Mandi Electronic Exchange: Orchestrating Indian Agricultural Markets for Maximizing Social Welfare

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Abstract— In this paper, we discuss the prevailing agricultural marketing system in India and identify the problems and inefficiencies. We propose that the government wholesale market called the Mandi should be transformed into an electronic marketplace (exchange) for agricultural produce. An important function of the electronic exchange is to match the supply of the farmers' produce with the demand from the wholesalers and retailers. We present a mixed integer programming model that the electronic exchange needs to solve in an iterative way to optimally match buyers with sellers. We present a stylized case study to illustrate the functioning of such a Mandi exchange. We believe such a Mandi exchange will have a translational impact on agricultural trading, particularly in India.

I. INTRODUCTION

As per the world agriculture statistics report, 2010, of the Food and Agriculture Organization of the United Nations [1], India is the world's largest producer of numerous fresh fruits and vegetables, and the second largest producer of wheat and rice, the world's major food staples. But agriculture in India (like that of many other developing countries) is characterized by small and marginal farms, lack of timely information (about the weather, prices, use of pesticides/fertilizers, etc.), insufficient resources and infrastructure, and inefficient post-harvest processing.

Inspite of being a world leader in agricultural production, India is a land locked economy with domestic production meeting domestic demand with less than 10% exports particularly in the food supply chain vertical. To meet the needs of an emerging economy with an increasing urban population, there is a need for storing and transporting agricultural produce efficiently using innovative and robust supply chains.

The agricultural marketing system is a network in which several players interact. The book by Easley and Kleinberg [5] is an excellent source for understanding networks, including trading networks, equilibrium prices in such scenarios, matching markets, auctions, etc. Kleinberg [7] talks about how social networks are formed to bridge structural holes. The chapter by Reardon et al. [8] traces the evolution of literature on agri-food output markets over the past 50 years, including the supermarket revolution.

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A. Contributions and Outline

The main contribution of this paper is to make a strong case for electronification of Mandi operations in the agriculture sector in India. We first critically analyze the agricultural marketing and trading system in India and identify the dynamics and social structure in this complex system. We make several powerful but empirical observations about this dynamical system which suggest a natural solution to transform a Mandi into an electronic exchange.

We formulate the mathematical foundations of the Mandi exchange using a mixed integer linear programming formulation that matches buyers and sellers in the market. The matching occurs over several rounds of bidding by buyers and sellers. Our formulation assumes that the buying agents and selling agents are honest and bid their preferences truthfully. We set up an illustrative case study and show how an efficient solution emerges after four rounds of bidding. The rest of this paper is organized as follows. Section II provides a description of a typical agricultural market in India. It discusses the players involved, the challenges before the farmers, and the existence of social networks in the Mandi system. Section III is devoted to an empirical, graph theoretic analysis of the Mandi network. Section IV lays out the details of how a Mandi can be transformed into an electronic exchange. Section V formulates the mathematical programming problem that describes the matching problem. Section VI presents an illustrative case study and numerical experimentation. Section VII concludes the paper.

II. DESCRIPTION OF A TYPICAL INDIAN AGRICULTURAL MARKET (MANDI)

The Indian government has established a large number of public wholesale market yards for agricultural products and regulates these market yards through an Agricultural Produce Market Committees (APMC) Act [1]. It is estimated that there are around 7000 such wholesale markets in India.

Typically, the state governments set up marketing boards called APM Committees which frame rules and supervise the wholesale trade of agricultural produce in markets called Mandis. *Wholesale trade of agricultural produce in the regulated areas has to happen under the Mandi framework. Trade outside is not permitted.* Under this system, the farmers bring the agricultural produce to the Mandi's physical location where it is auctioned and sold to traders, who are registered

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[1]For an overview of the APMC Act and the changes necessary, please see [6]. Some of these laws are being relaxed over time, providing better investment opportunities for the private sector.

with the Mandi. The auction format is the classical open-cry ascending price auction (English auction). The traders in-turn sell the produce to wholesalers, retailers, or companies. Mandis were created with the intention of providing farmers a centralized marketplace to sell their produce, and to ensure that they get fair prices. But over the years, this system has been monopolized by middlemen who dictate the prices. Moreover, the produce has to be transported by the farmers to the Mandi (sometimes for hundreds of kilometers) and the farmers have to wait for their turn of the auction process (for several days during the harvest season). Reports say that about 30% of the perishable commodities is lost due to such inefficiencies in post-harvest processing. With the advent of the Internet and the advances in Information and Communication Technologies (ICT), we believe that agricultural trading can be done in an efficient manner which is beneficial to both farmers and consumers, and we present an approach for the same.

A. Players in the Current Mandi System

Let us look at a simple model of the players in a typical Mandi-

a) Farmers- They have some items (agricultural produce) which have to be sold. They can sell it to a village trader, a commission agent, or a trader at the Mandi. Their objective is to get the best price for their produce.

b) Commission Agents- They buy produce from a farmer and sell to a trader. They take commission for the work done. They are the brokers or middlemen.

c) Traders- They are registered with the Mandi. They bid for items and buy them. They may in turn sell to wholesalers, industries or retailers.

d) APMC / Mandi Staff - Their role is to ensure that the auctioning process takes place smoothly and transparently in the market and maximum number of farmers derive the benefits of their service.

The industries and wholesalers are not players in this game but they are a part of the ecosystem and the whole trading process has a significant impact on them.

B. Farmers' Dilemma

The Indian farmer faces a huge dilemma- where and when should he sell the produce: Should he sell to the village trader or commission agent at the village, or travel to the nearest Mandi and sell it to a trader, or travel to another Mandi in a metropolitan city? We represent this dilemma as an extensive form game or a game tree (Figure 1) with the players being farmer (F), village trader or commission agent (VT/CA), and trader at Mandi (T). The payoff to each player in the form $(F, VT/CA, T)$ is written in parentheses at the leaf nodes.

The farmer can sell to a village trader or commission agent at a price C. Or he can travel to a Mandi and sell it at a price C'. But in the latter case, he also incurs a transportation cost T. (There is also a delay in auctioning the produce which leads to a risk of losing perishable commodities).

Due to the information asymmetry present in the current Mandi system, the farmers have no way of knowing whether
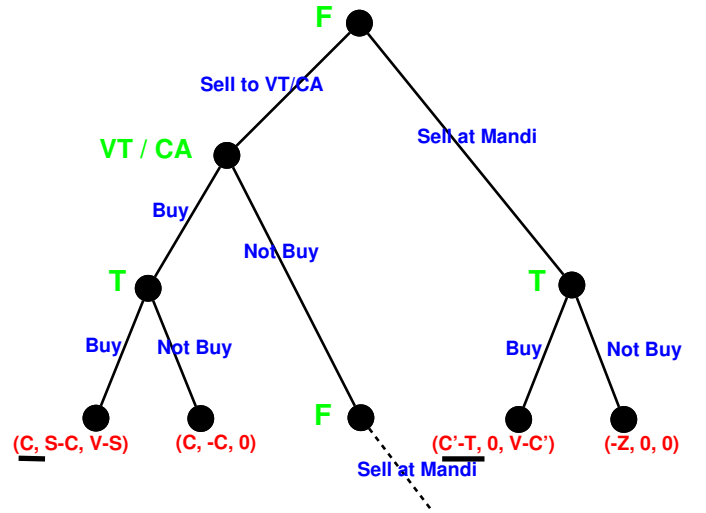

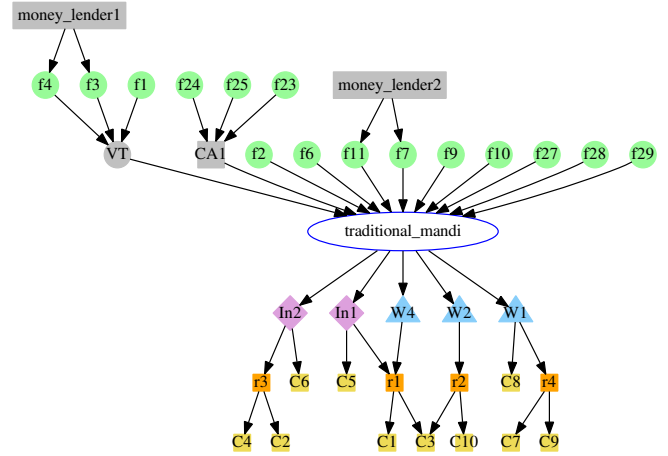Fig. 1. Game tree for farmers' dilemma

Fig. 2. Social networks in the Mandi system

the price C or the price $C' - T$ would be better for them. In Figure 1, S denotes the price at which a commission agent sells to a trader, and V is the price at which the trader sells to a consumer. Typically, there is enormous disparity between what a consumer pays (V) and what a farmer gets (C or C').

C. Social Networks in the Mandi System

Let us consider the Mandi as a single node and look at the social networks in the system, consisting of the players mentioned above. We have represented it graphically in Figure 2. In the figure, f* represents farmers (where * can be any digit), CA* represents commission agents, VT* represents village traders, In* represents industries, W* represents wholesalers, r* represents retailers, and C* represents consumers.

III. GRAPH THEORETIC ANALYSIS OF THE MANDI NETWORK

Observation 1: The current agricultural network has a structural hole.

Burt [3] coined the term 'structural hole' to denote the separation that exists when two groups of people have no
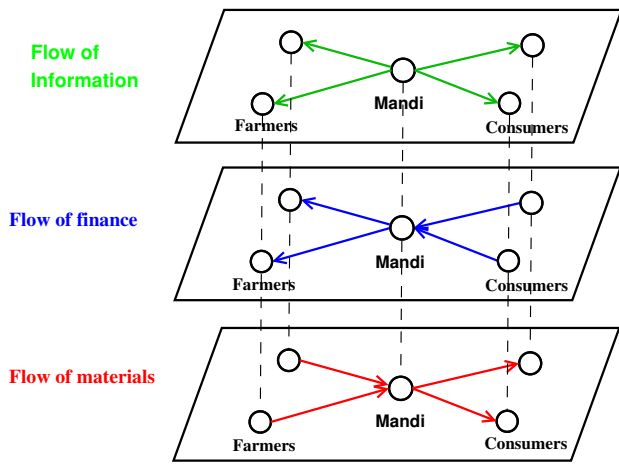
Fig. 3. Multi-layered graphical representation of a Mandi

direct contact with each other. In the Mandi network, on one side there is a group of farmers (sellers) and on the other side, there are consumers (buyers). These two groups are not allowed to buy/sell directly with each other and are forced to transact via the Mandi. Therefore there is a structural hole in the network. This fact can be observed in Figure 2.

Observation 2: The Mandi network is a multi-layered network.

There are three flows in the Mandi network as shown in Figure 3.

1) In one layer there is flow of produce/materials from farmers to consumers (supply chain network).
2) In the next layer, there is flow of finance/money in the opposite direction (financial network) i.e. consumers pay money for the produce and this reaches the farmer.
3) Finally, there is flow of information (crop prices, regulations, supply and demand). Information should have ideally flowed from consumers to farmers, but it starts from Mandi (traders) and is haphazard.

In both (1) and (2), there is loss of produce and finance due to intermediaries.

Observation 3: Trader monopoly

Blume et al. [2] discuss a game-theoretic model of trade, with buyers, sellers, and traders interacting on a network.

In the Mandi system, traders have a high bargaining power (a monopoly) on the prices. Traders are in a powerful position in the network (due to the geographical locations of farmers and consumers). Moreover, in some situations, the traders are a cartel and dictate the price to the farmers without auctioning the produce.

Observation 4: Supply Demand mismatch

Farmers are not aware of the demand for each commodity. They grow crops based on what they have grown traditionally or by being influenced by their neighboring farmers in the village. This results in huge mismatch between supply and demand.

IV. MANDI AS AN ELECTRONIC EXCHANGE

Sivakumar [9] presents the experiences of ITC in buying some commodities via electronic kiosks (*echoupals*) directly from farmers.

We propose that the Mandi be converted to a smart electronic marketplace in the form of an exchange for agricultural produce which will allow farmers to directly sell their produce online. Any person (consumer) can log on to the platform, place bids, and buy the items. In addition, the electronic exchange will provide the following information useful to farmers and will have local language support.

- Latest market price of all crops and minimum support prices (MSP) set by the government
- Access to financial services e.g. mobile payment system and microlending platform
- Real time weather information
- Information on where to get high yielding seeds, fertilizers, etc.

A. Characteristics of the Electronic Exchange

Case 1: With the APMC Act still in vogue

The Mandi as an Electronic Exchange (henceforth called 'Mandi Exchange') fills the structural hole in the agricultural network by connecting the farmers and the consumers. It takes care of the important task of matching supply and demand. It also has connections with transporters and ensures efficient transport of produce directly from farms to industrial or retail markets.

Quality control mechanism: The Mandi Exchange employs quality checkers who check the quality of the produce at the source. It also gives a reputation rating to farmers, quality checkers, and traders.

Case 2: With the APMC Act amended or removed

Based on Burt's theory [3], nodes get benefits (informational and economic) by filling structural holes in a network. In addition to the Mandi Exchange, there is a huge opportunity for new players to fill the structural holes and act as a bridge between farmers and consumers. The following types of players have an incentive to fill the hole:

- Private Players (like Reliance Fresh and ITC)
- Farmers' Cooperatives (like Amul, Safal and Nandini)

Do we need intermediaries at all?

Eventhough the Mandi Exchange removes intermediaries like middlemen and commission agents, other intermediaries like transporters and quality checkers still remain in the system. Moreover, we say that the Mandi Exchange itself is playing the role of an informational intermediary. Wu [10] says that intermediaries exist because they provide value! This value may be in the form of efficient transportation, storage, aggregating supply and demand, and protecting the sellers and buyers from risks. Info-mediaries (like the Mandi Exchange) provide several benefits including coordination, reducing the needs of direct negotiation, and synthesizing dispersed information.

TABLE I
NOTATION FOR THE OPTIMIZATION PROBLEM

$M = \{1, ..., m\}$	set of m buying agents
$N = \{1, ..., n\}$	set of n selling agents
$Z = \{1, ..., z\}$	set of z quality-levels
$i = 1, ..., m$	index for buying agents
$j = 1, ..., n$	index for selling agents
$k = 1, ..., z$	index for quality-levels
k_i	quality level demanded by buying agent i
k_j	quality level of items available with selling agent j
q_i	quantity of items needed by buying agent i of quality-level k_i or better
p_i	price per unit that buying agent i is bidding for quality-level k_i or better
Q_j	quantity of items of quality-level k_j that selling agent j wants to sell
s_j	price per unit that selling agent j is asking
$S(M, N)$	surplus with m buyers and n sellers
x_i^k	number of units allocated to buying agent i of quality-level k
y_j^k	number of units allocated to selling agent j of quality-level k
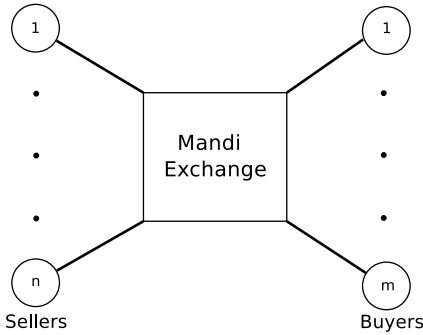
In the case of the Mandi, the two types of intermediaries (explained above in Cases 1 and 2) have different goals:

- The Mandi Electronic Exchange or farmers' cooperatives are interested in maximizing farmers' welfare.
- Private players try to maximize their own profit.

An important daily task of the Mandi Exchange is to match the farmers' supply with that of the demand from wholesalers and retailers (in a way that is beneficial for the farmers). Here, we show a formulation for the trade of a single item (for instance onions). If an exchange is dealing with multiple items, the formulation can be applied separately for each item.

V. MATCHING PROBLEM IN A MULTI-UNIT SINGLE-ITEM MANDI EXCHANGE

Let us look at how to match the supply and the demand in an exchange selling multiple units of a single item. We use notations similar to [4] to describe the exchange. (See Table I)

- There is a set of buying agents $M = \{1, ..., m\}$ and a set of selling agents $N = \{1, ..., n\}$.
- There is a set of quality-levels or grades of the produce $Z = \{1, ..., z\}$, where 1 corresponds to the highest or best quality level and z corresponds to the lowest.

- The buying agents submit bids $B = B_1, ..., B_m$, respectively. A bid B_i is of the form $[k_i, q_i, p_i]$ where q_i is the quantity of items of quality-level k_i that buying agent i wants, and p_i is the price per unit that buying agent i is bidding. (Note that a trader may be interested in buying items of more than one quality-level. Say, a trader wants items of w quality-levels, where $w \leq z$. We decompose this into w independent buying agents, one for each quality-level).
- The selling agents submit asks $A = A_1, ..., A_n$, respectively. An ask A_j is of the form $[k_j, Q_j, s_j]$ where Q_j is the quantity of items of quality-level k_j that selling agent j wants to sell, and s_j is the price per unit that j is asking. (Here again a farmer may be selling items of different quality-levels, but we decompose them into independent selling agents, one for each quality-level).

The objective of the exchange is to maximize its surplus (revenue). We define the surplus as the total payment received from all the winning buyers minus the total payment made to all the winning sellers.

Maximize

$$S(M, N) = \sum_{i=1}^{m} \sum_{k=1}^{z} x_i^k p_i - \sum_{j=1}^{n} \sum_{k=1}^{z} y_j^k s_j \quad (1)$$

subject to

$$\sum_{k:k \leq k_i} x_i^k \leq q_i , \quad \forall\, i \in M \quad (2)$$

$$\sum_{k:k \geq k_j} y_j^k \leq Q_j , \quad \forall\, j \in N \quad (3)$$

$$\sum_{i=1}^{m} x_i^k \leq \sum_{j=1}^{n} y_j^k , \quad \forall\, k \in Z \quad (4)$$

$$x_i^k \geq 0 \quad \forall\, i \in M, \, \forall\, k \in Z \quad (5)$$

$$y_j^k \geq 0 \quad \forall\, j \in N, \, \forall\, k \in Z \quad (6)$$

$$\sum_{k:k > k_i} x_i^k = 0 \quad (7)$$

$$\sum_{k:k < k_j} y_j^k = 0 \quad (8)$$

Constraint (2) guarantees that the total number of units allocated to a buying agent is less than or equal to its demand. Constraint (3) guarantees that the total number of units bought from a selling agent is less than or equal to its supply. Constraint (4) ensures that for each quality-level, the number of units sold does not exceed the number of units procured. Constraints (5) and (6) ensure non-negative allocation. (7) and (8) enforce quality constraints.

Note 1: When a buyer is interested in a quality k_i, it is okay if he is allocated a quality better than k_i. When a seller has an item of quality k_j, it is okay if his allocation is for a quality lower than k_j if he is getting the same price.

Note 2: Ties are resolved on a first-come-first-served basis.

Iterative Allocation

The allocation process mentioned above constitutes the first round or iteration. After the first round, sellers and buyers who have been allocated the items are removed from the system. For the second round, the sellers are given an opportunity to change their asks based on the demand observed in the first round. Similarly, the buyers are given an opportunity to increase their bids, and the next round proceeds. This process continues as long as sellers are present in the system or until the minimum support price for the commodity is reached.

The Mandi Exchange redistributes the surplus to the farmers after deducting a nominal maintenance fee. On the other hand, private players would treat the surplus as profit.

VI. EXPERIMENTAL RESULTS

In this section, we present results of the numerical experiments using our optimization model on a stylized case study.

A. Experimental Setup

We considered eight selling agents, ten buying agents, and three quality-levels for the experiment. (The quality-levels were 1, 2 and 3, with 1 being high quality, 2 being medium and 3 being low).

We generated uniformly distributed random bids of the ten buying agents, with the quality-level (k) in the range 1 to 3; the quantity in the range 10 to 100 (in steps of 10); and price per unit for quality-level 1 ($k = 1$) in the range 11 to 14, for ($k = 2$) in the range 7 to 10, and for ($k = 3$) in the range 3 to 6.We followed a similar method for generating the asks of the eight selling agents. We used the IBM ILOG CPLEX optimization studio solver package on a 3.40 GHz Intel Core i7 processor with 8-GB RAM to compute exact solutions.

B. Results

ROUND 1:
The generated bids are shown in Table II and asks in Table III.
ALLOCATION:
Buying agent 10 is allocated 50 units which is supplied by selling agent 7. The surplus to the exchange is 50. Buying agent 10's demand is met and is removed from the system. The total trade happening in round 1 is low because at the start of the trade, the sellers' (farmers') expectations are high leading to high ask prices. On the other hand the buyers (traders) want to pay a minimum amount, leading to low bid prices. After round 1 is complete, the selling and buying agents are given an opportunity to decrease their asks and increase their bids respectively. The second round of allocation then takes place.

ROUND 2:
Number of selling agents remaining = 8
Number of buying agents remaining = 9
The bids and asks are shown in Tables IV and V respectively.

TABLE II
BUYING AGENTS' BIDS FOR ROUND 1

	B_1	B_2	B_3	B_4	B_5	B_6	B_7	B_8	B_9	B_{10}
k_i	3	1	2	2	1	3	2	1	2	3
q_i	20	90	40	100	10	70	80	60	30	50
p_i	4	11	7	8	11	3	7	12	8	5

TABLE III
SELLING AGENTS' ASKS FOR ROUND 1

	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8
Quality (k_j)	2	3	1	2	2	1	3	3
Quantity (Q_j)	90	30	80	100	40	50	70	10
Price (s_j)	9	5	12	9	8	13	4	5

ALLOCATION:
Surplus to the exchange is 190. The allocation to the buying and selling agents is shown in Table VI, where BA_i represents the ith buying agent and SA_j represents the jth selling agent of the current round.

ROUND 3:
Number of selling agents remaining = 6
Number of buying agents remaining = 5
The bids and asks are shown in Tables VII and VIII respectively.
ALLOCATION:
Surplus obtained is 130. The allocation is shown in Table IX.

ROUND 4:
Number of selling agents remaining = 2
Number of buying agents remaining = 4
The bids and asks are shown in Tables X and XI respectively.
ALLOCATION:
Surplus to the exchange is 60. The allocation is shown in Table XII.

The trading comes to a close as there is no selling agent left in the system. In each round, the MILP formulation (1) - (8) is solved to obtain the allocation. In the considered case study where the bids were randomly generated, the solution is obtained in 4 rounds. Our experimentation shows that the convergence is quite fast.

For realistic problems encountered in practice, the number

TABLE IV
BUYING AGENTS' BIDS FOR ROUND 2

	B_1	B_2	B_3	B_4	B_5	B_6	B_7	B_8	B_9
Quality	3	1	2	2	1	3	2	1	2
Quantity	20	90	40	100	10	70	80	60	30
Price	5	11	7	9	12	4	7	12	8

TABLE V
SELLING AGENTS' ASKS FOR ROUND 2

	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8
Quality	2	3	1	2	2	1	3	3
Quantity	90	30	80	100	40	50	20	10
Price	8	5	11	9	8	12	4	4

TABLE VI

ALLOCATION FOR ROUND 2

Agent	Units Allocated
BA_1	20
BA_4	100
BA_5	10
BA_8	60
SA_1	90
SA_3	70
SA_5	10
SA_7	20

TABLE VII

BUYING AGENTS' BIDS FOR ROUND 3

	B_1	B_2	B_3	B_4	B_5
Quality	1	2	3	2	2
Quantity	90	40	70	80	30
bid	12	8	5	8	9

TABLE X

BUYING AGENTS' BIDS FOR ROUND 4

	B_1	B_2	B_3	B_4
Quality	1	2	3	2
Quantity	30	40	30	80
Price	13	9	6	9

TABLE XI

SELLING AGENTS' ASKS FOR ROUND 4

	A_1	A_2
Quality	2	2
Quantity	30	30
Price	8	8

TABLE XII

ALLOCATION FOR ROUND 4

Agent	Units Allocated
BA_2	40
BA_4	20
SA_1	30
SA_2	30

of buyers and sellers in each exchange is within 100 and the MILP can be solved quite efficiently.

VII. SUMMARY AND FUTURE WORK

The Mandi Exchange is playing the role of an orchestrator and connecting all the stakeholders in the agricultural ecosystem. It is a system designed to favor the farmers and empower them with information and choice. The Mandi Exchange will, over time, estimate the demand for each commodity in the country and advise farmers on how many hectares of cultivation is required. In addition, we hope that the Mandi Exchange will

- act as an enabler for farmers to become more connected socially and form cooperatives (like Amul, Safal).
- contribute to efficient post-harvest processing and robust agricultural supply chain networks.

As a future work, it would be interesting to explore efficient redistribution mechanisms to distribute the surplus of the exchange to the farmers in a fair manner. We are also interested in designing an incentive compatible mechanism for the exchange to do quality checking, i.e., to elicit the true

quality of produce from the sellers and the true valuations (prices) from the buyers.

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TABLE VIII

SELLING AGENTS' ASKS FOR ROUND 3

	A_1	A_2	A_3	A_4	A_5	A_6
Quality	3	1	2	2	1	3
Quantity	30	10	100	30	50	10
ask	4	11	8	8	11	4

TABLE IX

ALLOCATION FOR ROUND 3

Agent	Units Allocated
BA_1	60
BA_3	40
BA_5	30
SA_1	30
SA_2	10
SA_3	30
SA_5	50
SA_6	10