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GOVERNMENT INTERVENTION IN GRAIN MARKETS IN INDIA: RETHINKING THE PROCUREMENT POLICY

Neha Gupta
Email:nehagupta@econdse.org
Department of Economics
Delhi School of Economics

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Department of Economics, Delhi School of Economics

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Abstract

This paper reviews the rice procurement operations of the Government of India from the standpoints of cost of procurement as well as effectiveness in supporting farmers' incomes. The two channels used for procuring rice are custom-milling of rice and levy. In the first, the government buys paddy directly from farmers at the minimum support price (MSP) and gets it milled from private millers; while in the second, it purchases rice from private millers at a pre-announced levy price thus providing indirect price support to farmers. Secondary data reveal that although levy imposes a lower unit cost per quintal of paddy procured, over the last decade, custom-milling has become predominant, partly on the argument that it provides minimum price support to farmers. We analyze data from auctions of paddy from a year when levy was still important to investigate its impact on farmers' revenues. We use semi-nonparametric estimates of millers' values to simulate farmers' expected revenues and find these to be rather close to the MSP; a closer analysis shows that bidder competition is critical to this result. The level of competition in the year of the data for instance, was high enough to offset the impact of sub-optimal reserve prices on revenues. Finally, we use our estimates to quantify the impact of change in levy price on farmers' revenues through its effect on millers' values and competition; and use this to discuss ways to revive the levy channel.

Keywords: Structural Estimation, Auctions, Procurement Policy
JEL Classification: C14, D44, Q13, Q18

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1 Introduction

The Indian government is a large buyer of rice and wheat. Its stated objectives for doing so include (i) providing price support to farmers, (ii) distributing subsidized foodgrain to the poor through the targeted public distribution system (PDS), and (iii) maintenance of buffer stocks to ensure price stability and food security. Both the production as well as the procurement of these foodgrains have grown manifold over the last few decades. The rice output for instance, has trebled in the past 50 years, from a base of about 30 million tonnes in 1960; while the proportion of it procured by the government[1] has risen from about 10% in 1978-79 to 33% in 2010-11[2].

There have been in recent years several studies reviewing the efficiency, outreach and equity of the public distribution system generally; Khera (2010), Jha and Ramaswami (2010), Basu (2010), Dutta and Ramaswami (2002) are a few examples. In contrast, the government's procurement policy is relatively under-investigated. This is the focus of this paper. The government procures rice through two channels (the levy channel, and the custom-milled rice (CMR) channel). We document the steady increase in procurement through the CMR channel, at the expense of the levy channel; we discuss whether this shift can be justified on economic grounds. Our analysis based on a study of price formation in an auction market in the north-Indian state of Haryana suggests that it cannot; the levy channel is more cost-effective and can also be relied upon to provide price support just as well as the CMR channel.

The way in which the rice is procured is believed to have implications for farmers' revenues - and as noted above, providing price support to farmers is one of the stated objectives of government's procurement policy. The most salient way in which the government does this is by offering to purchase paddy (unmilled rice) directly from farmers at wholesale markets. This paddy is purchased at the minimum support price (MSP)[3] that the government announces at the beginning of the *kharif* (July-October) season. The objective of fixing an MSP is to provide a price support at which farmers would be willing to produce paddy, as well as to mitigate downward price risk. The Commission of Agricultural Costs and Prices (CACP) makes an MSP recommendation every year, in part as

[1] Rice is procured both by the Food Corporation of India, and by the procurement arms of state governments.

[2] Figures from Ministry of Agriculture, Directorate of Economics and Statistics, Agricultural Statistics at a Glance, various issues.

[3] The level of the MSP can sometimes be quite high relative to Indian and global prices, as was the case in the late 1990s and early 2000s; so the term '*minimum* support price' does not necessarily connote that this is a low price.

a markup on cost of cultivation estimates; the actual MSP adopted by a particular state can vary from this recommendation, as it is decided by the state government[4]. Quality inspectors of government food procurement agencies inspect paddy for quality; upon approving purchase, the paddy is picked up by government appointed private millers, who pay the MSP, and mill the paddy for the government. The government then gets the rice and pays the millers a consolidated sum for it. This essentially is the CMR channel of rice procurement.

The other channel that the government uses to procure rice is the levy channel. Private millers have to sell a fixed proportion of their rice output in the form of a levy, at a levy price that is determined by the government prior to harvesting. The levy price is based on estimates of milling costs, providing for a small markup on that and the MSP. The proportion of rice that a miller must sell to the government differs across states (and across time); in Haryana in 1999, it was 75%.

Till the early 1990s, the government procured more than 65% of its rice requirements through the levy channel; but since then, the CMR channel has been emphasized much more, and levy procurement is now just over 30% of total procurement (Table 1). In Haryana, the decline has been even more stark than the national averages indicate- the percentage of rice procured through the levy route declined from over 90% in 1990-91 to below 2% in 2010-11 (Table 2). Since the percentage of rice output that millers had to pay as levy stayed at 75%, the decline in levy procurement indicates that a previously thriving private trade has run dry. There are multiple reasons for this, that are discussed below, but these reasons point to at least a tacit emphasis on procurement through the CMR channel at the expense of the levy channel.

The Report of the High Level Committee on Long-Term Grain Policy (2002) appears to mark a distinct change in thinking in government circles on the two routes of procurement. This committee asserted that while procuring rice through the CMR route was more expensive than through the levy route, de-emphasizing the levy route and concentrating on the CMR route was desirable, from the viewpoint of providing better price support to farmers. As noted above, whether by design or not, rice procurement in the past decade has increasingly been along the CMR line as suggested by this Committee. In states where procurement infrastructure and procurement volume was large, the policy shift has been deeper, as seen in Table 3 in the case of Haryana. This point is made more generally by Kubo (2011) and Ramaswami (2010).

[4]For instance, in 1999 (the year for which we use auction data in this paper), the CACP-recommended MSP was Rs 495 per quintal (100 kg) for 'Grade A' paddy; the Haryana state government announced a 'bonus' of Rs 25 per quintal on top of this so in effect the MSP that year was Rs 520 in Haryana.

Previous work (example Umali-Deininger and Deininger, 2001) has noted that in the major states that rice is procured from, levy prices are consistently below market prices, discouraging private millers from participating in the foodgrain business. This is but one of the criticisms of government foodgrain policy as it stands today. Several authors (example Chand, 2002, Rashid, Gulati and Dev, 2008) have argued that various aspects of agricultural price policy need to be revisited.

This provides the context for the analysis in this paper, which has three main objectives. First, is to document using secondary data, the gradual shift in emphasis on procurement through the CMR channel; and also to compare the unit costs to the government of procurement through the levy and CMR routes. This enables an evaluation of which of the two is the more efficient policy instrument. Second, it attempts to assess the performance of the levy route in ensuring that revenues that farmers may expect to make are approximately the same as what would obtain under an MSP. The final objective in this paper is to examine the impact of changes in the levy price on farmers' expected revenues and to explore ways to revive procurement through the levy channel. This enables us, through simulations, to quantify the change in levy price needed to counteract changes in open market prices, if the objective is to insulate farmers' revenues from unexpected price fluctuations, one of the reasons why the government implements an MSP policy. The simulations also help in assessing the impact of a non-discriminatory price regime (one where the levy price is not lower than the CMR price) on farmers' revenues. We find that setting the levy price at par with the CMR price implies revenues from auctions that are on average, no less than the MSP.

In order to address the latter two objectives, we analyze paddy auction data from a market in an important rice-producing state in North India (district Panipat in the state of Haryana), in terms of a formal structural model of ascending auctions. Studying issues related to farmers' revenues from auctions necessitates knowledge of the underlying distributions of buyers' valuations for the lots of paddy. While the auctioneer cannot know the specific valuations of each buyer, the theory proceeds on the basis that he knows the distributions from which the valuations are drawn. Estimation of the underlying distributions requires that they be identified from the given data; auction theory can be used to map observed bids (sale prices) and other information into the latent values for which these bids are optimal. Taking advantage of some recent identification results as detailed subsequently, we estimate these value distributions, using semi-nonparametric methods, and incorporating bidder asymmetry. This is in contrast to earlier analyses that have relied on parametric approaches to estimating value distributions (see Meenakshi and Banerji, 2005). We find that the more general semi-nonparametric characterization represents a statistically significant improvement over parametric estimations. Having estimated millers' values for paddy, we investigate how well the auction market serves farmers' interests, in particular, how the revenues from auctions compare with the MSP.

Various factors determine the extent to which the auction mechanism affects prices and revenues in a given market. These include the number of buyers present (the greater the competition, the higher the price), the existence of collusion[5] (which would depress prices) and the level of the reserve price. Among these, only the reserve price is directly under the control of the auctioneer; setting it well is a way of fetching good revenues from sales. For the Panipat paddy market, we compute optimal (revenue-maximizing) reserve prices and compare these with those actually set by the auctioneer. We then compute expected revenues to farmers when the reserve prices are set at the levels observed and compare these with the maximum expected revenues. We also assess the role of competition in fetching revenues from auctions that are comparable to the MSP; and also in mitigating the impact of sub-optimality in setting of reserve prices on expected revenues. This is set out in two simple propositions and also explored empirically.

The analysis and results in this paper contribute to the literature in several ways. First, they enhance our understanding of the functioning of wholesale grain markets in India. These grain wholesale markets, or *mandis*, were mandated to be set up by Indian states by the Agricultural Produce Market Committee (APMC) Act, proposed at the Centre, and legislated in the states, in the 1960s. The few studies of these markets have all by and large criticized their functioning; contending that they are inefficient (Ramaswami and Balakrishnan, 2002, Umali-Deininger and Deininger, 2001), that market integration is absent (Palaskas and Harriss-White, 1996), and that there is collusion among buyers (Banerji and Meenakshi, 2004).

However, many insights about efficient functioning of markets can be gained from analyzing it in the context of the *trading mechanism* that is used; in some of these government-regulated markets, ascending auctions are employed, and in others, grain is traded through mutual negotiations between individual buyers and *katcha arhtias* or agents selling grain on behalf of farmers. But apart from Banerji and Meenakshi (2004, 2008), and Meenakshi and Banerji (2005), we are not aware of any studies that directly incorporate the trading mechanism in the analysis. A careful reading of these three papers suggests that in fact, in the grain markets where auctions are used, the negative impact of collusion on sale prices is quite limited; in that sense, these auction markets

[5]The effect of buyer collusion on farmers' revenues from paddy auctions has been studied earlier for this market (see Meenakshi and Banerji, 2005).

perform reasonably well. Our analysis in this paper throws light on a complementary, and key, indicator of the performance of auction markets, viz., the setting of reserve prices. Our findings corroborate the good functioning of auction markets (see Section 5). The APMC Act has been modified in the past decade in various ways to change some of the regulations that imposed entry barriers on buyers and proscribed farmers from selling outside of these *mandis*; our study suggests that a key part of the functioning of these markets, viz. the choice of the trading mechanism and its impact on farmers' revenues has not got the attention that it deserves.

Second, our study contributes to the fast growing literature on the structural estimation of auction models[6]. Structural estimation of auctions[7] is crucial to asking policy questions of the above sort, as it enables us to simulate alternative states of the world. There is now a large and growing literature on such estimation, starting with Paarsch (1992), Laffont, Ossard and Vuong (1995), Athey and Levin (2001) among others. See Athey and Haile (2005) for a survey. One of the first papers to estimate optimal reserve prices at auctions is Paarsch (1997). Semi-nonparametric estimation is increasingly popular (see Chen, 2007); our implementation for auctions is similar to that by Brendstrup and Paarsch (2006). Research on agricultural markets that uses the structural auction framework is recent and relatively limited (see Tostao, Chung and Brorsen, 2006, apart from the research by Banerji and Meenakshi, 2004, 2008, Meenakshi and Banerji, 2005).

The rest of the paper is organized as follows. Section 2 contains a general discussion of trends in procurement through the levy and the CMR channels. We also argue that the cost of procuring rice through the CMR route is higher than that through the levy route. Section 3 introduces the auctions data and discusses summary statistics. Section 4 provides a framework for using data from auctions in estimating the values that millers attach to the grain. We start by justifying the use of the independent private values framework and outline equilibrium bidding behavior in this setting. We then present the identification results that enable estimation of distributions and the semi-nonparametric methodology employed for estimation and the distributions thus estimated. In Section 5, we provide estimates of farmers' expected revenues from paddy sales in the absence of MSP support, when the government is a large purchaser through the levy route. We show that at the observed levels of bidder competition, these revenues are close to the MSP despite sub-optimal reserve price setting. Since the levy route provides indirect

[6]Auction theory explains players' bids as an equilibrium outcome that depends on their value distributions for the auctioned commodity. The structural approach to auctions uses data on bids and auction- and bidder-specific covariates and assumptions of some game-theoretic equilibrium to identify and estimate players' unobserved value distributions.

[7]Structural estimation of auction models uses data on bids and auction- and bidder-specific covariates

price support that works well in the context of functional grain auction markets, this leads us to question the emphasis on the CMR route. In Section 6, we simulate changes in expected revenues from auctions as a result of variations in levy price. The simulations allow us to explore some of the actions that the government can take to revive the levy route. Section 7 concludes.

2 Rice Procurement

2.1 Trends in Procurement

Overall there has been a trend away from procurement through levy to CMR. As can be seen from Table 1, the aggregate amount of rice procured has grown over 2.5 times, from 126.53 lac tonnes in 1990-91 to 325.97 lac tonnes in 2010-11. The bulk of this increase comes from increased procurement through the CMR route, which has grown almost 5.5 times. The amount procured though the levy channel has been virtually stagnant, going up from 85.8 lac tonnes in 1990-91 to 104.4 lac tonnes in 2010-11, an increase of about 1.2 times.

We next analyze the state-level trends in procurement. The procurement figures for rice from the two channels for the top 5 rice producing and contributing (towards procurement) states, viz. Punjab, Andhra Pradesh, Madhya Pradesh (including Chhatisgarh), Haryana and Uttar Pradesh (including Uttaranchal) are given in Table 2. Of these, it is only in Andhra Pradesh and Uttar Pradesh that the levy channel makes any significant contribution to procurement. In Punjab, the CMR operations have virtually entirely crowded out procurement through levy. In the *kharif* marketing season (KMS) 2010-11, over 99% of the rice procured in Punjab was through the CMR channel (see Table 2). Madhya Pradesh (and Chhatisgarh) and Haryana have also seen a gradual shift of emphasis from levy to CMR. The contribution of CMR to total procurement in KMS 2010-11 was over 98% in Haryana. The picture was dramatically different till about 2 decades back. Andhra Pradesh which has always been a predominantly levy state came a close second to Punjab in terms of overall procurement. In Punjab itself, the procurement was roughly evenly sourced from the two channels till the mid-1990s, after which the balance started tilting towards the CMR channel. In Haryana, Madhya Pradesh and Uttar Pradesh too, which were next in importance of procurement, the reliance on the levy channel was predominant. In Uttar Pradesh, levy still continues to be as important as CMR, but the overall procurement from Uttar Pradesh has declined relative to other states.

Table 1 All-India CMR vs Levy Procurement (Lac Tonnes)

Year	Levy rice	Paddy	Total in terms of rice
1990-91	85.80	61.09	126.53
2000-01	112.55	142.99	207.88
2010-11	104.40	332.36	325.97

Table 2 Statewise Procurement (Lac Tonnes)

State	1990-91			2000-01			2010-11		
	Paddy	Levy rice	Total rice	Paddy	Levy rice	Total rice	Paddy	Levy rice	Total rice
Punjab	45.53	17.78	48.13	86.29	11.82	69.35	128.86	0.01	85.92
Andhra Pradesh	0.24	33.19	33.35	4.3	68.86	71.73	24.43	73.26	89.55
Madhya Pradesh†	0.69	5.85	6.31	6.43	6.02	10.31	55.44	3.45	40.41
Haryana	1.96	9.32	10.63	13.63	5.68	14.77	24.82	0.24	16.79
Uttar Pradesh‡	0.09	13.42	13.48	6.03	8.12	12.14	14.61	18.47	28.21

† including Chhatisgarh

‡ including Uttaranchal

Source:

1. 1990-91 and 2000-01 data from High Level Committee Report on Long Term Grain Policy, July 2002, Department of Food and Public Distribution, Ministry of Consumer Affairs, Food and Public Distribution, Government of India
2. 2010-11 data from indiastat.com last accessed on December 4, 2012

Note:

1. 'Paddy' denotes the paddy picked up at the MSP as part of the CMR channel; the rice milled from one quintal of paddy is approximately (2/3) quintal.
2. 'Total rice' constructed by adding 'Levy rice' and two-thirds of 'Paddy'.

Table 3 Procurement in Haryana (Lac Tonnes)

Year	Production	Arrival	Millers (Leviable)	Millers (Basmati)	Agencies	Rice delivered to central pool
1997-98	38.3	32.3	22.1	8.6	1.6	12.12
1998-99	36.5	26.1	16.2	8.9	1.1	8.83
1999-00	38.7	28.7	17.1	8.2	3.4	10.85
2000-01	40.4	33.0	12.7	6.9	13.6	15.42
2001-02	40.9	33.1	7.6	9.7	15.7	14.30
2002-03	37.0	30.8	6.0	9.4	15.4	13.27
2003-04	41.9	36.0	13.4	12.4	10.2	13.50
2004-05	43.5	36.7	13.0	8.5	15.2	16.61
2005-06	48.2	45.1	9.8	11.7	23.6	20.62
2006-07	49.4	40.7	8.4	16.5	17.9	17.82
2007-08	54.2	42.8	8.4	16.5	17.9	16.10
2008-09	49.5	43.0	4.0	20.9	18.2	14.13
2009-10	53.7	50.2	1.8	22.0	26.4	18.47
2010-11	56.1	46.1	1.6	19.7	24.8	17.33
2011-12	56.4	53.1	0.8	22.7	29.3	19.93

Source: 'Haryana Food and Supplies Department' website:
203.134.203.24/$profileprocurement.aspx$ last accessed on December 10, 2012

Note:

1. 'Production', 'Arrival', 'Millers (Leviable)', 'Millers (Basmati)' and 'Agencies' correspond to paddy; while 'Rice delivered to central pool' corresponds to rice.
2. 'Millers (Leviable)' refers to the purchases of the leviable varieties of paddy by the millers. They are required to deliver $\frac{3}{4}$ths of the rice milled from this to the FCI. Further, given a paddy-rice conversion ratio of $\frac{2}{3}$, for every quintal of paddy purchased by the millers, $\frac{1}{2}$ quintal $= (\frac{3}{4} * \frac{2}{3}$ quintal) gets delivered to the central pool.
3. 'Millers (Basmati)' is the private purchase (by millers) of Basmati varieties. These are not leviable; the millers can export or sell all of the rice milled from these in the open market.
4. 'Agencies' refers to the paddy picked up at MSP as part of the CMR channel; every quintal of paddy gives approximately $\frac{2}{3}$ quintal of rice.
5. 'Rice delivered to central pool' constructed by adding half of 'Millers (Leviable)' and two-thirds of 'Agencies'.

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Since in this paper we analyze the price formation in a paddy market which is located in Haryana, we probe the procurement trends in Haryana a little more. Table 3 gives the amount of rice procured from the CMR and levy channels for all years since the late-1990s to the present. Till 1999-00, the bulk of the leviable[8] paddy was picked up by private millers and only a small fraction by the state agencies. In 1999-00[9] paddy picked up on the private account was 17.1 lac tonnes contributing to over three-fourths of the total procurement that year. Since then, private participation in purchase of leviable paddy has steadily declined; in particular after 2007-08. In 2011-12, private purchase of paddy has fallen to 0.8 lac tonnes contributing to a miniscule 0.4 lac tonnes of rice towards procurement. The purchase of paddy by the state agencies on the other hand has become almost 9 times, going up from 3.4 lac tonnes in 1999-00 to 29.3 lac tonnes in 2011-12, contributing to 19.5 lac tonnes of rice or about 98% of the total procurement. One reason for the drop in private millers' operating through the levy route and increasingly participating in custom milling could be the persistent gap between the CMR and levy prices. We demonstrate this point in greater detail below. The still sharper decline in private purchase post 2007-08 could be an outcome of the export ban on non-basmati varieties that was imposed in 2008 following a spike in global rice prices and the consequent export of such heavy volumes of rice that the government found it very hard to meet the procurement targets, despite several revisions in procurement prices within that season. Chand (2005) points out several additional reasons for the decline in private sector purchases of paddy, such as, retail prices growing at a slower rate than the procurement and wholesale prices signaling to the private traders that buying at the official procurement prices was not supported by demand-side factors. Also the excessive procurement and the consequent built-up of stocks implied the government would off-load massive grain in the open market at some point, which could cause the domestic prices to take a dip and result in potential losses for traders with pre-existing stocks. Chand also makes the point that private traders took full advantage of the government policy of offering grain for open market sale and for export at a heavy discount in the lean months, this being a cheaper source than buying from the market, where they would also have to pay statutory and other charges.

[8]Those varieties of rice on which the levy obligations apply and for which the MSP is binding.
[9]Which is also the year in which our data set was constructed.

2.2 Cost of Levy versus CMR

We argue in this section that procuring rice through the levy route is cheaper than through the CMR route. Direct evidence of this is available from secondary data on cost of procuring rice per quintal through the two routes, as recorded in Government of India, Department of Food and Civil Supplies Notes (various years) written for the procurement arms of state governments. This is summarized in Table 4. Data available for 11 of the past 12 years show that the cost of procuring rice per quintal through the CMR route was always higher, the difference averaged Rs 49, or about 3.8%.

Table 4 Year-wise CMR vs Levy Prices for Haryana

Year	MSP		Levy price		CMR price	
	Common	Grade A	Common	Grade A	Common	Grade A
1999-00	490	520	848.2	913.3	884.1	934.9
2000-01	510	540	904.2	954.3	899.2	950.1
2001-02	530	560	939.1	989.1	962.3	1013.2
2002-03	530	560	944.4	994.4	956.4	1007.3
2003-04	550	580	1003.0	1053.0	1024.5	1075.4
2004-05	560	590	1003.0	1053.0	1043.0	1093.7
2005-06	570	600	1013.4	1063.0	1072.6	1123.4
2006-07	620	650	1092.1	1141.6	1116.6	1165.5
2007-08	745	775	1245.4	1293.1	1313.6	1362.7
2008-09	900	930	1498.9	1546.6	1579.6	1628.7
2009-10	1000	1030	1676.0	1723.7	1763.8	1812.9
2010-11	1000	1030	1687.1	1734.8	1789.6	1838.5

Source: Notes prepared by Department of Food and Civil Supplies, Ministry of Food and Consumer Affairs, Government of India for the procurement arms of the Government of Haryana, various years.

As an example of this cost difference, in the year 2010-11, the cost of 1 quintal of rice (Grade A) through the levy route was Rs 1735, while that through the CMR route was about Rs 1839. Rs 1735 is the levy price that the government paid to millers per quintal of rice. Similarly, in the CMR route, the government delegates to millers the job of picking up paddy at the MSP, having it milled and transported to government storage. In return, in the year 2010-11, the government paid millers Rs 1839 per quintal, for this route. This gap has been even higher in the recent years, the three-year averages of levy and CMR prices over 2008-09, 2009-10 and 2010-11 are Rs 1668.37 and Rs 1760.03 respectively, a difference of about 5.5%.

Even though the government pays these amounts to millers for rice through both routes as a lumpsum per quintal, it works out detailed cost breakups of these amounts. For 2010-11, a typical year, we reproduce these breakups in Table 5. The breakups assume that grain is purchased at the MSP under both routes (though this is not necessarily the case for the levy route). There are various charges, including market fees, labor charges, storage costs etc.; there is a modest milling charge, and a conversion factor of 67% is assumed from paddy to rice. There is an allowance for the cost of bags to store the rice in, and for their depreciation. In 2010-11, for lots purchased through the CMR route, the government paid farmers Rs 1030 per quintal (the MSP); thus for 1 quintal of rice, Rs 1545 was assessed as paid out to farmers for 1.5 quintals of paddy; and Rs 294 was paid to millers as processing cost plus levies and fees, adding up to Rs 1839.

Table 5 CMR vs Levy Cost Breakup (Rupees), 2010-11

Head	Levy	CMR
MSP	1030	1030
Market fee @ 2% of MSP	20.6	20.6
Arhtia commission/dami @ 2.5% of MSP	25.75	25.75
R.D. cess @ 2% of MSP	20.6	20.6
Mandi labor	6.98	12.69
Driage @ 1% of MSP		10.3
CAP @ Rs 2.08 per Q per month for 2 months		4.16
Interest charges for 2 months @ 10.3% pa (contd in notes)		19.33
Milling charges	15	15
Cost of 1 Q of paddy	1118.93	1158.43
Out turn ratio	67%	67%
Cost of 1 Q of rice	1670.04	1729
Cost of 2 new 50kg gunny bags	64.74	78.24
Gunny depreciation		31.3
Grand total levy price	1734.78	1838.54

Source: Notes prepared by Department of Food and Civil Supplies, Ministry of Food and Consumer Affairs, Government of India for the procurement arms of the Government of Haryana, various years.

Note:

1. CAP denotes custody and maintenance charges.
2. Interest charges for 2 months @ 10.3% pa on MSP, statutory charges including notional VAT and mandi labor charges. Interest is allowed provisionally taking notional VAT @ 4% of MSP, dami.

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There are several notable features in relation to the fact that CMR costs exceed levy costs to the government. First, that this difference understates the true cost difference, as it does not take into account the fact that in order to procure paddy through the CMR route, the government has to maintain officials and infrastructure to inspect the quality of paddy in all wholesale grain markets such as the one we study[10]; such markets are dispersed across the rice growing areas of the state. The government must write, and monitor, contracts every season with millers in each such market to operate in the CMR route. These costs are not included in the government data of Table 5. While we do not have an estimate of these costs, they are likely to be substantial due to the nature of 'deep-handling' grain that the CMR route entails.

Second, small differences in the assessed notional cost breakups across levy and CMR routes result in a significant aggregate cost difference between the two routes (which equaled Rs 104 in 2010-11). Thus a higher allowance for labor cost is made under the CMR channel relative to the levy channel; moreover, under the CMR route, but not the levy route, allowances are made for driage (loss of grain weight due to drying of excess moisture), for interest costs to millers for holding and storing the grain until it is transferred to government granaries, and depreciation of rice bags. On driage, 1% of MSP is assessed as a cost to the miller of the paddy losing moisture and therefore about 1% of weight; this 'driage allowance' is not however given to millers for levy rice.

That some allowances are made for procurement via the CMR channel but not for that under the levy channel may appear intriguing at first. But these are possibly best seen as a device to simply have the CMR channel be more remunerative for millers: that is, to act as an *incentive* for millers to operate as paddy processors in the CMR route and to reduce their market participation through the levy route.

3 Parmal Paddy Auctions in Panipat

We use data from auctions of parmal paddy at the Panipat market, in the state of Haryana (North India). The data are taken from a primary survey conducted in October 1999 by Meenakshi and Banerji (2005) during peak market arrivals. The survey was supplemented using market committee records and interviews with millers and farmers. Paddy is raw harvested grain which on milling is converted into rice (grain separated from chaff and

[10] Of course, such infrastructure is spread across both paddy and wheat.

most often polished subsequently). Parmal varieties are high-yielding and the rice milled from Parmal paddy is shorter in length and thicker in width than traditional varieties. As a consequence, it is not as preferred in much of India as longer-grained rice. This and its high-yields result in the parmal rice selling at about one-fifths the price of the premium Basmati varieties, making it the cheapest rice in the market. It is therefore the natural choice for government procurement and public distribution. The Parmal arrivals begin in October and the marketing season lasts for about a month. About 60,000 quintals of paddy arrives in the surveyed market over the entire season, of which more than 60% is concentrated in the first 3 weeks of October. The arrivals peak around the end of the first week, with about 3000 quintals arriving per day.

Panipat *mandi* is a regulated wholesale grain market set up by the Government under the APMC Act and run by a Market Regulation Committee[11]. The mode of selling the grain is through auctions. The interacting players on the ground in this market include commission agents (*katcha arhtias*) who sell the grain on behalf of the farmers, and millers who purchase the grain. The government also purchases paddy at these auctions, through a commission agent (the participation of the government in this and many other markets in Haryana was very limited in the given year, 1999, though). When it participates in the auction of a paddy lot, the government bids the MSP that it announced for paddy during sowing season. Commission agents are registered with the market committee and their license is renewed annually.

The buyers' side of the market is rather concentrated. Though 25 distinct buyers were recorded over the entire marketing season, the combined market share of the two largest buyers (with large mills located within 5 km from the *mandi*) was about 45% of the total arrivals. The remaining buyers had smaller mills and picked up smaller shares of the market arrivals. It was observed that the two large buyers avoided competing with each other by alternating the days on which they made large purchases. Such collusion is expected, *ceteris paribus*, to depress the win price. Meenakshi and Banerji (2005) undertake parametric maximum likelihood estimation (MLE) of both the noncooperative and the collusive models (for this market) and compare them using Vuong's test. Their results support the hypothesis of collusion, in the form of simple bid rotation by the 2 largest buyers. In the present study, therefore, we work with the maintained assumption of bid rotation among the two large buyers.

The sellers side of the market by contrast is far from concentrated. A *katcha arhtia* typically serves between 100 and 500 farmers; and earns a commission of 2% of the total

[11] Referred to as the 'market committee' elsewhere in the paper.

value of sales from the farmer. There were 49 *katcha arhtias* in this market with small individual shares (none exceeding 5%).

The parmal paddy lots are sold through oral ascending auctions. Based on a visual inspection of a lot for quality, the auctioneer announces a reserve price for the lot, following which the bidders whose valuation for the lot is less than this reserve price leave. The remaining bidders are the active bidders for the lot. The auctioneer then raises the price in small increments, as long as there are at least two interested bidders (active bidders keep exiting as the price goes past their valuation). The auction ends when only a single bidder is still interested. This bidder wins the object and pays an amount equal to the price at which the second-last bidder dropped out. The auctioneer receives 0.8% of the win price.

Table 6 Summary Statistics of the Sample

	Mean	Standard Deviation	Minimum	Maximum
Reserve price (Rs/quintal)	483.86	30.01	350	580
Win price (Rs/quintal)	505.36	23.64	400	611
No. of potential bidders per lot	8.58	0.66	7	9
No. of active bidders per lot	3.34	0.70	2	5
Moisture content	2.35	0.57	1	3
Uniformity in grain size	2.43	0.57	1	3
Presence of chaff	2.07	0.56	1	3
Presence of brokens	1.46	0.50	1	2
Grain lustre	1.59	0.49	1	2
Green and immature grain	1.17	0.38	1	2
Others	1.37	0.48	1	2

Note:

1. Sample size = 275.
2. Quality attributes are categorical variables taking **integer values** as follows.
   (a) Quality in terms of moisture content, uniformity in grain size and presence of chaff improving on a scale from 1 to 3.
   (b) Quality in terms of presence of brokens, grain lustre, green and immature grain and others improving on a scale from 1 to 2.

Parmal paddy is heterogeneous in several quality characteristics, variations in which affect the valuation a bidder may have for a lot. Based on information from agricultural scientists, market committee officials and bidders at auctions, Meenakshi and Banerji (2005) focus on the following seven quality characteristics: moisture content, uniformity of grain size, grain lustre, absence of chaff, green and immature grains, broken grains and a category for other variables (encapsulating evidence of disease or pest infestation). The auctions proceed at a fast pace, so laboratory testing of a sample for quality at the auction site was not possible. The bidders perform visual and other simple on-the-spot tests (such as breaking the grain and looking at the cross-section for evidence of brittleness). To construct quality variables, for each lot, the quality characteristic was evaluated on a scale of either 1 to 3 (worst to best) or 1 to 2 (poor and good); the determination of quality was done using the same visual and other tests, by a trained enumerator. The number of distinct winners on any given day was used as a proxy for

Table 7 Regressing Log Win Price on Quality Characteristics, Week Dummies and Number of Bidders

	Parameter Estimate	t-statistic
Constant	6.0640	571.7332***
Moisture content	0.0222	8.4927***
Uniformity of grain	0.0158	5.8711***
Presence of chaff	0.0095	3.4803***
Presence of brokens	0.0090	2.7540***
Lustre of grain	0.0137	4.1303***
Others	0.0020	0.6745
Green and immature grain	0.0085	2.2149**
Week 2 dummy	-0.0298	−7.7864***
Week 3 dummy	-0.0044	-1.2213
Number of active bidders	0.0038	1.8303*

Note:

1. Sample size by week- week 1 : 95, week 2 : 70, week 3 : 110.
2. *, **, *** indicate significance at 10%, 5%, 1% levels respectively.
3. t-statistics are calculated using robust standard errors.

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the number of potential bidders for all auctions on that day[12]. The bidders who continued to participate in the auction once the reserve price was announced, constituted the set of active bidders for that auction.

Thus the information recorded for each auction included the seven covariate quality vector, reserve price, win price, identity of the winner, number of potential and active bidders and the date of the auction. Data for the sample (275 auctions[13]) are summarized in Table 6. Notable is the large number of potential bidders, indicative of a good level of competition in the market. Also noticeable is the sharp drop between the number of potential bidders and active bidders: this indicates that the reserve price was set high enough to be greater than the values of about half the bidders on a lot, and yet, not so high as to exclude all bidders in this fashion. Note also that the grain quality appears to vary significantly; the fairly large variation in sale prices is actually reflective of this variation in quality.

To further describe the data, we regress the log of the win price on quality characteristics, number of potential bidders, and week dummies. This regression is reported in Table 7. The regression brings out the dependence of the win price on quality: moisture, uniformity, absence of chaff or broken grain, and lustre, all have a positive effect on win price, and are highly significant. The win prices are also positively and significantly affected by the number of bidders (or the level of competition) in the auctions of the different lots[14]. The week dummies are used to capture other influences on the market prices: these could range from price fluctuations in other markets, to the effect on millers' valuation for grain in successive weeks of higher levels of grain inventory.

[12] Bidders generally stay through the bidding all day, and it is unlikely that there are bidders who don't win even a single lot.

[13] In all, data for 298 auctions was collected, but in 23 of these, the paddy lot was sold to the government agent at the MSP. We do not include these in our analysis since these not only constituted a very small proportion of the sample (7.7%) but also because the MSP support was quite ad-hoc. Many lots meeting the minimum quality standards (specified by the CACP) were ignored by the government's agent and got sold at prices lower than the MSP; while some very poor quality lots were bought by the government at the MSP. The price formation at these auctions was thus unnatural, making these unfit for inclusion in the estimation of the auction market.

[14] Amongst other explanatory variables considered and found to be not significant was the size of the lot.

4 Levy Policy and Millers' Values

4.1 Bidding in IPV Ascending Auctions

We study this market with oral ascending auctions as the selling mechanism under the independent private values (IPV) assumption. The framework used here is standard (see Krishna, 2002). Each bidder i is assumed to have a valuation, or value v_i for a given lot of paddy (the valuation is specific to the given lot, as discussed later). That is, the bidder's payoff from winning this lot at a price of P equals $v_i - P$. A key assumption in auction theory is that these values of bidders are not known to the auctioneer. This makes the auction a good mechanism for making a sale; if values were known, the auctioneer could simply select the bidder with the highest valuation, and negotiate a high price with him.

In addition, the private values auction model assumes that each bidder i's value v_i for a given lot of grain is privately known (to him) and that bidders do not know other bidders' values. Thus auction theory is cast in the framework of games of incomplete information, or Bayesian games with the above uncertainty being modeled by assuming that the values are random variables with a joint distribution that is common knowledge, and further, in the *independent* private values (IPV) case, that these are independent random variables. We will denote i's marginal distribution by $F_{V_i}(.)$.

In our paddy auction setting, the bidders are millers. A bidder's valuation for a paddy lot depends upon the difference between the price he expects to receive from selling rice (paddy is processed into rice in mills) and the cost of processing paddy. Millers operating in this market are required to sell 75% of their rice to the government at Rs 913 per quintal[15]. The quantity and quality of rice (better quality rice fetches a higher price) that a lot of paddy produces depends on its observable quality characteristics. But the processing cost of paddy is mill-specific[16] and privately known. Thus, an IPV specification for valuations, conditional on observed quality of paddy, is a reasonable assumption for this market.

In an ascending auction, a bidder's bid is the price at which he decides to drop out of the bidding, and with IPV, it is optimal to bid the value. As a result, the win price or sale price in an ascending auction is essentially the second-highest bid, which coincides with the second-highest valuation in an IPV setting. This lies at the heart of uncovering

[15]These were the levy percentage and levy price figures for Grade A rice for *kharif* 1999-2000 in the state of Haryana.

[16]With the large millers' costs typically being lower than the smaller millers' costs.

the latent value distributions of the players in econometric analysis: if the price at which the last player dropped out in an auction is observed, when there are p potential bidders, then under the assumption of equilibrium bidding, the realization of the second highest order statistic of the random variables $V_1, \ldots, V_p$ (the upper case is used here to denote random variables, with the lower case $v_1, \ldots, v_p$ denoting realized values of the bidders) is observed as the win price.

4.2 Nonparametric Identification and Semi-nonparametric Estimation of Value Distributions

For the asymmetric (where bidders draw values from different distributions) independent private values framework, nonparametric identification results follow from Athey and Haile (2002). These build on earlier results by Arnold, Balakrishnan and Nagaraja (1992) and Meilijson (1981).

In the asymmetric IPV model, assuming that each $F_{V_i}(.)$ is continuous and that the support of the distributions $supp[F_{V_i}(.)]$ is the same for all i, each $F_{V_i}(.)$ is identified if the win price *and the identity* of the winner are observed (Athey and Haile, 2002, Theorem 2). In this paper, we use the asymmetric model, owing to the asymmetry in bidder values that we can infer from the market shares of the millers: recall that the 2 large millers won about 45% of the lots, while the others won uniformly small shares. Our data set contains information on the win price and the identity of the winner; thus the model is nonparametrically identified.

We use a semi-nonparametric[17] technique to estimate the value distributions using a recently proposed strategy by Brendstrup and Paarsch (2006); see Chen (2007) for a general survey[18]. We assume that at the t^{th} auction for a lot with covariate vector z_t, the valuation of player i of type j is given by

$$ln\ v_{it}^j = z_t\beta \ +\ \mu\ +\ u_{it}^j \tag{1}$$

[17]Estimation of value distribution through kernel density methods is not feasible since they require a substantial number of data points *for each* unique covariate vector of quality attributes and number of bidders. Our data set has only a few observations per such unique covariate vector.

[18]Following Chen (2007) and others, we define a semi-nonparametric model as one that has both finite and infinite dimensional parameters of interest ((β, μ) and u_{it}^j). In contrast, the term semi-parametric model is used if the parameter of interest is finite dimensional and the nuisance parameter is infinite dimensional. In our application, the vector (β, μ) in Eq.(1) that follows is a finite-dimensional parameter and the *density* of u_{it}^j is infinite-dimensional.

The 10-tuple covariate vector z_t is composed as follows: the first term is to allow for a baseline week 1 valuation and carries a value of 'one'. The terms two through eight record the quality of the lot with respect to the following seven characteristics: (i) moisture content, (ii) uniformity of grain, (iii) presence of chaff, (iv) presence of brokens, (v) lustre of grain, (vi) others and (vii) green and immature grain. The ninth and the tenth terms of z_t are dummies to record whether the lot was sold in the second or third week respectively of the sample. The parameter vector β that captures the marginal effect of each lot-specific characteristic, is unknown and needs to be estimated. By type or class of bidder we refer to two bidder classes: '1' refers to the two large bidders; '2' refers to the rest of the (small) bidders. Owing to bid rotation, only one large bidder is present at each auction, the rest being the small bidders. So, μ is the parameter that captures the asymmetry between the two bidder classes

$$\mu \begin{cases} \neq 0 & \text{for the large bidders}(j = 1) \\ = 0 & \text{for small bidders}(j = 2) \end{cases}$$

u_{it}^j which is the idiosyncratic component of bidder i's (of type j) valuation at auction t is assumed to

1. be independently and identically distributed (i.i.d.) for all bidders with distribution function $F_U(.)$,
2. have $E[u_{it}^j|z_t] = 0$,
3. be independent of z_t.

Thus we will call u_{it}^j simply as u_t.

We denote the large bidders' valuation density and distribution functions by $f_{V_1}(.)$ and $F_{V_1}(.)$ and small bidders' valuation density and distribution functions by $f_{V_2}(.)$ and $F_{V_2}(.)$ respectively.

Note that the auction data is a three-week long series; for simplicity, we assume the u term to be i.i.d., while admitting temporal variation in values through dummies for the weeks. In part, this modeling springs from the possibility that over time, accumulation of inventory can affect millers' values for the grain.

We approximate the density function $f_U(.)$ of u by a Hermite series expansion (see Appendix 8.1). Gallant and Nychka (1987) show that a density with mean zero, support $(-\infty, +\infty)$ can be estimated using a Hermite series. The Hermite series is in the form of a (orthogonal) polynomial squared times a normal density function (with mean zero) with the coefficients of the polynomial restricted so that the series integrates to one[19]. The rule for determining series length is data-dependent: the greater the sample size, the longer the length of the series (Chen, 2007). Given the size of our sample (275 data points), a Hermite series of order two is reasonable; this gives ordinary polynomials of up to the fourth degree.

The density function $f_U(.)$ of u_t is approximated as

$$\hat{f}_U(s) = [\sum_{k=0}^{2} \gamma_k \ h_k^*(s)]^2 \ exp[\frac{-s^2}{2(0.4)^2}] \tag{2}$$

where $h_k^*(.)$ is the k^{th} order normalized (and modified) Hermite polynomial. γ_k are the coefficient parameters to be estimated[20]. Note that we employ as weighting function, a normal density with mean zero and standard deviation[21] 0.4.

Let $G(.|F_{V_1,V_2})$ be the joint distribution of the win price (second-highest order statistic) and the winner identity (the last remaining bidder). We need to estimate $F_{V_1}(.)$, $F_{V_2}(.)$ using $G(.|F_{V_1,V_2})$. This is implemented using the method of maximum likelihood.

Maximum likelihood estimation requires determination of $\hat{f}_{V_1}(.)$, $\hat{f}_{V_2}(.)$ such that

$$(\hat{f}_{V_1}, \hat{f}_{V_2}) \quad = \quad argmax_{f_{V_1},f_{V_2}} \ \frac{1}{T} \sum_{t=1}^{T} \ ln \ g(y_t|F_{V_1,V_2}) \tag{3}$$

where $g(y_t|F_{V_1,V_2})$ is the joint probability density function of the win price and the winner identity for lot t; we give details of this density shortly. From Eq.(1), we see that the estimated densities $\hat{f}_{V_1}$ and $\hat{f}_{V_2}$ are related to $\hat{f}_U$, the estimate of the idiosyncratic component of value, as follows.

$$\hat{f}_{V_1}(v) \ = \ \frac{1}{v} \ \hat{f}_U(ln \ v \ - \ z_t\hat{\beta} - \hat{\mu}) \tag{4}$$

$$\hat{f}_{V_2}(v) \ = \ \frac{1}{v} \ \hat{f}_U(ln \ v \ - \ z_t\hat{\beta}) \tag{5}$$

[19]This ensures that we have a density function.

[20]Subject to the restriction $\sum_{k=0}^{2} \gamma_k^2 = 1$, in order that $\hat{f}_U(.)$ is actually a density function (i.e., such that it integrates to one). See the next section.

[21]To circumvent some computational problems, we performed the optimization routine for MLE over a grid of standard deviations for the weighting function, and found that the likelihood is maximized with a standard deviation of 0.4.

To ensure that $\hat{f}_{V_1}, \hat{f}_{V_2}$ are in fact densities, the following constraints must be imposed

$$\int_0^{+\infty} \hat{f}_{V_1}(y)\, dy \quad = \quad 1 \tag{6}$$

$$\int_0^{+\infty} \hat{f}_{V_2}(y)\, dy \quad = \quad 1. \tag{7}$$

This can be implemented through the following restriction on the parameter space

$$\int_{-\infty}^{+\infty} \hat{f}_U(u)\, du \quad = \quad 1. \tag{8}$$

From the definition of the Hermite series, this implies the following restriction on the Hermite coefficients:

$$\gamma_0^2 \; + \; \gamma_1^2 \; + \; \gamma_2^2 \quad = \quad 1. \tag{9}$$

Thus to obtain $\hat{f}_{V_1}, \hat{f}_{V_2}$, we maximize $\sum_1^T \; ln \; \hat{g}(.)$ with respect to β, μ, γ_k $(k = 0, 1, 2)$ subject to the restriction that the norm of the Hermite coefficients equals one.

The number of potential bidders p at an auction is assumed to be the same as the number of distinct winners on the day of that auction. But assuming there is collusion among the two large bidders, the effective number of potential bidders at an auction reduces to $p - 1$.

The joint probability density of the win price and a specific small bidder winning is given by (see Appendix 8.2) (Banerji and Meenakshi, 2004):

$$\begin{pmatrix} p-3 \\ n-1 \end{pmatrix} F_{V_1}(r)(F_{V_2}(r))^{p-n-2}(1 - F_{V_2}(w))(n-1)(F_{V_2}(w) - F_{V_2}(r))^{n-2} f_{V_2}(w)$$

$$+ \quad \begin{pmatrix} p-3 \\ n-2 \end{pmatrix} (F_{V_2}(r))^{p-n-1}(1 - F_{V_2}(w))[(n-2)(F_{V_2}(w) - F_{V_2}(r))^{n-3} f_{V_2}(w)$$
$$(F_{V_1}(w) - F_{V_1}(r)) + (F_{V_2}(w) - F_{V_2}(r))^{n-2} f_{V_1}(w)]$$

The joint probability density of the win price and a specific large bidder winning is given by

$$\begin{pmatrix} p-2 \\ n-1 \end{pmatrix} F_{V_2}(r)^{p-n-1}(1 - F_{V_1}(w))(n-1)(F_{V_2}(w) - F_{V_2}(r))^{n-2} f_{V_2}(w)$$

4.3 Estimated Value Distributions

We now present the results from our constrained maximum likelihood estimation using semi-nonparametric approximation to the true density functions. The estimation was performed by writing code in GAUSS. Constrained optimization routines in GAUSS based on quasi-Newton methods were used to estimate the parameters and Hermite coefficients that characterize the value distributions.

We have estimated the $10-tuple$ covariate coefficient vector β, the parameter capturing the difference in means μ and the coefficients in the Hermite series expansion γ_0, γ_1, γ_2. The estimates for β and μ are listed in Table 8. The Hermite coefficients as estimated in our exercise are $\hat{\gamma}_0 = 0$, $\hat{\gamma}_1 = 0$, $\hat{\gamma}_2 = 1$. Figure 1 provides a plot of the density of residuals (additive stochastic term u in the specification of bidder value in Eq.(1)) based on the Hermite polynomial estimates.

Thus the estimated densities are

$\hat{f}_{V_1}(v) \ = \ \frac{1}{v} \ \hat{f}_U(ln\ v \ - \ z_t\hat{\beta} - \hat{\mu})$

$\hat{f}_{V_2}(v) \ = \ \frac{1}{v} \ \hat{f}_U(ln\ v \ - \ z_t\hat{\beta})$

where,

$\hat{\beta} = (5.9481, 0.0336, 0.0185, 0.0203, 0.0205, 0.0263, -0.0003, 0.0049, -0.0559, 0.0039)$

$\hat{\mu} = -0.1468$

$\hat{f}_U(s) = \frac{(s^2-1)^2}{0.76} exp[\frac{-s^2}{2(0.4)^2}]$.

Since all the seven paddy characteristics are measured on a scale that is increasing in quality (either 1 to 2 or 1 to 3), they are expected to have positive signs. Our results are consistent with this expectation. Moisture content has the largest coefficient (also highly significant) suggesting that a substantial quality premium is associated with this characteristic. Three of the characteristics, viz., brokens, green and immature grain and other are found to be not significant in the sample. A negative coefficient for week 2 dummy implies that a lot of a specific quality has a lower valuation in week 2 than in week 1. One reason for this could be that prices in this market get influenced by those prevailing in the other bigger markets. A negative sign on the parameter estimate (highly significant) for difference in means implies that the large bidders draw their valuations from a higher distribution than the small bidders, i.e., given a lot with a particular quality vector, the large bidders have a greater valuation for it than the small bidders.

Figure 1: Residual Density Plot

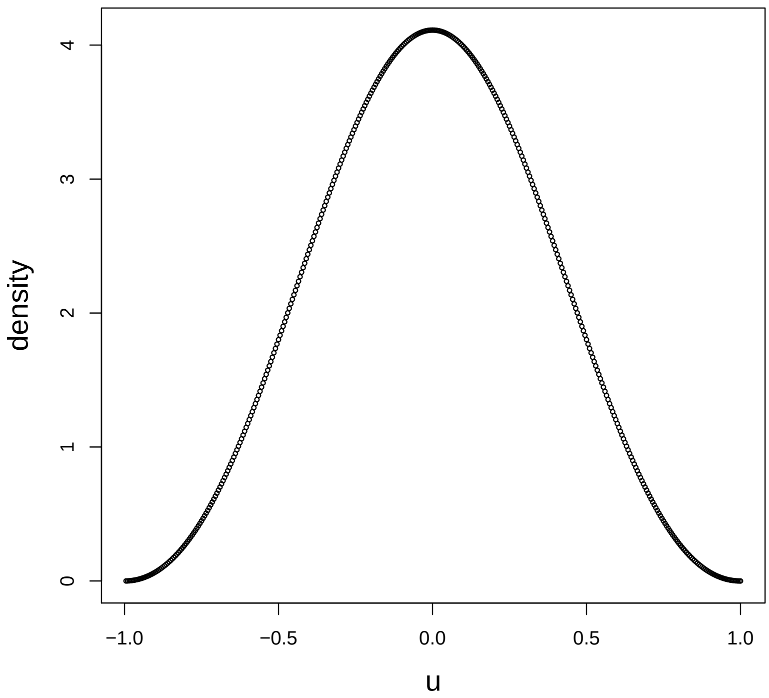


Table 8 Semi-nonparametric Maximum Likelihood Estimates for the Asymmetric Bidders Specification

	Parameter estimate	t-statistic
Constant	5.9481	105.6501***
Moisture content	0.0336	2.2400**
Uniformity of grain	0.0185	1.1935
Presence of chaff	0.0203	1.3097
Presence of brokens	0.0205	1.0847
Lustre of grain	0.0263	1.3698
Others	-0.0003	-0.0181
Green and immature grain	0.0049	0.2149
Week 2 dummy	-0.0559	2.5294**
Week 3 dummy	0.0039	0.1902
Difference in means	-0.1468	−5.6680***
Mean log-likelihood	-3.32904	

Note: *, **, *** indicate significance at 10%, 5%, 1% levels respectively.

The valuation distributions of bidders in this market have previously been estimated parametrically, using a lognormal distribution, see Meenakshi and Banerji (2005). Lognormal functional forms are quite popular with researchers seeking to approximate positive (or right) skewed distributions because they allow flexibility on two accounts - location and variance. We therefore test whether for the asymmetric bidders specification, the semi-nonparametrically estimated model is indeed an improvement over the lognormal approximation. Following our estimation of the two models, the value of the Vuong's statistic for testing the lognormal versus the semi-nonparametric model is computed to be -10.21046, which strongly suggests that the semi-nonparametric model is closer to the actual data-generating process.

5 Well-functioning Markets and Price Support

In 1999, millers in Haryana who milled rice in the CMR channel were paid a gross amount about Rs 21 higher than the levy price that was paid to millers who operated in the free market for rice. Nevertheless, this levy price, along with the opportunity to sell a quarter of one's rice output on the private market (including export markets) provided enough incentive for millers to operate in the levy channel as well. It thus seems natural to ask: in a market where paddy is auctioned, is the influence of the levy policy alone large enough for expected revenues from paddy sales to be somewhere in the MSP ballpark? Data from the year 1999, and more generally from the 1990s and early 2000s provide a good opportunity to answer this question, because the CMR route was used for only a small part of procurement needs; in 1999, for only 21% of procurement from Haryana. As a result, most of the procurement was in effect in the absence of direct MSP support.

We use the millers' semi-nonparametrically estimated value distributions (conditional on observed quality) to estimate the expected revenue from the sale of each lot in our sample. With collusion between the two large bidders taking the form of bid-rotation (both never participate in any one auction together), the analysis and derivation of optimal reserve price follows the assumption of non-cooperative behavior among the bidders with the number of large bidders at an auction being equal to 1.

Suppose there are N_i bidders of type $i, i = 1, 2$ (large and small bidders respectively). If a specific bidder of the i^{th} type wins the auction, the distribution of the highest of the values of all other bidders is given by $G_i(.)$ below:

$$G_1(x) = F_2(x)^{N_2} F_1(x)^{N_1-1}$$

$$G_2(x) = F_1(x)^{N_1} F_2(x)^{N_2-1}$$

The expected payment of a bidder of type i with value $x \geq r$ is

$$m_i(x,r) = rG_i(r) + \int_r^x y g_i(y) dy. \tag{10}$$

Note that in this section, we use the symbol x to represent a bidder's value for a lot. The first term captures the expected payment of a bidder if none of the other bidders' values is greater than r, the probability of which happening is $G_i(r)$. If on the other hand, there is (are) other bidder(s) with values exceeding r, but less than x, the object is sold to our bidder at the highest of other values; so as the auctioneer raises the price from r, the probability of our bidder winning at a price y, is $g_i(y)$; thus, the second component of the expected payment integrates from r through x, the product of each value with the probability of our bidder winning at that value.

Let w denote the win price. Then the *ex-ante*[22] expected payment of a bidder of type i is

$$E[m_i(X,r)] = \int_r^w m_i(x,r) f_i(x) dx$$

$$= r(1 - F_i(r))G_i(r) + \int_r^w y(1 - F_i(y)) g_i(y) dy \tag{11}$$

The overall expected revenue of the seller from setting a reserve price $r \geq x_0$ is

$$\Pi \;=\; N_1 \; E[m_1(X,r)] \;+\; N_2 \; E[m_2(X,r)] \;+\; F_1(r)^{N_1} \; F_2(r)^{N_2} \; x_0 \tag{12}$$

where x_0 denotes the seller's reservation utility. In this context it refers to the price that the farmer can expect to get elsewhere for a lot that goes unsold in the present auction.

We evaluate the expected revenue Π for each lot. The distributions and densities are conditioned on the observed quality of the lot, and the reserve price used is that set by the auctioneer for the lot (observed reserve price). The farmer's reservation utility x_0 is unknown to us, but based upon our knowledge of the functioning of the market (gained by interviewing the farmers) we can impute a value on x_0. We describe in Appendix 8.3

[22]Before the value is drawn.

our procedure for doing this; we note though that our results are quite robust to varying this reservation utility in a band around the value that we actually ascribe to x_0. Part of the reason is that with a large number of bidders, the probability of a lot going unsold is low, so the third term in Eq. (12) is small; indeed lots in this auction market go unsold quite infrequently - possibly less than 2% of the time.

The estimated expected revenue (with a baseline penalty[23] of Rs 100[24]) averaged across all lots is Rs 517.6, with a standard error of 1.36 (Table 9). So the levy route was fetching farmers an expected revenue quite close to the MSP of Rs 520[25].

Table 9 Optimal versus Observed Reserve Prices

	Mean	Std Error	Minimum	Maximum	Expected Revenue Mean	Expected Revenue Std Error
Observed start price	483.86	1.81	350	580	517.61	1.36
Optimal reserve price	517.08	1.46	449.33	556.64	520.01	1.37

Table 10 Reserve Prices and Expected Revenues - Various Penalties

Penalty	Observed Reserve Price (r_S)	Optimal Reserve Price (r^*)	Expected Revenue with r_S	Expected Revenue with r^*
100	483.86	517.08	517.61	520.01
110	483.86	508.84	516.39	518.02
120	483.86	500.69	515.16	516.29

Technically however, the government is obliged to pick up only those lots at the MSP, which meet certain minimum quality standards [26]. A more tenable comparison of the

[23]Penalty refers to the discount at which a farmer would have to sell the lot (elsewhere, in another market, representing the 'outside option' (see Appendix 8.3)) if it remains unsold at the auction as well as in mutual negotiations with a miller in this *mandi*.

[24]All the simulations that follow assume (unless otherwise specified) a penalty amount of Rs 100.

[25]We also computed the expected revenues allowing for even lower outside option payoffs for farmers, corresponding to penalties of Rs 110 and Rs 120 below expected second highest value (at an auction in this market), in the event of the lot going unsold at the auction and the farmer exploiting this outside option. The averages of the expected revenues (with these specifications of the outside option) for all the lots in the sample are Rs 516.39 and Rs 515.16 respectively, which are still within Rs 5 of the MSP (Table 10). So the result that expected revenues for farmers in the absence of MSP was nevertheless comparable to the MSP is quite robust to variations in what outside options fetch for the farmers, even when the reserve prices are sub-optimally set. The extent of bidder competition in this market ensures that the probability of all bidders' values falling short of a reasonable reserve price is low; thus causing the expected revenues to be mostly unaffected by what the outside options are.

[26]Though in practice, as noted in Section 3, this obligation was very poorly met, at least in the year the data was collected.

MSP with the expected revenues without MSP support would therefore exclude lots that are of such poor quality that their purchase by the government at the MSP is ruled out. Fourteen lots in the data have the poorest quality for moisture content, and are certain to not meet the minimal quality requirements. When we drop these lots, the expected revenue works out to be Rs 519.2, which was practically the MSP.

This is a striking result. However, it needs to be analyzed further, to understand under what conditions and parameter bounds, the closeness of expected revenue to the MSP holds for this and other auction markets. The two most important parameters in this regard are the level of competition (the number of potential bidders) and the choice of reserve price by the auctioneer. In what follows, we simulate the effect of varying these on expected revenue.

5.1 Reserve Prices and Expected Revenues

We start by investigating how well the reserve prices were in practice being set in terms of fetching maximum possible revenues for the farmers. The revenue-maximizing reserve price is termed as the *optimal* reserve price. It can be derived from the first order condition for revenue maximization of the seller given a lot of a specific quality (Eq.(12)), stated in Eq.(13) below (see Appendix 8.4 for the derivation). Putting $N_1 = 1$, we get the expression (in implicit form) for the optimal reserve price (r^*) under simple bid rotation by the 2 large bidders in our data. Given our parameter estimates and the lot-specific covariates, Eq.(13) is solved for r^* for every lot in the data. Confidence intervals around these are constructed using the Delta method (see Appendix 8.5).

$$\begin{aligned} & N_1 \; [1 - (r^* - x_0)\lambda_1(r^*)][1 - F_1(r^*)]F_2(r^*) \\ & + \; N_2 \; [1 - (r^* - x_0)\lambda_2(r^*)][1 - F_2(r^*)]F_1(r^*) \quad = \quad 0 \end{aligned} \tag{13}$$

The mean of the estimated optimal reserve prices is Rs 517.08, which is about Rs 33 higher than the mean of the observed reserve prices of Rs 483.86 (Table 9). The observed reserve prices are also seen to lie below the 45 degree line when plotted against the optimal reserve prices (Figure 2). The mean absolute difference between the two series is Rs 35.21. The t-statistic for difference in means of the two series is -14.28 and the confidence intervals around the optimal reserve prices are within Rs 2, so there is a significant difference between these and the observed reserve prices.

Figure 2 : Observed Reserve Prices against Optimal Reserve Prices

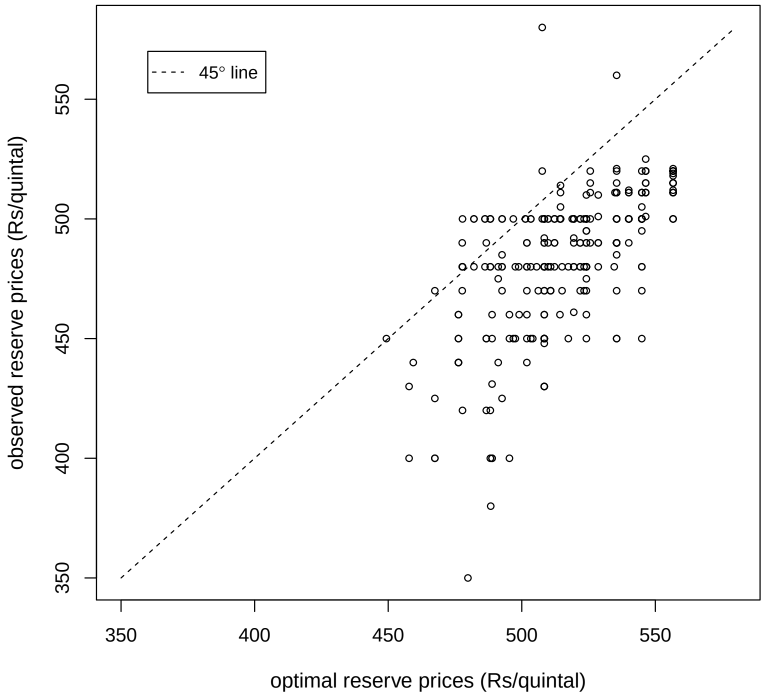
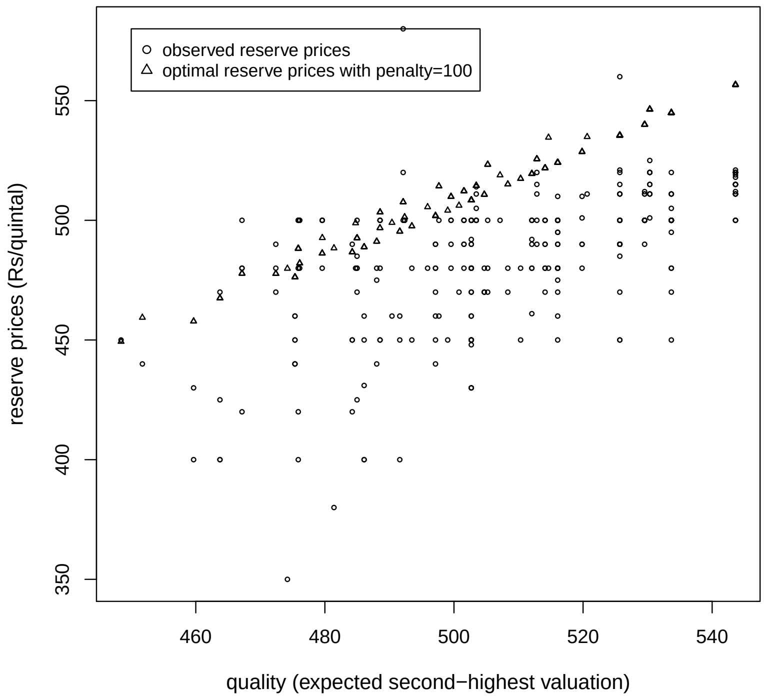


Figure 3 : Observed and Optimal Reserve Prices against Quality



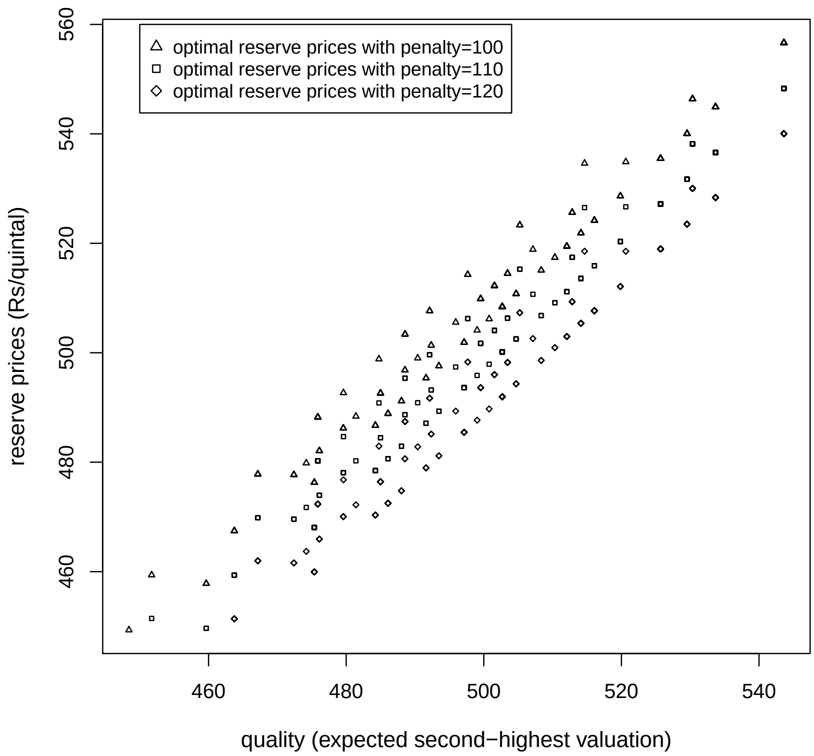
The optimal reserve prices also closely reflect the quality of the paddy lots, unlike the observed reserve prices. To see this, we present a plot of the optimal and the observed reserve prices of lots arranged in increasing order of quality (Figure 3); we use the expected second-highest valuation as a proxy for quality. There is a monotonically increasing relationship between quality and optimal reserve prices. This is to be expected given the theoretical relationship between the expected second-highest value and the optimal reserve price, as both vary positively with the quality of a lot[27]. The plot of the observed reserve prices by contrast, has a lot of noise, though the overall relationship with quality is positive (Figure 3). Moreover, there appears to be clumping around certain reserve prices such as 480, 500, 520. These are probably salient reserve prices in the auctioneer's mind, corresponding to 'quality grades'. Finally, we note that varying the level x_0 of the reservation utilities of the seller leads to variation in the *levels* of the optimal reserve prices, but not the *degree of monotonicity* of the optimal reserve prices with respect to the quality and the tight relationship between the two (Figure 4). Irrespective of the level, the discrepancy between this close relationship between optimal reserve prices and the absence of it in the case of the observed reserve prices becomes obvious.

Having established that the reserve prices set by the auctioneer are on average significantly lower than the optimal reserve prices, it is natural, and of greater importance, to ask: by how much would farmers' expected revenues increase if the reserve prices are set optimally? To evaluate this, we compute the expected revenue for each lot under the alternative scenarios that the reserve price equals (i) the observed reserve price and (ii) the optimal reserve price. The mean difference between the two series of expected revenues at Rs 2.40 is very small in magnitude and not significant at a level of 5%. Thus the non-optimality of the reserve prices does not make a significant difference to farmers' revenues[28]. A closer analysis (see below) shows that bidder competition in the market is critical to this result. Some of the factors that possibly prevent the reserve prices from being set at still lower levels are as follows. First, the auctioneer has several years

[27]The optimal reserve price in the asymmetric bidders specification is a weighted average of the inverse hazard rates of the distributions of the two types of bidders; as the quality improves, inverse hazard rates increase, and so does the the optimal reserve price.

[28]We also compute optimal reserve prices under alternative penalty amounts of Rs 110 and Rs 120; the results are presented in Table 10. The means of the corresponding optimal reserve prices are estimated to be Rs 508.84 and Rs 500.69, both significantly different from the mean of the observed reserve prices (t-statistics (Welch two-sample t-test) for differences in means being -10.75 and -7.26 for the optimal reserve prices with penalty amounts 110 and 120 respectively compared to the reserve prices set by the auctioneer). The expected revenues under these alternative (relatively lower) optimal reserve prices are even closer to those under observed reserve prices (Table 10). We thus find that variations in x_0 do not affect expected revenue significantly because the probability of all of the bidders' values falling short of a reasonable reserve price is very low, given the extent of market competition.

Figure 4 : Optimal Reserve Prices (various penalties) against Quality



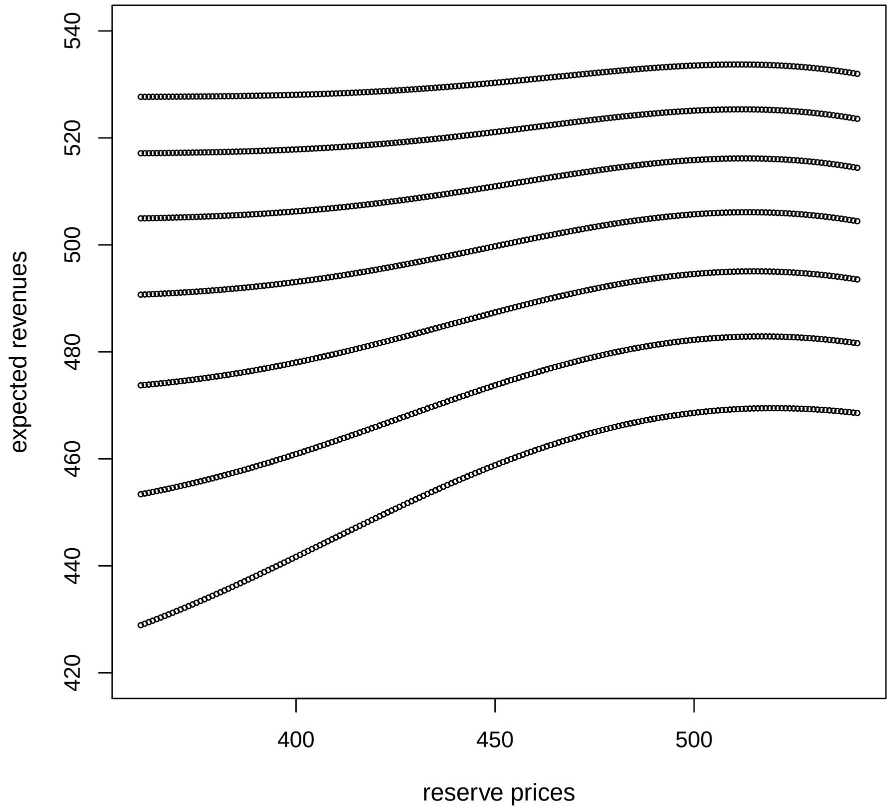
of market experience and this could translate into a reasonable idea about the value distributions of bidders, as well as the relationship between reserve prices and expected revenues. Second, the auctioneer is paid a (small) percentage of the sale price; so his incentives are aligned with maximizing revenue from each sale. Finally, the presence of the sellers (farmers) in the marketplace possibly disciplines market transactions.

5.2 Impact of Competition

We see next that the level of competition is an important factor that affects not just the level of expected revenue given a reserve price but also how it varies with the reserve price. We find that under conditions satisfied by the data, a higher number of bidders results in a flatter expected revenue curve; and consequently, a smaller revenue loss from a sub-optimal reserve price. We demonstrate this first using simulations and then collect the conditions in a proposition.

We start by simulating the impact of competition on maximal expected revenues (i.e., assuming the reserve prices are set optimally). This is done by evaluating Eq. (12)

Figure 5: Impact of Competition on Expected Revenues



Note: Simulations correspond to a paddy lot with quality that is an average over all the week 1 lots in the sample. The number of large bidders is fixed at 1 (given evidence of bid rotation on part of the two large millers in this market). The number of small bidders varies from 1 to 7, as we go from the lowest to the highest curve.

Table 11 Impact of Competition on Expected Revenue

Number of small bidders	2	3	4	5	6	7	8
Exp Rev (r^*)	469.48	482.89	495.06	506.11	516.17	525.34	533.73
Exp Rev (r^*-40)	465.96	479.42	491.81	503.24	513.65	523.15	531.85
Exp Rev (r^*-80)	455.75	470.47	484.39	497.31	509.02	519.60	529.16
Exp Rev (r^*-120)	441.69	460.19	477.29	492.54	505.90	517.60	527.91

Note: *Exp Rev (r^*)* gives expected revenue at the optimal reserve price. *Exp Rev ($r^* - 40$)* corresponds to the expected revenue when the reserve price is set Rs 40 below the optimal reserve price; similarly for *Exp Rev ($r^* - 80$)* and *Exp Rev ($r^* - 120$)*.

(expected revenue) at r^* for a typical lot (whose quality equals the average for all lots in week 1). We assume the presence of one large bidder (given evidence of bid rotation on part of the two large millers) and vary the number of small bidders from 2 through 8. The results are presented in Table 11. It can be noticed that with a level of competition that actually existed in the market (number of small bidders mostly between 6 and 7), the maximal expected revenues are very close to the MSP. The maximal expected revenue with 6 small bidders is Rs 516.17 while with 7 small bidders, it is Rs 525.34; averaging to Rs 520.76 (average number of small bidders over the entire sample is 6.58), which is practically the MSP. It is also evident that the revenue is moderately sensitive to the number of competing bidders. The expected revenue with a slightly lower level of competition where there are 5 small bidders is Rs 506.11, almost Rs 14 lower than the MSP. Very low bidder participation like when there are two small bidders can imply a revenue as less as Rs 469.48, about Rs 50 lower than the MSP. On the other hand, slightly stiffer competition such as with 8 small bidders can be expected to fetch revenues as high as Rs 534.

Next, we examine the impact on revenues of sub-optimal reserve price setting for different levels of competition (see Table 11 and Figure 5). At the observed levels of competition, moderate departures from the optimal reserve prices have little impact on the revenues. The expected revenue with 6 small bidders when the reserve price is Rs 40 below the optimal level is Rs 513.65, about Rs 3.48 lower than the maximal expected revenue. With 7 small bidders, it is Rs 523.15 which is Rs 2.19 lower than the maximal level of Rs 525.34. Averaging across these two levels of competition with reserve price Rs 40 lower than the optimal, implies an expected revenue of Rs 518.4, which is very close to the MSP. The expected revenue averaged over 6 and 7 small bidders, with greater sub-optimality in reserve price setting such as when it is Rs 80 lower than optimal, is Rs 514.31 which is still within 2% of the MSP. Further, we observe that even with slightly less competition such as when there are 5 small bidders and reasonably set out reserve prices (within Rs 40 of the optimal), the expected revenue is still within 3% of the MSP. Lower levels of competition though imply greater drops in the revenues from the maximal levels when the reserve prices are sub-optimal (this was also seen to be the case by way of the two propositions above). For instance, a reserve price that is Rs 80 below the optimal implies an expected revenue of Rs 455.75 when there are 2 small bidders, Rs 13.73 lower than the maximal level of Rs 469.48, and Rs 84.25 lower than the MSP. This is in sharp contrast to the impact on the expected revenue (for this amount of sub-optimality in reserve prices) when the competition is at the level observed for this market; as noted above, the expected revenue from Rs 80 lower reserve price is Rs 514.31, a drop of Rs

6.45 from the maximal level of Rs 520.76 (which is also almost the MSP) when the small bidders are between 6 and 7. Greater levels of competition such as with 8 small bidders would make the departures of reserve price from the optimal matter even less. A Rs 80 lower reserve price for example, causes the expected revenue to drop to Rs 529.16, less than Rs 5 lower than the maximal of Rs 533.73, but still reasonably higher than the MSP.

The simulations therefore show that with one large bidder and six to eight small bidders, as in our data, the expected revenue curve is rather flat: so that, moderately well-targeted reserve prices achieve close to maximal expected revenues. We state in the proposition that follows, sufficient conditions for expected revenue to respond weakly to changes in reserve price as the number of potential bidders increases. The proposition is stated and proved for an asymmetric market similar to the one under study, but it also nests the symmetric specification.

Proposition 1 *Consider an ascending auction with asymmetric bidders such that one bidder's value is drawn from F_1 while the remaining N bidders' values are drawn from F_2, and values are independently distributed. The concavity of the expected revenue as a function of the reserve price decreases as N increases provided (i) F_1 dominates F_2 in the reverse hazard rate (ii) $f_i'(r^*) \geq \frac{-2f_i(r^*)}{r^*-x_0}, i = 1,2$ (iii) $1 + NlogF_2(r^*) < 0$ where r^* is the optimal reserve price.*

Proof. See Appendix 8.6. Reverse hazard rate dominance of F_1 over F_2 is perhaps a reasonable condition since F_1 is the distribution of the 'large' bidders. The other two conditions are also reasonable and easily met given our estimates for this market[29]. We close this discussion with the qualification that the above conditions though sufficient for a flat expected revenue, are not essential for well-functioning markets. If the expected revenue were more sensitive to the reserve prices for instance, the auctioneer would probably learn this at some point and thereafter set reserve prices that are even closer to the optimal and fetch revenues close to the maximum possible.

[29] The density of the values is positive everywhere, r^* is greater than x_0 and the optimal reserve price is estimated as being not too high relative to the value distribution implying that $f_i'(r^*) \geq \frac{-2f_i(r^*)}{r^*-x_0}, i = 1,2$ holds. The condition $(1 + NlogF(r^*)) < 0$ is also met quite easily given our estimates. For the average week 1 quality vector, $F(r^*)$=0.80828. Also, as the number of bidders goes up, $(1 + NlogF(r^*))$ becomes lower, so if the condition can be met for the lowest level of competition in the market, it is not binding for higher levels of competition. Recall that while the average number of potential bidders in this market is 8.51; the minimum number is 5, this corresponds to 1 large bidder and 4 small bidders. With 5 symmetric small bidders, the condition implied is $F(r^*) < 0.818731$ (note that 5 symmetric small bidders is a weaker specification than 1 large bidder and 4 small bidders, with the latter specification, the inequality would be met even more strongly) which is clearly satisfied.

We thus conclude that an active system of levy and an active private trade by millers in auction markets similar to the present one[30] can fetch revenues close to the MSP, if auctioneers do just reasonably well in setting reserve prices.

6 Using the Levy Price as a Policy Instrument

We now explore ways to revive procurement through the levy channel and also discuss how it can be used for targeting farmers' revenues. We find that increasing the levy price to close the gap between the CMR and levy price, at least partially, (along with other policies such as permitting them to export a part of their output) will attract millers back to this route. Increasing the levy price will also increase the expected revenues of farmers; we are interested to know by how much. When the levy route is a significant channel of procurement, changes in the open market price of rice also affect farmers' expected revenues. Again, our estimates can help us to quantify this effect. For downward unanticipated shocks to open market prices, we are also interested in quantifying the change in levy price required to nullify the downward impact on farmers' expected revenues.

We discuss first how, given the number of bidders, a given increase in the levy price translates into higher values for paddy and further into higher revenues for farmers. A higher level of the levy price, however, is also likely to impact the size of the bidder set, especially if the increase is part of a credible policy shift toward encouraging the levy channel. We therefore argue subsequently that a systemic shift towards higher levy prices not only raises farmers' revenues, but in addition, by inducing greater private purchase of paddy and entry of more millers into the auctions, improves the performance of auctions and helps in reviving the levy channel in procurement operations.

Changes in levy price and open market price affect the value distributions of millers; expected revenues change as a consequence of this shift in distributions (F_1 and F_2 in Eq.(12)). It is reasonable to assume that these price changes act as mean shifters for these distributions. We unify the analysis by first computing a mapping from the means of these value distributions to expected revenue. We then show that levy and open market price changes will shift the means of these value distributions in a simple way; and we can use the mapping to study the impact of these mean shifts in value on expected revenue.

We undertake this analysis for a paddy lot of average quality in week 1 of the data set. We vary the mean μ of the distribution F_1 on a fine grid that includes the estimated

[30]Within bounds in terms of parameters such as reservation utilities of farmers.

mean of F_1 for a lot of this quality; the mean of F_2 is tied to that of F_1 by an estimated mean shifter (see Section 4), and therefore also varies alongside. So, each point in the grid corresponds to a pair (F_1, F_2) of distributions; the pair (F_1, F_2) for some point ξ and the pair $(F_1^{'}, F_2^{'})$ corresponding to another point $\xi^{'}$ on the grid differ only in their means. For each point on the grid, and corresponding value distributions, we compute the optimal reserve price r^*, and then the expected revenue according to Eq.(14) below.

$$\pi \;=\; N_1\; E[m_1(X, r^*)] \;+\; N_2\; E[m_2(X, r^*)] \;+\; F_1^{N_1}(r^*)\; F_2^{N_2}(r^*)\; x_0 \qquad (14)$$

We then interpolate using a cubic spline to obtain expected revenue as a function of the mean: $\pi = h(\mu)$. Change in expected revenue as a result of a change in this mean is simply $\Delta\pi = h(\mu + \Delta\mu) - h(\mu)$.

Next, we model the effect of changes in rice prices on mean shifts in value distributions as follows. Millers had to sell three-quarters of their rice output to the government at the levy price L and one-quarter in the open market at a market price of say P. Their revenue from 1 quintal of rice was thus $(3/4)L + (1/4)P$. If the processing cost for a quintal of rice of a given quality is C, and the conversion ratio of paddy to rice is 2/3, then their value for 1 quintal of *paddy* of this quality is $(2/3)\,((3/4)L + (1/4)P - C)$. A change in the levy price by ΔL, leaves processing costs unchanged; so it shifts value, and therefore the mean of the value distribution by $(2/3)(3/4)\Delta L = (1/2)\Delta L$. Similarly, a change in the open market price by ΔP shifts the mean of the value distribution by $(1/6)\Delta P$. A change in levy price has three times the impact of a change in the open market price because the quantity of rice going towards the levy is three times that sold on the open market.

We now see how the levy price can be used to target farmer revenues.

Effect of a change in levy price on expected revenue

What would be the expected revenue to farmers if the levy price had been set equal to the cost of procuring rice through the CMR route?

The reason for studying this question, as stated above, is to find out what would happen to expected revenue of farmers if the levy price was set at a level that *did not* discriminate against the levy channel. The CMR cost of rice for 1999 was Rs 934, or Rs 21 higher than the levy price; so the discrimination against the levy was mild compared to the trend in the subsequent decade. Raising the levy price by this amount would imply that on three-quarters of their rice (the levy percentage), millers would be paid

Rs 21 more per quintal. The mean of a miller's value distribution for paddy would shift up by (1/2)21, or Rs 10.5. Now using the mapping h, we evaluate the equation $\Delta\pi = h(\mu + \Delta\mu) - h(\mu)$ for change in expected revenue. μ is the estimated mean of F_1 for a lot of average quality in week 1 of the data, and $\Delta\mu = 10.5$. For this increase in levy price and bidder competition that roughly corresponds to the average in week 1, we find that expected revenue increases from Rs 516.2 to Rs 525.8 (see Table 12).

Table 12 Impact of Change in Levy Price on Expected Revenue

Number of small bidders	Original Expected Revenue	New Expected Revenue
1	454.70	459.91
2	469.48	476.00
3	482.90	490.47
4	495.07	503.49
5	506.12	515.22
6	516.19	525.81
7	525.36	535.39

Note:

1. The number of large bidders is fixed at 1 (given evidence of bid rotation on part of the two large millers) while the number of small bidders varies as given in the table.
2. *Original Expected Revenue* corresponds to a levy price of Rs 913.3 which was prevalent in 1999-00; while *New Expected Revenue* figures are based on a levy price of Rs 934.9, which was the level of the CMR price that year.

. Next, we quantify the change in levy price required to offset the impact of fluctuations in open market prices on farmer revenues.

Using the levy price to counter market fluctuations

Small changes in open market prices have a negligible impact on expected revenue. For instance, if the open market price drops by Rs 10 from the level prevailing in 1999, the expected revenue decreases by Rs 1.5. This is partly because value distributions[31] shift left by only one-sixth of Rs 10; further, due to the nature of the function h[32] in the relevant range, a Rupee 1 drop in the means of the value distributions results in slightly less than a Rupee 1 drop in expected revenue.

[31] Corresponding to average week 1 quality.
[32] Given average week 1 level of bidder competition.

A large drop of say Rs 100 in the open market price (which in 1999, would have amounted to about a 10% decrease), would reduce expected revenue by Rs 15 (or about 2.9%). Thus the high proportion of rice sold as levy, softens the impact of any change in open market prices on the expected revenue earned by farmers. Our analysis also indicates the change in levy price needed to nullify the reduction in expected revenue caused by a drop in the open market price. Given the levy proportion of three-fourths of output, the requisite increase in levy price is (1/3)100 or about Rs 33.

For any given level of bidder competition, a higher levy price increases the millers' surplus: the gross surplus going to a miller for every quintal of rice sold to the government via the levy route is essentially the levy price minus the price of 1.5 quintals of paddy and processing costs. This higher surplus will attract more millers into the levy channel (and draw millers away from operating through the CMR channel). But with the greater competition that ensues, the qualitative nature of the market would have undergone a change. First, a higher amount of paddy purchased on private account would crowd out some (or possibly all) government purchases at MSP. Second, farmers' revenues would be higher than those that would obtain with the increased levy price but the original level of competition (see Table 12). Consider for instance, an increase of Rs 21 in the levy price from the level prevalent in the year of the study. With one large bidder and 6 small bidders, expected revenue increases by Rs 9; but if there is *more entry* of millers, this is not a sufficient answer. If one more bidder enters, expected revenue increases not by Rs 9, but by Rs 20 (Table 12). Third, greater competition makes the auctions function even better. As noted in Section 5, with more private millers participating in the auctions, departures of reserve prices from the optimal levels make lesser difference to the win prices, in other words, it becomes easier to fetch the maximal expected revenues for the farmers.

The implications of the above analysis for markets similar to the one studied are as follows. In recent years, paddy purchases have come to be predominated by the CMR channel, private purchases are close to negligible. We discussed at length in Section 2, the persistent gap between the CMR and levy prices and noted that it was about Rs 104 in KMS 2011-12. An upwardly revised levy price is likely to imply revenues for millers (from sale of rice)[33] which are not lower than those in the CMR route (which pays the CMR price) while the paddy costs would be lower (as noted above, private trade has dried up, and so auctions at such low levels of competition would imply low sale prices of paddy).

[33]Three-fourths of rice milled from such paddy would fetch them a price equal to that in the CMR route, while one-fourths could be sold in the open market where prices typically rule higher than the government's procurement prices (CMR prices).

In CMR, the millers would have paid the farmers the MSP, whereas, in an auction, with 1 large and 3 small bidders for example, the expected paddy price for a typical lot is Rs 476 (Table 12). Higher rice revenues and lower paddy costs clearly imply greater surplus with the millers - such an opportunity for profit-making is unlikely to remain unnoticed for long. As more millers enter the market, the prices and therefore farmers' expected revenues would be driven up to levels comparable or even greater than the MSP. One caveat however - a crucial link in the above outlined scenario is the signalling to millers of low paddy prices in the market. This however can happen only if the government (temporarily at least) abstains from buying paddy directly from the farmers at the MSP. This may be politically tricky, but if followed, can be expected to eventually clinch the twin goals of switching over from CMR to levy while still providing price support to farmers.

7 Conclusions

Our focus in this paper is on reviewing the rice procurement policy of the government. To do this, we compare and contrast the two modes of procurement, viz., CMR and levy for their cost to the exchequer as well as their effectiveness in providing price support to farmers growing paddy. We start by noting the trends in state-wise and national procurement using data from secondary sources. It is found that over the last decade, there has been a gradual shift in emphasis from procurement through the levy channel towards the CMR route.

We further argue that procuring rice through the levy route is cheaper than through the CMR route; providing direct evidence from secondary data on procurement *price*[34] per quintal of rice through the two routes. In Haryana, for each of the last ten years, the CMR price was higher than the levy price with the difference averaging Rs 52.9 or about 4.2%. A closer look at the break-up of the prices reveals two kinds of allowances in the CMR price (and absent in the levy price) - first, on account of poor quality of paddy (implying lower out-turn ratio) being picked up by government agents and second, interest costs, depreciation of rice bags and higher allowances for labor costs. This second set of allowances has been increasing in value steadily over time and appears intriguing. It can be best perceived as a furtive incentive for millers to operate as paddy processors in the CMR route and curtail their direct participation in the trade central to the levy route.

[34] Which is in fact an underestimate of the procurement *cost* per quintal of rice.

The preference for procurement through the CMR channel is often justified on the grounds that it provides definitive price support to farmers whereas the price support implied through the levy channel is indirect, through the market and therefore iffy. We analyze price data from auctions of paddy from a market (Panipat in Haryana) and a year (1999) when direct price support at the MSP was near-absent. Millers' values for paddy are estimated using a structural estimation approach in order to compute what are the implied levels of expected revenues from auctions. It is found that the expected revenue is on average (across all lots in the sample) Rs 517.6, which is close to the MSP of Rs 520; if we exclude lots that are of such poor quality that their purchase by the government at the MSP is ruled out, the average expected revenue turns out to be Rs 519.2 which is practically the MSP. It is interesting to note that this proximity of revenues to MSP holds despite the reserve prices being set sub-optimally. The reserve prices were on average Rs 28 below the optimal level, but the expected revenues were still just about Rs 2 below the maximum. We argue that bidder competition in the market is critical to this result. Higher levels of competition not only imply greater revenues but also lesser responsiveness of revenues (especially around the peak) to reserve prices. Some of the other factors that possibly have a role in preventing reserve prices from being set at even lower levels are the auctioneer's experience, his incentives being aligned with maximizing revenue from each sale and the presence of sellers (farmers) in the marketplace. We thus conclude that in markets such as the one under study where auctions function well and private trade abounds, an active system of levy results in paddy prices within a narrow range of the MSP.

Finally, we analyze the effect of changing the levy price on expected revenue. This helps in determining, first, how the levy price can be used to counter the impact of shocks in the open market price on expected revenue. Second, in demonstrating that a non-discriminatory policy, where the levy price is not lower than the CMR price can potentially help in reviving the levy channel. A higher levy price can incentivize millers into purchasing on their private account and at the same time, sales through auctions can ensure that competition among millers drives up the prices close to the MSP.

The paper therefore shows that if the government is a large purchaser of levy rice, then that itself can, in the presence of functioning grain auction markets, provide price support to farmers at levels that it desires. Thus we make a case for reviving the levy route. However, we should note here that some of the arguments made in favor of the levy route can also support a move to government purchases of rice on the open market and through rice tendering; a discussion of this lies outside the scope of this paper.

8 Appendix

8.1 Hermite Polynomials

Hermite polynomials are a class of orthogonal polynomials that have support over the entire real line and the Gaussian function $exp(-x^2/2)$ as the weighting function. The advantage of polynomial approximations using orthogonal (rather than ordinary) polynomials has to do with efficiency[35]. The n^{th} order Hermite polynomial is defined by (Paarsch and Hong, 2006):

$$H_n(x) = (-1)^n \; exp(\frac{x^2}{2}) \; \frac{d^n}{dx^n}(exp(\frac{-x^2}{2}))$$

where $\frac{d^n}{dx^n}$ refers to the nth derivative. The n^{th} order normalized Hermite polynomial is defined by $h_n(x) = \frac{H_n(x)}{\sqrt{n!\sqrt{2\pi}}}$. As explained in Section 4, given the size of our sample, a Hermite series of order 2 is reasonable.

The first three Hermite polynomials are $H_0(x) = 1$, $H_1(x) = x$, $H_2(x) = x^2 - 1$. The first three normalized Hermite polynomials are $h_0(x) = \frac{H_0(x)}{\sqrt{\sqrt{2\pi}}}$, $h_1(x) = \frac{H_1(x)}{\sqrt{\sqrt{2\pi}}}$, $h_2(x) = \frac{H_2(x)}{\sqrt{2\sqrt{2\pi}}}$.

Since we employ as weighting function, a normal density with mean zero and standard deviation 0.4, the Hermite polynomials must also be suitably modified so that they are orthonormal with respect to the weighting function $exp(\frac{-x^2}{2(0.4)^2})$. The first three modified normalized Hermite polynomials are

$h^*_0(x) = \frac{H_0(x)}{\sqrt{1.0026}}$, $h^*_1(x) = \frac{H_1(x)}{\sqrt{0.5013}}$, $h^*_2(x) = \frac{H_2(x)}{\sqrt{0.752}}$.

8.2 Specifying the Joint Density of the Win Price and Winner's Identity

The joint probability density of the win price and a specific small bidder winning is given by (Banerji and Meenakshi, 2004):

[35] See Paarsch and Hong (2006). We are projecting a function onto a lower dimensional space. So they draw an analogy with OLS, where we project the dependent vector onto the range space of the data matrix X. The efficiency analogy between orthogonal polynomials is with the case of OLS estimates when X is an orthogonal matrix.

$$\begin{pmatrix} p-3 \\ n-1 \end{pmatrix} F_{V_1}(r)(F_{V_2}(r))^{p-n-2}(1-F_{V_2}(w))(n-1)(F_{V_2}(w)-F_{V_2}(r))^{n-2}f_{V_2}(w)$$

$$+ \quad \begin{pmatrix} p-3 \\ n-2 \end{pmatrix} (F_{V_2}(r))^{p-n-1}(1-F_{V_2}(w))[(n-2)(F_{V_2}(w)-F_{V_2}(r))^{n-3}f_{V_2}(w)$$

$$(F_{V_1}(w)-F_{V_1}(r))+(F_{V_2}(w)-F_{V_2}(r))^{n-2}f_{V_1}(w)]$$

The first term in this equation corresponds to the case where the large bidder's valuation is less than the start price r. The probability that the large bidder's valuation is less than r is $F_{V_1}(r)$; the probability that a specific small bidder's valuation is more than w is $(1-F_{V_2}(w))$. The realized set of remaining $(n-1)$ bidders (all small) could be any one of $\begin{pmatrix} p-3 \\ n-1 \end{pmatrix}$ different possibilities. The probability that one of these has valuation equal to w while the rest have valuations between r and w is $(n-1)f_{V_2}(w)(F_{V_2}(w)-F_{V_2}(r))^{n-2}$. Finally, the probability that the valuations of all the (remaining) $(p-n-2)$ potential bidders are less than the reserve price is $(F_{V_2}(r))^{p-n-2}$.

The second term consists of two possibilities, the large bidder's valuation being between r and w, and it being exactly w. In either case, the probability that a specific small bidder's valuation is greater than w is $(1-F_{V_2}(w))$, the realized set of non-winning active small bidders can be one of $\begin{pmatrix} p-3 \\ n-2 \end{pmatrix}$ different combinations, and the probability that the $(p-n-1)$ remaining small bidders are inactive is $(F_{V_2}(r))^{p-n-1}$. Given this, the probability that the large bidder's valuation is exactly w and that the $(n-2)$ small bidders valuations are between r and w is $f_{V_1}(w)(F_{V_2}(w)-F_{V_2}(r))^{n-2}$; while the probability that the win price valuation belongs to one of $(n-2)$ small bidders and that the large bidder's and $(n-3)$ small bidders' valuations lie between r and w is $(n-2)f_{V_2}(w)(F_{V_1}(w)-F_{V_1}(r))(F_{V_2}(w)-F_{V_2}(r))^{n-3}$.

The joint probability density of the win price and a specific large bidder winning is given by

$$\begin{pmatrix} p-2 \\ n-1 \end{pmatrix} F_{V_2}(r)^{p-n-1}(1-F_{V_1}(w))(n-1)(F_{V_2}(w)-F_{V_2}(r))^{n-2}f_{V_2}(w)$$

The probability that a specific large bidder's valuation is greater than the win price is $(1-F_{V_1}(w))$. The realized set of the other $(n-1)$ active bidders who are all small is akin to a random draw from the set of $(p-2)$ small potential bidders and could be one of $\begin{pmatrix} p-2 \\ n-1 \end{pmatrix}$ different combinations. The probability that one of these $(n-1)$ small bidders has valuation equal to the win price while the rest $(n-2)$ small non-winning active bidders' valuations are between the reserve price and the win price is $(n-1)f_{V_2}(w)(F_{V_2}(w) - F_{V_2}(r))^{n-2}$. Finally, the probability that $(p-n-1)$ small bidders' valuations are less than r is $(F_{V_2}(r))^{p-n-1}$.

8.3 Estimating Farmer's Reservation Utility for a Lot of Paddy

In the event of a lot going unsold at the formal auction, it goes back to the shop of the *katcha arhtia* through whom the farmer sells his grain. Typically, it gets sold to some private miller later through mutual negotiations. The private miller is free to opt out of this possibility of a purchase and not get anything; the farmer is free to opt out of the sale and take his grain to some other market to sell. Thus it is useful to think of these negotiations in terms of bilateral bargaining with outside options.

We use a stylized model here, namely the complete information bargaining model of Rubinstein (1982), augmented with outside options (see for example Muthoo, 1997 for a textbook exposition). Let the miller's (buyer's) valuation for the lot be v. We denote by s, the seller's (farmer's) use value for the lot, which is the worth that the farmer attaches to a lot that does not get sold anywhere and is eventually privately used. In the absence of outside options, the subgame perfect equilibrium shares of the players in Rubinstein's model are $\frac{r_S}{r_B+r_S}$ $(v-s)$ (buyer), and $\frac{r_B}{r_B+r_S}$ $(v-s)$ (seller), where r_B and r_S are the buyer's and seller's respective discount rates. In the presence of outside options, the unique subgame perfect equilibrium division of the surplus $(v-s)$ can be either the Rubinstein division, or a division in which one of the players gets a payoff equal to his outside option and the other gets the residual surplus. The idea is that if an outside option payoff is larger than what a player gets as his Rubinstein payoff, then the other player is forced to concede this payoff in the bargaining.

We assume the buyers (millers) to have a discount rate equal to 15% per annum (which corresponds to the rate at which they could have borrowed from banks at that time), while the sellers (farmers) were able to borrow from the co-operative societies or the *katcha arhtias* at about 2% per month (i.e., 24% per annum). In the course of our interviews with them, farmers stated that if a lot goes unsold, then transporting it and selling it elsewhere (possibly at another market where auctions are not employed) can mean a discount of up to Rs 100 compared to the price obtainable in this market through auctions. We therefore estimate the outside option of the farmer, for each lot, as the expected second-highest valuation for that quality minus a *penalty* amount of Rs 100. On the other hand, if the miller opts out of the bargaining, his payoff is zero; in effect, the model then is one of alternating offers bargaining with an outside option for the seller.

The farmer's equilibrium payoff in the bargaining model with an outside option available to him is the larger of his Rubinstein share $s + \frac{r_B}{r_B+r_S}(v-s)$ and his outside option. This equilibrium payoff is the x_0 that we plug into Eq.(12). With v fixed at a small miller's expected valuation for the lot and s being allowed to vary from zero to a small miller's expected valuation discounted by Rs 100, we find that this reservation utility (x_0) for the lot equals the farmer's payoff from the outside option.

8.4 Derivation of Optimal Reserve Prices

Differentiating Π with respect to r

$$\begin{aligned}\frac{d\Pi(r)}{r} &= N_1 \frac{d}{dr}E[m_1(X,r)] + N_2 \frac{d}{dr}E[m_2(X,r)] \\ &+ N_1\, F_1(r)^{N_1-1}\, f_1(r)\, F_2(r)^{N_2}\, x_0 \\ &+ N_2\, F_1(r)^{N_1}\, F_2(r)^{N_2-1}\, f_2(r)\, x_0 \end{aligned} \tag{15}$$

where

$$\frac{d}{dr}E[m_i(X,r)] = [1 - F_i(r) - r\, f_i(r)]\, G_i(r) \tag{16}$$

Thus

$$\begin{aligned}\frac{d\Pi(r)}{dr} &= N_1\, [1 - F_1(r) - rf_1(r)]\, G_1(r) + N_2\, [1 - F_2(r) - rf_2(r)]\, G_2(r) \\ &+ N_1\, f_1(r)\, G_1(r)\, x_0 + N_2\, f_2(r)\, G_2(r)\, x_0 \end{aligned} \tag{17}$$

Since

$$f_i(r) \;=\; \lambda_i(r)\;[1 - F_i(r)] \tag{18}$$

where $\lambda_i(.)$ is the *hazard-rate* function, we have

$$\begin{aligned}
\frac{d\Pi(r)}{dr} \;&=\; N_1\;[1 - F_1(r) - r\;\lambda_1(r)(1 - F_1(r))]\;G_1(r) \\
&+\; N_2\;[1 - F_2(r) - r\;\lambda_2(r)(1 - F_2(r))]\;G_2(r) \\
&+\; N_1\;\lambda_1(r)\;[1 - F_1(r)]\;G_1(r)\;x_0 \\
&+\; N_2\;\lambda_2(r)\;[1 - F_2(r)]\;G_2(r)\;x_0
\end{aligned}$$

$$\begin{aligned}
&=\; N_1[1 - (r - x_0)\lambda_1(r)]\;(1 - F_1(r))\;F_2(r)^{N_2}\;F_1(r)^{N_1 - 1} \\
&+ N_2[1 - (r - x_0)\lambda_2(r)]\;(1 - F_2(r))\;F_1(r)^{N_1}\;F_2(r)^{N_2 - 1} \;=\; 0
\end{aligned} \tag{19}$$

Dividing throughout by $F_1(r)^{N_1-1}F_2(r)^{N_2-1}$ we get

$$\begin{aligned}
&N_1\;[1 - (r^* - x_0)\lambda_1(r^*)][1 - F_1(r^*)]F_2(r^*) \\
&+ N_2\;[1 - (r^* - x_0)\lambda_2(r^*)][1 - F_2(r^*)]F_1(r^*) \;=\; 0
\end{aligned} \tag{20}$$

The above equation gives for a lot of a specific quality, the first order condition for profit maximization of the seller.

8.5 Confidence Intervals for Optimal Reserve Prices

We use the Delta method to construct confidence intervals around the optimal reserve prices.

Recall that for a lot with quality vector $\mathbf{z}$, the valuation of player i of type j is given by

$$ln\;v^{ij} \;=\; \mathbf{z}\beta \;+\; \mu \;+\; u^i \tag{21}$$

The first-order condition for revenue-maximization (Eq.(13) in Section 5), which gives the optimal reserve price r^* can be rewritten as an implicit function of r^* and the parameter vector β

$$\gamma(r^*, \beta) \;=\; 0 \tag{22}$$

where

$$\begin{aligned}\gamma(r^*, \beta) \quad &= \quad N_1 \;\; [\; 1 - F_1(r^*, \beta) - (r^* - x_0) f_1(r^*) \;] \;\; F_2(r^*) \\ &\quad + \; N_2 \;\; [\; 1 - F_2(r^*, \beta) - (r^* - x_0) f_2(r^*) \;] \;\; F_1(r^*)\end{aligned} \tag{23}$$

We now obtain the asymptotic distribution of the optimal reserve price based on the semi-nonparametric estimates.

Gallant and Nychka (1987) prove the consistency of SNP estimators for multivariate data. Fenton and Gallant (1996b) specialize it to the univariate case. Wong and Severini (1991) establish root-n asymptotic normality and efficiency of semi-nonparametric maximum likelihood estimators.

Consider an estimator $\hat{\beta}$ of β that is consistent and distributed normally asymptotically. Thus,

$$T^{1/2} \; (\hat{\beta} - \beta) \;\; \rightarrow^{d} \;\; N(\mathbf{0}, \mathbf{V}), \tag{24}$$

where $\mathbf{V}/T$ is the variance-covariance matrix of $\hat{\beta}$. Then $\hat{r}^*$, an estimator of r^* solves

$$\gamma(\hat{r}^*, \hat{\beta}) \;=\; 0. \tag{25}$$

Expanding $\gamma(\hat{r}^*, \hat{\beta})$ in a Taylor's series about $(r^*, \hat{\beta})$

$$\begin{aligned}\gamma(\hat{r}^*, \hat{\beta}) \;=\; 0 \;=\; &\gamma(r^*, \beta) \;+\; \gamma_{\hat{r}^*}(r^*, \beta)(\hat{r}^* - r^*) \\ &+ \; \nabla_{\hat{\beta}} \gamma(r^*, \beta)'(\hat{\beta} - \beta) \;+\; U.\end{aligned} \tag{26}$$

Ignoring U, as it will be negligible in the neighborhood of (r^*, β), we obtain

$$(\hat{r}^* - r^*) \ = \ \frac{-\nabla_{\hat{\beta}}\gamma(r^*, \beta)'(\hat{\beta} - \beta)}{\gamma_{\hat{r}^*}(r^*, \beta)} \ \equiv \ \mathbf{m}'(\hat{\beta} - \beta). \tag{27}$$

Thus,

$$T^{1/2} \ (\hat{r}^* - r^*) \ \to^d \ N(0, m'\mathbf{V}m). \tag{28}$$

In practice, we work with approximations, so let

$$m \ = \ \frac{-\nabla_{\hat{\beta}}\gamma(\hat{r}^*, \hat{\beta})(\hat{\beta} - \beta)}{\gamma_{\hat{r}^*}(\hat{r}^*, \hat{\beta})}. \tag{29}$$

We use the parameter estimates ($\hat{\beta}$) to compute[36] the optimal reserve price ($\hat{r}^*$) and the value of m at $\hat{r}^*$. Then we construct 95% confidence intervals around $\hat{r}^*, \hat{\beta}$ as follows.

$$\left(\hat{r}^* - (1.96) * \left(\frac{m'\mathbf{V}m}{T}\right)^{1/2} \ , \ \hat{r}^* + (1.96) * \left(\frac{m'\mathbf{V}m}{T}\right)^{1/2}\right) \tag{30}$$

8.6 Proof of Proposition 1

Differentiating the expected revenue (Eq. 12) with respect to reserve price and setting $N_1 = 1$ and $N_2 = N$ we get

$$\frac{d}{dr}\Pi(r) \ = \ \Big(1 - F_1(r) - (r - x_0) \ f_1(r)\Big)G_1(r)$$

$$+ \ \ N \ \Big(1 - F_2(r) - (r - x_0) \ f_2(r)\Big)G_2(r) \tag{31}$$

where

$$G_1(r) \ = \ F_2^N(r)$$

$$G_2(r) \ = \ F_1(r)F_2^{N-1}(r)$$

[36] For each covariate vector.

Second derivative of $\Pi(r)$ with respect to r is thus given by

$$\frac{d^2\Pi(r)}{dr^2} \;=\; C_1 F_2^N(r) \;+\; N C_2 F_1(r) F_2^{N-1}(r)$$

$$+\; N\Big(1 - F_1(r) - (r - x_0) f_1(r)\Big) F_2^{N-1}(r) f_2(r) \tag{32}$$

$$+\; N\Big(1 - F_2(r) - (r - x_0) f_2(r)\Big)\Big(f_1 F_2^{N-1} + (N-1) F_1 F_2^{N-2} f_2(r)\Big)$$

where

$$C_1 \;=\; -\,2 f_1(r) \;-\; (r - x_0) f_1'(r)$$

$$C_2 \;=\; -\,2 f_2(r) \;-\; (r - x_0) f_2'(r)$$

Simplifying further, we get

$$\frac{d^2\Pi(r)}{dr^2} \;=\; C_1 F_2^N(r) \;+\; N C_2 F_1(r) F_2^{N-1}(r)$$

$$+\, N\Big(1 - F_1(r) - (r - x_0) f_1(r)\Big) F_2^N(r) \frac{f_2(r)}{F_2(r)} \,+\, N^2\Big(1 - F_2(r) - (r - x_0) f_2(r)\Big) F_1(r) F_2^{N-1}(r) \frac{f_2(r)}{F_2(r)}$$

$$+\; N F_2^{N-2}\Big(1 - F_2(r) - (r - x_0) f_2(r)\Big)\Big(f_1(r) F_2(r) - F_1(r) f_2(r)\Big) \tag{33}$$

$$=\; C_1 F_2^N(r) \;+\; N C_2 F_1(r) F_2^{N-1}(r)$$

$$+\; N\Big[\Big(1 - F_1(r) - (r - x_0) f_1(r)\Big) F_2^N(r) \;+\; N\Big(1 - F_2(r) - (r - x_0) f_2(r)\Big) F_1(r) F_2^{N-1}(r)\Big] \frac{f_2(r)}{F_2(r)}$$

$$+ \ \ NF_2^{N-2}\Big(1 - F_2(r) - (r - x_0)f_2(r)\Big)\Big(f_1(r)F_2(r) - F_1(r)f_2(r)\Big) \tag{34}$$

Evaluating this at $r = r^*$ and using $\frac{d\pi(r)}{dr}|_{r=r^*} = 0$ we get

$$\frac{d^2\Pi(r)}{dr^2}|_{r=r^*} \ = \ C_1F_2^N(r) \ + \ NC_2F_1(r)F_2^{N-1}(r)$$

$$+ \ \ NF_2^{N-2}\Big(1 - F_2(r) - (r - x_0)f_2(r)\Big)\Big(f_1(r)F_2(r) - F_1(r)f_2(r)\Big) \tag{35}$$

To see how the curvature of $\Pi(r)$ responds to changes in the number of bidders, we differentiate $\Big(\frac{d^2\Pi(r)}{dr^2}|_{r=r^*}\Big)$ with respect to N (even though N takes integer values in actual fact)

$$\frac{d}{dN}\Big(\frac{d^2\Pi(r)}{dr^2}|_{r=r^*}\Big) \ = \ C_1F_2^N(r)logF_2(r) + C_2F_1(r)F_2^{N-1}(r)\Big(1 + NlogF_2(r)\Big)$$

$$+ \ \ F_1F_2^{N-1}\Big(1 - F_2(r) - (r - x_0)f_2(r)\Big)\Big(\Big(1 + NlogF_2(r)\Big)\Big(\frac{f_1(r)}{F_1(r)} - \frac{f_2(r)}{F_2(r)}\Big) \tag{36}$$

Now $f(r^*) > 0$, $r^* - x_0 > 0$ and $f_i'(r^*) \geq \frac{-2f_i(r^*)}{r^*-x_0}$

$\Rightarrow \quad C_i < 0, i = 1, 2$

Along with $1 + NlogF_2(r^*) < 0$, this implies the first two terms on the R.H.S. of Eq.(36) are positive. Also, since F_1 dominates F_2 in the reverse hazard rate, we have $\frac{f_1}{F_1} > \frac{f_2}{F_2}$; it also implies first-order stochastic dominance (FOSD) of F_1 over F_2. For the FOC $\frac{d\pi(r)}{dr} = 0$ to hold with F_1 FOSD F_2, we must have $1 - F_1(r^*) - (r^* - x_0)f_1(r^*) > 0$ while $1 - F_2(r^*) - (r^* - x_0)f_2(r^*) < 0$. So the third term on R.H.S. of Eq.(36) is also positive. QED.

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