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## How Integrated is the Indian Wheat Market?

### Abstract

*Applying the momentum threshold autoregressive (M-TAR) model due to Enders and Granger (1998), this paper examines the relationship between the various prices of wheat quoted at different market centres in four Indian states. We find evidence of M-TAR asymmetric adjustments of wheat prices, indicating that price signals within states are transmitted over time in an asymmetric manner. This type of price adjusting behavior is consistent as to how price differentials may respond to poor dissemination of knowledge regarding market conditions and high transactions costs. The results offer important policy implications.*

**Keywords:** *Cointegration, M-TAR, Asymmetric price adjustment, Spatial integration, Indian wheat market.*

**JEL Classification:** *C22, C32, Q13, Q18*

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## 1. Introduction

Integration of agricultural commodity markets has been an important area of empirical research in development economics. Many developing countries have embarked on liberalising their agricultural markets in the context of implementing structural adjustment and market reform programs. It has been extensively argued that liberalisation of agricultural commodity markets can lead to allocative efficiency and long term growth in agriculture. There have been further suggestions that eliminating government intervention in internal trade and maintaining its price stabilisation activities can lead to positive aggregate welfare benefits to the economy (Jha and Srinivasan 2000). Liberalisation programs are important to market integration, as they rely on price signals being correctly transmitted across regions so that both producers and consumers benefit from trade.

According to Barrett (2008) the concept of market integration is most usefully described as tradability between markets. Tradability signals the transfer of excess demand from one market to another captured as actual or potential trade flows. Positive trade flows are sufficient to demonstrate spatial market integration under the tradability standard, though prices may not be equilibrated across markets (Barrett 2008). This concept of market integration includes the market clearance process in which the demand, supply and transactions costs in different markets jointly determine prices and trade flows as well as the transmission of price shocks from one market to another, or both (Barrett and Li 2002). Considering the approach of price transmission, market integration could be viewed as a situation where price signals and information between different regions are transmitted so that the prices of the commodity in spatially separated markets move together over time.<sup>1</sup> From an econometric point of view this would mean that the prices of the commodity in different regions should be cointegrated. Barrett (1996) notes that employing price data alone for studying market integration is not sufficient, and that analysis of transactions costs and trade flow data need to be carried out as well to test for market integration. However, there is a lack of reliable transactions cost and trade flow data for many developing countries, including India. Transactions costs in a developing country like India, may give rise to a threshold over which arbitrage possibilities are obliterated, resulting in an absence of market integration. Threshold cointegration can account for the possibility of non-stationary transfer costs which can lead to valuable information for policy makers. It may be noted however, that despite the recent sophistication in econometric techniques there is no single best approach that addresses all the shortcomings of empirical analysis of market integration. In

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3 this paper we have examined spatial integration of wheat markets in India, using an approach  
4 of cointegration with threshold adjustment.  
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7 The study of food market integration is important in evaluating the necessity of  
8 government intervention in the food grain markets in the context of market liberalisation  
9 programs. Government interventions in Indian food grain markets have been in the form of  
10 price support and procurement, maintenance of buffer stock, public distribution system (PDS)  
11 and open market operations. There are also various restrictions on internal trade in  
12 agricultural commodities, including licensing requirements and stocking limits for the  
13 wholesale and retail trade, restrictions on storage, pricing and the movement of food grains  
14 across regions. These interventions were considered necessary for promoting agricultural  
15 growth, maintaining price stability and improving food security.  
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23 However, in recent years, these interventions have been found to cause adverse effects  
24 on gross domestic product (GDP) and consumer welfare, particularly of the poor (Parikh *et*  
25 *al.*, 2003). Moreover, the World Bank (1999) has reported that the government's  
26 procurement, distribution, and buffer stock programs have had negative impact of repressing  
27 private trading in food grains and undermining its potential contribution to long-term food  
28 security, causing an excessive burden of stock and food subsidies. This prompted many to  
29 argue in favor of the same structural adjustment and liberalisation programs in agriculture in  
30 general and food grains in particular as the Indian government have been implementing in the  
31 case of trade, industry and finance since 1991. For example, the World Bank (1999) proposes  
32 that the government should intervene only when price fluctuations are outside the desired  
33 price-band. Suryanarayana (2000) argued that private trade by itself can take care of inter-  
34 regional flows of food grains in normal crop years, but government intervention would be  
35 needed in drought years. Jha and Srinivasan (2000) argued that freeing domestic trade from  
36 government interventions and making the PDS operations depend on market purchases would  
37 benefit both producers and consumers.  
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49 The case for minimising the government interventions in food grain markets depends  
50 on the nature of functioning of these markets. Since the integration of markets implies that  
51 price signals in one market will be transmitted to other markets and thus, enhances regional  
52 balance among food-deficit, food-surplus and non-food cash crop-producing regions, the  
53 government may minimise its efforts in procurement and open market sale of food grains for  
54 price stability across regions. Market integration has been particularly significant in  
55 predicting the impacts of price changes in surplus areas on markets in food deficit areas.  
56 Policy makers may be interested in knowing the relationship between price dynamics of  
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3 staple foods in different regions given that their production can be influenced by exogenous  
4 shocks. Markets that are integrated may convey accurate price signals which in turn may help  
5 marketing decisions by producers and efficient food grain movements.  
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9 Naturally, the success of price policy in achieving agricultural growth and stability in  
10 food prices depends largely on market integration. In an integrated market system, the effects  
11 and incentives of any policy would be transmitted smoothly to all the regional markets. For  
12 example, the incentive in the form of price support to promote agricultural growth would  
13 reach all the regions and produce desired result, if the agricultural commodity markets are  
14 integrated. If the markets are not integrated, agricultural price policy will have limited  
15 operational significance. Similarly, the extent of dissemination of the effects and incentives  
16 of any liberalisation policy, removing restrictions on the private sector or withdrawing  
17 government intervention in agricultural markets, depends on market integration. The  
18 significance of market integration for agricultural price policy and liberalisation programs  
19 makes it imperative to examine how and to what extent Indian food grain markets are  
20 integrated.  
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## 32 **2. Literature Review and Motivation**

33 The methodology, most commonly used in the past for testing market integration, involved  
34 the bivariate correlation between price changes in different markets [see, for example,  
35 Cummings (1967), Lele (1967, 1971)]. This method, despite its simplicity, came under strong  
36 criticisms from Blyn (1973), Harriss (1979), Heytens (1986) and Ravallion (1986, 1987). The  
37 studies based on bivariate correlation involved serious methodological flaws, due to their  
38 failure to recognise the possibility of spurious regression in the presence of common  
39 exogenous trends, common periodicity, and autocorrelated and heteroskedastic residuals in  
40 the regression with nonstationary prices [Barrett (1996) and Palaskas and Harriss-White  
41 (1993)]. The shortcoming of spatial price correlations to evaluate market integration involves  
42 the influences of common components such as population growth, inflation or climate  
43 patterns. As documented by Abdulai (2006), the assertion by Sen (1981) that Ethiopian food  
44 markets were relatively integrated during the famine of 1972-1974 was later challenged by  
45 Devereaux (1988) being due to population movements rather than food. Although the  
46 dynamic model of spatial price differentials proposed by Ravallion (1986) is a significant  
47 improvement upon the earlier methods, and mitigates the major methodological limitations of  
48 the bivariate correlation method, it involves serious problems that result in inefficient  
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3 estimators, which are used for testing alternative hypotheses of market integration and  
4 segmentation [Palaskas and Harriss-White (1993)].  
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7 The growing trend towards the liberalisation of food markets and recent advances in  
8 the time series econometrics have generated a lot of interest among researchers to investigate  
9 spatial integration of agricultural commodity markets in many countries [see, for example,  
10 Ravallion (1986), Ardeni (1989), Faminow and Benson (1990), Goodwin and Schroeder  
11 (1991), Baffes (1991), Dahlgram and Blank (1992), Alexander and Wyeth (1994), Dercon  
12 (1995), Goletti *et. al.* (1995), Baulch (1997), Ismet *et. al.* (1998), Zantias (1999), Asche *et. al.*  
13 (1999), Bessler *et. al.* (2003) and Awokuse and Bernard (2007)].  
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19 Some of the researchers [for example, Dercon (1995), Ismet *et. al.* (1998)] tried to  
20 relate market integration to liberalisation. Dercon (1995) argued that since the extent of  
21 spatial market integration determines the transmission speed of price changes due to any  
22 policy reforms across regional markets, the effects of market liberalisation and other  
23 structural changes in markets should be evaluated not only on the basis of what happens to  
24 the level of prices for producers and consumers but also on the basis of the functioning of  
25 markets. He observed that liberalisation had positive effect on the functioning of the  
26 Ethiopian grain (teff) markets through increased short-run integration. Ismet *et. al.* (1998)  
27 argued that since the Indonesian rice markets are highly integrated, the government may limit  
28 its intervention by rationalising its price stabilisation activities and buffer stock policies and  
29 letting the private sector contribute as much as possible.  
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39 In the Indian context, attempts were made to evaluate the spatial integration of food  
40 markets, using the cointegration techniques [see, for example, Ghosh (2000, 2003, 2008), Jha  
41 *et. al.* (1997) and Palaskas and Harriss-White (1993)]. Applying the Engle and Granger  
42 (1987) method of cointegration to the weekly prices of rice, potato and mustard, Palaskas and  
43 Harriss-White (1993) observed that the prices of the central and the peripheral markets are  
44 cointegrated for most of the pairs. Using the binary and multivariate cointegration tests based  
45 on the Engle and Granger (1987), Engle and Yoo (1987) and Goletti-Ravallion [Goletti  
46 (1994), Ravallion (1986)] methods to the prices of rice and wheat, Jha *et. al.* (1997) observed  
47 that all pairs of I(1) prices of rice and wheat are cointegrated, and the food markets all over  
48 India are integrated. Ghosh (2000, 2003) applied the maximum likelihood (ML) method of  
49 cointegration [Johansen (1988) and Johansen and Juselius (1990)] to the monthly prices of  
50 wheat and rice, and concluded that the markets are spatially linked in the long run and the  
51 prices provide relevant market signals within and across Indian states. Based on the results,  
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3 Ghosh (ibid) argued in favor of liberalisation of the food grain markets, limiting government  
4 intervention and allowing the private sector to contribute its best in the integrated markets.  
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7 Most of the studies on price transmission in agricultural commodity markets have  
8 focused on symmetric price adjustments, using approaches, which underlie price transmission  
9 process to be linear. Standard co-integration techniques, used in the literature on spatial  
10 integration of agricultural product markets, have been criticised on the grounds that they  
11 ignore the potentially important role played by transactions costs by estimating linear models,  
12 which are inconsistent with discontinuous trade (Baulch 1997). Transactions costs are  
13 generally high in a developing country like India. This can result from inadequate  
14 transportation and communications infrastructure, the long distance between markets and  
15 unstable political environment. Given that transactions costs data are unavailable and difficult  
16 to measure, their impact on market integration has not been studied.  
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24 This study takes account of transactions costs by allowing for asymmetric adjustment  
25 of prices via threshold autoregressive models. If transport bottlenecks are present between  
26 different regions within states, then the flow of commodities from surplus to deficit regions  
27 can be restricted which may result in persistence of depressed or high prices. Price  
28 differentials could change over time due to the poor dissemination of knowledge regarding  
29 market conditions. For example, traders may not be aware of profit maximising opportunities  
30 that may exist when these price differentials occur. One must bear in mind that storage can  
31 smooth supply shocks. However, storage can also promote inventory holding behavior that  
32 may result in asymmetries in the adjustment of prices. Naturally, the imposition of linearity  
33 on the adjustment of prices to disequilibrium is likely to provide misleading results, if the  
34 price changes, in reality, follow non-linear relationships. A few studies reported evidence of  
35 asymmetric adjustment of the prices of food grains in India. For example, Jha and Nagarajan  
36 (2002) found that in the case of rice markets in India, the average speed of adjustment is  
37 slower when the price declines than in the case of price increase. The asymmetric price  
38 adjustments are often attributed to asymmetries in information, transaction costs, imperfectly  
39 competitive markets, and government interventions through price support and marketing  
40 quotas.  
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55 Against this background, we examine the relationship between the various prices of  
56 wheat quoted at different market centres in four Indian states, using an approach of  
57 cointegration with threshold adjustment. An attractive method of estimation and testing  
58 follows the approach by Enders and Granger (1998) using momentum threshold  
59 autoregressive (M-TAR) models. Under the M-TAR model, the underlying price series might  
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3 display asymmetry of the following form: when the prices of two commodities are decreasing  
4 (increasing), the gap between the prices decreases at a faster rate as opposed to the case when  
5 both prices are increasing (decreasing) (Ghoshray 2002). This type of asymmetric price  
6 behavior differs from the symmetric adjustment scenario where both prices move together  
7 and any transitory deviation by 'rates of change' is corrected in a symmetric manner. A  
8 significant advantage of the M-TAR model is that it allows for an accumulation of changes in  
9 the price gap above and below the threshold followed by a sharp adjustment to the long run  
10 equilibrium (Abdulai 2006). This type of price adjusting behavior is consistent with the  
11 arguments made earlier as to how price differentials may respond to poor dissemination of  
12 knowledge regarding market conditions and high transactions costs.  
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21 In the linear cointegration framework we determine whether a stable long run  
22 relationship exists between the pair of price series considered. In other words, employing the  
23 Engle Granger (1987) framework, we find out whether the residuals from the long run  
24 regression (alternatively the price spread) are stationary. However, in this framework, the  
25 underlying assumption is that the tendency to move towards the long run equilibrium is  
26 always present (although movement towards equilibrium may not occur in every period  
27 (short run deviations may arise). It has been argued that transactions costs may prevent  
28 traders/economic agents from adjusting to any deviations in a continuous fashion. This  
29 limitation is addressed by the M-TAR model due to Enders and Granger (1998) by allowing  
30 deviations from equilibrium to adjust in a threshold process. A significant advantage with the  
31 M-TAR model is that it can capture an accumulation of changes in the price spread below  
32 and above the threshold followed by a sharp movement back to the equilibrium position.  
33 When the change in the price spread is decreasing then it is an indication of an increase in the  
34 price of one market relative to another, triggering a response by economic agents in the latter  
35 market to restore the price spread. However, in this framework, when the change in the price  
36 spread is increasing, then it is an indication of a decrease in the price of one market relative to  
37 another, which can trigger a very different response by economic agents in the latter market  
38 to restore the price spread. This leads to asymmetric adjustment.  
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53 Nonlinearities and asymmetric adjustment remains an important issue to be explored  
54 in the area of price transmission. Although asymmetric adjustment may also be the outcome  
55 of market imperfections it is possible that price support policies result in positive and  
56 negative changes in the price of a market affecting the price of another market in different  
57 ways. For example, policies such as price support mechanisms may give rise to such  
58 adjustment process. Rapsomanikis *et. al.* (2006) call for such two-regime threshold  
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cointegration which they argue may be beneficial as it provides additional information in the form of the threshold. The approach, they further argue, also provides a rough indication of transfer costs. Transfer costs in a developing country like India, may give rise to a threshold over which arbitrage possibilities are obliterated, resulting in an absence of market integration. Threshold cointegration can encompass the possibility of non-stationary transfer costs which can lead to valuable information for policy makers (Rapsomanikis *et. al.* 2006).

We examine whether this type of asymmetric price adjusting behavior is present in the wheat prices of selected states of India. The rest of the paper is organised as follows. Section 3 describes the econometric methodology, Section 4 describes the data and the empirics, and Section 5 summarises the main findings and draws policy conclusions.

### 3. Econometric Model

The Engle and Granger (1987) two-step method to test for cointegration between two variables, say prices  $P_{1t}$  and  $P_{2t}$  entails using ordinary least squares (OLS) to estimate the long-run equilibrium relation of the LOP. This is given by the equation below:

$$P_{1t} - P_{2t} = \alpha + \varepsilon_t \quad (1)$$

where  $P_{1t}$  and  $P_{2t}$  are non-stationary I(1) prices,  $\alpha$  is an arbitrary constant that accounts for the differential (transportation costs and quality differences) and  $\varepsilon_t$  is the error term which may be serially correlated. To test the hypothesis, (1) is estimated using OLS. The second step advocates an Augmented Dickey-Fuller test on the estimated residuals  $\hat{\varepsilon}_t$ , of (1) of the following kind:

$$\Delta \hat{\varepsilon}_t = \zeta \hat{\varepsilon}_{t-1} + \sum_{i=1}^p \psi_i \Delta \hat{\varepsilon}_{t-i} + \omega_t \quad (2)$$

where  $\omega_t$  is a white noise error term and  $p$  denotes the number of lags to make the residuals a white noise process. The number of lags is selected using the Schwartz Bayesian Criteria (SBC). Rejecting the null hypothesis ( $H_0 : \zeta = 0$ ) of non-stationarity implies that the residuals of (1) are stationary. Thus equation (1) is like an attractor such that its pull is strictly proportional to the absolute value of  $\hat{\varepsilon}_t$ .

In the analysis that follows we bring cointegration techniques to bear on the issue of price linkages that may exist between the different wheat prices. However, Enders and Granger (1998) argue that the test for cointegration and its extensions are mis-specified if adjustment is asymmetric. They consider an alternative specification, called the Momentum –

Threshold autoregressive (M-TAR) model, such that the estimated residuals  $\hat{\varepsilon}_t$  from (1) can be written as:

$$\Delta \hat{\varepsilon}_t = I_t \zeta_1 \hat{\varepsilon}_{t-1} + (1 - I_t) \zeta_2 \hat{\varepsilon}_{t-1} + \omega_t \quad (3)$$

where  $I_t$  is the Heaviside indicator function such that:

$$I_t = \begin{cases} 1 & \text{if } \Delta \hat{\varepsilon}_{t-1} \geq \tau \\ 0 & \text{if } \Delta \hat{\varepsilon}_{t-1} < \tau \end{cases} \quad (4)$$

In this case, the series  $\hat{\varepsilon}_t$  exhibits more momentum in one direction than the other. This specification allows for asymmetric adjustment. If the system is convergent, then the long run equilibrium value of the sequence is given by  $\hat{\varepsilon}_t = \tau$ . The sufficient conditions for the stationarity of  $\hat{\varepsilon}_t$  are  $\zeta_1 < 0$ ,  $\zeta_2 < 0$  and  $(1 + \zeta_1)(1 + \zeta_2) < 1$  (Petrucci and Woolford 1984). The above model along with equation (4) depicts the momentum threshold autoregression (M-TAR) model. The M-TAR model can be used to capture a different type of asymmetry. If for example,  $|\zeta_1| < |\zeta_2|$ , the M-TAR model exhibits little adjustment for positive  $\Delta \hat{\varepsilon}_{t-1}$  but substantial decay for negative  $\Delta \hat{\varepsilon}_{t-1}$ . In other words, increases tend to persist, but decreases tend to revert quickly back to the attractor irrespective of where disequilibrium is relative to the attractor. To estimate the threshold we use the methodology proposed by Chan (1993). The estimated residual series was sorted in ascending order, that is,  $\Delta \hat{\varepsilon}_1 < \Delta \hat{\varepsilon}_2 < \dots < \Delta \hat{\varepsilon}_T$  where  $T$  denotes the number of usable observations. The largest and smallest 15% of the  $\hat{\varepsilon}_t$  series were eliminated and each of the remaining 70% of the values were considered as possible thresholds. For each of the possible thresholds the equation was estimated using (1), (3) and (4). The estimated threshold yielding the lowest residual sum of squares was deemed to be the appropriate estimate of the threshold.

To implement in this test the case of the M-TAR adjustment, the Heaviside Indicator function is set according to equation (4) and estimate equation (3) accordingly. The  $\Phi$ -statistic for the null hypothesis of non-stationarity of  $\hat{\varepsilon}_t$ , that is,  $H_0 : (\zeta_1 = \zeta_2 = 0)$  is recorded. The value of the  $\Phi$ -statistic is compared to the critical values computed by Enders and Granger (1998). If we can reject the null hypothesis, it is possible to test for asymmetric adjustment since  $\zeta_1$  and  $\zeta_2$  converge to multivariate normal distributions (Tong 1990). The F statistic is used to test for the null hypothesis of symmetric adjustment, that is,  $H_0 : (\zeta_1 = \zeta_2)$ . Diagnostic checking of the residuals are undertaken to ascertain whether the

$\omega_t$  series is a white noise process using the Ljung-Box  $Q$  tests. If the residuals are correlated, equation (3) is re-estimated in the form:

$$\Delta \hat{\varepsilon}_t = I_t \zeta_1 \hat{\varepsilon}_{t-1} + (1 - I_t) \zeta_2 \hat{\varepsilon}_{t-1} + \sum_{i=1}^p \phi_i \Delta \hat{\varepsilon}_{t-i} + \omega_t \quad (5)$$

Equation (5) is comparable to (3) except that it incorporates lagged first differences of the dependent variable to correct for the autocorrelation in the error term  $\omega_t$ . The SBC is used to determine the lag length.

According to the Granger Representation Theorem, the existence of cointegration justifies estimating an Error Correction model (ECM). In this context, the ECM allows us to nest together the long run and short run dynamics of the Indian wheat prices. The ECM can be described by the following equations below:

$$\Delta P_t^i = \mu \hat{\varepsilon}_{t-1} + \sum_{k=1}^p \psi_i \Delta P_{t-k}^i + \sum_{k=1}^p \delta_i \Delta P_{t-k}^j + u_t^i \quad (6)$$

$$\Delta P_t^j = \pi \hat{\varepsilon}_{t-1} + \sum_{k=1}^p \eta_j \Delta P_{t-k}^j + \sum_{k=1}^p \lambda_j \Delta P_{t-k}^i + u_t^j \quad (7)$$

where  $P_t^i$  and  $P_t^j$  denote the prices of any region  $i$  and  $j$  respectively,  $\hat{\varepsilon}_{t-1}$  refers to the error correction term, which is the estimated one period lagged error of the long run equilibrium relationship between the prices of the two regions, and finally both  $u_t^i$  and  $u_t^j$  are white noise errors. The number of lags  $p$  is determined using the SBC.

Similarly, the finding of cointegration with threshold adjustment justifies the estimation of the following Threshold Error Correction Model (TECM). The TECM takes the form:

$$\Delta P_t^i = \mu_1 M_t \hat{\varepsilon}_{t-1} + \mu_2 [1 - M_t] \hat{\varepsilon}_{t-1} + \sum_{k=1}^p \psi_i \Delta P_{t-k}^i + \sum_{k=1}^p \delta_i \Delta P_{t-k}^j + u_t^i \quad (8)$$

$$\Delta P_t^j = \pi_1 M_t \hat{\varepsilon}_{t-1} + \pi_2 [1 - M_t] \hat{\varepsilon}_{t-1} + \sum_{k=1}^p \eta_j \Delta P_{t-k}^j + \sum_{k=1}^p \lambda_j \Delta P_{t-k}^i + u_t^j \quad (9)$$

$$\text{where } M_t = \begin{cases} 1 & \text{if } \Delta \hat{\varepsilon}_{t-1} \geq \hat{\tau} \\ 0 & \text{if } \Delta \hat{\varepsilon}_{t-1} < \hat{\tau} \end{cases}$$

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4 and both  $u_t^i$  and  $u_t^j$  are white noise errors. Following Enders and Granger (1998), the  
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6 number of lags  $p$ , for both ECM and TECM is determined using the SBC.  
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#### 9 10 **4. Empirical Results**

##### 11 *4.1 Database*

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13 The data set used for the analysis consists of monthly wholesale prices of wheat for the  
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15 period from March 1984 to June 2003. The data relating to the state-specific variety of wheat  
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17 for different market centres of four selected states viz., Haryana, Punjab, Rajasthan and Uttar  
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19 Pradesh (UP) were compiled from various issues of *Agricultural Situation in India*, a monthly  
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21 journal published by the Ministry of Agriculture, Government of India. Detailed description  
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23 and characteristics of the data have been documented in the Appendix.

24 Figure 1 illustrates the time path of the wheat prices used in this study.

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27 [Figure 1 about here]  
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31 From the graph we can observe that prices generally show trending behavior. The  
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33 prices generally seem to move together over time and display an upward drift. Whether the  
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35 prices are characterised by deterministic or stochastic trends is hard to tell, and appropriate  
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37 unit root tests would need to be conducted to ascertain the nature of underlying trends in the  
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39 wheat prices. Besides, when considering the price relationships between the different  
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41 varieties of wheat employed in this study, it is necessary to consider the underlying properties  
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43 of the process that generate the time series variables.

##### 44 45 *4.2 Univariate Time Series Properties*

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47 All the price series used in this study are tested for their order of integration as a prelude to  
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49 the examination of the relationships that may exist between them. The standard augmented  
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51 Dickey Fuller (ADF) test is applied to the data in levels and first differences. The unit root  
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53 tests are summarised in Table 1.

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56 [Table 1 about here]  
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59 For most of the data in levels we cannot reject the null of a unit root while it can be  
60 rejected in first differences. From these results we can infer that barring Kalpi for UP, and

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3 Alwar and Kota for Rajasthan, the prices are non-stationary and integrated of order one, that  
4 is, I(1). Given that the ADF test suffers from poor size and power properties, we conduct two  
5 further and more powerful tests – the Elliot, Rothenberg and Stock (ERS) test due to Elliot *et.*  
6 *al.* (1996), and the Perron and Ng (1996) test. The lag length given in parentheses (see Table  
7 1) is chosen according to the Modified Akaike Information Criterion (MAIC).<sup>2</sup> All the unit  
8 root tests confirm that the price series are non-stationary I(1) except for the additional price  
9 series for Bharatpur of Rajasthan.

### 17 4.3 Cointegration Results

18 The bivariate approach to test for cointegration of prices allows for the tests of asymmetry to  
19 be carried out. In this case we make use of directional asymmetry (that is, M-TAR).<sup>3</sup> Asche  
20 *et. al.* (1999), and more recently Ghoshray (2010), argue that if a group of commodities are to  
21 be in the same market, all the prices of the commodities must be cointegrated in pairs. This  
22 follows from the common trends approach by Stock and Watson (1988). The analysis is  
23 similar to a multivariate test because it implies that if there is only one common stochastic  
24 trend in a vector of  $n$  prices, then there exist  $n-1$  cointegrating vectors in a multivariate  
25 framework, or  $n(n-1)/2$  pairs that cointegrate in a bivariate framework.

26 In the analysis that follows, a test is made for cointegration between the different  
27 wheat prices (those found to be I(1)) in pairs as given by (1). Following the Engle Granger  
28 (1987) methodology, the first step entails estimating the long run equilibrium relationship  
29 given by equation (1) and then conducting the ADF test on the residuals of (1). The results of  
30 the test between different varieties of wheat are shown in the second column of Table 2. The  
31 key point to note is that the null hypothesis of non-stationarity can be rejected for all the  
32 pairs, implying that the prices of wheat are highly integrated, and one may conclude that the  
33 wheat prices for each of the states form a robust long run relationship.

34 The residuals of (1) are then estimated in the form of the M-TAR models.  
35 Considering the M-TAR specification, we find from Table 2 (column 6) that the null  
36 hypothesis of non-stationarity can be rejected for all price pairs. The statistic  $\Phi$  is found to be  
37 greater than the critical value for all possible pairs. The threshold values  $\tau$ , estimated  
38 according to the methodology proposed by Chan (1993) described earlier, are reported (in  
39 column 5). These estimated thresholds shed light on the magnitude of the price spread above  
40 which prices adjust to long run equilibrium. The M-TAR model picks up directional  
41 asymmetry, that is, if the price differential is increasing so that it exceeds the threshold, then  
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3 the rate of adjustment is different to that when the price differential is decreasing. Given that  
4 we find cointegration, the null hypothesis of symmetric adjustment can be tested using the  
5 standard F distribution. For all the pairs we find that the null hypothesis  $H_0 : [\zeta_1 = \zeta_2]$  can be  
6 rejected in 10 out of a possible 18 pairs at the 10 per cent or lower level of significance.  
7 Overall, the results lend support to asymmetric adjustment. Finally, the Ljung Box  $Q$  statistic  
8 was employed to test for model mis-specification. We find that none of the models suffer  
9 from problems of serial correlation.  
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18 [Table 2 about here]  
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22 The results in Table 2 lead us to make an important observation. Using the M-TAR  
23 consistent model, we can find that 10 of the possible 18 pairs of prices show asymmetric  
24 adjustment. The finding of asymmetric adjustment leads us to conclude that the M-TAR  
25 results should be taken into consideration over the Engle Granger tests, as the M-TAR model  
26 has more power than the Engle Granger tests [Enders and Granger (1998), Enders (2001)]  
27 when there is evidence of asymmetry.  
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32 Where asymmetry is found to exist, the point estimates of  $\hat{\zeta}_1$  and  $\hat{\zeta}_2$  are observed to  
33 test for convergence of the M-TAR model. All of the autoregressive coefficients are  
34 statistically significant, indicating that adjustment takes place only in both directions when  
35 both prices are increasing as well as decreasing. For instance, when we find that for two  
36 pairs, both  $\hat{\zeta}_1$  and  $\hat{\zeta}_2$  are significant at conventional levels and that  $|\zeta_1| < |\zeta_2|$ , this would  
37 imply that the M-TAR model exhibits little adjustment for positive  $\Delta\varepsilon_{t-1}$  but substantial  
38 decay for negative  $\Delta\varepsilon_{t-1}$ . In other words, increases tend to persist, but decreases tend to revert  
39 quickly back to the attractor.  
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48 In general, the rate of adjustment (autoregressive decay) for all pairs is quite high.  
49 This would imply that the signals are transmitted quite quickly, albeit in an asymmetric  
50 fashion. To interpret the results let us take as an example the (Barnala, Ludhiana) pair. In this  
51 case we find evidence of asymmetric adjustment. We find that for this pair, both  $\hat{\zeta}_1$  and  $\hat{\zeta}_2$   
52 are significant at conventional levels and that  $|\zeta_1| < |\zeta_2|$ . This would imply when prices  
53 are increasing the deviation between Barnala and Ludhiana prices is corrected at a slower rate  
54 than when both the prices are decreasing. As another example, let us consider the (Ambala,  
55 Karnal) pair. When both prices are increasing, the gap between Ambala and Karnal closes at  
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3 a faster rate than when prices are decreasing. These results play an important part when  
4 considering how price signals are transmitted between regions in a given state. For the four  
5 states considered in this study, we find that there is evidence of this type of asymmetry within  
6 regions in each state.  
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10 Thus, employing the tests for cointegration we find evidence of a long run  
11 relationship between all pairs of wheat prices, with a little over 55% of the pairs displaying  
12 asymmetric adjustment. In the absence of region specific information on the factors  
13 underlying the variations in the nature of market integration (symmetric or asymmetric), such  
14 variations across market pairs may, in general, be attributed to the regional differences in  
15 infrastructure endowment, institutional structure of the markets, marketing costs, distance,  
16 and consumer preferences for different varieties of wheat.<sup>4</sup>  
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#### 24 4.4 Error Correction Model

25 The existence of cointegration between price pairs allowing for both symmetric and threshold  
26 adjustment, justifies estimating an Error Correction model (ECM). The finding of  
27 cointegration allows us to estimate an ECM described by equations (6) and (7), while the  
28 finding of cointegration with threshold adjustment allows us to construct a threshold ECM or  
29 TECM.<sup>5</sup> In this context, both the symmetric and threshold ECM allows us to nest together the  
30 long run and short run dynamics of the Indian wheat prices. The results for the TECM and  
31 ECM are reported together in Table 3.  
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41 [Table 3 about here]

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43 For the TECM, we find that in the case of the Rohtak/Sonepat price pair, Sonepat prices only  
44 adjust to correct disequilibrium when both the prices are increasing; while Rohtak prices only  
45 adjust to correct disequilibrium when both the prices are decreasing. This sort of adjustment  
46 process can be found for other price pairs as well such as Ambala/Karnal, Karnal/Sonepat  
47 and Baharaich/Gorakhpur. For example, when considering the case of Baharaich/Jhansi, if  
48  $\Delta \hat{\varepsilon}_t - \tau < 0$ , then this implies an increase in the price of Jhansi relative to Baharaich triggers  
49 a response by traders in Baharaich to restore the price spread by their increasing prices.  
50 However, when  $\Delta \hat{\varepsilon}_t - \tau > 0$ , indicative of a price decrease in the Jhansi market, the response  
51 by Baharaich traders is relatively less resulting in asymmetric behaviour in the price spread.  
52 In other words, for the Baharaich/Jhansi price pair, we find the speed of adjustment for the  
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Jhansi price to be significant irrespective of whether the prices are increasing or decreasing. The speed of adjustment, however, is higher when both Baharaich and Jhansi prices are increasing. Baharaich prices only seem to adjust when both prices are increasing and show no evidence of adjustment when both prices are decreasing. A similar behavior is reflected when we observe prices for the Jaipur/Jodhpur pair. In the case of Barnala/Amritsar pair, prices for both Barnala and Amritsar adjust to disequilibrium. However, the adjustment only takes place when both prices are decreasing. A similar though opposite case arises when we observe the Ludhiana/Amritsar pair.

For the ECM we find evidence for at least three price pairs, that one price is evolving independently while the other price adjusts to maintain the long run equilibrium relationship. This can be found for Ambala/Rohtak, Barnala/Ludhiana, Jalandhar/Amritsar and Gorakhpur/Jhansi. If we consider the Ambala/Rohtak pair for example, we find that Ambala prices adjust to any deviation in the long run equilibrium that is formed by the two prices. This implies that Rohtak prices evolve independently over time. One may infer from these results that between the Ambala/Rohtak pair, prices are independently formed in Rohtak, while prices in Ambala adjust to any deviations in a symmetric manner. In the Punjab, we find Barnala prices to evolve independently while Ludhiana prices adjust to disequilibrium and in the case of Jalandhar/Amritsar, Amritsar prices adjust to any deviation from equilibrium while prices in Amritsar evolve independently over time.<sup>6</sup> For the remaining price pairs we find adjustment from both prices in each price pair that is considered. For instance, in the case of the Sriganganagar/Jodhpur pair, we find that in response to a disequilibrium, Sriganganagar prices increase and Jodhpur prices decrease to maintain the long run equilibrium relationship over time.

From the short run side, we conduct tests for Granger causality. Granger causality is tested by conducting a joint hypothesis tests from the error correction models to find out whether lagged  $\Delta P_t^i$  (say) can be used to forecast  $\Delta P_t^j$ . For instance in equation (9), we test the hypothesis  $H_0 : [\delta_1 = \delta_2 = \dots = \delta_p = 0]$ . Rejecting the null hypothesis would imply that  $\Delta P_t^j$  Granger causes  $\Delta P_t^i$ , or alternatively,  $\Delta P_t^j$  can be used to forecast  $\Delta P_t^i$ . We find 11 price pairs to display unidirectional causality. For instance, when considering the Karnal/Sonepat price pair, we find that Sonepat prices are Granger caused by Karnal but not the other way round. One can therefore infer that Karnal prices can be used to forecast Sonepat prices. Bidirectional causality is found to exist for five out of the eleven pairs. For instance, Barnala prices can be used to forecast Amritsar prices while Amritsar prices in turn,

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3 can be used to forecast Barnala prices. In general, apart from the finding that asymmetric  
4 adjustment exists in the underlying dynamic behavior of Indian wheat prices, no clear pattern  
5 emerges as to whether this asymmetry is specific to any state.  
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## 10 **5. Summary and Policy Conclusions**

11 We have examined the relationship between the prices of wheat quoted at different market  
12 centres in four Indian states, using momentum threshold autoregressive (M-TAR) models.  
13 Threshold and linear error correction models are also estimated to nest the long run and short  
14 run dynamics of the wheat prices. While the standard tests for cointegration with symmetric  
15 adjustment provide evidence of a long run relationship between pairs of wheat prices, M-  
16 TAR models show that wheat prices adjust in an asymmetric manner in a little over 55 per  
17 cent of the markets pairs considered, but in a symmetric manner in the remaining 45 per cent  
18 of the cases.  
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26 The results our study have important implications for agricultural price policy and  
27 food market liberalisation. The primary objectives of price policy in India are to promote  
28 growth in agricultural production and to ensure food security and price stability. Government  
29 interventions in various forms in food grain markets were considered necessary on the  
30 presumption that the food grain markets are not well developed and the private sector may  
31 not ensure fulfillment of the objectives of agricultural price policy. However, with the  
32 adoption of structural adjustment and liberalisation programs in trade, industry and finance  
33 since 1991, many argued in favor of the same programs for agriculture in general and food  
34 grains in particular.  
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42 Our results lend support to the argument for liberalisation of food grain markets and  
43 for minimising government intervention in the food economy. In the integrated food grain  
44 markets, the objective of price stability can be achieved by limiting government intervention  
45 and allowing the private traders to contribute as much as possible in the markets. In these  
46 markets, market forces will ensure stability of prices by ensuring regional balance between  
47 demand and supply of food grains. Hence, food grain markets may be allowed to function  
48 effectively by removing the restrictions on licensing requirements and stocking limits for the  
49 wholesale and retail trade, storage, pricing and movement of food grains across regions.  
50 Removal of these restrictions and barriers to entry into the wholesale and retail trade in food  
51 grains would promote competition and strengthen spatial integration in the markets. Since the  
52 effects and incentives of different policies will be transmitted smoothly in the integrated  
53 markets, the government could promote growth in production and ensure price stability with  
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3 lower costs of operation by suitably designing price policy and rationalising its activities in  
4 the food grain economy.  
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7 Since the differences in the nature of adjustment (symmetric or asymmetric) of wheat  
8 prices across regions could be due to regional disparities in infrastructure endowment and  
9 institutional structure of the wheat markets, infrastructure development could be helpful in  
10 improving market integration and managing price risk through adjustment of price  
11 differentials at uniform rate across regional markets. The regional markets could be more  
12 integrated, and the government could achieve the objectives of agricultural price policy by  
13 limiting its direct intervention in the food grain markets, but increasing its attention to  
14 provisioning of physical and institutional infrastructure development needed for  
15 strengthening the spatial integration of food grain markets. Reliance on direct intervention of  
16 the government in the food grain markets can be reduced significantly, if the government  
17 promotes efficient trading in food grains by removing unnecessary restrictions on inter-  
18 regional trade, improves the transport and communication networks, and provides storage  
19 facilities and short- and long-term finances to private traders.<sup>7</sup>  
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## End Notes

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1. A definition of market integration with testable components has proven to be difficult (Gonzalez-Rivera and Helfand 2001). Asche *et al.* (1999) argue that definitions of the market provided by Cournot, Marshall and Stiglitz are based on the relationships between prices. The definitions state that markets are integrated when prices move proportionally to each other over time (Asche *et al.* 1999, Asche *et al.* 2001).

2. It turns out that the standard lag selection procedures used in specifying the ADF regression tend to underfit, that is, choose too small a lag length, creating additional size distortion in unit root tests. Following the recommendation by Ng and Perron (2001) the Modified AIC is chosen for lag selection in the unit root tests only, to minimise this problem.

3. To our knowledge, in a multivariate framework, such tests of directional asymmetry do not exist.

4. To an extent, this is based on Mukim *et al.*'s (2009) observation that the nature and extent of integration between markets depends on the factors like (i) the level of transaction costs determined primarily by transport and communication infrastructure and contract enforcement mechanism; (ii) the degree of perfection of knowledge regarding market condition; and (iii) storage facilities.

5. The M-TAR model picks up directional asymmetry, that is, if the price differential is increasing so that it exceeds the threshold, then the rate of adjustment is different to that when the price differential is decreasing. This momentum approach cannot be incorporated in the threshold framework by Hansen and Seo (2002). However, the TAR approach due to Hansen and Seo (2002) was examined and there was no evidence of threshold effects. Results are available from the authors on request.

6. The markets, in which prices evolve independently over time, could possibly be in the surplus regions in comparison to other markets. However, lack of information on whether these markets belong to surplus or deficit regions does not allow empirical testing of the proposition.

7. The Indian government has been implementing various policy reforms in agriculture since the mid-1990s, but mostly from 2001-02. Some of them are in the direction suggested by the results of our study. Domestic market reforms were introduced to improve the efficiency of the marketing system, to attract private investment in agriculture and to allow private sector to contribute its best to the markets. These include, among others, amendments of Agricultural Produce Marketing Regulations (APMR) Act and Essential Commodities Act 1955, creation of network of regulated markets, withdrawal of the restrictions on inter-regional movement of farm produce, removal of the licensing requirements and stocking limits for wholesale and retail trade, abolition of selective credit controls, curtailment of State trading activities and restructuring of the PDS. Some of the reforms are in tune with the recommendations of the World Bank (1999).

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Tables in main text.

Table 1: Unit Root Tests					
Market Centers	ADF		Elliot et. al.	Perron–Ng	
	Level	First-Difference	ERS	MZa	MZt
Ambala	–1.68 (10)	–18.17(0)**	–1.71 (10)	–5.21 (10)	–1.58 (10)
Karnal	–1.55 (10)	–14.07(0)**	–1.67 (10)	–4.81 (10)	–1.49 (10)
Rohtak	–1.26 (10)	–14.39(0)**	–1.55 (10)	–3.96 (10)	–1.35 (10)
Sonepat	–2.21(9)	–15.25(0)**	–1.86 (9)	–6.53 (9)	–1.79 (9)
Barnala	–1.92 (10)	–16.02(0)**	–1.66 (10)	–4.59 (10)	–1.49 (10)
Jalandhar	–1.19 (10)	–15.84(0)**	–1.64 (12)	–4.84 (12)	–1.51 (12)
Ludhiana	–1.70 (11)	–17.43(0)**	–1.81 (9)	–5.11 (9)	–1.58 (9)
Amritsar	–2.02 (10)	–15.76(0)**	–1.78 (10)	–5.68 (10)	–1.67 (10)
Baharaich	–2.06 (10)	–15.01(0)**	–1.99 (10)	–8.28 (10)	–1.99 (10)
Gorakhpur	–2.01 (11)	–14.76(0)**	–2.84 (12)	–16.03 (12)	–2.82 (12)
Jhansi	–2.25 (8)	–14.20(0)**	–2.36 (8)	–12.01 (8)	–2.42 (8)
Kalpi	–4.10 (0) **	NA	–4.09 (0)**	–29.89 (0)**	–3.82(0)**
Alwar	–3.93 (0)**	NA	–3.80 (0)**	–26.74 (0)**	–3.57(0)**
Bharatpur	–2.91 (4)	–11.07(1)**	–2.88 (4)	–19.46 (4)**	–3.00 (4)**
Jaipur	–2.19 (9)	–11.40(1)**	–2.49 (7)	–14.43 (7)	–2.66 (4)
Jodhpur	–2.69 (3)	–19.84(0)**	–2.77 (3)	–15.37 (3)	–2.64 (3)
Kota	–4.28 (0)**	NA	–4.28 (0)**	–32.4 (0)**	–3.96(0)**
Sriganganagar	–2.02 (9)	–11.55(1)**	–2.20 (9)	–9.15 (9)	–2.11 (9)

*Notes:* \*\*, and \* denote significance at the 1% and 5% levels, respectively. The numbers in parentheses denote the lag length chosen according to the modified Akaike Information Criterion. NA implies not applicable.

Table 2: Cointegration Tests

Market Pairs	EG	$\zeta_1$	$\zeta_2$	$\tau$	$\Phi$	$H_0 : [\zeta_1 = \zeta_2]$	LB-Q
<b>Haryana</b>							
Ambala/Karnal	-8.34 <sup>a</sup>	-0.94 <sup>a</sup>	-0.67 <sup>a</sup>	0.021	84.64 <sup>a</sup>	4.27[0.04]	4.19[0.38]
Ambala/Rohtak	-13.61 <sup>a</sup>	-0.96 <sup>a</sup>	-0.76 <sup>a</sup>	0.022	94.39 <sup>a</sup>	2.31[0.13]	2.21[0.69]
Ambala/Sonepat	-8.37 <sup>a</sup>	-0.72 <sup>a</sup>	-0.96 <sup>a</sup>	-0.055	74.72 <sup>a</sup>	2.56[0.11]	2.95[0.56]
Karnal/Rohtak	-10.44 <sup>a</sup>	-0.51 <sup>a</sup>	-0.68 <sup>a</sup>	0.048	55.23 <sup>a</sup>	1.26[0.26]	2.10[0.71]
Rohtak/Sonepat	-10.73 <sup>a</sup>	-0.84 <sup>a</sup>	-0.56 <sup>a</sup>	0.051	60.67 <sup>a</sup>	4.46[0.03]	1.04[0.90]
Karnal/Sonepat	-9.01 <sup>a</sup>	-0.42 <sup>a</sup>	-0.69 <sup>a</sup>	-0.026	44.11 <sup>a</sup>	5.34[0.02]	2.48[0.64]
<b>Punjab</b>							
	EG	$\zeta_1$	$\zeta_2$	$\tau$	$\Phi$	$H_0 : [\zeta_1 = \zeta_2]$	LB-Q
Barnala/Jalandhar	-9.98 <sup>a</sup>	-0.52 <sup>a</sup>	-0.76 <sup>a</sup>	-0.053	52.16 <sup>a</sup>	3.47 [0.06]	5.21[0.26]
Barnala/Ludhiana	-10.03 <sup>a</sup>	-0.54 <sup>a</sup>	-0.74 <sup>a</sup>	-0.051	51.9 <sup>a</sup>	2.53 [0.11]	3.97[0.41]
Barnala/Amritsar	-8.90 <sup>a</sup>	-0.38 <sup>a</sup>	-0.64 <sup>a</sup>	-0.009	42.97 <sup>a</sup>	5.22 [0.02]	4.31[0.36]
Jalandhar/Ludhiana	-8.72 <sup>a</sup>	-0.37 <sup>a</sup>	-0.82 <sup>a</sup>	-0.018	46.42 <sup>a</sup>	12.77[0.00]	1.59[0.81]
Jalandhar/Amritsar	-10.08 <sup>a</sup>	-0.61 <sup>a</sup>	-0.72 <sup>a</sup>	0.050	58.96 <sup>a</sup>	0.85 [0.35]	2.06[0.72]
Ludhiana/Amritsar	-8.17 <sup>a</sup>	-0.65 <sup>a</sup>	-0.20 <sup>b</sup>	-0.031	44.85 <sup>a</sup>	17.95[0.00]	3.04[0.55]
<b>Uttar Pradesh</b>							
	EG	$\zeta_1$	$\zeta_2$	$\tau$	$\Phi$	$H_0 : [\zeta_1 = \zeta_2]$	LB-Q
Baharaich/Gorakhpur	-6.97 <sup>a</sup>	-0.21 <sup>a</sup>	-0.46 <sup>a</sup>	0.007	28.03 <sup>a</sup>	6.35[0.01]	3.53[0.47]
Baharaich/Jhansi	-5.83 <sup>a</sup>	-0.85 <sup>a</sup>	-0.32 <sup>a</sup>	0.069	38.74 <sup>a</sup>	14.28[0.00]	5.62[0.23]
Gorakhpur/Jhansi	-8.23 <sup>a</sup>	-0.49 <sup>a</sup>	-0.33 <sup>a</sup>	-0.041	34.94 <sup>a</sup>	1.91[0.17]	4.71[0.32]
<b>Rajasthan</b>							
	EG	$\zeta_1$	$\zeta_2$	$\tau$	$\Phi$	$H_0 : [\zeta_1 = \zeta_2]$	LB-Q
Jaipur/Jodhpur	-6.21 <sup>a</sup>	-0.43 <sup>a</sup>	-0.19 <sup>a</sup>	0.027	23.07 <sup>a</sup>	6.59[0.01]	4.92[0.29]
Jaipur/Sriganganagar	-5.19 <sup>a</sup>	-0.21 <sup>b</sup>	-0.33 <sup>a</sup>	0.019	14.05 <sup>a</sup>	1.08[0.29]	1.09[0.89]
Jodhpur/Sriganganagar	-9.41 <sup>a</sup>	-0.62 <sup>a</sup>	-0.45 <sup>a</sup>	-0.014	45.64 <sup>a</sup>	2.17[0.14]	2.04[0.72]

**Notes:** <sup>a</sup> and <sup>b</sup> denote significance at the 1% and 5% levels, respectively. The numbers in square brackets denote probability values. The column heading EG refers to the Engle-Granger test for cointegration.  $\zeta_1$  and  $\zeta_2$  denote the autoregressive decay of the M-TAR model and the estimates of these parameters are reported under these columns.  $\Phi$  denotes the hypothesis of no cointegration which is an F test under the null  $H_0 : [\zeta_1 = \zeta_2 = 0]$ .  $H_0 : [\zeta_1 = \zeta_2]$  denotes the null hypothesis of symmetry.  $\tau$  denotes the estimated threshold. The final column reports the results of the Ljung Box Q statistic for serial correlation.

Table 3: Threshold ECM and Symmetric ECM Results

	Ambala/ Rohtak		Ambala/ Sonepat		Karnal/ Rohtak		Barnala/ Jalandhar		Barnala/ Ludhiana		Jalandhar/ Amritsar		Gorakhpur /Jhansi		Jaipur/ Sriganganagar		Sriganganagar/ Jodhpur	
	$\Delta P_t^A$	$\Delta P_t^R$	$\Delta P_t^A$	$\Delta P_t^S$	$\Delta P_t^K$	$\Delta P_t^R$	$\Delta P_t^B$	$\Delta P_t^J$	$\Delta P_t^B$	$\Delta P_t^L$	$\Delta P_t^J$	$\Delta P_t^A$	$\Delta P_t^G$	$\Delta P_t^J$	$\Delta P_t^J$	$\Delta P_t^S$	$\Delta P_t^S$	$\Delta P_t^{JO}$
$EC_{t-1}^+$	-0.37 (2.65)	0.43 (1.07)	-0.38 (2.40)	0.29 (2.15)	-0.28 (1.85)	0.27 (1.69)	-0.16 (1.28)	0.31 (2.10)	0.11 (0.97)	-0.48 (3.71)	0.19 (1.19)	-0.36 (2.19)	-0.31 (4.03)	0.09 (1.38)	-0.13 (2.63)	0.13 (2.74)	0.34 (4.38)	-0.27 (3.72)
$EC_{t-1}^-$	NA	NA	NA	NA	NA	NA	-0.45 (2.53)	0.21 (1.01)	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
$\Delta P_{t-1}^i$	-0.17 (1.34)	-0.04 (0.37)	-0.09 (0.63)	0.05 (0.39)	0.01 (0.05)	0.11 (0.71)	0.003 (0.02)	0.17 (1.14)	-0.06 (0.55)	-0.02 (0.17)	-0.24 (1.51)	0.11 (0.68)	-0.13 (1.50)	-0.18 (2.33)	-0.16 (2.27)	0.13 (1.93)	-0.23 (2.76)	-0.19 (2.41)
$\Delta P_{t-2}^i$	-0.06 (0.70)	-0.10 (1.18)	-0.01 (0.06)	-0.01 (0.03)	-0.16 (1.22)	-0.08 (0.57)	-0.06 (0.46)	0.05 (0.38)	-0.16 (1.44)	-0.21 (1.60)	-0.29 (1.91)	0.08 (0.57)	-0.12 (1.59)	-0.15 (2.23)	-0.02 (0.27)	-0.03 (0.50)	-0.18 (2.29)	-0.10 (1.38)
$\Delta P_{t-3}^i$			-0.12 (0.96)	-0.07 (0.67)	-0.07 (0.70)	0.02 (0.15)	0.01 (0.04)	0.03 (0.23)	0.03 (0.36)	-0.06 (0.51)	-0.06 (0.49)	-0.12 (0.91)					-0.14 (2.02)	-0.21 (3.13)
$\Delta P_{t-4}^i$			-0.10 (1.04)	-0.11 (1.32)			-0.35 (3.53)	-0.40 (3.39)	-0.21 (2.28)	-0.11 (1.08)	-0.14 (1.33)	-0.07 (0.68)						
$\Delta P_{t-1}^j$	0.18 (1.47)	0.18 (1.62)	0.07 (0.43)	-0.01 (0.04)	0.13 (0.89)	0.03 (0.18)	-0.05 (0.38)	-0.11 (0.74)	0.02 (0.14)	-0.02 (0.02)	0.24 (1.52)	-0.14 (0.90)	0.42 (4.12)	-0.21 (2.28)	0.11 (1.37)	-0.14 (1.91)	0.05 (0.62)	
$\Delta P_{t-2}^j$	-0.04 (0.41)	-0.06 (0.69)	-0.09 (0.68)	-0.07 (0.58)	-0.02 (0.13)	-0.11 (0.83)	-0.06 (0.56)	-0.05 (0.47)	0.11 (1.16)	0.13 (1.16)	0.17 (1.17)	-0.15 (0.99)	0.11 (1.07)	0.02 (0.17)	0.20 (2.78)	0.03 (0.46)	0.20 (2.45)	0.03 (0.49)
$\Delta P_{t-3}^j$			0.06 (0.53)	0.06 (0.57)	-0.01 (0.08)	-0.09 (0.80)	-0.10 (0.98)	-0.05 (0.47)	-0.13 (1.40)	-0.06 (0.55)	-0.06 (0.48)	-0.04 (0.31)					0.09 (1.31)	-0.06 (0.96)
$\Delta P_{t-4}^j$			-0.06 (0.65)	-0.10 (1.12)			0.03 (0.34)	0.09 (0.47)	-0.11 (1.40)	-0.12 (1.37)	-0.02 (0.19)	-0.08 (0.77)						
LB(4)	3.37 [0.49]	3.48 [0.47]	0.91 [0.92]	1.26 [0.87]	10.5 [0.64]	3.66 [0.45]	2.63 [0.61]	1.49 [0.82]	2.59 [0.63]	1.46 [0.83]	2.49 [0.64]	1.38 [0.84]	0.33 [0.98]	2.74 [0.60]	1.38 [0.84]	4.46 [0.34]	0.13 [0.99]	0.90 [0.92]
G.C	2.05 [0.13]	0.82 [0.43]	0.89 [0.46]	0.74 [0.56]	0.56 [0.64]	0.69 [0.56]	0.51 [0.73]	4.25 [0.00]	2.45 [0.04]	0.98 [0.41]	1.42 [0.22]	0.41 [0.80]	8.51 [0.00]	3.94 [0.02]	3.98 [0.02]	2.65 [0.07]	3.24 [0.02]	0.63 [0.59]

Table 3 (contd): Threshold ECM and Symmetric ECM Results

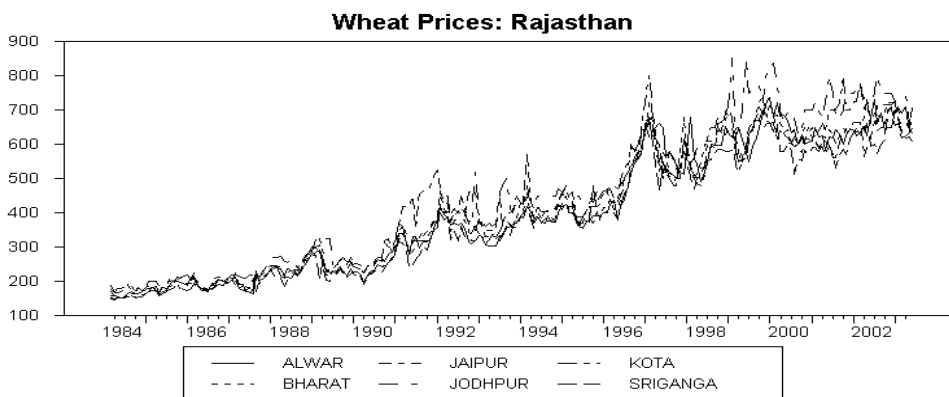
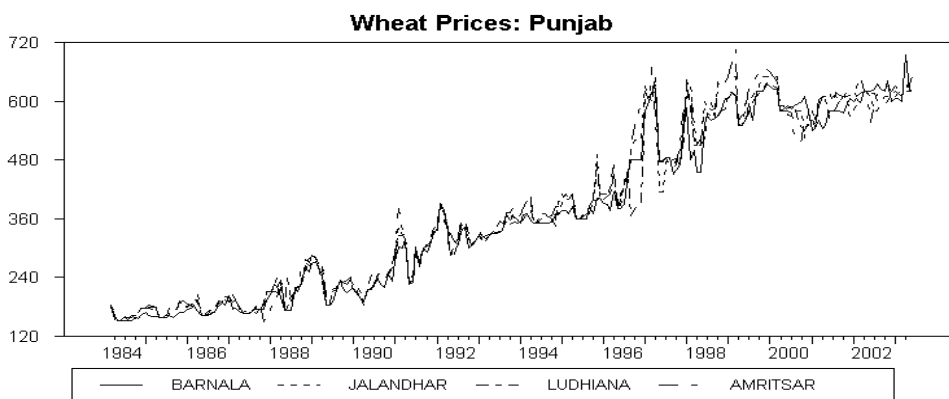
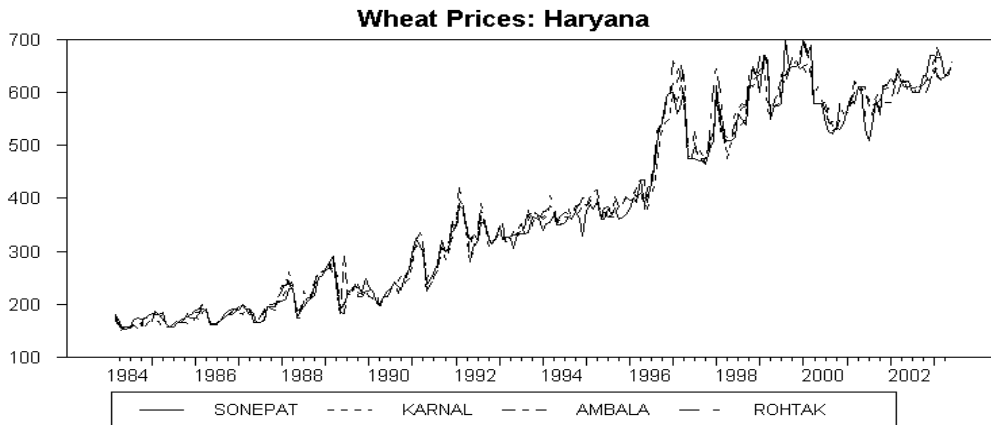
	Ambala/ Karnal		Rohtak/ Sonapat		Karnal/ Sonapat		Barnala/ Amritsar		Jalandhar/ Ludhiana		Ludhiana/ Amritsar		Baharaich/ Gorakhpur		Baharaich/ Jhansi		Jaipur/ Jodhpur	
	$\Delta P_t^A$	$\Delta P_t^K$	$\Delta P_t^R$	$\Delta P_t^S$	$\Delta P_t^K$	$\Delta P_t^S$	$\Delta P_t^B$	$\Delta P_t^A$	$\Delta P_t^J$	$\Delta P_t^L$	$\Delta P_t^L$	$\Delta P_t^A$	$\Delta P_t^B$	$\Delta P_t^G$	$\Delta P_t^B$	$\Delta P_t^J$	$\Delta P_t^{JA}$	$\Delta P_t^{JO}$
$EC_{t-1}^+$	-0.68 (2.82)	0.22 (1.07)	-0.22 (1.10)	0.43 (2.38)	-0.12 (0.85)	0.23 (1.67)	-0.10 (0.82)	0.21 (1.51)	-0.09 (0.68)	0.37 (2.70)	-0.39 (3.45)	0.20 (1.70)	0.09 (0.99)	0.19 (1.97)	-0.42 (2.72)	0.32 (2.34)	-0.23 (3.16)	0.13 (1.96)
$EC_{t-1}^-$	-0.21 (0.97)	0.45 (2.38)	-0.28 (1.91)	0.12 (0.91)	-0.36 (1.99)	0.24 (1.36)	-0.29 (2.53)	0.30 (2.18)	-0.56 (2.64)	0.37 (1.79)	-0.02 (0.14)	0.14 (0.28)	-0.22 (2.45)	0.13 (1.41)	-0.10 (1.47)	0.15 (2.53)	-0.05 (0.96)	0.09 (1.66)
$\Delta P_{t-1}^i$	-0.06 (0.31)	0.001 (0.01)	0.05 (0.37)	0.24 (1.79)	0.16 (1.20)	0.26 (1.96)	-0.10 (0.98)	0.06 (0.52)	0.09 (0.68)	-0.06 (0.45)	-0.14 (1.37)	-0.09 (0.84)	0.09 (0.94)	0.37 (3.59)	-0.05 (0.59)	0.08 (1.09)	-0.05 (0.69)	0.07 (1.06)
$\Delta P_{t-2}^i$	0.09 (0.51)	-0.03 (0.20)	-0.19 (1.43)	-0.01 (0.08)	-0.22 (1.67)	-0.05 (0.39)	-0.10 (0.96)	-0.01 (0.03)	-0.16 (1.29)	-0.28 (2.21)	-0.08 (0.81)	-0.02 (0.28)	0.06 (0.63)	0.25 (2.48)	-0.12 (1.59)	-0.08 (1.30)	0.10 (1.34)	0.15 (2.25)
$\Delta P_{t-3}^i$	0.16 (1.06)	-0.01 (0.09)	-0.16 (1.33)	-0.01 (0.13)	-0.12 (1.02)	-0.07 (0.64)	0.07 (0.73)	0.07 (0.62)	0.04 (0.36)	-0.05 (0.42)	-0.11 (1.19)	-0.15 (1.62)	0.15 (1.58)	0.17 (1.80)			0.06 (0.89)	0.04 (0.63)
$\Delta P_{t-4}^i$	0.11 (0.93)	-0.02 (0.22)	-0.12 (1.14)	-0.09 (0.99)	-0.20 (1.84)	-0.12 (1.16)	-0.34 (3.83)	-0.30 (2.82)	0.15 (1.42)	0.08 (0.77)	-0.27 (3.24)	-0.14 (1.59)						
$\Delta P_{t-1}^j$	0.02 (0.13)	0.08 (0.48)	0.07 (0.52)	-0.15 (1.12)	-0.07 (0.54)	-0.17 (1.27)	0.09 (0.90)	-0.01 (0.05)	-0.15 (1.07)	-0.06 (0.47)	0.05 (0.53)	0.03 (0.35)	-0.09 (0.98)	-0.25 (2.59)	0.31 (3.35)	0.09 (1.14)	-0.16 (2.04)	-0.32 (4.39)
$\Delta P_{t-2}^j$	-0.22 (1.28)	-0.14 (0.97)	0.01 (0.05)	-0.13 (1.03)	0.06 (0.48)	-0.05 (0.39)	0.003 (0.03)	-0.02 (0.21)	0.06 (0.53)	0.18 (1.45)	0.06 (0.62)	0.01 (0.09)	-0.21 (2.30)	-0.34 (3.67)	0.03 (0.39)	-0.15 (1.98)	-0.08 (1.09)	-0.21 (2.91)
$\Delta P_{t-3}^j$	-0.27 (1.72)	-0.08 (0.62)	0.10 (0.84)	0.03 (0.32)	0.04 (0.40)	0.07 (0.63)	-0.20 (2.21)	-0.17 (1.58)	-0.12 (1.02)	-0.08 (0.69)	-0.06 (0.70)	-0.06 (0.60)	-0.19 (2.31)	-0.22 (2.64)			-0.06 (0.86)	-0.27 (4.01)
$\Delta P_{t-4}^j$	-0.22 (1.86)	-0.15 (1.42)	-0.01 (0.13)	-0.11 (1.22)	0.003 (0.03)	-0.05 (0.55)	0.04 (0.58)	0.06 (0.66)	-0.42 (4.01)	-0.32 (3.02)	0.12 (0.16)	-0.31 (0.34)						
LB(4)	0.77 [0.94]	1.63 [0.80]	0.77 [0.94]	1.39 [0.84]	1.92 [0.75]	0.96 [0.91]	1.93 [0.74]	0.67 [0.95]	2.58 [0.62]	2.34 [0.67]	0.81 [0.93]	1.68 [0.79]	3.93 [0.41]	1.38 [0.84]	5.54 [0.23]	6.55 [0.16]	1.62 [0.80]	0.21 [0.99]
G.C	1.87 [0.11]	0.04 [0.99]	0.42 [0.79]	2.00 [0.09]	0.39 [0.81]	2.63 [0.03]	2.92 [0.02]	2.96 [0.02]	4.85 [0.00]	2.13 [0.07]	1.01 [0.40]	1.11 [0.35]	2.71 [0.04]	4.82 [0.00]	5.78 [0.00]	2.32 [0.10]	1.47 [0.22]	1.73 [0.16]

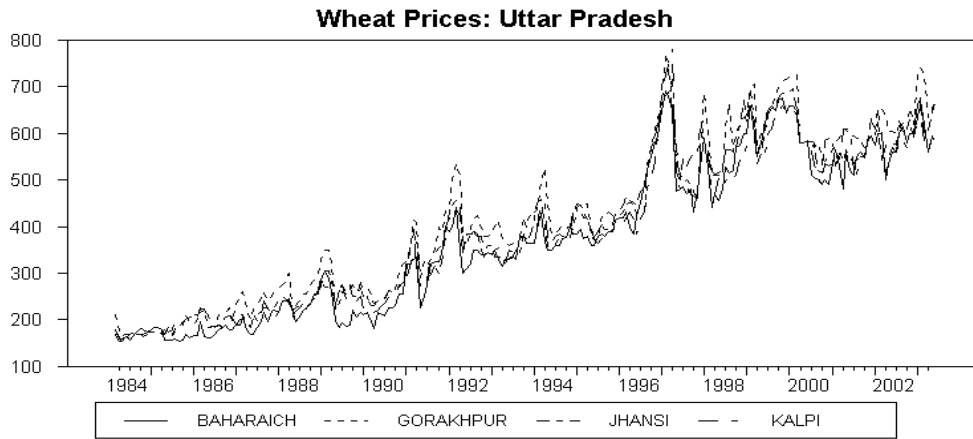
The numbers in parentheses denote the t-ratios, and the numbers in square brackets denote p-values. LB denotes the Ljung Box Q statistic where the lag length is set equal to 4. G.C. denotes the Granger causality test. Where columns denote NA (not applicable) for  $EC_{t-1}$ , we are dealing with symmetric Error Correction Models and positive or negative deviations do not apply in these cases.  $EC_{t-1}^+$  and  $EC_{t-1}^-$  refer to positive and negative changes in the error terms.

Table in Appendix

Table A: Descriptive Statistics							
Market Centers	Moments of the Wheat prices				Volatility of the Wheat Prices		
	Mean	Standard Deviation	Skewness	Kurtosis	Volatility	Adjusted Volatility	ARMA (p,q)
Ambala	382.98	171.17	0.23	1.58	0.077	0.066	(0,1)
Karnal	377.87	170.79	0.24	1.58	0.066	0.058	(0,2)
Rohtak	385.82	172.76	0.22	1.58	0.070	0.061	(0,2)
Sonepat	379.18	169.86	0.31	1.68	0.066	0.058	(0,2)
Barnala	370.83	168.06	0.25	1.60	0.069	0.062	(1,1)
Jalandhar	380.73	170.49	0.23	1.56	0.082	0.068	(0,2)
Ludhiana	376.11	165.80	0.25	1.59	0.082	0.071	(1,1)
Amritsar	383.06	173.98	0.24	1.59	0.079	0.070	(1,1)
Baharaich	376.56	163.20	0.23	1.73	0.078	0.069	(0,1)
Gorakhpur	417.04	169.08	0.16	1.78	0.087	0.072	(0,2)
Jhansi	399.67	165.86	0.20	1.71	0.067	0.061	(0,0)
Kalpi	387.83	156.64	0.21	1.86	0.072	0.068	(0,0)
Alwar	401.87	182.77	0.28	1.60	0.062	0.058	(0,0)
Bharatpur	404.43	183.88	0.23	1.61	0.067	0.064	(0,0)
Jaipur	420.02	173.33	0.07	1.67	0.078	0.071	(0,1)
Jodhpur	446.13	200.60	0.30	1.76	0.076	0.067	(3,0)
Kota	418.34	188.11	0.25	1.70	0.068	0.063	(0,0)
Sriganganagar	384.98	170.23	0.23	1.62	0.074	0.068	(0,1)

Figure 1. Wheat Prices in Four States: Haryana, Punjab, Rajasthan and Uttar Pradesh





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## Appendix

### *Description of Data*

The choice of the states and the market centres from each state was constrained by the availability of consistent data for the period. On that basis, the following market centres are chosen: Ambala, Karnal, Rohtak and Sonapat from Haryana; Amritsar, Barnala, Jalandhar and Ludhiana from Punjab; Alwar, Bharatpur, Jaipur, Jodhpur, Kota and Sriganganagar from Rajasthan; Bahraich, Gorakhpur, Jhansi and Kalpi from UP. The price series of the *Mexican* variety reported in Ambala, Karnal, Rohtak and Sonapat are used for Haryana. For Punjab, the price series of the *WL-711/Kalyan* variety quoted in Amritsar, Barnala, Jalandhar and Ludhiana are used. For Rajasthan, we have used the price series of the *Mexican* variety collected from six market centres viz., Alwar, Bharatpur, Jaipur, Jodhpur, Kota and Sriganganagar. Finally, for UP, the price series of the *Mexican/FAQ* variety quoted in Bahraich, Gorakhpur, Jhansi and Kalpi are used.

An analysis of the descriptive statistics of the wheat prices used in this study can be found in Table A. The Table summarises some of the facts about the eighteen prices chosen for this study that we shall make reference to when we discuss the empirical results of the paper.

[Table A about here]

We find from Table A that the average prices of wheat are generally close for the different regions within the states. However, the average wheat prices for different states are noticeably different especially when comparing the price of wheat in Haryana, Punjab and UP, which are relatively lower than those of Rajasthan. This finding may be explained using information on wheat production and procurement in the four states. The data on average production of wheat during the period from 1984-1985 to 2002-2003 revealed that the first three states are the major wheat producing states, accounting for 67.25 per cent of the average wheat production in India (59.64 million tonnes), with UP contributing 34.9 per cent, Punjab 21.44 per cent and Haryana 11.69 per cent. On the other hand, Rajasthan has been a minor wheat producing state, contributing only 8.18 per cent to average wheat production during the same period (see CMIE 2006). The data on average procurement of wheat by government agencies during the period from 1986-1987 to 2002-2003 revealed that while the first three states contributed 95.74 per cent to average wheat procurement in India (11.56 million tonnes) with Punjab accounting for 58.3 per cent, Haryana 26.14

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3 per cent and UP 11.3 per cent, Rajasthan contributed only 2.53 per cent (see  
4 Government of India 2000, 2005). Since procurement is made mostly from the surplus  
5 states, it may be inferred (from the state-wise wheat production and procurement data)  
6 that while Rajasthan was a deficit state, Punjab, Haryana and UP had relatively large  
7 surplus in wheat, which was transported to the deficit states. Under this condition, it  
8 may be argued that average wheat prices would be higher in Rajasthan relative to  
9 those in the surplus states due to, among other things, transfer costs.

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12 One can also notice from Table A that descriptive features of the data are  
13 categorised into their first to fourth order moments and variability. At a general  
14 glance, the mean and the standard deviations of wheat prices in Rajasthan are  
15 relatively higher than those in Punjab, Haryana and UP. All wheat prices demonstrate  
16 positive skewness, implying that there are few downward spikes to match the upward  
17 spikes. However, the upward spikes do not seem to be significantly more pronounced  
18 than the downward spikes given the estimates of skewness. All wheat prices display  
19 significant kurtosis, implying that the distribution of wheat prices have tails that are  
20 thicker than that of the normal distribution.

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23 Given that stochastic trends are found to exist in the commodity prices,  
24 measuring the standard deviation of the logarithm of price differences [that is,  
25  $\ln(P_t/P_{t-1})$ ], would be an appropriate measure for volatility. If one were to adopt this  
26 measure, we find that the volatility ranges from 6.2 per cent to 8.7 per cent. However,  
27 according to Moledina *et. al.* (2004) the stochastic or unpredictable component of the  
28 price process is the appropriate measure of volatility. We find that after controlling for  
29 seasonality and other predictable irregular movements in the data (described by the  
30 ARIMA representation of the data) the volatility only marginally decreases. One can  
31 observe from Table A that the estimated volatility is within the range 5.8 per cent to  
32 7.2 per cent. One may therefore discount the effect of seasonality on price variability  
33 of the Indian wheat prices considered in this study.

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36 The observed differences in the nature of variability of wheat prices across  
37 regions may be explained, drawing inferences from the functioning of grain markets  
38 in India. Marketable produce of food grain generally reaches the ultimate consumer  
39 from the farm gate, passing through various marketing channels involving trading  
40 among farmers, wholesalers, retailers and consumers at various stages (See Chand,  
41 2009 for details).

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3 **Manuscript ID: FJDS-2009-Sep-0042.R2**  
4 **How Integrated is the Indian Wheat Market?**  
5

6 **Response to Referee # 1**

7 Thank you for the positive comments on the manuscript. The following describes responses  
8 to your comments with reference to page numbers and paragraphs in the revised manuscript,  
9 where appropriate changes have been made.  
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11  
12 1. For the ECM we adopt the SBC to determine the lag length. This is the same criterion that  
13 Enders and Granger (1998) choose in their paper as well. For the unit root tests we adopt the  
14 Modified AIC following the recommendation by Ng and Perron (2001). We have added an  
15 end note to make it clear why we make this distinction.  
16

17  
18 2. Thank you for pointing this out. A section of the paragraph was repetitive. This part has  
19 now been removed.  
20

21  
22 3. The sentence has been edited.  
23

24 4. Section 5 has been rewritten to make it short. It now summarizes the main findings and  
25 draws policy implications. Some parts of this section are moved to paragraph 2 (page 2) and  
26 endnotes 4 and 7.  
27

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29 5. The data set used in our study covers the period ending in June 2003. However, the policy  
30 reforms in agriculture by the Indian government have been adopted mostly from 2001-02.  
31 Naturally, the findings of our study should not be interpreted as a consequence of these policy  
32 changes. These policy changes are listed to indicate that some of the policies are in the  
33 direction suggested by the findings of our study. To avoid breaking the flow of the  
34 conclusion, the paragraph is now moved to endnote 7.  
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38 **Response to Referee # 2**

39 Thank you for the positive comments on the manuscript. The following describes responses  
40 to your comments.  
41

42  
43 A significant advantage of the M-TAR model is that it allows for an accumulation of changes  
44 in the price gap above and below the threshold followed by a sharp adjustment to the long run  
45 equilibrium (Abdulai 2006). This type of price adjusting behaviour is consistent with the  
46 arguments made earlier as to how price differentials may respond to poor dissemination of  
47 knowledge regarding market conditions and high transactions costs. In the linear  
48 cointegration framework the underlying assumption is that the tendency to move towards the  
49 long run equilibrium is always present although movement towards equilibrium may not  
50 occur in every period giving rise to short run deviations. Transactions costs may prevent  
51 traders/economic agents from adjusting to any deviations in a continuous fashion. This  
52 limitation is addressed by the M-TAR model which can capture an accumulation of changes  
53 in the price spread below and above the threshold followed by a sharp movement back to the  
54 equilibrium position. When the change in the price spread is decreasing then it is an  
55 indication of an increase in the price of one market relative to another, triggering a response  
56 by economic agents in the latter market to restore the price spread. However, in this  
57 framework, when the change in the price spread is increasing, then it is an indication of a  
58 decrease in the price of one market relative to another, which can trigger a very different  
59 response by economic agents in the latter market to restore the price spread.  
60

A more elaborate discussion is provided on page 6.