significantly improve the transaction success rate and achieve the relative fairness between the two parties.

3. Preliminaries

3.1. The Market Model

This paper study the problem of online auction mechanism design to aging sensitive commodity in an online double auction market where multiple buyers and sellers arrive dynamically overtime and depart with their time limits and trade the same commodity, both buyers and sellers bid for the trading commodity. The market mechanism need to collect the bids over a specified interval of time and then clears the market at the expiration of the interval, that is, decides the match and calculate payment for every matched trader [1].

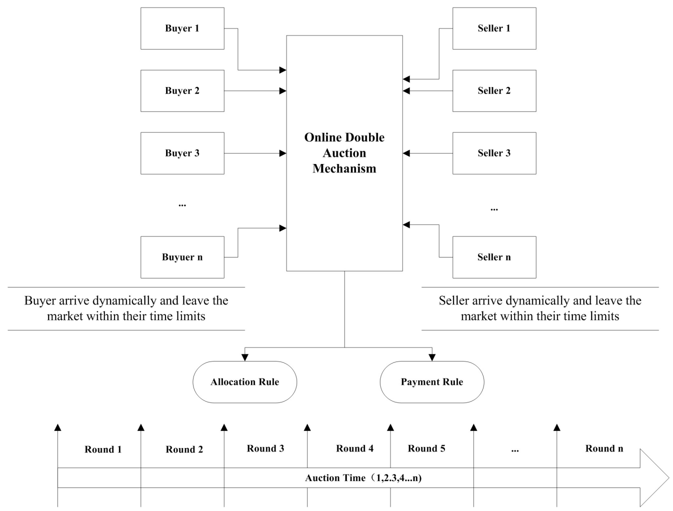

Fig. 1. The aging sensitive commodities market concept model

For the sake of simplicity, this paper assumes that each trader only supply or demand one unit of the commodity, and the residual value of the aging sensitive commodity failed to trade is 0. The market model can be described as follows, we first define a discrete time rounds $T = \{1, 2, \dots\}$ indexed by t, which represent multiple trade interval. B is the set of all buyers, S is the set of sellers, and $B \cap S = \Phi$, which means a trader can only modeled as one role, buyer or seller. The private information of trader is the type, $\theta_i = (V_i, a_i, d_i)$, where V_i, a_i, d_i, are non-negative real numbers, V_i is the valuation of trader i for a single unit of the commodity, d_i is the departure time. The duration between arrival time and departure time $[a_i, d_i]$ is defined as active period of the trader i and trader can repeatedly participate in the auction over several period but immediately leave market once trade success.

According to the revelation principle, we only consider the direct mechanism, which require trader report their private type to the auctioneer. Due to game theory, traders are self-interested and rational, so one can make a claim about his type $\theta_i^{'} = (V_i^{'}, a_i^{'}, d_i^{'}) \neq \theta_i$ if there is an incentive to manipulate the type to improve the profit. But the misreporting must be no early-arrival and no late-departure, that is to satisfy $a_i^{'} \leq d_i^{'}$ and $[a_i^{'}, d_i^{'}] \subset [a_i, d_i]$, the intuition behind this constraint is that traders do not participate in the auction before their arrival time and they cannot get utility for any trade which happened after their true departure time, in other words, misreporting early-arrival or late-departure time is not feasible to the trader. As explained in Table 1, misrepresenting those values is not beneficial or feasible to the seller or the buyer. The aging sensitive commodities market concept model is shown as Fig. 1.

3.2. Desiderata and Objective

We define $\theta^{'t}$ as the set of trader types reported in round t, $\theta^{'} = (\theta^{'1}, \theta^{'2}, \dots \theta^{'t}, \dots)$ denote a complete reported type profile, let $\theta^{'\leq t}$ denote the reported type profile restricted

Table 1. Inadequacy of seller or buyers misreporting

	Arrival Time		Departure Time	
	Ealier	Later	Earlier	Later
Seller	Infeasible	Less chance for matching	Less chance for matching	Over due
Buyer	Infeasible	Less chance for matching	Less chance for matching	Delay of resale

to trader whose reported arrival time no later than the round t. A report $\theta_i^{'t} = (V_i^{'t}, a_i^{'t}, d_i^{'t})$ is a type made by trader i at round t, which satisfy $t \subset [a_i^{'t}, d_i^{'t}]$. Let a buyer i's bid $\theta_i^{'t} = (V_i^{'t}, a_i^{'t}, d_i^{'t})$ and a seller j's ask $\theta_j^{'t} = (V_j^{'t}, a_j^{'t}, d_j^{'t})$, then the online double auction mechanism $M = (\pi, p)$ where $\pi \subset \{0, 1\}$ denote the allocation rule, 1 means the matched trader and 0 means the unmatched trader, $p \subset R$ denote the payment rule, indicates the payment made by buyer or the seller's revenue.

Definition 1 (Matchability). A buyer i's bid $\theta_i^{'t} = (V_i^{'t}, a_i^{'t}, d_i^{'t})$ and a seller j's ask $\theta_j^{'t} = (V_j^{'t}, a_j^{'t}, d_j^{'t})$ are matchable, when$(V_j^{'t} \leq V_i^{'t}) \wedge ([a_i^{'t}, d_i^{'t}] \cap [a_j^{'t}, d_j^{'t}]) = \phi)$.

Definition 2 (Feasibility). A mechanism is feasibility if $\forall A$

$$\sum_{i \subset B} \pi_i(\theta^{'t}) = \sum_{j \subset S} \pi_i(\theta^{'t}) \tag{1}$$

Definition 3 (Buyer's Utility). Traders are modeled as risk-neutral and Buyer j's utility at time round t is

$$u(\theta_i^t, \theta_i^{'t}, (\pi, p)) = \sum_{t \in [a_i, d_i]} ((p(\theta_i^{'t}) - v(\theta_i^t)).\pi_i(\theta_i^{'t}))i \in B \tag{2}$$

Definition 4 (Seller's Utility). Traders are modeled as risk-neutral and Seller j's utility at time round t is

$$u(\theta_j^t, \theta_j^{'t}, (\pi, p)) = \sum_{t \in [a_j, d_j]} ((p(\theta_j^{'t}) - v(\theta_j^t)).\pi_j(\theta_j^{'t}))j \in S \tag{3}$$

Definition 5 (Utility maxization). An online DA, $M = (\pi, x)$is utility maximizing when among a set of function π and x that satisfy the other constrains, the mechanism selects π and x that maximize

$$u(\widehat{\theta}^{\leq t}) = \sum_{i \in S} \sum_{j \in B} (\sum_{t \in [a_i, d_i]} ((p(\theta_i^{'t}) - v(\theta_i^t)).\pi_i(\theta_i^{'t})) + \sum_{t \in [a_j, d_j]} ((p(\theta_j^{'t}) - v(\theta_j^t)).\pi_j(\theta_j^{'t}))) \tag{4}$$

The main objectives of the mechanism are as follows:

1. Incentive Compatibility. All traders could maximize their utilities when they truthfully report the private type to auctioneer.
2. Individual Rationality. The mechanism does not bring negative returns to the trader.
3. Social Welfare Maximization. In simple terms, allocate the goods to the trader who values them most highly.

In consideration of the aging sensitivity commodity in our market, apart from the above objectives, we also aim at improving the transaction success rate and realize fairness between the matched traders at the same time.

4. Mechanism design

In this section, we will propose a deterministic and truthful online double auction mechanism DAPA which includes the allocation and payment rule. Before doing that, let us first briefly introduce the current most commonly employed matching rule for double auction markets in static environment named equilibrium matching. Fig. 2 shows demand and supply curves in a static double auction market.

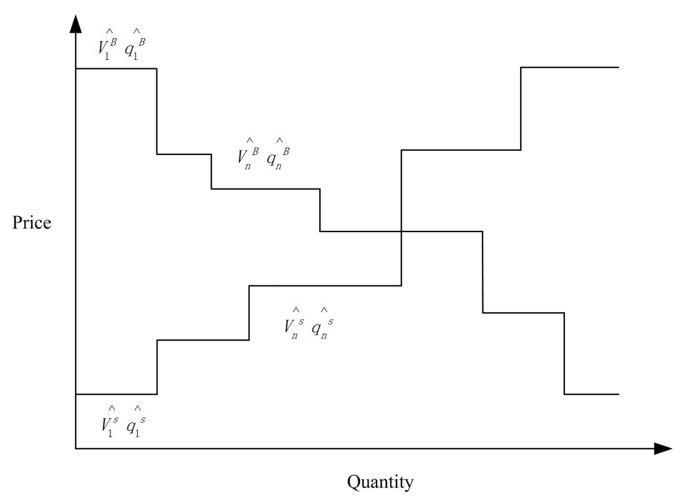

Fig. 2. A static double auction market

4.1. Equilibrium Matching

The basic ideas of equilibrium matching is to find a uniform equilibrium price p so that all bids with value $v \geq p$ and all asks with value $v \leq p$ are matched, the number of matched pair is called equilibrium number [6]. The matching process can be described as follows:

1. Collect all unmatched bids and all unmatched asks in current round t.

2. Sort all unmatched bids (asks) in descending (ascending) order with regard to their value.
3. Based on this sort order, beginning at the top, match each ask-bid if bid's value is more than or equal to the enquiry value.
4. Make a symbol to all matched bids and asks.
5. Continue to the round t+1.

Program equilibrium-matching describes the implementation process of Equilibrium matching rule.

```
Program Equilibrium-matching (Output)
Input: all unmatched bids and all unmatched asks
in current round t
Begin
For t = ai -> di Do
  Collect all unmatched bids and all unmatched asks
  While( Asks != null and  Bids != null ) Do
    Sort(v(Asks),ascend),Sort(v(Bids),descend);
    Ask <- I-th ask from Asks;
    Bid <- I-th bid from Bids;
    If v(Ask) <= v(Bid) then
      Matching <- Matching and {(Ask,Bid)};
      I <- I+1;
    Else
      Break;
  Then
    t=t+1;
End.
```

4.2. Time-based Matching Rule

Since the goods are aging sensitive in our market model, the seller will suffer loss when they fail to match [31], in order to improve the traders' profit and establish opposite fair price-making among matched pair, the mechanism need to improve the trade success rate, that is , the number of matched pair [4] [25]. However, the equilibrium matching cannot maximize the number because the uniform equilibrium price might prohibit some suited traders from being matched. So we present time-based matching rule aims at improving the number of matched pair, the matching process can be depicted as follows:

1. Collect all unmatched bids and all unmatched asks in current round t.
2. Calculate the critical value for every unmatched bid and ask according to the departure time d and current round t.
3. Sort all unmatched bids and asks in descending order with regard to their critical value.
4. Based on this sort order, beginning at the fist unmatched ask, match the ask to a unmatched bid if the bid's value is more than or equal to the enquiry value until there is no match able bid or all asks are matched.
5. Mark a symbol to all matched bids and asks.

6. Continue to the round t+1.

Program Time-based Matching describes the implementation process of Time-based matching rule.

```
Program Time-based Matching (Output)
Input: All unmatched bids and all unmatched asks
in current round t
Output: Matching result
Begin
For t = ai -> di Do
Collect all unmatched bids and all unmatched asks
  While( Asks != null and  Bids != null ) Do
    Calculate the critical value 1/(d-t);
    Sort(Asks(1/(d-t)),descend),Sort(Bids(1/(d-t)),descend);
    Ask <- I-th ask from Asks;
    Bid <- J-th bid from Bids;
    If v(Ask) <= v(Bid) then
      Matching <- Matching and {(Ask,Bid)};
    Else
      J <- J + 1;
    End
      I <- I + 1;
  End
  Then
    t = t + 1;
End.
```

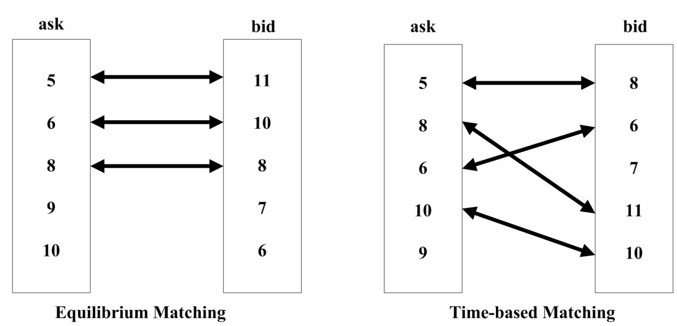

Fig. 3. Compare Equilibrium Matching to Time-based Matching

4.3. Payment rule

For any round t, we assume that there are m buyers and n sellers active who are unmatched, if the number of matched pair is N in round t, then define $j = \{1, 2, \ldots, N\}$

as the j-th trader in all matched buyers(or sellers) .So regarding a matched trader i, let V_i^t be the valuation of trader i in round t, and $M(v_i^t)$ be the valuation of the trader who matched with trader i, hence trader i's payment in round t can be described as:

$$p_i^t = \begin{cases} \max\ (v_{B,j-h}^t, M(v_i^t)) & \text{if } i = seller_{-j} \cap i\ win \\ \max\ (v_{S,j-l}^t, M(v_i^t)) & \text{if } i = buyer_{-j} \cap i\ win \end{cases} \tag{5}$$

Where $seller_{-j}$ denote j-th seller among all the matched sellers, and $buyer_{-j}$ denote the j-th buyer among all the matched buyers, $V_{B,j-h}^t$ represent the j-$high$ bid among all buyers who participate in round t, and $V_{S,j-l}^t$ represent the j-low ask among all sellers who participate in round t.

```
Program Payment (Output)
Input: all bids and all asks in current round t
result from the time-based matching
Begin
For t = ai -> di Do
  Collect all matched bids and all matched asks
  While (Asks != null and  Bids != null) Do
    For (Ask <- J-th ask from matched Asks)
      M(v)<-the valuation of bid which matched with agent i;
      V <- j-high bid among all buyers in round t;
      P = max(V,M(v));
      For (Bid <- J-th bid from matched Bids)
      M(v)<-the valuation of ask which matched with agent i;
      V <- j-low ask among all sellers in round t;
      P = min(V,M(v));
  End
End.
```

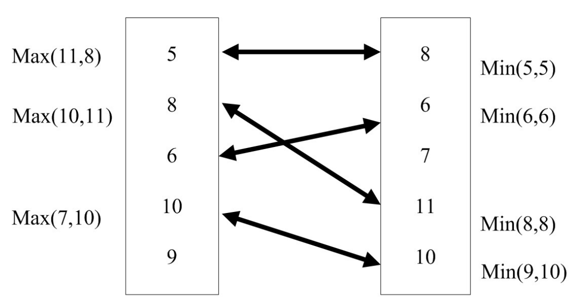

Fig. 4. Payment Policy

Fig. 4 shows the payments of matched agents based on Fig. 1, time-based matching, and the payment of unmatched agents are not calculated since they can continue to participate next round. From the above example we can easily find out the M_{time} is running a deficit since the total revenue is 28 which is less than the total payment 36, in other words, is not budget-balanced, and the budget balance is not considered in our paper.

4.4. Properties of the DAPA

Theorem 1. DAPA is truthful for both arrival and departure time and valuation.
Proof. We will prove above theorem 1 for buyers and sellers respectively, include both time and valuation.

First for buyers: Since the mechanism DAPA sort all traders based on their critical value $\frac{1}{d-t}$, for a matched buyer i, misreport departure time does not improve the probability to be matched. As for a unmatched buyer j, when decrease the departure time to get matched, the payment will be more than his valuation lead to a negative utility, increase the value is meaningless. Moreover, since the mechanism does not use buyer's arrival time for decision-making, there is no motivation for buyers to misreport their arrival and departure time.

As to valuation, let V_i^t be the valuation of trader i in round t, let M be the matching given by the time-based allocation and $M(V_i^t)$ be the valuation of trader who matched with trader i. For a matched buyer i, increase the V_i^t will not improve the utility, when decrease the valuation such that$V_i^t \geq V_i^{'t}$ and $V_i^{'t} \geq min((V_{s,j-l}^t), M(V_i^t))$, the payment is remained unchanged and also is the utility. If trader i decrease his valuation such that $V_i^t \geq V_i^{'t}$ and $V_i^{'t} \leq min((V_{s,j-l}^t), M(V_i^t))$, then i will fail to be matched in round t. For a unmatched buyer, when increase the valuation to get matched in round t, the payment will all improve lead to a lower utility, yet decrease the valuation is nonsense. Then all buyers cannot improve utility by misreporting valuation.

For sellers: The proof process is same to buyers in terms of misreporting arrival and departure time because of the critical value $\frac{1}{d-t}$, so all the sellers are no encourage to manipulate the two values.

For valuation, a matched seller i, decrease the V_i^t will not improve utility, when the valuation increase such as $V_i^{'t} \geq V_i^t$ and $V_i^{'t} \leq max((V_{B,j-h}^t), M(V_i^t))$, the payment is remained unchanged and also is the utility. If trader i increase his valuation such as $V_i^{'t} \geq V_i^t$ and $V_i^{'t} \geq max((V_{B,j-h}^t), M(V_i^t))$, then i will not be matched. For an unmatched seller, if decrease the valuation to get matched in round t, the utility will reduce, yet increase valuation is meaningless. And then all sellers cannot improve their utility by misreporting valuation.

5. Simulation experiment

To test and verify the superiority of DAPA presented in Section 3, we conduct an experiment to simulate the online double auction market. In our experiment, we select 500 buyers and 500 sellers randomly, and assume the every trader supply or demand one unit commodity. The trader arrival to the market randomly and let the buyer's departure time be 12 hours after its arrival and the seller's departure time be 48 hours after its arrival, which implies that the value of goods begin to reduce two days after production since the aging sensitivity .We set up ten minutes as one unit time, and DAPA clear the market each hour, that is six units time, with the traders arrival randomly. The experimental results are shown as follows Fig. 5 and Fig. 6.

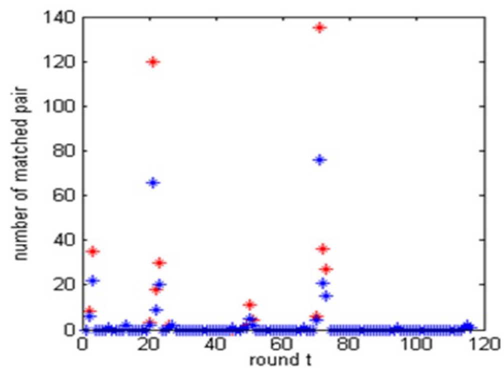

Fig. 5. Number of matched pair in round t

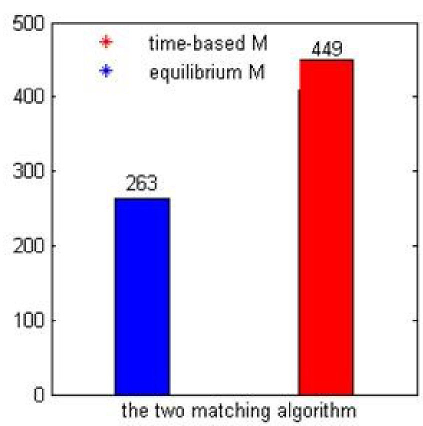

Fig. 6. Total number of the matched pair

The Fig. 5 shows the number of matched pair in every round, while Fig. 6 shows the total number of matched pair after the whole auction ending. The blue symbol means the matched pair results from equilibrium matching while the red means the result of time-based matching. From the Fig. 5, we can find that the time-based matching lead to more matched pair than equilibrium matching among most rounds, although some round are less. The Fig. 6 shows that our allocation rule produce 449 matched pair, the success rate is 89.8% since there are 500 traders pairs altogether. While the number of equilibrium matching is only 263, and the corresponding success rate is 52.6%. The two pictures above explain that time-based matching is clearly superior to equilibrium matching in improving the match success rate.

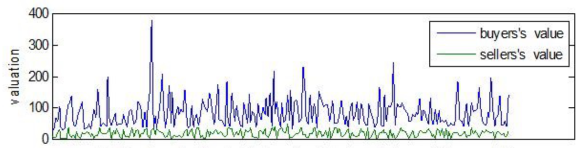

Fig. 7. The valuation distribution of matched agents in equilibrium matching

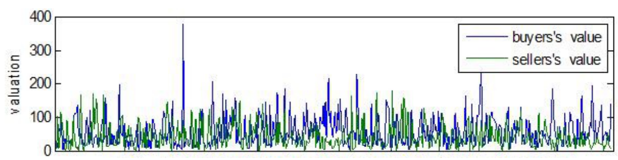

Fig. 8. The valuation distribution of matched agents in time-based matching

Fig. 7 and Fig. 8 show the valuation distribution of matched traders in equilibrium matching and time-based matching respectively. It is clearly that the difference between the matched buyer's valuation and the matched seller's valuation in time-based matching is less than the equilibrium matching, in other words, our allocation algorithm could realize the trade fairness between matched traders, which is superiority when compared with equilibrium matching.

6. Conclusion

We have considered the problem of mechanism design in online double auction market, different from traditional market, the commodity trade in our market is aging sensitive. So we presented a allocation algorithm named time-based matching, we have proved that our algorithm can improve the trade success rate significantly and realize the fairness between matched agents at the same time when compared to equilibrium matching, the mostly used algorithm in current double auction. We then developed our payment policy based on the time-based matching and proved the mechanism M_{time} is truthful.

It is easy to see that our mechanism is not budget-balanced, that is our mechanism is running a deficit, which can be regard as an interesting direction for future research, although it is often hard to achieve all desired properties even in simple static double auction cases.

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