

A Decision Method in B2B E-Commerce Model based on Multi-Items Auction

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Abstract: This paper proposes a new B2B electronic commerce model from bidding information in double auctions. In B2B electronic commerce, buyers try to purchase multiple items at the same time, since a buyer develops something products by using purchased items. Also suppliers have an incentive of making coalitions, since buyers want to purchase multiple items in the model. A mechanism designer has to consider an optimal mechanism which calculates an optimal matching between buyers and suppliers. To find an optimal matching is very hard, since a mechanism calculates all combinations between buyers and suppliers. Consequently, we propose a calculation method which has two steps; first the mechanism determines winners of buyers' side, second the mechanism determines coalitions and winners of suppliers by using the result of buyers' side. This paper also discusses the improved method with dynamical mechanism design by using the bidding information. Advantages of this paper are that each developer can procure the components to develop a certain item and tasks are allocated to suppliers effectively. The previous result of auction data can be available to shorten the period of winner determinations. Contribution of this paper includes two parts. One is creating a mathematical model of procurement auction, which is able to apply to practical situation. The other is proposing dynamic mechanism for the procurement auction.

Keywords: procurement auction, B2B e-commerce, coalition making, auction protocol

1. Introduction

In recent years, electronic commerce has been developing as multiple forms of trading and is researched and analyzed by many researchers. Regarding B2C (Business to Consumer) and C2C (Consumer to Consumer) trading models like electronic auctions, many researchers work on them in researches of multi-agent system and mechanism design [1], [2], [3]. In previous studies, they assume incomplete information on their trading mechanism and did not design auction protocols with bidding value information. However, in actual e-marketplace, if we are able to use the information, it is possible to design further effective trading schemes and to make high-speed algorithms. Also, in B2B (Business to Business), there are many auction-based trading models; auctions where a company procures resources/items are typical [4], [5], [6]. In procurement auctions, the procurement parties generally try to acquire multiple items simultaneously. On the other hands, many suppliers provide same sort of items in the market. When they negotiate with each other to trade, multiple suppliers have an incentive to make a coalition if procurement parties bid complementary. However, coalition formation needs negotiations by suppliers and has demerit regarding the negotiation monetary and time costs. To solve the problem, we propose a new dynamical coalition formation method for suppliers by us-

ing result of auctions of procurement parties. The procurement auction is a combinatorial double auction with multiple bidders and suppliers. In such auctions, it is difficult to analyze the properties and features and is not available, since the computational costs of tasks/items allocation are very large. Thus, we propose, in this paper, a method to improve the mechanism dynamically by reusing bidding trends information.

Contribution of this paper includes two parts. One is creating mathematical model of procurement auction, which is applicable to practical situation. In fact, vehicle manufacturers already use this trading model as very simple case. The other is proposing dynamic mechanism for the procurement auction. In the Internet environment, there are many auction participators, which are bidders and sellers, and welter of items. Therefore the auctioneer should shorten one auction's time. The auctioneer is required not exact result but approximation result to shorten auction time. So our dynamic mechanism would be computable fast to the winner determination problem, since our mechanism compute the problem separately and each problem does not have combinatorial structure.

The rest of the paper is organized as follows. Section 2 clarifies the problem establishment for our work. In Section 3, we describe our focused problem and a fundamental economic model. In Section 4, we give some definitions and assumptions. We also describe the proposed model as a mathematical formulation. In Section 5, we describe the coalition formation method for suppliers. Then, in Section 6, we propose an auction protocol by using bidding information. In Section 7, we discuss ex-post incentive compatibility of our proposed mechanism. In this section

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we show the *approximately ex-post incentive compatibility*. We provide our concluding remarks in Section 8.

2. Related Work

Milgrom analyzed the shill-biddable feature in Vickrey-Clarke-Groves (VCG) [3]. The VCG mechanism is a notional mechanism of economic behaviors. There exists Generalize Vickrey Auction mechanism which is one of VCG based mechanisms for using the auction transaction. Bidders in GVA can profitably use shill bidders to intentionally increase competition to generate a lower price. Thus, a Vickrey auction provides opportunities and incentives for collusion among low-value, losing bidders. This feature is a result of the monotonic increase problem. However, this work does not refer to a method for calculating an appropriate side payment rate.

Yokoo et al. reported the effect of false-name bids in combinatorial auctions [7]. To solve the problem, Yokoo, Sakurai and Matsubara proposed a novel auction protocol robust against false-name bids [8], called the Leveled Division Set (LDS) protocol. The LDS protocol is a modification of the GVA, that utilizes the reservation prices of auctioned goods for making deciding whether to sell goods in a bundle or separately. They also proposed an Iterative Reducing (IR) protocol that is robust against false-name bids in multi-unit auctions [9]. The IR protocol is easier to use than the LDS, since the combination of bundles is automatically determined in a flexible manner based on the declared evaluation values of agents. They concentrate on designing mechanisms as alternatives to GVA. However, these researches never refer to a computational method to develop an economic mechanism.

Matsuo et al. proposed a computational method to detect shills in combinatorial auctions [10]. In the mechanism, the payment amounts of bidders are calculated depending on their valuations. However, this is essentially the difference between this research and our proposed research.

There are many theoretical approaches for combinatorial auctions. Lehman et al. discussed some combinatorial auctions, where utility functions are decreasing marginal functions [11]. They model the utility function as submodular function. Also they consider some classes of the value functions. When the value function satisfies complement-free or gross substitution, then the winner determination problem of the combinatorial auction using the value function is able to solve in polynomial time. This polynomial time algorithm uses Bikhchandani's integer programming method [12]. And it is known that there exists a Walrasian equilibria when every value functions are gross substitute [13], [14]. The paper [11] proposed a 2-approximation algorithm for submodular value function's auction.

3. Problem Setting

We analyze our proposed model for procurement dealings of manufacturers. A product in which a manufacturer provides to end-users in an actual marketplace is configured from a lot of parts. Manufacturers procure their parts for creating added value as the product. For example, in the automobile industry, when a manufacturer makes an automobile, it use tens of thousands of

parts, and it purchases these parts from several suppliers. There are attractive values of these parts not for end-users but for the manufacturer. The value of these parts influences the value of the product. Therefore, it is important for manufacturers not only to reduce the purchasing cost, but also to optimize their costs.

The parts which compose the product are complementary goods for manufacturers, since if manufacturers can purchase all parts they can make and provide the product stably. Hence the suppliers have an incentive that they cooperate with each other, and sell their parts as a bundle for improved profit.

In this paper, we define dealing for end-users as primary trading, and B2B dealing of parts suppliers and manufacturers as secondary trading. In secondary trading, manufacturers have to purchase optimal parts a bundle, since there are two or more parts suppliers. Our proposed B2B trading is included in the class of multi-sided and multi-items dealing in which several sellers and purchasers exist. There are some double auction models as the class of multi-sided trading [15], [16], [17], [18]. The double auction is the dealing in which buyers and sellers bid for the same kind of good, and the mechanism makes several pair of buyers and sellers. We are not able to use this auction protocol in our proposed model, since in basic double auction models it is not possible to deal in different kinds of goods. Therefore, we use a combinatorial auction model in the secondary trading scheme. In this scheme, suppliers and manufacturers bid individually. The suppliers' auction is a single item auction, and manufacturers' auction is a combinatorial auction. We use manufacturers auction results to decide the coalition structures for the suppliers' side, and use bidding results of the suppliers' auction to make coalitions. In our research, we discuss a case where suppliers bid is individual.

4. Preliminaries

We describe the secondary trading model. **Figure 1** shows the relationship between primary trading and secondary trading. Manufacturers try to optimize procurement plans to reduce costs in business processes. When we analyze in detail the market supply process, manufacturer 1 and 2 procure necessary parts from n parts suppliers. Manufacturer 1 and 2 make product A and B by using procured parts. They provide their products to end-users. In secondary trading, suppliers who provide some parts make pseudo-coalitions. It seems that a manufacturer dealing the parts

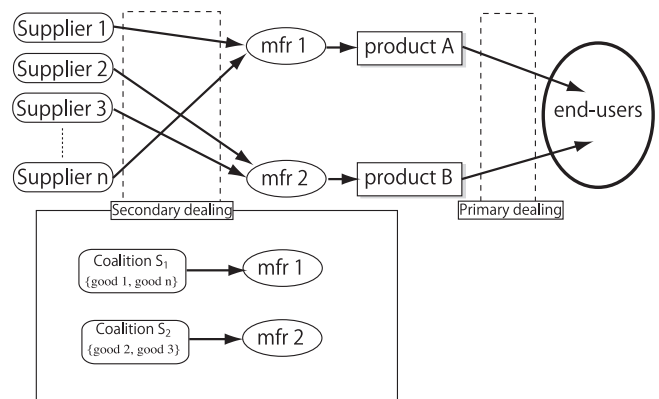


Fig. 1 Business model.

with a pseudo-coalition. In primary trading, each manufacturer is providing the end user with a service that assembles procured parts.

It is effective to use an auction mechanism when manufacturers procure using secondary trading. In an optimal auction mechanism, it is known to satisfy some of the following conditions [7], [19].

Ex-post incentive compatibility An auction satisfies ex-post incentive compatibility if bidding true evaluations is dominant strategy.

Pareto efficiency / optimal We say an auction protocol is Pareto optimal when the sum of all participants' utilities (including that of the auctioneer), i.e., the social surplus, is maximized in a dominant strategy.

Individual rationality When all participants' utilities are not negative, the designed mechanism exhibits individual rationality.

4.1 Model

We describe several terms and assumptions. Participants of the auction are suppliers and manufacturers. Each supplier bids a nonnegative value for providable items. Also, each manufacturer bids a nonnegative value for desirable items.

Definition of terms

- Let $N = \{1, \dots, n\}$ be a set of suppliers.
- Let $M = \{1, \dots, m\}$ be a set of manufacturers.
- Let $G = \{a_1, \dots, a_k\}$ be a set of items (parts).
- Let $\mathcal{B} \subseteq 2^G$ be a subset family of G , and $B_j \subseteq \mathcal{B}$ be a bundle set of manufactures j . If the auction treat k th items, the number of combination of bundle is $2^k - 1$. Hence a bundle set of manufacturer j is $B_j = \{B_j^1, \dots, B_j^{2^k-1}\}$.
- Let $c_i(a_\ell)$ be a cost when supplier i supplies item a_ℓ .
- Let $v_j(B_j^l)$ be a evaluate value in which manufacturer j bids for bundle B_j^l .
- Let p_j be a payoff of manufacture j .
- We define an allocation set for the manufacturer as $X = \{x_1, \dots, x_m \subseteq G | \forall a, b \in M, x_a, x_b \in X, x_a \cap x_b = \phi\}$. In this regard, for all $j \in M, x_j \in B_j$.

Assumption 1 (quasi-linear utility) An utility u_j of manufacture j is defined by the difference between manufacture j 's payoff p_j and its evaluate value v_j as $u_j = v_j - p_j, \forall j \in M$. Such an utility is called a quasi-linear utility, and we assume quasi-linear utility. Also, we define supplier i 's utility as $u_i = \hat{p}_i - c_i, \forall i \in N, \forall j \in M$. In this regard, \hat{p}_j is the payoff to supplier i ($\hat{p}_j \leq p_j$).

Assumption 2 (complementarily bids) We assume manufacturers' evaluation values satisfy the following condition. For every $B_j^l, B_j^k \in B_j$, for all $j \in M$:

$$v_j(B_j^l) + v_j(B_j^k) \leq v_j(B_j^l \cup B_j^k)$$

Assumption 3 (completeness) There is no shill bidding, since all participants in this auction finish registration before auction.

Assumption 4 (no risk) There is no risk to dealing items. The quality is fixed for the some type of item, and there is no non-performance of contract.

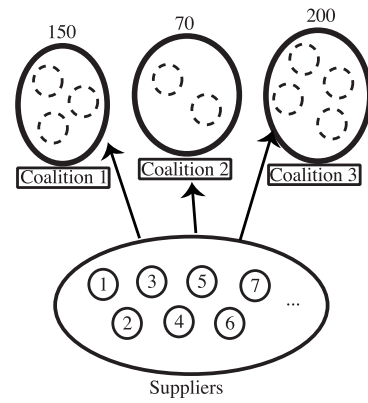


Fig. 2 Auction result reuse concept.

In this paper, we assume that each supplier can provide only one item.

4.2 Allocation Mechanism

Our trading model uses the GVA mechanism. GVA mechanism satisfies an optimal auction's properties when there is no shill bidding [2]. We calculate the allocation of each manufacturer and their payoff by using GVA mechanism. If X^* is an optimal allocation, then X^* is calculated as follows.

$$X^* = \operatorname{argmax}_{X=\{x_1, \dots, x_m\}} \sum_{j \in M} v_j(x_j) \tag{1}$$

We define an allocation without manufacturer j as follows.

$$X_{-j}^* = \operatorname{argmax}_{X \setminus x_j} \sum_{M \setminus j} v_m(x_m) \tag{2}$$

We calculate manufacturer j 's payoff p_j .

$$p_j = \sum_{m \neq j, x_m^* \in X_{-j}^*} v_m(x_m^*) - \sum_{m \neq j, x_m^* \in X^*} v_m(x_m^*) \tag{3}$$

We define a winner set by GVA mechanism as $M' = \{j | x_j^* \neq \phi\} \subseteq M$.

5. Suppliers Coalition

We get information which is the optimal allocation X^* and the payoff $p_j, \forall j \in M'$. Next, we make a coalition of suppliers by using the manufacturer's auction result. The manufacturer's auction result includes an allocation set X^* and a payoff set $P = \{p_j | j \in M'\}$. These two sets play as suppliers' coalition structures and outcomes of each coalition. We show a concept of coalition decision in Fig. 2. In this Fig, the auction result is given by $X^* = \{\{a, b, c\}_1, \{d, e\}_2, \{f, g, h, i\}_3\}$, $P = \{150_1, 70_2, 200_3\}$. Then, suppliers are able to make three coalitions which depends on the auction result X^* . It seems that the X^* -induced coalitions are the best coalition set by the auction property. Also, we reduce the calculation cost, since we use the predetermined coalition structure information beforehand. If we do not use the auction information, we do not make a best coalition set, since the manufacturer's information is incomplete.

When we use an auction information, we do not hope to show the information to suppliers, because the suppliers have an incentive of bid-rigging by knowing the information. Hence, the information is used by only an auctioneer or a mechanism.

Let $S = \{S_{x_1}, \dots, S_{x_m}\}$ be a coalition set based on manufac-

Table 1 Bidding table of manufacturers.

Mfr	{a}	{b}	{c}	{a, b}	{b, c}	{a, c}	{a, b, c}
mfr 1	5	7	3	20	15	10	30
mfr 2	7	5	0	20	0	0	20
mfr 3	6	4	9	14	18	25	35

turers’ auctions. Our mechanism takes the suppliers’ auction for making coalition. In suppliers’ auction, we analyze only individual bidding. Individual bidding is that each supplier’s bid does not depend each other. In this condition, each coalition’s total cost is defined as summation of each supplier’s cost. Hence the total cost of coalition S_{x_j} is defined as follows.

$$C(S_{x_j}) = \sum_{i \in S_{x_j}, a_i \in x_j} c_i(a_i)$$

We make an optimal coalition set by the following formula.

$$S^* = \operatorname{argmax}_{S = \{S_{x_1}, \dots, S_{x_m}\}} \sum_{j \in M} \{p_j - C(S_{x_j})\} \quad (4)$$

We define an optimal coalition set without supplier i as $S_{-i}^* = \{S_{x_1, -i}^*, \dots, S_{x_m, -i}^*\}$.

$$S_{-i}^* = \operatorname{argmax}_{j \in M} \{p_j - C(S_{x_j, -i})\}$$

Each supplier’s outcome o_i when participating in coalition S_{x_j} is calculated as follows.

$$o_i = c_i(a_i) + \{C(S_{x_j, -i}^*) - C(S_{x_j}^*)\} \quad (5)$$

Suppliers can make additional surplus, since we assume complementary bidding.

$$p_j \geq \sum_{i \in S_{x_j}^*} o_i$$

Let $Sur = p_j - \sum_{i \in S_{x_j}^*} o_i$ be a coalition $S_{x_j}^*$ ’s surplus. Each supplier who participates in coalition $S_{x_j}^*$ reallocates its surplus. In this paper we assume a reallocation method as equitable distribution. We describe the protocol of secondary trading.

Step1. Each supplier declares its available item and its nonnegative cost. Also, each manufacturer declares own desirable bundles and it’s nonnegative evaluation values. Manufacturers’ evaluation values satisfy complementary.

Step2. We calculate an optimal allocation and its payoff based on GVA mechanism.

Step3. We decide supplier’s coalition structure based on the manufacturers’ auction result. Then we calculate a supplier’s optimal coalition set.

Step4. We calculate each supplier’s outcome, and surplus.

We show an example. Given a manufacturers’ bid set as **Table 1**, and a suppliers’ bid set as **Table 2**, the result of manufacturers’ auction is (mfr 1, {a, b, c}). Manufacture 1’s payoff is $p_3 = 35$. Hence we decide optimal coalition with structure {a, b, c} in suppliers’ auction. In this case, coalition $S_{x_3}^*$ is $S_{x_3}^* = \{sup. 3, sup. 5, sup. 6\}$, and its total cost is $C(S_{x_3}^*) = 24$. We calculate each supplier’s outcome as follows.

$$o_3 = c_3(\{a\}) + \{C(S_{x_3, -3}^*) - C(S_{x_3}^*)\} = 7 + (27 - 24) = 10 \quad (6)$$

Table 2 Bidding table of suppliers.

Suppliers	{a}	{b}	{c}
supplier 1	10	0	0
supplier 2	0	8	0
supplier 3	7	0	0
supplier 4	0	0	12
supplier 5	0	7	0
supplier 6	0	0	10

$$o_5 = c_5(\{b\}) + \{C(S_{x_3, -5}^*) - C(S_{x_3}^*)\} = 7 + (25 - 24) = 8 \quad (7)$$

$$o_6 = c_6(\{a\}) + \{C(S_{x_3, -6}^*) - C(S_{x_3}^*)\} = 10 + (26 - 24) = 12 \quad (8)$$

As a result, the surplus of coalition $S_{x_3}^*$ is 5. Therefore each supplier gets 5/3.

6. Dynamic Protocol Developing Based on Bidding Information

In this section, we consider a dynamic protocol developing method by using auction information. Also we treat a simple combinatorial auction model. A general combinatorial auction calculates an item allocation and winners, which it tries to maximize social surplus by using all bids’ values. The more items and participators are increasing, the more expensive calculation cost is spent in an allocation problem. Also, if we try to find an optimal solution, we have to do a full search. If we solve the problems, we earn two advantages. First, we can adapt combinatorial auction mechanism to real-time Internet auctions. Second, we can prevent illegal tenders by the pattern of bidding.

In an auction which assumes incomplete information, a mechanism is able to know only bundles and its evaluations. The mechanism is not able to do high-speed calculations in this condition. Therefore, our new method is to declare own bidding patterns. The bidding pattern is, for example, “complementary bids,” “substitute bids” and “normal bids.” We define this new term as follows. A bid type is the complementary bids, if $\forall a_i \in G, v(a_i) = 0$ and $\forall B \in \mathcal{B} = \{B \in \mathcal{B} \mid |B| > 1\}, v(B) \geq 0$, a bid type is the substitute bids, if $\forall B \in \mathcal{B}, v(B) = \sum_{a_i \in B} v(a_i)$, and a bid type is the normal bids, if the bids function has no restriction without nonnegativity. Each pattern has an accent which is about bidding. For example, a complementary bid is that an agent interests to only to get multi object at one auction. If a bidding pattern is complementary bid, we search only bundles and reduce the searching area. Also, in a substitute bid, we can ignore bundles bidding.

We introduce a new method in which a mechanism develops a protocol dynamically for high speed calculation.

The protocol’s steps used by dynamic protocol are stored in a database. The mechanism uses their stored steps to develop a better protocol. When the mechanism develops it, the mechanism selects best steps from database by using the auction information. In the detail, a mechanism adapts the following sub-protocols to dynamic protocol based on whole of bidders’ bids patterns.

(1) A case of one or more complementary bidders. The mechanism compares the most large size bundles in complementary bidders. An agent who bids the most expensive value is to be semi-winner (complementary bidder). Other agents

Table 3 Example of bidding table for showing the dynamic mechanism.

	{a}	{b}	{c}	{a, b}	{b, c}	{a, c}	{a, b, c}	Bidding type
1	0	0	0	10	12	15	20	Complemental
2	0	0	0	0	0	0	40	Complemental
3	0	8	0	8	8	0	8	Substitute
4	3	7	3	10	10	6	13	Linear (Normal)

are losers. By way of exception, let B be a bundle and \mathcal{B} be a set of bundles, if $\mathcal{B} \setminus B \neq \phi$ and $\mathcal{B} \setminus B \cap B = \phi$ is justified, then we can find B' such that $B \cap B' = \phi$ and $B' \in \mathcal{B} \setminus B$. Hence we decide the semi-winner (complementary bidder) from $\mathcal{B} \setminus B$.

(2) A case of one or more substitute bidders. A mechanism focuses on single object bids in substitute bidders, calculates a combination that social surplus becomes the maximum. Also the mechanism decides the semi-winners (substitute bidders).

(3) Final determination A mechanism determines the final winners from step 1's semi-winner, step 2's semi-winner and standard bidders.

(4) Payoff determination In the case that the semi-winner (complementary bidder) was the final winner, we consider two situations. If the semi-winner's (complementary bidder) allocation is equal to the number of total items, the payoff of the final winner is a maximum social surplus which is decided from the semi-winner (substitute bidders) and standard bidders. Otherwise if there exists two or more semi-winners (complementary bidders), a mechanism focuses on bundle bids, and calculates payoffs based on GVA method.

In the case that the semi-winner (substitute bidder) was the final winner, a mechanism focuses on single object bids in substitute bidders and calculates a payoff based on GVA method.

Otherwise, a mechanism calculates a payoff by using evaluation without complementary bidders based on GVA method.

We consider a simple example of the dynamic mechanism. **Table 3** shows an example of a bidding table where there are four bidders and three types of items.

Step 1. The mechanism compares some complemental bidders.

In this example, bidder 1 and 2 are complemental bidders, and bid 20 and 40 for the largest bundle $\{a, b, c\}$, respectively. This step decides the bidder 2 as a pre-winner.

Step 2. The mechanism compares some substitute bidders. Bidder 3 is a substitute bidder and bids 8 for the item $\{b\}$. The mechanism calculates the winner determination problem of single item bidding. Through step 2, bidder 3 is a pre-winner of this step.

Step 3. The mechanism calculates a winner determination problem of some normal bidders and pre-winners of Step 1 and 2. In this example, the mechanism focuses on bidder 2's bid for $\{a, b, c\}$, bidder 3's bid for $\{b\}$ and all bids of bidder 4. In this example, the mechanism decides bidder 2 as the final winner and allocates $\{a, b, c\}$ to the final winner.

Step 4. The mechanism decides some payment of winners. The mechanism computes each bidder's payment by elimination the relevant bidder from the auction. Therefore the mechanism eliminates the relevant bidder, and run the Step 1 to

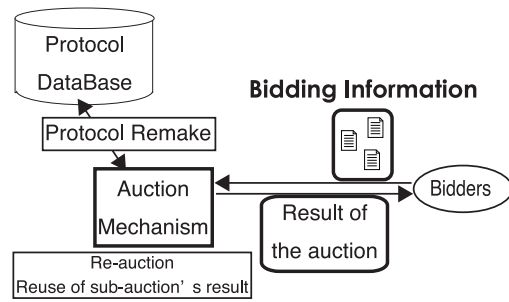


Fig. 3 Modified auction process.

Step 3.

We can reduce a calculation cost by using dynamic protocol developing. If we compute normally, then we have to search $O(n \cdot 2^k)$ candidates of bundles. However we employ the dynamic protocol, then we have to search only $O(n_1 \cdot (2^k - k) + n_2 \cdot k + n_3 \cdot 2^k) = O((n_1 + n_3)2^k)$ candidates of bundles, where n_1 , n_2 and n_3 show number of the complimentary bids, the substitute bids and the normal bids, respectively. This fact shows clearly reduced candidates compared with normal protocol. The auction process including upgrade protocol is shown by **Fig. 3**. A mechanism selects some sub-protocols from the database, and develops an upgrade protocol by using the bidding patterns. In upgrade protocol, a mechanism decides the semi-winners by using the patterns, and does the re-auction. On the special case, a mechanism reduces some sub-protocols. In the detail, if all bidders are complementary bidders, a mechanism can reduce the sub-protocols without considering substitute and standard bidders.

7. Discussion

In this section, we discuss our protocol's ex-post incentive compatibility. According to Norm et al. [20], it is known that do not exist approximate mechanisms which satisfy fully ex-post incentive compatibility, hence, our mechanism does not satisfy fully ex-post incentive compatibility, since it is an approximate allocation method. However, Kothari et al. [21] discusses approximate ex-post incentive compatibility. They give an upper bound of increasing utility by using approximation degree when agents do all strategy operations. In addition they propose approximate ex-post incentive compatibility by using upper bound. We give a definition of approximate ex-post incentive compatibility as follows.

Definition 1 (Approximate ex-post incentive compatibility). *A mechanism is ϵ -approximate ex-post incentive compatibility if and only if agents' utilities increase at most ϵ by all strategies.*

We assume our mechanism has ϵ -approximate allocation method ($\epsilon > 0$). Let V be a maximum social surplus by using our mechanism. Our mechanism satisfies $(\epsilon/1 + \epsilon)V$ -approximately ex-post incentive compatibility. Also, it is known that true bidding is dominant strategy in approximate ex-post incentive compatible mechanism.

8. Conclusion

We proposed a trading protocol for a class of multi-sided combinatorial auction. Some past studies only treat very simple transactions. For example, there exist some bidders which have a sim-

ple preference and only one seller. The studies do not analyze some complex situations such as our procurement auctions. In the future environment, it is important to analyze their complex markets. In this paper, we suggested this importance. We used gradual GVA mechanism which operates GVA to both manufacturers' auction and suppliers' auction. Gradual GVA mechanism used manufacturers' auction result to decide the supplier's coalition structures.

Also, we introduced a new method which is dynamic protocol developing based on information reuse. In dynamic protocol developing, we reused the sub-protocol in the database. If a mechanism developed an upgrade protocol dynamically, the winner determination problem was solved faster.

Our future work is, first, to develop an algorithm which guarantees an approximately allocation. Second, we verify the stability of the protocol by running the simulation of bidding pattern. We will consider a new mechanism for our trading model, since the GVA mechanism has a very large computation cost.

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