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Defection-free exchange mechanisms based on an entry fee imposition

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Abstract

We propose a safe exchange mechanism involving indivisible goods and divisible goods. A typical situation is an exchange involving goods and money in a person-to-person trade in an Internet auction. Although the Internet and agent technologies have facilitated world-wide trade, we sometimes encounter risky situations, such as fraud, in the process of exchanges involving goods and money. This problem is becoming more serious with the growing popularity of person-to-person trade. One of the reasons why fraud is becoming widespread is that obtaining a new identifier in a network is cheap. This makes it almost impossible to exclude malicious agents from trade. One solution is to impose an entry fee. However, if the entry fee is too high, it will discourage newcomers from starting deals. To resolve the conflict between safety and convenience, we developed three exchange mechanisms that can guarantee against defection from a contract. Two of them reduce the entry fee by integrating multiple deals and controlling the flow of goods and money. The other reduces the entry fee by incorporating a third-party agent into the exchange process. We examine the lower bound of the entry fee for both of these mechanisms and describe a calculation method by which this value can be obtained in linear time. Our results show that the described mechanism can effectively reduce the lower bound of the entry fee.

Keywords: Game theory; Electronic commerce; Online fraud; Information goods; Multiagent systems

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1. Introduction

Agent technologies offer new opportunities for trading goods/resources/tasks. First, in agent-mediated electronic commerce, agents can handle a variety of tasks including finding goods, finding sellers/buyers, and negotiating prices, which reduces our workload and mitigates information overload [6]. For example, many of Internet auction sites provide automatic bidding agents. Second, agent technologies can contribute to solve resource allocation problems. It becomes significant to develop an efficient method for utilizing distributed information resources such as CPU time, storage spaces, and databases in the Internet.

To date, many multiagent researchers have discussed good/resource/task trading problems among self-interested agents, including insincere and strategic agents, and have tried to provide a theoretical framework for these problems based on economics and game theory, e.g., negotiation protocols [8,14,17] and auction protocols [5,12,16,21–23].

However, these research efforts have not given sufficient attention to the process after the good/resource/task is assigned, namely, whether each agent is motivated to carry out its contract, although some research projects have focused on exchange processes [18,19]. Sandholm et al. described an unenforced exchange mechanism whereby self-interested agents carry out their exchange obligations without defection [18,19].

In the real-world trading in the Internet, there have been reports of auction winners transferring large sums of money to sellers who then disappear without delivering any goods [11]. Namely, such online deals have become risky, i.e., there is much fraud in the process of exchanges involving goods and money. The fact that it is difficult to identify and trace each seller/buyer in a network environment makes this problem serious. Even if we can consult the trade data, it often costs a lot to actually reach the problematic seller/buyer. Similar risks are associated with the trading environment including artificial agents. Therefore, developing safe exchange mechanisms is an urgent task and this is a challenge to make agents to work in the real trading environment.

One of the reasons why online fraud is widespread is that obtaining a new identifier in a network is cheap, for example, it is easy to obtain a free e-mail account. This feature raises various problems. In the process of allocating goods by using an auction protocol, a bidder's strategic manipulation benefits him/her by allowing the bidder to submit bids under multiple identifiers. Earlier, we addressed this problem, that is, we discussed the robustness of auction protocols against false-name bids [15,23]. In contrast, in the process of exchanges involving goods and money, the above feature makes it difficult to exclude a dishonest seller or buyer from deals, because he or she can reappear under a new identifier without paying any penalty.

This paper concentrates on exchange processes after some trading contracts are entered into, especially exchanges between indivisible goods and divisible goods. Here, an indivisible good is a good that cannot be divided into small portions or, even if it can be divided into small portions, each portion cannot be given a valuation value, while a divisible good is a good that can be divided into small portions and each portion can be given a valuation value. The former includes software, information, audio/video content, and computation results, while the latter includes money, CPU time, memory, and storage spaces.

An agent's defection like that described for the Internet auction example may occur in several domains as follows:

- person-to-person trade in Internet auctions: agents of auction winners transferring large sums of money to seller agents, who then disappear without delivering any goods.
- task delegation in peer-to-peer networks: a peer agent being asked to carry out some calculation tasks by another peer agent, who then disappears without paying any compensation fee.
- task exchange between agents in a temporally organized group: *agent*1 executing delivering task *task*2 for *agent*2, who then disappears without executing delivering task *task*1 for *agent*1, where *task*2 includes more than one goods but *task*1 includes a single good.

In the rest of this paper, we discuss exchange processes involving goods and money in electronic commerce, although our discussion can be extended to the other situations described above.

One way to prevent participants from defecting is to verify the identity of each seller/buyer agent by associating its user with an established identifier, e.g., by requiring a copy of his/her driver's license. However, checking identifiers of a large number of sellers/buyers is expensive and can discourage good sellers/buyers from participating in deals. For example, people change their behaviors if they have to use the same identifier for their hobbies as well as for business. This restricts their activities. The aim of this research is to develop mechanisms that can guarantee safe exchange while allowing participants to have more than one identifier.

One available method for allowing participants to have more than one identifier while enabling them to avoid defection is by using escrow services. Escrow services have recently come to be provided by many Internet auction sites. The mechanism is as follows. First, the buyer sends money to the center. Then the seller sends the good to the buyer. After the buyer inspects the good, if there is no problem, the center sends the money to the seller. This protocol does not motivate either the seller or the buyer to defect at any point in the exchange. However, escrow services do not appear to be popular. One reason is that the escrow-service fee is high.

To solve the problem of online fraud, we impose an entry fee on newcomers under the assumption that the participants will make repeated deals. Note that in different domains from person-to-person trade, imposing an entry fee corresponds to imposing a provision of CPU resources, or an execution of some tasks on newcomers. If this entry fee is sufficiently high, no offending buyer/seller would consider defecting since he/she would get paid less, because the temporary profit would be spent to cover the second entry fee. However, if the entry fee is too high, it will discourage newcomers from starting deals. Therefore, it is necessary to reduce the entry fee while preventing participants from defecting.

To solve this conflict, we developed three exchange mechanisms that guarantee safe exchanges. Two of them reduce the entry fee by integrating multiple deals and controlling the flow of goods and money. Gathering multiple deals together is feasible and can be done, for example, at auction sites. The other mechanism reduces the entry fee by incorporating a third-party agent into deals. The procedures of these mechanisms seem complicated for humans but are not complicated for artificial agents.

Moreover, we examine the lower bound of the entry fee for our mechanisms and derive conditions so that completion is dominant over defection, that is, completing the transaction results in a Nash equilibrium. We believe that an equilibrium analysis is an appropriate approach because it enables us to predict what happens in a mechanism in a broader context. Then, we develop an efficient method for finding the lower bound of an entry fee and a group division and prove that this method can provide the lower bound of an entry fee.

The use of an entry fee has been discussed by Friedman and Resnick [2]. They addressed the iterated prisoner's dilemma problem concerning the fact that obtaining a new identifier is cheap. The original contribution of our paper (1) introduces a formal model of an entry fee design for a defection prevention problem, (2) gives the analysis of the lower bound of an entry fee, (3) introduces three exchange protocols that reduce the entry fee, (4) proves that our methods can prevent agents from defecting, and (5) experimentally shows that our mechanism can reduce the entry fee.

An interesting point of our mechanisms can be explained as follows. Another way to prevent an agent's defection instead of using an entry fee is to split the exchange process into small parts, so that each seller/buyer can at no point obtain profits larger than the profits obtained by carrying out the remainder of the exchange [19]. This splitting-exchange protocol is based on the same idea as our protocol: to prevent the emergence of a state where an agent has both the goods and a large amount of the money. The difference between these protocols is that while the splitting-exchange protocol implements the idea by splitting a transaction in terms of a time axis, our protocols implement the idea by splitting transactions in terms of a set of agents.

Section 2 describes the model of exchanges involving goods and money. In Section 3, we discuss an entry fee for a single deal, and, in Section 4, we discuss an entry fee for multiple deals. In Section 5, we explain how the entry fee can be reduced by incorporating a third-party agent. Section 6 discusses related research. In Section 7, we provide our conclusions.

2. The basic model of exchanges involving goods and money

This section describes the model of exchanges involving goods and money. There are agents (sellers/buyers), goods, and a center. The agents are self-interested, i.e., they behave in a way to maximize their profit. Each agent can make a deal with other agents. The center collects entry fees in the manner described below and controls the flow of goods and money.

This paper assumes the following. First, we assume that the center can be trusted, while the agents may defect. Second, we assume that each agent makes deals repeatedly. Third, we assume that the goods may be indivisible. If we deal with information goods, such as software, audio/video contents, or market information, they should be treated as indivisible.

A deal is defined as follows.

Definition 1. A $deal_i$ is defined as a 3-tuple (p_i, c_i, v_i), where p_i is the dealing price, c_i is $seller_i$'s valuation of the good, and v_i is $buyer_i$'s valuation of the good. The value of c_i can be viewed as the cost for the seller to produce the good.

The dealing price means a selling price, and is determined by using a pricing method, such as an auction. While the problem of price determination, especially for information goods, is important [7,10,20], it is beyond the scope of this paper.

The profit of each agent from a deal is defined as follows.

Definition 2. After $deal_i$ is completed, the seller obtains a profit by $p_i - c_i$, and the buyer obtains a profit by $v_i - p_i$.

Here, we assume that $seller_i$ bears cost c_i just before delivering the good to $buyer_i$, i.e., if the seller stops the exchange, he/she does not have to pay cost c_i. Because both the seller and the buyer agree on the deal, the condition that $c_i \leqslant p_i \leqslant v_i$ must be held.

Each round t has $n(t)$ deals. In this paper, we fix $n(t)$ at n. In each round, each agent makes, at the most, one deal under one identifier, i.e., the following results do not occur in any round: (1) an agent sells more than one good to different buyers, (2) an agent buys more than one good from different sellers, (3) an agent sells goods and buys other goods at the same time.[1] Newcomers may participate in places where deals occur, but no participant can opt out of a place. That is, it is assumed that all agents will make periodic deals in the future, as mentioned above.

We impose entry fee p_e on each agent. The place where deals are made is described as follows.

Definition 3. The place of deals M in round t is defined as a 4-tuple $(\{agent_i\}, \{good_j\}, \{deal_k\}, p_e)$ $(1 \leqslant k \leqslant n)$.

Here, $\{agent_i\}$ denotes the set of agents in the place of deals M.

There are two ways to impose an entry fee on the agents:

Method 1. The entry fee will be collected only for the first deal from each participant, and it is not refunded. Paying the entry fee in this case means obtaining the right to permanently participate in deals.

Method 2. The entry fee will be collected for each deal from each participant and refunded after the deal is completed. However, the entry fee will not be refunded to a participant who defects from the deal.

In later sections, we will discuss mechanisms that can reduce the entry fee. The worth of reducing the entry fee is slightly different in the above methods. In method 1, because

[1] We can allow an agent to pay entry fees twice for two identifiers and make two deals under these two identifiers by slightly modifying the discussion in later sections. Even if an agent fakes a deal by using two identifiers and tries to deceive other agents, our method can prevent this deception.

the entry fee is not refunded, reducing the fee directly leads to encouraging newcomers to participate in deals.

In contrast, in method 2, because the entry fee is refunded, reducing it seems unimportant. However, let's consider a case where agents do not have enough money to pay both a high entry fee and the price of the good, while they have enough money to pay both a low entry fee and the price of the good. In this case, if the entry fee is high, the agents cannot participate in the deal, even if the entry fee is refunded after the deal is completed. Thus, reducing the entry fee in method 2 also encourages the agents to participate in a deal, although not all agents benefit from it.

Additionally, the workload of the center in method 2 is greater than that of the center in method 1. The reason for this is as follows. While the role of the center in method 1 is to collect an entry fee, keep the list of participants, and provide information about the flow of goods and money, the center in method 2, in addition to the functions described for the center in method 1, has to decide whether to give the entry fee back to the agents. Which method should be adopted depends on the nature of the place of the deals.

3. Exchange between two agents

This section describes a single deal, i.e., a good/money exchange between a seller and a buyer, and examines the necessary conditions for the entry fee to complete the exchange without defection. Defection means that the seller does not send the good to the buyer while the seller receives the money from the buyer, or, that the buyer does not send the money to the seller while the buyer receives the good from the seller. If an agent defects, he/she cannot keep using the same identifier because the center will exclude deals under that identifier.

We compare the following strategies:

- **defecting:** to obtain a greater profit by defecting from the current round and take on a new identifier paying an entry fee in the next round.
- **completing:** to obtain a smaller profit by completing the exchange in the current round and use the same identifier without paying the entry fee in the next round.

If we adopt method 2 described in Section 2, i.e., refunding the entry fee to all agents after the deal is completed, the above defection strategy means that the agents obtain a greater profit by defecting from the current round and give up getting the entry fee back, while the above completion strategy means that the agents obtain a smaller profit by completing the exchange in the current round and get the entry fee back. The following discussion in this paper addresses the situation described in method 1 in Section 2, namely, when the entry fee is not refunded. We can have a similar discussion about the situation described in method 2, namely, when the entry fee is refunded.

A necessary condition for the entry fee to be effective in preventing an agent's defection is that the profit obtained by defection is less than the profit obtained by completion of the deal. Note that, in this paper, we assume that agents do not defect if the profit obtained by defecting is equal to the profit obtained by completing the exchange.

We consider two simple protocols. In one, the seller first delivers the good to the buyer, and then the buyer pays the money to the seller. In the other, the buyer first makes a payment to the seller, and then the seller delivers the good to the buyer.

In the former case, the condition for the buyer where $v_i - p_e \leqslant v_i - p_i$, i.e., $p_i \leqslant p_e$, must be satisfied to prevent the buyer from defecting. This inequality means that the profit obtained by completion of the deal (on the right) must be larger than or equal to the profit obtained by defection (on the left). In this condition, the term representing the entry fee for the first participation, p_e, is omitted from both sides, because its payment is the same in both the defection and the completion strategies. Term $-p_e$ on the left of the inequality represents the second entry fee that the buyer must pay for taking on a new identifier in the next round. In this case, we do not have to consider the seller's defection, because the seller cannot defect.

In the latter case, however, the condition for the seller, $p_i - p_e \leqslant p_i - c_i$, i.e., $c_i \leqslant p_e$, must be satisfied to prevent the seller from defecting.[2] This inequality means that the profit obtained by completing the deal (on the right) must be larger than or equal to the profit obtained by defecting (on the left). In this condition, the term representing the entry fee for the first participation, p_e, is also omitted from both sides. In this case, we do not have to consider the buyer's defection, because the buyer cannot defect.

From the condition that $c_i \leqslant p_i \leqslant v_i$ described in Section 2, the lower bound of entry fee p_e becomes c_i when the latter protocol is adopted. Our objective is to reduce this bound.

Our basic idea in designing a safe exchange protocol is to prevent the emergence of a state where the agent has both the good and a large amount of the money. We will examine the following protocol for reducing the entry fee. Here, note that a good may be an indivisible good. In the place of deals, the center keeps a blacklist that lists the identifiers of agents who committed fraud in the past.

One seller/one buyer exchange protocol.
For $deal_i$,

(1) $seller_i$ and $buyer_i$ report their identifiers to the center. If both of identifiers or either of identifiers is listed on the blacklist, the center stops the exchange.
(2) If $seller_i$ is a newcomer, he/she pays entry fee p_e to the center. If $buyer_i$ is a newcomer, he/she pays entry fee p_e to the center.
(3) $buyer_i$ pays down payment x to $seller_i$.
(4) If $seller_i$ receives down payment x, he/she delivers $good_i$ to $buyer_i$.
(5) When $buyer_i$ receives the good, he/she pays the remainder, $p_i - x$, to $seller_i$.

If either of the participants defects in the middle of the exchange process, the exchange process stops and the identifier of the participant who defected is reported to the center.

[2] The entry fee is imposed only in the first participation. Therefore, even if the entry fee is high, if each agent makes several deals, the participation can benefit the agent, i.e., the participation can be individually rational. If we adopt method 2, in which the entry fee is refunded after the deal is completed, individual rationality always holds.

We then examined the lower bound of the entry fee. The point where *seller*$_i$ may defect is after step 3. The condition for *seller*$_i$ not to defect, i.e., to deliver the good after he/she receives down payment x, is given by the following inequality:

$$x - p_e \leqslant p_i - c_i. \tag{1}$$

The left side represents the profit obtained by defecting and paying the entry fee once again, while the right side represents the profit obtained by completing the exchange, i.e., the difference between the seller's income and the cost for him/her to produce the good. In this inequality, the term representing the entry fee for the first participation, p_e, is omitted from both sides, because its payment is the same in both the defection and the completion strategies. From this inequality, we can conclude that to prevent *seller*$_i$ from defecting, no one must pay *seller*$_i$ a down payment exceeding $p_i - c_i + p_e$.

On the other hand, the point where *buyer*$_i$ may defect is after step 4. The condition for *buyer*$_i$ not to defect, i.e., to pay the remainder, $p_i - x$, is given by the following inequality:

$$v_i - x - p_e \leqslant v_i - p_i. \tag{2}$$

The left side represents the profit obtained by defecting, i.e., $v_i - x$, and paying the entry fee once again, while the right side represents the profit obtained by completing the exchange, i.e, the difference between the buyer's valuation of the good and his/her payment. In this inequality, the term representing the entry fee for the first participation, p_e, is omitted from both sides, because its payment is the same in both the defection and the completion strategies. From this inequality, we can conclude that to prevent *buyer*$_i$ from defecting, we have to make *buyer*$_i$ pay a down payment of more than $p_i - p_e$.

From the above discussion, in order to prevent both the seller and the buyer from defecting, the above conditions, (1) and (2), must be satisfied. This means that if we impose an entry fee that satisfies these conditions, completing the exchange is in a Nash equilibrium for both the seller and the buyer [4]. That is, compared to defecting, completing the transaction results in a payoff.

Proposition 1. *The lower bound of entry fee p_e to prevent an agent from defecting is half of seller$_i$'s valuation for good c_i. In this case, down payment x is $p_i - c_i/2$.*

Proof. Entry fee p_e becomes minimum at the point where the down payment that a seller is allowed to receive is equal to the down payment that a buyer has to pay. By satisfying this condition for balance in the down payment, i.e., $p_i - c_i + p_e = p_i - p_e$, we find that $p_e = c_i/2$. In this case, the down payment is calculated to be $x = p_i - p_e = p_i - c_i/2$. □

Example 1. For deal $(200, 100, 300)$, i.e., when the dealing price is 200, the seller's valuation is 100, and the buyer's valuation is 300, the minimum entry fee is calculated to be $100/2 = 50$. If we set the entry fee at 49, the buyer must not pay more than $200 - 100 + 49 = 149$ to the seller to prevent the seller from defecting, while we have to make the buyer pay more than $200 - 49 = 151$. Therefore, no entry fee lower than 50 can prevent both the seller and the buyer from defecting.

In bilateral trade negotiations, telling the truth about valuations is not in equilibrium for agents on the condition that the ex post efficiency and individual rationality are satisfied [9].

If we do not know the seller's true valuation of the good, we use an estimated value. If we cannot estimate an accurate value, we can substitute dealing price p_i for seller's valuation c_i. This is because p_i is the upper bound of c_i. However, if the difference between p_i and c_i is too large, this requires an entry fee that is very large.

4. Integrating multiple deals

4.1. Problems in integrating multiple deals

In the place of deals M, there are n deals in each round. For example, at an auction site, multiple deals can be made in a day, and each seller's cost and/or dealing price can differ from that of others. To prevent agents from defecting in a deal, we have to set an entry fee of a value determined as follows: (1) calculate the minimum entry fee for each deal by using the method described in the previous section, and (2) apply the maximum value of all these minimum entry fees to all deals. This is because the center cannot impose different entry fees on different agents, since the center does not know in advance what deals each agent will make in the future.[3]

If the center sets the entry fee at the maximum value, some agents who intend to make deals involving only a small sum will be discouraged from participating in deals, because they will have to pay too high an entry fee to buy what they want. Thus, to encourage agents to participate in deals, we need a method to reduce the entry fee for multiple deals.

In this section, we describe three protocols: the time-priority exchange protocol, the entry-fee-priority exchange protocol, and the third-party-agent exchange protocol.

The time-priority exchange protocol can reduce the entry fee by controlling the order of delivering goods and making payments. The basic idea is as follows. This protocol divides a deal set into two subsets, G_H and G_L. First, agents in G_H start to carry out transactions, and then agents in G_L carry out transactions. In this protocol, payments are made between G_H and G_L, that is, buyers in G_H pay sellers in G_L and buyers in G_L pay sellers in G_H. This means that agents in G_L act as intermediaries between sellers and buyers in G_H as if the agents in G_L are the center that provides escrow services. This is how our protocol can reduce the entry fee.

Payments between buyers and sellers of different deals may seem unrealistic. However, this is possible because money can be paid by any buyer to the seller if the budget balances, while the good is delivered from the seller to the buyer directly, especially if the good is an information good. That is, the buyer does not care to whom he/she pays as long as he/she can obtain the good without paying more than his/her dealing price. The seller also does not care from whom he/she receives the money as long as he/she can obtain the same amount of money as his/her dealing price.

The principle of payments between buyers and sellers of different deals is described as follows. Let c_1 be the maximum value of all the sellers' valuations ($c_1 > c_i,\ 2 \leqslant i \leqslant n$).

[3] If we adopt method 2 described in Section 2, namely, the entry fee is collected for each deal from each agent and is refunded after each of the deals is completed, the center can impose different entry fees on different agents. However, a uniform entry fee makes it easy for the center to manage many deals.

Suppose that entry fee p_e is set at a value less than $c_1/2$. In *deal*$_1$, the upper bound of the down payment that *seller*$_1$ is allowed to receive is $p_1 - c_1 + p_e$, and the lower bound of the down payment that *buyer*$_1$ must pay is $p_1 - p_e$. The amount in excess of the down payment can be expressed as follows:

$$(p_1 - p_e) - (p_1 - c_1 + p_e) = c_1 - 2p_e > 0.$$

Because the amount in excess of the down payment, $c_1 - 2p_e$, cannot be held by either *seller*$_1$ or *buyer*$_1$, our protocol asks sellers in G_L to hold this excess amount.

The entry-fee-priority protocol is a variation of the time-priority exchange protocol. Before we describe the difference between the time-priority and the entry-fee-priority protocols, we define the dealing time as follows.

Definition 4. It takes one step to complete each of the following processes: the buyer pays money to the seller, and the seller delivers the good to the buyer.

If multiple deals in a round are made separately, the number of steps to complete a round is three. The time-priority exchange protocol enables completing each round in five steps, and the entry-fee-priority exchange protocol enables further lowering the entry fee but requires $2n + 1$ steps, in the worst-case scenario, for each round to be completed.

The third-party-agent exchange protocol can reduce the entry fee by incorporating third-party agents into exchange processes. In our protocol, third-party agents act as intermediaries between sellers and buyers as if these third-party agents are the center that provides escrow services. This is how our protocol can reduce the entry fee. Note that the third-party-agent exchange protocol as well as the former two protocols assumes that a center exists. The difference between third-party agents and the center in our protocol is that third-party agents are assumed to be self-interested, while the center is not.

4.2. Time-priority exchange protocol

Time-priority exchange protocol.

(1) Divide deal set $\{deal_i\}$ in a round into two subsets, G_H and G_L. The method of division is described in Section 4.3.
(2) *buyer*$_i$ of *deal*$_i$ in G_H pays $x1 = p_i - c_i + p_e$ to *seller*$_i$ of *deal*$_i$, and $x2 = (p_i - p_e) - (p_i - c_i + p_e) = c_i - 2p_e$ to sellers of deals in G_L. In these payments, payment $x3$ for *seller*$_j$ of *deal*$_j$ in G_L must not exceed $\min\{p_j - c_j + p_e, p_j\}$. We will explain later why the budget that exceeds the down payment is balanced. Note that the center determines the assignment of the down payment so that condition $x3 \leqslant \min\{p_j - c_j + p_e, p_j\}$ is satisfied.
(3) If *seller*$_i$ of *deal*$_i$ in G_H receives down payment $x1$ and learns that some other agents received $x2$ from *buyer*$_i$, *seller*$_i$ delivers *good*$_i$ to *buyer*$_i$.
(4) If *buyer*$_i$ of *deal*$_i$ in G_H receives *good*$_i$, *buyer*$_i$ pays the remainder, $p_i - x1 - x2$, to *seller*$_i$.

(5) If *buyer*$_j$ of *deal*$_j$ in G_L learns that *buyer*$_i$ receives *good*$_i$, *buyer*$_j$ pays $x3$ to *seller*$_i$ of *deal*$_i$ and $x4 = \max\{p_j - c_j/2 - x3, 0\}$ to *seller*$_j$ of *deal*$_j$. The value of $x3$ is the same as that of $x3$ in step 2.
(6) If *seller*$_j$ of *deal*$_j$ in G_L receives down payments $x3$ and $x4$, he/she delivers *good*$_j$ to *buyer*$_j$.
(7) If *buyer*$_j$ of *deal*$_j$ in G_L receives *good*$_j$, *buyer*$_j$ pays the remainder, $p_j - x3 - x4$, to *seller*$_j$.

In each step, if a seller/buyer defects, no buyer/seller pays/delivers anything to him/her in the later steps. Although the information about defections is managed by the center, for simplicity, we omit communication between the sellers/buyers and the center from the above description.

In step 2, if payment $x3$ for *seller*$_j$ of *deal*$_j$ in G_L exceeds $p_j - c_j + p_e$, *seller*$_j$ defects, and if payment $x3$ exceeds p_j, an amount of money equal to $x3 - p_j$ must be further transfered from *seller*$_j$ to the others, which makes deals complicated. Thus, payment $x3$ must not exceed $\min\{p_j - c_j + p_e, p_j\}$.

The condition that an inequality, $x3 \leqslant \min\{p_j - c_j + p_e, p_j\}$, is maintained for each payment from buyers of deals in G_H to sellers of deals in G_L in step 2 is given by the following inequality:

$$\sum_{deal_i \in G_H} \max\{c_i - 2p_e, 0\} \leqslant \sum_{deal_j \in G_L} \min\{p_j - c_j + p_e, p_j\}. \tag{3}$$

The left side represents the sum of the amount in excess of the down payments for deals in G_H, while the right side represents the sum of the amounts of money that sellers in G_L can hold after step 2.

The condition for the down payment whereby neither sellers nor buyers of deals in G_L are motivated to defect in steps 6 and 7, is given by the following inequality:

$$p_e \geqslant \max_{deal_j \in G_L} c_j/2. \tag{4}$$

This is obtained from Proposition 1.

If we set p_e at a sufficiently large value, both conditions (3) and (4) are satisfied. Thus, a value of p_e must be set so that a feasible assignment of payments can be made.

Example 2. There are two deals in a round: *deal*$_1$: $(200, 100, 300)$ and *deal*$_2$: $(400, 200, 600)$.

If we handle the two deals separately, based on Proposition 1, the minimum entry fees to prevent agents from defecting are $p_e = 100/2 = 50$ for *deal*$_1$ and $p_e = 200/2 = 100$ for *deal*$_2$. Therefore, if we impose a uniform entry fee on all agents, the entry fee must be set at 100. This means that if the agents of *deal*$_1$ are newcomers, each of them must pay 100 as an entry fee while the profit of each agent from the deal will be equal to 100 (*seller*$_1$: $200 - 100 = 100$, *buyer*$_1$: $300 - 200 = 100$).

Consider the case when the time-priority exchange protocol is used for the above two deals. Let $deal_2 \in G_H$ and $deal_1 \in G_L$. If $p_e = 50$, both condition (3), i.e., $200 - 2p_e \leqslant \min\{200 - 100 + p_e, 200\}$, and condition (4), i.e., $p_e \geqslant 100/2$, are satisfied; thus $p_e = 50$.

This means that, in contrast to the former case, in this case we can lower the entry fee from 100 to 50. Let us examine the exchange process in detail:

1. $buyer_2$ pays $400 - 200 + 50 = 250$ to $seller_2$, and $200 - 2 \times 50 = 100$ to $seller_1$.
2. $seller_2$ delivers $good_2$ to $buyer_2$.
3a. $buyer_2$ pays the remainder, $400 - 250 - 100 = 50$, to $seller_2$.
3b. $buyer_1$ pays 100 to $seller_2$, and $200 - 100/2 - 100 = 50$ to $seller_1$.
4. $seller_1$ delivers $good_1$ to $buyer_1$.
5. $buyer_1$ pays the remainder, $200 - 100 - 50 = 50$, to $seller_1$.

Step 3a and step 3b can be done in parallel. As mentioned earlier, if we handle multiple deals separately, each round is completed in three steps, because all exchanges can be done in parallel. In contrast, if we use the time-priority exchange protocol, each round requires five steps to be completed.

In each step, completion of the transaction results in a payoff compared with defection. Moreover, each agent's budget is balanced after the last step.

The following proposition guarantees that our protocol can prevent agents from defecting, i.e., no agent is motivated to defect if other agents complete their exchanges.

Proposition 2. *In the time-priority exchange protocol, it is in a Nash equilibrium for each agent to complete the exchanges.*

Proof. For sellers and buyers of deals in G_H, it is clear that conditions (1) and (2) are satisfied. Next, let's consider sellers and buyers of deals in G_L. In the case of $x3 \leqslant p_j - c_j/2$, the seller received $x3 + x4 = p_j - c_j/2$ before step 6, i.e., before delivering the good, and the buyer already paid $x3 + x4$ for receiving the good after step 6. Here, $p_j - p_e \leqslant p_j - c_j/2 \leqslant p_j - c_j + p_e$ is maintained because the value of p_e is such that condition (4) is satisfied. This satisfies conditions (1) and (2). In the case where $x3 > p_j - c_j/2$, i.e., $x4 = 0$, the seller did not receive more than $p_j - c_j + p_e$ before step 6, and the buyer already paid more than $p_j - c_j/2$ after step 6. This satisfies conditions (1) and (2). In the other steps, both conditions (1) and (2) are also satisfied. This means that no agent can obtain a profit greater than the profit obtained by completing the exchange, even if he/she defects in any of the steps. Thus, if the other agents do not defect, no agent is motivated to defect. □

As we proved above, a Nash equilibrium means a strategy combination where no agent has the incentive to deviate from his/her strategy given that the other agents do not deviate. However, there are many equilibrium concepts, one of which is a dominant strategy equilibrium. A dominant strategy equilibrium is a strategy combination consisting of each agent's dominant strategy. Here, a dominant strategy means one that is a strictly best response to any strategies the other agents might pick [13]. Although the completion strategy is in a Nash equilibrium in the proposed protocol, it is not in a dominant strategy.

Some researchers say that a Nash equilibrium is not an appropriate solution concept in the Internet environment because a priori information is limited for an agent [3]; namely, an agent cannot ascertain whether the other agents face the same situation. However, it is often difficult to design a mechanism that has a dominant strategy. Especially in trade situations, if a buyer/seller deviates, the corresponding seller/buyer cannot avoid suffering a loss. Therefore, we believe that an analysis based on a Nash equilibrium is appropriate in trade situations.

4.3. Deal-set division and entry-fee calculation

We will now describe how a deal set is divided into two subsets and how the entry fee is calculated. Our method enables deal-set division and minimum-entry-fee calculation in $O(n)$ time. Because the terms in labeling a deal are arbitrary, let $c_1 \geqslant c_2 \geqslant \cdots \geqslant c_n$. Let's assume that G_H includes $deal_1, \ldots, deal_k$, and G_L includes $deal_{k+1}, \ldots, deal_n$. We rename p_e as p_e^1 and p_e^2 so that these satisfy the equality in conditions (3) and (4), respectively. Changing the value of k from 1 to $n-1$, we choose $k = k^*$ so that $\max\{p_e^1, p_e^2\}$ is minimized. The minimum entry fee, p_e^*, to prevent agents from defecting becomes the value of $\max\{p_e^1, p_e^2\}$ for k^*.

Example 3. The following two examples show how to divide a deal set. Here, we assume that $c_i = p_i$.

Case 1 (the distribution of dealing prices is uniform): Let's assume that we have $deal_i$ $(1 \leqslant i \leqslant 8)$ so that $p_i = 900 - 100i$. Our method of division gives an entry fee of 230 and the following two subsets:

$$G_H = \{deal_1, deal_2, deal_3, deal_4\},$$

$$G_L = \{deal_5, deal_6, deal_7, deal_8\}.$$

Case 2 (only one dealing price is high): Let's assume that we have $deal_1$ $(p_1 = 1000)$, $deal_2, \ldots, deal_9$ $(p_i = 100\ (2 \leqslant i \leqslant 9))$. Our method gives an entry fee of 100 and the following two subsets:

$$G_H = \{deal_1\},$$

$$G_L = \{deal_2, deal_3, \ldots, deal_9\}.$$

We will now show that p_e^* is the lower bound for preventing agents' defection in the time-priority exchange protocol. To make the discussion simple, we assume that $c_i = p_i$. This corresponds to a case where the market is competitive or when p_i, i.e., the upper bound of c_i, is used because the true value of c_i is unknown. The case where $c_i < p_i$ can be analyzed in the same way as follows.

Proposition 3. *In the time-priority exchange protocol, entry fee p_e^* that is calculated by our method is the lower bound for preventing agents' defection.*

To prove this proposition, we used the following lemmas.

Lemma 4. *Place all dealing prices, p_i, in descending order. Let G_H include the first k deals and G_L include the rest of the deals. The maximum value of all the dealing prices in G_L is represented by p_{Lmax}. Here, we perform new divisions (G'_H, G'_L) by transferring some deals other than the deal of p_{Lmax} from G_L to G_H. If we take 1 to $n-1$ to be the value of k, $\{(G_H, G_L)\} \cup \{(G'_H, G'_L)\}$ covers all possible divisions.*

Lemma 5. *Place all dealing prices, p_i, in descending order. Let G_H include the first k deals and G_L include the rest of the deals. The maximum value of all the dealing prices in G_L is represented by p_{Lmax}. Here, even if we transfer some deals other than the deal of p_{Lmax} from G_L to G_H, the minimum entry fee does not decrease.*

Proof. Because p_{Lmax} does not change, p_e^2, calculated based on condition (4), does not change. Based on condition (3), p_e^1 is the value that satisfies the following equation:

$$\sum_{i=1}^{k} \max\{p_i - 2p_e^1, 0\} = \sum_{i=k+1}^{n} \min\{p_e^1, p_i\}. \tag{5}$$

Here, p_e^1 is obtained as the point of intersection between $y = \sum_{i=1}^{k} \max\{p_i - 2p_e^1, 0\}$ and $y = \sum_{i=k+1}^{n} \min\{p_e^1, p_i\}$. Now, let $p_e^{1'}$ denote the value of p_e^1 for a division performed by transferring p_j from G_L to G_H. $p_e^{1'}$ is the value that satisfies the following equation:

$$\begin{aligned}
&\sum_{i=1}^{k} \max\{p_i - 2p_e^{1'}, 0\} + \max\{p_j - 2p_e^{1'}, 0\} \\
&\quad = \sum_{i=k+1}^{n} \min\{p_e^{1'}, p_i\} - \min\{p_e^{1'}, p_j\}.
\end{aligned} \tag{6}$$

The left sides of Eqs. (5) and (6) are non-increasing functions to $p_e^1(p_e^{1'})$, and the latter is always larger than or equal to the former; the right sides of Eqs. (5) and (6) are non-decreasing functions to $p_e^1(p_e^{1'})$, and the former is always larger than or equal to the latter. By considering the point of intersection between $y = \sum_{i=1}^{k} \max\{p_i - 2p_e^1, 0\}$ and $y = \sum_{i=k+1}^{n} \min\{p_e^1, p_i\}$, and the point of intersection between $y = \sum_{i=1}^{k} \max\{p_i - 2p_e^{1'}, 0\} + \max\{p_j - 2p_e^{1'}, 0\}$ and $y = \sum_{i=k+1}^{n} \min\{p_e^{1'}, p_i\} - \min\{p_e^{1'}, p_j\}$, we find that inequality $p_e^1 < p_e^{1'}$ is held.

(1) If $p_e^1 \leqslant p_e^2$ and $p_e^{1'} \leqslant p_e^2$, the minimum value of the entry fee does not change because $p_e^* = \max\{p_e^{1'}, p_e^2\} = p_e^2$.
(2) If $p_e^1 \leqslant p_e^2$ and $p_e^{1'} > p_e^2$, the minimum value of the entry fee does not decrease because $p_e^* = \max\{p_e^{1'}, p_e^2\} = p_e^{1'} > p_e^2$.
(3) The case of $p_e^1 > p_e^2$ and $p_e^{1'} \leqslant p_e^2$ does not occur because $p_e^1 < p_e^{1'}$.
(4) If $p_e^1 > p_e^2$ and $p_e^{1'} > p_e^2$, the minimum value of the entry fee does not decrease because $p_e^* = \max\{p_e^{1'}, p_e^2\} = p_e^{1'} > p_e^1$.

Thus, transferring a deal other than the deal of p_{Lmax} from G_L to G_H does not reduce the minimum entry fee. For cases when we transfer more than one deal from G_L to G_H, a similar discussion holds. □

Proof of Proposition 3. From the above lemmas, the entry fee calculated by the division performed by placing all dealing prices, p_i, in descending order, while letting G_H include the first k deals and G_L include the rest of the deals, is the minimum value of all the divisions where the value of p_{Lmax} is the same. Thus, if we choose the minimum value when taking 1 to $n-1$ as k, the value is the minimum value of all possible divisions. □

We point out that although the procedure of the proposed protocol seems complicated, it is not for an artificial agent.

We showed a method for calculating the lower bound of an entry fee, if a deal set is given. However, we cannot know in advance what deal each agent will make in the future. Therefore, we first estimate the probability distribution of the seller's valuation and dealing price of all deals, and then calculate, based on this probability distribution, the appropriate amount of the entry fee.

4.4. Experimental evaluation

We evaluated the effectiveness of the time-priority exchange protocol by comparing this protocol with a protocol that handles all deals separately. In this evaluation, we assumed that seller's valuation c_i was equal to dealing price p_i. We examined two types of dealing-price distributions: uniform and exponential.

In an exponential distribution, there are many trades whose dealing prices are low and a few trades whose dealing prices are high. A market place is likely to exist that has many trades of cheap commodity and a few trades of expensive valuables. This situation is one of the situations in which a simple separate-deal protocol does not work well. This is because a buyer/seller whose dealing price is low will be discouraged from starting a deal if a high entry fee is imposed. Thus, the proposed protocol should be examined in this situation to evaluate its performance.

In a uniform distribution case, the dealing price is drawn from a uniform distribution over $[100, 200]$. In an exponential distribution case, the dealing price is drawn from an exponential distribution for which the probability density function is $f(p_i) = a \cdot \exp(-(p_i - 100)/10)$ $(100 \leqslant p_i \leqslant 200)$, where a is a constant such that an integral of $f(p_i)$ in interval $[100, 200]$ is equal to 1. We also assumed that the dealing prices included in each round are independent. Under these conditions, the value of the entry fee that prevents agents' defection ranges from 50 $(= 100/2)$ to 100 $(= 200/2)$ in both distributions.

Fig. 1 shows our experimental results, i.e., the entry fee for the case when multiple deals are handled separately, and the entry fee for the case when the time-priority exchange protocol is used. In these figures, the x-axis represents the number of deals in a round, while the y-axis represents the minimum value of the entry fee that prevents agents' defection. Each point in the figures represents an average value of the minimum entry fees in 100 instances.

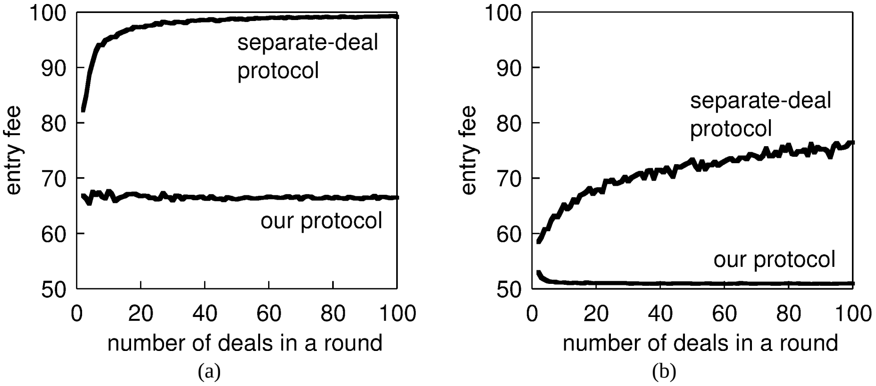

Fig. 1. Entry-fee comparison. (a) Uniform distribution. (b) Exponential distribution.

These figures indicate that if multiple deals are handled separately, an entry fee must be set at a higher value, i.e., the highest value of the entry-fee values in these 100 instances. Therefore, as the number of deals in a round increases, the entry fee must become higher.

However, the described method can lower the entry fee regardless of the number of deals in a round. In particular, in the exponential distribution, we can set the entry fee at a value around 50, that is, the lower bound, because the dealing price is around 100 in most deals and the dealing price is high only in a small number of deals.

The following list summarizes the properties of the time-priority exchange protocol compared to the protocol that handles all deals separately:

- The time-priority exchange protocol can reduce the entry fee compared to a simple separate-deal protocol. Especially in the exponential distribution case, the performance of our protocol becomes the lower bound of the entry fee.
- The load for the center increases. However, the load of calculating an assignment of payments is not great because this is done by assigning the maximum down payment, $\min\{p_j - c_j + p_e, p_j\}$, to each $seller_j$ in the G_L in increasing order of c_j.
- In all deals, information on who is the seller and who is the buyer is disclosed to someone other than the seller and the buyer. However, no participant can know about other pairs of sellers and buyers outside of his/her own deal.

4.5. Entry-fee-priority exchange protocol

By ordering multiple deals in a round, we can lower the entry fee even further compared to the entry fee in the time-priority exchange protocol. The reason is as follows.

The time-priority exchange protocol can lower the entry fee by dividing a deal set into two subsets, G_H and G_L, and having agents in G_L act as intermediaries between sellers and buyers in G_H. Here, if condition (3) is not binding, we can further lower the entry fee by increasing the number of intermediaries. This procedure is as follows. First, divide G_L into two subsets, G_{L1} and G_{L2}, in the same way as when we divided a deal set into G_H and G_L. Then, have agents in G_{L2} act as intermediaries between sellers and buyers in G_{L1}. A necessary condition for this mechanism to work is that agents in G_{L1} must be the first to start carrying out transactions, and then the agents in G_{L2} carry out transactions. This is because, if these transactions are carried out at the same time, some sellers in G_{L1} may be left with a large amount of money in one of the steps, in which case defection will become dominant over completion.

From the above discussion, the entry fee can be lowered by increasing the number of group divisions and carrying out transactions in each group in order. We call this protocol "the entry-fee-priority exchange protocol". It requires $2n+1$ steps to complete a round in the worst case.[4] Here, n is the number of deals in a round.

The outline of the entry-fee-priority exchange protocol is as follows. Goods are delivered to buyers one by one, that is, no more than one good is delivered at the same time. Let's assume that $c_1 \geqslant c_2 \geqslant \cdots \geqslant c_n$. First, $buyer_1$ pays down payment $p_1 - c_1 + p_e$ to $seller_1$ and down payments to $seller_i$ $(2 \leqslant i \leqslant n)$ so that the amount of these payments is equal to $p_1 - p_e$. Here, let $p'_{1,i}$ denote a down payment from $buyer_1$ to $seller_i$. Second, $seller_1$ delivers $good_1$ to $buyer_1$. Third, $buyer_1$ pays the remainder, p_e, to $seller_1$. Until the amount of money paid to $seller_1$ becomes equal to p_1, $buyer_i$ $(2 \leqslant i \leqslant n)$ pays an amount of money that does not exceed $buyer_i$'s dealing price p_i to $seller_1$. Here, let $p''_{i,1}$ denote a payment from $buyer_i$ to $seller_1$. Next, $buyer_2$ pays down payment $\max\{p_2 - c_2 + p_e - p'_{1,2}, 0\}$ to $seller_1$ and down payments to $seller_i$ $(3 \leqslant i \leqslant n)$ so that the amount of these payments is equal to $p_2 - p_e$. These payments and deliveries continue until all exchanges have been carried out.

Although we omitted a detailed description of this protocol, the following example illustrates the exchange process.

Example 4. There are three deals: $deal_1$: $(100, 100, 120)$, $deal_2$: $(80, 80, 100)$, and $deal_3$: $(20, 20, 40)$.

If we use the time-priority exchange protocol, the minimum entry fee needed to prevent agents' defection is 40. Here, let the entry fee be 30.

1. $buyer_1 \to seller_1$: 30, $buyer_1 \to seller_2$: 20, $buyer_1 \to seller_3$: 20.
2. $seller_1 \to buyer_1$: $good_1$.
3a. $buyer_1 \to seller_1$: 30, $buyer_2 \to seller_1$: 40.
3b. $buyer_2 \to seller_2$: 10.
4. $seller_2 \to buyer_2$: $good_2$.
5. $buyer_2 \to seller_2$: 30, $buyer_3 \to seller_2$: 20.
6. $seller_3 \to buyer_3$: $good_3$.

Each participant's budget balances because each seller's income is as follows: $seller_1 = 30 + 30 + 40 = 100$, $seller_2 = 20 + 10 + 30 + 20 = 80$, $seller_3 = 20$; and each buyer's payment is as follows: $buyer_1 = 30 + 20 + 20 + 30 = 100$, $buyer_2 = 40 + 10 + 30 = 80$, $buyer_3 = 20$. In each step, a down payment that each buyer makes or each seller receives satisfies conditions (1) and (2) to prevent agents' defection.

[4] Each deal, $deal_i$, takes three steps to be completed. However, the last step in $deal_i$ and the first step in $deal_{i+1}$ can be done in parallel. Thus, this protocol requires $2n + 1$ steps to complete a round. Additionally, in some steps, there may be nothing to do.

We want to point out that if exchange processes are carried out by artificial agents, any increase in the dealing time will not be significant, because each step can be completed instantaneously.

5. Incorporating a third-party agent

If there are agents in a place of deals who do not have deals in a round, the entry fee can be reduced by incorporating these agents into exchange processes.

The third-party-agent exchange protocol.

(1) $seller_i$ and $buyer_i$ report their identifiers to the center. If both of identifiers or either of identifiers is listed on the blacklist, the center stops the exchange.
(2) If $seller_i$ is a newcomer, he/she pays entry fee p_e to the center. If $buyer_i$ is a newcomer, he/she pays entry fee p_e to the center.
(3) The center informs $seller_i$ and $buyer_i$ of a third-party agent who is not listed on the blacklist and who has no deals in the current round.
(4) $seller_i$ pays down payment $x1$ to $seller_i$ and $x2$ to the third-party agent.
(5) The third-party agent informs $seller_i$ that he/she has received $x2$ from $buyer_i$.
(6) If $seller_i$ receives down payment $x1$ and learns that the third-party agent has received $x2$, $seller_i$ delivers $good_i$ to $buyer_i$.
(7) If $buyer_i$ receives the good, $buyer_i$ pays the remainder, $p_i - x1 - x2$, to $seller_i$ and asks the third-party agent to pay $x2$ to $seller_i$.
(8) If the third-party agent receives the request from $buyer_i$, he/she pays $x2$ to $seller_i$.

If either agent defects in the middle of the exchange process, the exchange process stops and the identifier of the agent who defected is reported to the center.

The conditions, under which the seller/buyer/third-party agent are not motivated to defect, are given as follows.

$$x1 - p_e \leqslant p_i - c_i \quad (seller_i)$$
$$v_i - x1 - x2 - p_e \leqslant v_i - p_i \quad (buyer_i)$$
$$x2 - p_e \leqslant 0 \quad \text{(a third-party agent).}$$

Each of the left sides represents the profit obtained by defecting and paying the entry fee once again, while each of the right sides represents the profit obtained by completing the exchange.

Proposition 6. *The lower bound of p_e for preventing agents' defection is a third of $seller_i$'s valuation for the good, i.e., $c_i/3$. In this case, down payment $x1$ is $p_i - 2c_i/3$, and down payment $x2$ is $c_i/3$.*

Proof. From the discussion in Section 4, if we set entry fee p_e at a value less than $c_i/2$, the difference between the down payment that the buyer must pay and the down payment that the seller is allowed to receive so that neither agent defects is $c_i - 2p_e$. This is the amount paid to the third-party agent, i.e., $x2 = c_i - 2p_e$. The entry fee is minimized if the amount paid to the third-party agent is equal to a maximum value such that he/she is not motivated to defect, i.e., $x2 - p_e = c_i - 2p_e - p_e = 0$. Therefore, $p_e = c_i/3$. In this case,

$$x1 = p_i - c_i + p_e = p_i - c_i + c_i/3 = p_i - 2c_i/3 \quad \text{and} \quad x2 = p_e = c_i/3. \qquad \square$$

Compared with Proposition 1, this protocol lowers the entry fee from $c_i/2$ to $c_i/3$.

The properties of the third-party-agent exchange protocol, compared with a protocol that handles each deal separately, can be summarized as follows:

- The entry fee can be reduced by incorporating a third-party agent. The greater the number of these third-party agents gets, the lower the entry fee. The entry fee can be further reduced by combining this protocol with the time-priority/entry-fee-priority exchange protocol.
- In a deal, the third-party agent will have information about the seller-buyer pair. However, if none of the third-party agents knows how many third-party agents there are, he/she cannot know the dealing price.

6. Discussion

In this paper, we described three protocols: the time-priority exchange protocol, the entry-fee-priority exchange protocol, and the third-party-agent exchange protocol. This section compares these entry-fee-based protocols with other related techniques and clarifies the advantages and disadvantages of our protocols.

As mentioned in Section 1, escrow services have come to be available at many auction sites, but they have not yet become popular. One of the reasons is that an escrow fee is high. This is because the cost of managing the center is high. This cost can be reduced by using our protocols, because the center in our protocols handles not goods and money but information about the flow of goods and money. This means that while the center that provides escrow services has to check all instances of receiving money in all deals, the center in our protocols does not have to do this because this task is distributed among all sellers.

In addition to checking, most of the tasks of the center except collecting money can be managed by participants themselves in a dealing place, if we adopt a policy of collecting an entry fee for the first deal, which is not refunded, from each participant. That is, if a set of deals is given, the assignment of down payments can be calculated by participants, although the amount of communication between agents increases. Thus, especially in a dealing place with relatively stable participants, the center has only the task of maintaining a blacklist that lists the identifiers of agents who had committed fraud in the past, which results in a reduction of managing costs of the center.

One disadvantage of our protocols is our assumption that each agent makes repeated deals. If this assumption does not hold, an agent may defect in the middle of an exchange.

This problem can be mitigated by exchanging information about good participants between the places of deals and discounting the entry fee for good participants.

Another disadvantage of our protocols is that a malicious agent may benefit from selling short. In our protocol, a seller receives a down payment before delivering the good. Therefore, an agent can obtain the down payment by pretending to be the seller and disappearing after receiving the down payment. In this case, this dishonest agent's profit becomes equal to the difference between the down payment and the entry fee, i.e.,

$$-p_e + (p_i - c_i + p_e) = p_i - c_i.$$

However, if the market is competitive, dealing price p_i becomes close to seller's valuation c_i. Thus, a dishonest agent cannot obtain an unfair profit. Although the market is not always competitive, if we substitute p_i for c_i, a dishonest agent cannot obtain an unfair profit. Also, Friedman and Resnick pointed out that an entry fee includes not only a monetary transfer, but also the time consumed by the registration process, such as when answering a questionnaire [2]. Therefore, a malicious agent will be discouraged from committing fraud because he/she cannot obtain a large amount of money worth committing this fraud.

Another disadvantage of our protocol is that we assume that an entry fee is calculated based on the estimated probability distribution of the seller's valuation and dealing price of all deals. We believe that obtaining the probability distribution is not difficult because dealing prices can be observed by the center in auction places and sellers' valuation values can be substituted by the dealing prices, although describing a way of estimating the probability distribution is beyond the scope of this paper. Unfortunately, the center may fail to obtain an accurate probability distribution. Even in such a case, we can achieve safe exchanges by separating high dealing-price deals from other deals and resort to other methods such as escrow services for the separated deals, which results in reducing the total cost for handling all deals.

Another way to prevent an agent's defection is to split the exchange process into small parts [19], as mentioned in Section 1. The splitting-exchange protocol has the advantage of not requiring a center, that is, the seller and buyer do not have to pay anything to a center. However, we cannot apply this method to indivisible goods such as software deals, while our protocols can be used for exchanges involving indivisible goods and divisible goods. As mentioned earlier, software is usually an indivisible good. Even if software could be divided into modules, the seller and buyer would still need to agree on how to divide the good, and the seller would need to know the buyer's valuation of each module. This would become an overhead in the exchange process. In addition, if a good is divisible, we can further lower the entry fee by incorporating the technique of the splitting-exchange protocol into our protocols.

A limitation of our protocol is that one of the goods to be exchanged must be divisible goods such as money. Although we can calculate an entry fee that can prevent agents from defecting in an exchange involving only indivisible goods, the entry fee becomes high. In such a case, escrow services are more suitable than our protocol.

Finally, we will describe other approaches to solving the online-fraud problem, which are different from the game-theoretic approach. One is based on developing security measures, such as cryptographic techniques. For example, an optimistic fair exchange protocol has been described [1]. This protocol is based on a digital-signature scheme and can be used only for digital goods (information goods), such as electronic money. In this protocol, a center ensures fairness of exchanges, but this process is only used in the presence of exceptions or in the case of dishonest participants who do not follow the protocol. This reduces the cost for the center. However, when there is trouble, this protocol can provide only the evidence that some agent sent or received money/goods. Thus, if a dishonest participant can disappear after receiving money, and then reappear under a different identifier without paying any penalty, he/she can obtain an unfair profit. Therefore, this protocol does not work if we allow participants to use multiple identifiers, which is a virtue in transactions over the Internet.

Another approach is based on information-filtering techniques. For example, rating mechanisms for electronic marketplaces have been described [24]. Calculation methods were provided for rating participants. Under this approach, participants can obtain more precise information about other participants, whereas our protocols only exclude dishonest agents. However, in the beginning of exchanges, such rating mechanisms do not seem to work because there is a lack of data.

7. Conclusion

We described three exchange mechanisms involving goods and money that can solve the conflict between safety and convenience. The mechanisms can prevent agents from defecting by imposing an entry fee on all agents; this can contribute to solving the online-fraud problem on the Internet. We showed that these mechanisms can reduce the entry fee without compromising safety by integrating multiple deals and/or by incorporating a third-party agent, which facilitates the participation of newcomers. These mechanisms have a trade-off because the lower the entry fee, the greater the amount of information disclosed to other agents.

When our mechanism is applied to the real-world trading, a payment method may become a problem. In this paper, we do not consider the cost of money handling by the agent. However, if a processing fee is charged on every payment, an effectiveness of our mechanism is reduced because a payment process is divided into more than one parts in our mechanism. Implementing an agent having an ability to produce a settlement in a manner consistent with existing trading mechanisms is one of our future work.

Another potential hurdle to apply our mechanism to the real-world trading is a problem of transparency of the mechanism, i.e., comprehensibility. This means that our mechanism may give a rather strange feeling to a user in that his/her agent makes a payment to other agents who are not directly related to his/her deal, although his/her budget balances. Examining this problem is another of our future work.

A different method to obtain an appropriate entry fee is to form groups in which the variation in the sellers' valuations for goods is small. To enable forming such groups and keeping them attractive, it is important that research on communities complements research on mechanism design and vice versa.

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