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Combinatorial Coalition Formation for multi-item group-buying with heterogeneous customers

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ABSTRACT

A group-buying market may offer multiple items with non-additive values (i.e., items may be complementary or substitutable), to buyers who are often heterogeneous in their item valuations. In such a situation, the formation of buying groups should concentrate buyers for common items while taking into consideration buyers' heterogeneous preferences over item bundles. Also, it should permit non-uniform cost sharing among buyers in the same group, which benefits all buyers by drawing more group-buying participants. We introduce the concept of Combinatorial Coalition Formation (CCF), which allows buyers to announce reserve prices for combinations of items. These reserve prices, along with the sellers' price-quantity curves for each item, are used to determine the formation of buying groups for each item. Moreover, buyers in the same group may not necessarily all pay the same price. The objective of CCF is to maximize buyers' total surplus.

Determining the optimal coalition configuration in CCF is NP-hard, and the stability of such a configuration relies on the cost sharing rule within each group. We thus propose a heuristic algorithm for CCF based on augmented greedy selections, along with a cost sharing rule satisfying certain stability properties. Simulation results show that our approximate algorithm generates fairly good solutions compared to the optimal results, and is greatly superior to a simpler distributed approach. Furthermore, our algorithm's performance is enhanced when items are complementary or strongly substitutable, especially in settings when the prices decrease either rapidly or slowly with the quantities. Evaluations of the sellers' revenue under CCF demonstrate that sellers should offer a more gradually decreasing price-quantity curve for complementary or strongly substitutable items, and a more abruptly decreasing curve for weakly substitutable items. In addition, sellers may benefit from greater sales generated by simpler price-quantity curves with fewer steps.

1. Introduction

1.1. Motivation

Group-buying has been in vogue for many years in various industries [14,20]. Demand aggregation in group-buying benefits sellers, offering lower marketing costs and coordinated distribution channels, as well as buyers, who enjoy lower costs for product purchases [11]. The Internet provides a powerful tool for demand aggregation and hence is a natural platform to facilitate group-buying. It is thus not surprising that online group-buying was perceived as one of the most innovative business models of e-commerce, and has been employed by many companies. Although some early pioneers failed, online group-buying has been reviving in Europe, North America and Asia in recent years [7], in part thanks to the increasing connection of people in online forums and social networks [27]. In fact, web-facilitated group-buying is now a major phenomenon in China, under the name "tuangou" [2] (see [7] for a recent list of the successful tuangou websites). Since group-buying is driven by the demand of buyers, a central issue within a group-buying mechanism is how to improve the satisfaction of buyers. But this is not always easy.

As noted by [16], the early group-buying firms faced the dilemma of choosing between developing a wide product selection and mandating a large buying group: Consumers may have diverse preferences over products, and therefore offering a wide product selection can fragment the customer base. Thus, in order to form large-size buying groups, the early group-buying firms often limited product selection within each category [16,27]. But such limited choice of products detracted from consumers' experience, reducing their surplus. In contrast, the successful tuangou service providers in China offer a great variety of products and services to their members [27].

Buyers' surplus depends on both their valuation of the purchased items and the purchasing costs they pay. To maximize buyers' surplus

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is particularly complex in multi-item group-buying environments, as when buyers are offered a variety of products, their product selections determine not only the values they receive from the purchased items, but also influence the sizes of the buying groups for each item and thus their purchasing costs. We discuss the values and costs in greater details below.

The value of an item to a buyer is measured by the buyer's willingness-to-pay (reserve price) for the item. It is common that product values may not be simply additive: Items may be *substitutes*; that is, the total value of a combination of the items may be less than the sum of the values of individual items (items are *perfect substitutes* if the value of the combination is equal to the maximum of the single-item values). Items may also be *complements*; that is, the total value may be more than the sum of individual values (items are *perfect complements* if each single item alone has no value). For example, two cars of different models are typically substitutes, while a couch and a coffee table may be complements. Due to such non-additive values, the marginal value of an item to a buyer depends on the *other* items acquired by the buyer, by her participation in their buying groups. We refer to this effect as the *externality among items*. Due to this effect, a buyer's choice of buying groups should be made considering the values of combinations of multiple items.

In a group-buying market, the price of an item depends on the aggregated demand of buyers in the buying group for that item. Thus, whether or not a buyer should join a group depends on the number of participants in that group. We refer to this effect as the *externality among buyers*. Due to this effect, a buyer may not join the groups of her most preferred items. For example, a car buyer choosing between two car models may join the group for her less valued model if the aggregated demand for that model brings the price to a sufficiently low level. Or, a furniture buyer that is interested in both a couch and a coffee table may end up buying neither, even when a good deal is available for the coffee table, if not enough buyers join the group for the couch. These examples illustrate that buyers should be coordinated in their choices of buying groups.

Another critical issue faced by many group-buying markets is how to improve customer participation [16]. This is important because buyers' surplus from group-buying is driven by the aggregated demand of customers. A buyer will not join a group if she expects to pay a price higher than her willingness-to-pay. Thus lowering the prices for some buyers that would otherwise not be able to participate may be beneficial for all buyers. This can be seen in the following example.

Example 1. *Buyer 1 and 2 both want to buy a digital camera. Buyer 1 does not want to pay more than $350, and Buyer 2 can pay at most $300. The unit price provided by the seller is $350 for one camera and $310 for two.*

In Example 1, if the two buyers purchase alone, Buyer 1 would purchase at a price $350 and Buyer 2 would not be able to purchase, both having zero surplus. But if they form a group, then they can enjoy a surplus of $30 together. However, for Buyer 2 to join the group, she cannot pay more than $300, and thus Buyer 1 has to pay at least $320; for example, Buyer 1 pays $335 and Buyer 2 pays $285. With such non-uniform cost sharing, although Buyer 1 has to subsidize Buyer 2, she is better off than she would be purchasing alone.

The above example shows that customers should not be ignored in a group-buying market, even if their willingness-to-pay is lower than the group-buying price: Under non-uniform cost sharing, these low-value buyers may be able to join a group and drive down the price, benefitting all buyers. Such a benefit can be significant in a group-buying market for two reasons. First, group-buying markets have a heavy focus on the categories of expensive durable goods, such as home appliances, home remodeling materials, cars, and electronics [16,27]. For these products, the heterogeneity of customer values is usually high, due to different tastes on the design, quality, function, or brand of the product, as well as different budget constraints among customers. Second, customers interested in group-buying tend to be price-sensitive buyers. Thus there is likely a considerable portion of low-value customers in a group-buying market.

Motivated by the above considerations of multiple items with non-additive values and customer heterogeneity in item preferences and willingness-to-pay, we propose an innovative group-buying mechanism, *Combinatorial Coalition Formation* (CCF). CCF assigns buyers to buying groups of multiple items based on their reserve prices for combinations of items, with buyers in the same group not necessarily paying the same price. The objective of CCF is to maximize the total surplus of buyers. CCF is different from traditional group-buying mechanisms, which are usually based on a single item and uniform cost sharing: CCF balances the need of aggregating buyers for common items and the need of incorporating buyers' heterogeneous preferences of items, improving customer participation by allowing non-uniform cost sharing among buyers. Though CCF does not currently exist in practice, we believe that it can be implemented for real group-buying markets. Its implementability is discussed in the following subsection.

1.2. Implementability and difference from combinatorial auctions

CCF can be implemented in a centralized group-buying market in which a coordinator exists to configure the buying groups based on buyers' reports of their preferences. (This contrasts with a distributed mechanism in which buyers separately make their own decisions of which items to buy, based on their observations of groups' sizes and price-quantity curves.) Some existing group-buying markets exhibit features of a centralized mechanism. For example, in a typical purchasing process at UniStar (www.unistarllc.com), the firm first collects a buyer's information on spending and target prices. Then the firm analyzes the buyer's information and its own offering to establish a purchasing solution for the buyer. The latter stage usually takes a few weeks, which may allow the firm to aggregate demand from several buyers. A typical tuangou process in China also takes a centralized form: After buyers express their preferences and interests in joining a team, a leader or a committee is usually elected to conduct the negotiation with vendors and organize the buying groups. The solution often takes into consideration customer preferences over multiple items (although it is unlikely a result of CCF). For example, [2] reports a tuangou team of buyers that were interested in the Chevrolet Aveo, a new General Motors subcompact. The car had two models that were preferred by different buyers. In the end, some buyers in the team received the less expensive model and some bought the more expensive one. In another case reported by [2], a team of cabinet buyers reached deals for both cabinets and hinges, two complementary items.

Non-uniform cost sharing may currently be rare in group-buying markets; traditionally, buyers in a group pay the same price. Nevertheless, we believe that non-uniform cost sharing can be implemented in a straightforward manner in a centralized nontransparent market such as UniStar. (In a nontransparent market, buyers do not know each other but only interact with the coordinator.) Since a buyer is not aware of the other buyers' prices, it is relatively easy to charge different prices to buyers. However, implementing non-uniform cost sharing can be challenging in a transparent market, in which buyers know each other and are informed of each buyer's payment. Tuangou may be considered as such an example: In a tuangou event buyers gather together and meet in person during their visits to vendors. To implement non-uniform cost sharing in a transparent market, it is important to ensure that the cost sharing solution is fair and is in the best interest of all buyers. Otherwise, some buyers may not accept the solution but search for an alternative that would bring them better results. We consider this issue in our design of cost sharing rules.