Incentive Compatible Mechanisms for Efficient Procurement of Agricultural Inputs for Farmers through Farmer Collectives

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ABSTRACT

Sourcing the right quality and quantity of agricultural inputs such as seeds, fertilizers, and pesticides, constitutes a crucial aspect of agricultural input operations. This is a particularly challenging problem being faced by the small and marginal farmers in any emerging economy. Farmer collectives (FCs) which are cooperative societies of farmers, launched under Federal Government initiatives in many countries, offer the prospect of enabling cost-effective procurement of inputs with assured quality. We seek, in this work, sound and explainable mechanisms for the above important use-case. In particular, we propose the use of incentive compatible auction mechanisms that could be used by an FC to procure quality inputs in bulk. The idea is the following. An FC collects from the farmers their individual requirements for inputs and aggregates them into different buckets. For each bucket, the FC identifies suppliers who meet the quality criteria and engages them in a competitive procurement auction. We explore in this paper, two particular types of procurement auctions: volume discount auctions and combinatorial auctions in the framework of Vickrey-Clarke-Groves (VCG) mechanisms. These are explainable mechanisms that induce truthful bids from the suppliers as well as maximize the social welfare. We show their efficacy through carefully designed thought experiments. Our field studies of FCs give us the confidence that such mechanisms, if deployed systematically, can become a game changer, benefiting a massive community of smallholder farmers.

CCS CONCEPTS

• **Social and professional topics → Economic impact**.

KEYWORDS

procurement auction,farmer collectives,VCG mechanisms,small and marginal farmers,agricultural input planning

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1 INTRODUCTION

In order to maximize yield, it is necessary for farmers to use the right quantities of high quality inputs. In addition to labour, there are mainly two categories of agricultural inputs: consumable and capital. Consumable inputs include seeds, fertilizers, and pesticides. Capital inputs entail larger investments and include farm equipment like tractors, agricultural robots, trellising materials, and other gardening infrastructure. In this paper, we focus on consumable inputs.

High quality seeds facilitate smooth farming; low quality seeds can lead to crop losses and even crop destruction. The use of pesticides in right quantities at the right time saves the crops from being wiped away. Fertilizers are any materials of natural or synthetic origin which are applied to soil or to plant tissues to supply plant nutrients.

1.1 The Context

In many emerging economies, most of the farmers are small or marginal farmers, holding less than 5 acres of land. Their economic condition is weak and they mostly depend on credit for sustaining their operations. Approximately 50 percent of the total cost goes towards inputs. Often, they end up with low quality inputs leading to crop losses or even crop failure.

A seemingly simple and promising way in which this problem could be solved is to create economies of scale in procuring high quality inputs through a collective action. In many countries, the Governments have taken up the initiative to launch farmer collectives or farmer cooperatives (FCs) to help out the small and marginal farmers in various input and output operations. In particular, FCs would be extremely helpful for reducing the input burden on the farmer through bulk procurement of inputs, after collecting information on the input requirements of individual farmers. This paper specifically focuses on this problem and explores the use of rigorous procurement mechanisms for harnessing the bargaining power of farmer collectives.

1.2 Evidence from Two Farmer Collectives

To gain a first-hand experience and knowledge of the real situation on the ground, our research group undertook a field study of two FCs, Anekal Horticulture Producers Company Limited and Rajaghatta Horticulture Farmer Producer Company Limited, both within 50 km from Bangalore. Both FCs have a membership of about 1000 farmers each. Small and marginal farmers tend to be low on education and are particularly vulnerable to the strategic tactics of intermediaries, especially on the input side. Since the intermediaries offer credit to the farmers for sourcing the inputs, the intermediaries are able to wield their influence in the marketing and selling of the produce as well. In the process, the farmers end up on the losing side. The FCs play a key role in streamlining the supply of inputs to the farmers and counter the selfish moves of the intermediaries.

Our team had a detailed discussion with the FCs on how they collect indents, aggregate the input requirements of the farmers and bulk-procure the right quantities of inputs to be sold subsequently to the farmers at affordable prices. During these conversations, we also realized numerous issues which were hampering a successful execution of the bulk procurement process. For example, FCs do need a healthy amount of money and resources to execute this process more efficiently. We also discussed with the FCs the discounts that they would be able to obtain because of both volume and variety of their purchases. Here again, we found that the discounts on offer from the suppliers could be much higher if the right kind of procurement protocols are put in place.

1.3 Use-Case: Chili Pepper Seeds Procurement

We followed up the above field interactions with a study of how agricultural inputs are typically purchased by the farmers where there is no FC. Our study led to some illuminating insights on how discounts could be obtained if an FC were purchasing the inputs rather than individual farmers. Our study focussed on chili pepper seeds, a very prominent agricultural input in one of the counties, about 300 km away from our University campus.

In the county that we surveyed, the seed requirement is about 160 tonnes. Assuming five FCs for this county, this translates to about 32 tonnes of chili pepper seeds requirement for each FC. Chili pepper seeds are sold in packets of 4 Kg each, so this becomes 8000 packets of chili pepper seeds to be procured by the FC.

There are numerous varieties of chili pepper seeds (more than 50). These could be grouped under five main varieties, say **A**, **B**, **C**, **D**, and **E**. The prices per packet of these five varieties range from $6.58 to $17.11 with **Variety A** commanding the highest price and **Variety E** being sold at the lowest price. Not all farmers can buy **Variety A** and many of them settle for **Variety E**. They often go for a mixed crop of two or three varieties, depending on their budget limitations.

Example 1.1. The FC can use a mobile app to collect the individual requirements of the farmers which will make up the 8000 tonnes of seeds comprising these five varieties. We were able to break down the requirement into the following five buckets: 2000 tonnes of **Variety A**, 1000 tonnes of **Variety B**, 1000 tonnes of **Variety C**, 1000 tonnes of **variety D**, and 2500 tonnes of **Variety E**. The FC can then bulk-procure these from major suppliers of these seeds and then distribute the required volume and variety of seeds to farmers at affordable prices. This paper looks into this specific problem and presents thought experiments and simulations on the proposed mechanisms.

1.4 Contributions and Outline

We propose the use of (a) volume discount auctions (b) combinatorial auctions in the framework of Vickrey-Clarke-Groves mechanisms [5, 6]. The use of VCG mechanisms will ensure *allocative efficiency* (allocation is done to suppliers who deserve most because of their low costs) and *dominant strategy incentive compatibility* (suppliers bid truthfully and do not have to worry about the possible bids of the other suppliers). It is intuitively obvious that volume discount auctions and combinatorial auctions will be cost-effective compared to naive auctions without discounts. In addition, the proposed mechanisms have two benefits: (a) They are intuitive and the suppliers can relate to them easily (b) By using the VCG payment rule, we are achieving two desirable properties out of the strategic suppliers and moreover, these properties are rigorously explainable.

Procurement auction mechanisms are well known in the literature. Some of the relevant works for our use-case include [1, 2, 4]. We provide a brief survey of these in Section 2.1. In Section 2.2, we describe the auction mechanisms that we took up for thought experimentation and simulation. In Section 3, we present the results of our experimental study. We conclude the paper in Section 4.

2 VOLUME DISCOUNT AUCTIONS AND COMBINATORIAL AUCTIONS FOR PROCUREMENT

Volume discount auctions or *quantity discount auctions* are covered in [1, 2, 4]. In a volume discount auction, the buyer wishes to secure a large volume of a homogeneous item and the sellers bid *supply curves* or *volume discount bids*. A supply curve specifies the discounted prices offered by the seller. For example, the supplier may offer a per unit price of $20 when the quantity is in the range 1-500; a per unit price of $18 when the quantity is in the range 501-1000; and a per unit price of $16 when the quantity range is 1001-2000. If the seller is supplying 1600 units, the total bid will be $500 \times 20 + 500 \times 18 + 600 \times 16$. The other case of volume discount where a fixed rate of discount is applied to the whole bundle, depending on the quantity, can also be represented in the above fashion by tweaking the discounts accordingly.

Combinatorial auctions where the buyer wishes to procure a bundle of multiple units of multiple varieties or items (e.g., 2000 units of **Variety 1** and 1000 units of **Variety 2**) are those in which the suppliers place combinatorial bids. A combinatorial bid will specify a subset of the varieties, quantities, and a single price for the entire bundle. Combinatorial auctions are surveyed comprehensively in [3, 7, 8]. Combinatorial procurement auctions are covered in [1, 2, 4].

2.1 Procurement Mechanisms Explored in this Paper

A simple way of procuring the bundle described in Example 1.1 would be to procure each bucket separately by contacting all suppliers for each bucket and asking them to send quotations, negotiating, and picking the one who has quoted the least price after negotiations. While this method may have worked well traditionally, there is merit in engaging with the strategic suppliers in more scientific ways. We experiment with the following different categories of auctions.

Individual Item Auctions without Volume Discounts where for each item, the FC conducts an individual auction and the suppliers bid the number of units they can supply and a per unit price. The FC will minimize the total cost of procurement by choosing the lowest bidders.

Individual Item Auctions with Volume Discounts where the bidders specify discounts based on the volumes they supply. They are specified in terms of supply curves, which have been described in Section 2. Volume discounts make the selection of suppliers (so as to minimize the cost of procurement) an interesting problem. The winner determination problem turns out to be an NP-hard combinatorial optimization problem in the formulation used in our experiments [4].

Combinatorial Auctions where the bids are more general and are for subsets of the item varieties. Typically, the supplier will specify a *package discount* based on the bundling. An example of a combinatorial bid would be of the form: (2000 A, 1000 C, 2500 E; $56000) meaning that the supplier is willing to supply 2000 units of **Variety A**, 1000 units of **Variety C**, and 2500 units of **Variety E** at $56000. Clearly, different suppliers may bid different combinations and different levels of package discounts. The winner determination problem in combinatorial auctions could have very high computational complexity [1, 3, 7, 8]. An NP-hard combinatorial optimization formulation is presented in [4]. This is the formulation we have used in our experiments.

2.2 Payment Mechanism

We use the VCG payment rule in which the winning bidders are paid an amount that is computed using the Clarke payment rule [5, 6]. This payment rule will ensure that the auction mechanism is dominant strategy incentive compatible, that is bidding their willingness to sell (WTS) values is a dominant strategy for each player (optimal bid irrespective of what is bid by the other players). For example, suppose the bids from the three suppliers in the individual item auction without discounts are as above and the Clarke payment rule is used, then rational suppliers will bid $15, $14, and $13, being the true willingness-to-sell values of supplier 1, supplier 2, and supplier 3, respectively. The Clarke mechanism is a strictly budget balanced mechanism where payment to a supplier depends on the valuation of the remaining suppliers in the absence of that supplier. The Clarke payment rule, by providing a supplier's marginal contribution as their incentive, turns out to be incentive compatible.

The choice of volume discount auctions and combinatorial auctions is motivated by their intuitive appeal. They are easily understood and easy to explain to stakeholders. The choice of VCG mechanisms is driven by the two properties - allocative efficiency and dominant strategy incentive compatibility - that VCG mechanisms satisfy. They induce honest behavior from suppliers. It must be noted that the VCG payment rule needs to be explained carefully to all the stakeholders in a clear way. Computation of VCG payments involves solving as many winner determination problems as the number of winners [5, 6] but is of manageable complexity since the number of suppliers is usually well within 20.

2.3 Business Rules

To guarantee fairness, it is important to ensure that the auction does not give undue advantage to any single supplier or to a small number of suppliers. At the same time, it is important to ensure that the procurement orders are not fragmented amongst a large number of suppliers which could exacerbate logistics, book-keeping, and transportation issues. Some of these fairness constraints could be imposed by specifying a minimum number of suppliers, a maximum number of suppliers, and a maximum business constraint (for example, not more than 50% business to any single supplier). These constraints will have to be incorporated into the winner determination problem such as in [4].

3 EXPERIMENTAL STUDY

For simulation experiments, we have chosen the example of chili pepper seeds procurement discussed in Section 1.3. Our interactions with stakeholders confirm chili pepper seeds procurement as a fit case for implementation by FCs. We consider five varieties of seeds for procurement. Usually, there is a base price for each variety of chili pepper seeds, which is the bare minimum cost price for the seeds. On this base price, a supplier will have a minimum profit margin (q percent). Base price plus q percent of the base price becomes the willingness to sell (WTS) of the supplier. Typically this is private information of the supplier. We assume q to be uniformly distributed over $\{8, 9, 10, 11, 12\}$. This means WTS will be on an average 10% higher than the base price. After due consultations with stakeholders, the base price for the five varieties (based on the actual base price in market) has been assumed to be: $17.11 for **Variety A**, $14.47 for **Variety B**, $13.15 for **Variety C**, $9.21 for **Variety D**, and $6.58 for **Variety E**.

We consider the procurement scenario of Example 1.1. If bought at base price, the total cost of procurement will be $87500. Call this *no-profit cost*. This is a lower bound on the total procurement cost on a no-profit basis to the suppliers. In case all of them are bought at WTS prices, the total cost will be on an average 10% higher, which will be $96250. This is a lower bound on the total procurement cost when the suppliers are provided an average of 10% profit over the base price. Call this *minimum profit cost*.

Depending on the volume of units supplied or bundle of varieties being supplied, there is a certain discount that a supplier will offer. We assume the maximum discount offered as y percent. This is usually supplier dependent. We assume that the maximum value of y for any supplier is 10 percent. In a volume discount bid, y could be the discount for the highest range of quantities and is gradually decremented for smaller ranges of quantities. For a combinatorial auction, different suppliers will offer different package discounts (y) on different combinations.

Item(s) Procured	Cost in $ with No Volume Discount	Cost in $ with Volume Discount
2000 **A**	37489.61	35156.13
1000 **B**	15844.34	14873.75
1000 **C**	14405.26	13521.59
1000 **D**	10065.72	9437.91
2500 **E**	18005.76	16901.98
All Items	95810.69	89891.35

Table 1: Costs of procurement in $ in VCG auction with volume discount and without volume discount

Package Discount	Individual Item Auction	Combinatorial Auction
2 %	95810.69	95727.52
4 %	95810.69	93783.85
6 %	95810.69	91732.21
8 %	95810.69	89790.33
10 %	95810.69	87872.74

Table 2: Costs of procurement in $ in VCG auction with combinatorial bids and without combinatorial bids

We have three types of bidding methods (individual item without volume discounts, individual item with volume discounts, and combinatorial); and we either apply business rules or not. This gives us different types of auction methods to be explored. In this paper we provide results for four representative methods. The results given below are computed as averages over 200 runs with bid amounts generated according to a uniform distribution around the respective base values for different parameters. We run 200 simulation experiments with random numbers generated for all appropriate variables and take an average over those 200 simulations.

3.1 Experiments with Volume Discount Auctions

First, we consider a simple auction for each individual variety without any volume discounts, under the VCG payment scheme. Due to incentive compatibility, each supplier bids its WTS. Next, we consider a volume discount auction for each individual variety assuming that each volume discount bid has four equal segments offering 2.5%, 5%, 7.5%, and 10% discount on per-unit price. As an example, for **Variety A**, the 2000 units are divided into four segments, namely, [1,500], [501,1000], [1001, 1500], and [1501, 2000] and in these segments, the discounts offered are 2.5%, 5%, 7.5%, and 10%, respectively over the bid amount when discounts are not offered. We observe from Table 1 that the cost of procurement is lowered under volume discounts. By forcing an auction, we are making the suppliers bid competitively and this results in decreased procurement cost. It is notable that the total cost of procurement is higher than the *no-profit cost* but lower than the *minimum profit cost*.

Package Discount (y)	Without Business Rules	With Business Rules
2 %	95727.52	96486.67
4 %	93783.85	94493.24
6 %	91732.21	92465.91
8 %	89790.33	90425.25
10 %	87872.74	88759.01

Table 3: Costs of procurement in $ for combinatorial auction with and without business rules

3.2 Experiments with Combinatorial Auctions

For the above procurement scenario, we now consider a combinatorial auction where each supplier bids for different combinations. For experimentation purposes, we assume that each supplier bids for exactly one combination. In particular, we assume the following combinations for the 10 suppliers. These combinations have been chosen based on informal market consultations.

> Supplier 1: (2000 A); Supplier 2: (2500 E); Supplier 3: (2000 A; 1000 B); Supplier 4: (1000 B; 1000 C); Supplier 5 : (1000 C; 1000 D); Supplier 6: (1000 D; 1500 E); Supplier 7: (1000 B, 1000 D); Supplier 8: (1000 B, 1000 C, 2500 E); Supplier 9: (2000 A; 1000 C; 1000 D); Supplier 10: (2000 A; 1000 D; 2500 E).

Here, we compare the cost of procurement in individual procurement versus combinatorial procurement. We assume five different levels of y (*package discount*): 2%, 4%, 6%, 8%, and 10%, which implies that on the total cost of the entire bundle, a discount of y% is given. For example, if $y = 6$, then the supplier 9 offers a discount of 6 percent on the total cost, computed using WTS, of 2000 units of **Variety A**, 1000 units of **Variety C**, and 1000 units of **Variety D**. Table 2 provides the comparison between non-combinatorial auction (Column 2) and combinatorial auction (Column 3). It is again notable that the total cost of procurement is higher than the *no-profit cost* but lower than the *minimum profit cost*.

We find that combinatorial auction, like volume discount auction, leads to reduction in the cost of procurement in each case. In fact, combinatorial auction with $y = 10$ has lower cost than that of volume discount auction. We omit any detailed comparison between combinatorial auction and volume discount auction due to space constraint. Suppliers can be told about these two protocols so that they are fully aware of the winner determination and payment determination.

3.3 Experiments with Business Rules

Table 3 shows the total cost of procurement for the entire bundle when business rules are applied. In our experiment the minimum and maximum number of winning suppliers is specified as 3 and 6 respectively. Clearly, the total cost in the presence of business rules is higher. What is comforting is that it is only marginally higher. This happens because of a sufficient number of suppliers being available. It is notable that fairly sophisticated business rules, reflecting various desirable fairness and business criteria, can be captured in the optimization problem as constraints.

4 ONGOING AND FUTURE WORK

We have demonstrated an attractive opportunity to help reduce input costs at assured quality levels for smallholder farmers through farmer collectives. Simulation experimentation on a variety of incentive compatible procurement auction methods on a stylized but realistic example has clearly shown the efficacy of this approach. The mechanisms are intuitive and are easy to explain to the suppliers. Suppliers also relate to these mechanisms since they practice volume discounts and package discounts routinely in their transactions. A big plus point is that the proposed mechanisms guarantee certain nice properties and induce honest bidding behavior from the suppliers. There is, however, a wide gap between a simulated thought experiment like this one and an actual practical implementation and demonstration. Nonetheless, the work provides clear evidence that the proposed mechanisms will be more cost-effective than existing traditional methods, in addition to many other benefits they bring in, such as inducing honesty in bidding, bargaining power, selecting deserving suppliers, and the possibility to ensure fairness of allocation.

In our ongoing and future work, we are striving to impress upon selected FCs to adopt these mechanisms in some form or other. Technology (like mobile apps) can be leveraged to automate and streamline the entire procurement process. There are many avenues for extending our work in various directions. In the bidding methods, one can generalize the structure of the combinatorial bids. We have assumed that each supplier places only one combinatorial bid; this is quite restrictive. There is rich literature on bidding languages in combinatorial auctions and this literature can be invoked for implementing more powerful auctions [7]. On the payment side, a VCG auction maximizes social welfare but may not minimize the total cost of procurement. In this connection, optimal volume discount auctions and optimal combinatorial auctions need to be looked into [6] and this is a promising research direction.

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