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Examining Export Volatility, Structural Breaks in Price Volatility and Linkages between Domestic and Export Prices of Onion in India§

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Abstract

This paper has investigated the export volatility, identified the structural breaks and determined the short-run and long-run relationships between onion export and domestic prices using cointegration and Granger causality test. The study is based on the monthly arrival data of five major regulated markets from three major onion-producing states of India, namely Azadpur from Delhi, Lasalgaon, Pune and Solapur from Maharashtra, Bangalore and Hubli from Karnataka along with the export price. After checking for the presence of seasonal and non-seasonal unit roots, suitable SARIMA model has been applied for modelling the onion export. The ARCH-LM test has been applied to find the presence of conditional heteroscedasticity. To model the conditional heteroscedasticity as well as asymmetricity in volatility, exponential GARCH model has been applied. The analysis of structural breaks in volatility has revealed the situations of price shocks in the years 2007, 2010, 2011 and 2013, when onion prices went abnormally high and created disturbances in the markets. The application of Johansen method of cointegration has revealed that prices in all the markets share stable long-run relationship. The Granger causality test has shown that all the major domestic markets of onion Granger cause export prices on one hand and export prices Granger cause prices in Delhi, Bangalore, Hubli and Solapur markets. These results have been supported by the impulse response function.

Key words: Export volatility, structural breaks, onion price transmission, cointegration, and Granger causality

JEL Classification: Q13, Q17

Introduction

India is the second largest producer of onion in the world. Onion is grown and consumed across the country. It is usually grown in the winter (*rabi*) season in northern parts of the country, but is grown in both *rabi* and *kharif* seasons in the southern and western states of India like Karnataka, Andhra Pradesh, Tamil Nadu, Maharashtra and Gujarat. The onion production in the country has witnessed a spectacular increase. It increased from 4.83 Mt in 2000-01 to 19.36 Mt in 2014-15, exhibiting a growth of 12.71 per cent per year during this period. However, the area under onion has increased only from 0.45 Mha in 2000-01 to 1.19 Mha in 2014-15, indicating that this growth was mainly productivity-driven. Close to 70 per cent of the total onion produced in the country come from Maharashtra, Karnataka, Madhya Pradesh, Gujarat and Bihar. With its contribution of 30 per cent to the total productivity,

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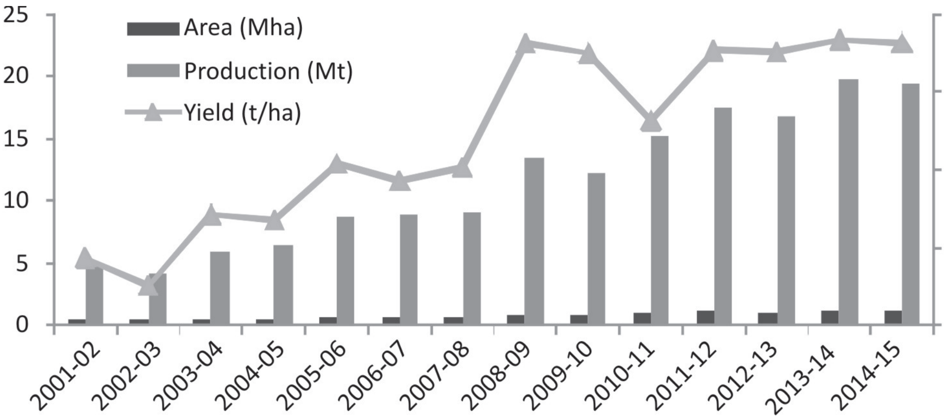

Figure 1. Area, production and productivity of onion in India, 2001-2014

Maharashtra is the highest onion-producing state in India, followed by Karnataka.

Due to the changing consumer tastes and preferences and availability of a wide variety of products in the market with onion as the basic ingredient, the demand for onion has increased not in the urban areas but in the rural areas also. India exports also a sizable quantity of onions to a number of countries, it exported onion worth US$ 322 million in the year 2014-15.

Despite tremendous production growth and trade opportunities, the country suffers from very high volatility in onion production. The problems due weather conditions, pests and diseases, floods, etc. affect the onion production negatively. The country does not follow any mechanism of administered price policy for onion and onion prices are largely determined by the market. These externalities in onion production along with the market dynamics affect the prices and create the situation of price shocks in the country. During the past five years, the country has faced two onion crisis situations, which affected the consumers as well as policymakers in the country. The price fluctuations in onion have a significant effect on the interests of both producers and consumers. The variability in onion prices being a matter of concern in domestic markets as well as international markets, it is important to understand the linkages among markets and nature of volatility in onion prices.

The market integration can be measured in terms of strength and speed of price transmission between markets across various regions of the country (Ghafoor *et al*., 2009). The degree to which consumers and producers would benefit depends on how domestic markets are integrated with world markets and how different regional markets are integrated with each other (Varela *et al*., 2012). Conforti (2004) has indicated a significant degree of linkage between India's domestic and world reference prices; the estimates indicated the evidence of long-run equilibrium in the spatial transmission between domestic and world reference prices of wheat, maize, cassava, milk powder, and to some extent rice also. However, Hazell *et al*. (1990) have argued that fluctuations in world market prices were in general transmitted to country's export unit values, but not to producer prices due to government intervention.

This paper has looked into the export volatility of onion and its price transmission across domestic markets in India using cointegration and Granger causality testing. It has also examined short-term and long-term price movements through error correction mechanism and impulse response analysis in the domestic and export prices.

Data and Methodology

The data from three major onion-marketing states were taken into consideration on the basis of market arrivals in Azadpur market of Delhi, Lasalgaon (Pune) and Solapur markets of Maharashtra and Bangalore and Hubli markets of Karnataka. The monthly data for onion export and domestic prices were collected from the National Horticultural Research and Development Foundation (NHRDF) for the period April, 2005 to December, 2014. All the variables were taken in the natural logarithms to avoid the problems of heteroscedasticity. The information related to area, production and productivity was compiled from NHRDF for the period 2001-02 to 2013-14.

Identification of Structural Breaks

The usual assumption of constant mean and variance over time for a time series data is often violated in practice. Sometimes, the series exhibit an interesting behaviour of stationarity for some time, then suddenly the variability of error-term changes; it stays constant again for some time at this new value, until another change occurs (Ang and Bekaert, 2002). If in the analysis of a series, this factor is not taken into consideration, then results may be misleading (Clements and Hendry, 1998). The change in variance of the series at certain time epochs must be identified whether be a single or multiple.

Many studies are available in literature on identifying the point of changes in a sequence of independent random variables. The detection of change points in a series is very important to correctly interpret the behaviour of the series. In the past, there have been lot of applications of the technique of structural break in stock returns, but there is lack of application to agricultural prices. For a single structural change, At Most One Change Point (AMOC) algorithm has been applied for the identification of structural breaks in onion export prices. The algorithm for detection of multiple change points in a series was first given by Inclan and Tiao (1994) in the form of Iterated Cumulative Sum of Squares (ICSS). In recent years, using this algorithm efficient method for multiple change points detection has been developed as 'Pruned Exact Linear Time' (PELT) by Killick *et al.* (2012). PELT has been applied for the identification of multiple structural breaks in domestic and export prices of onion.

GARCH Model for Estimating Volatility

The GARCH(q) model, proposed by Bollerslev (1986), for the series $\{\varepsilon_t\}$ is defined by specifying the conditional distribution of ε_t given the information available up to time $t-1$. Let ψ_{t-1} denote this information. GARCH (p, q) model for the series $\{\varepsilon_t\}$ is given by $\varepsilon_t|\psi_{t-1}\sim N(0,h_t)$, and the conditional variance h_t is expressed as: $h_t = a_0 + \sum_{i=1}^{q} a_i \varepsilon_{t-i}^2 + \sum_{j=1}^{p} b_j h_{t-j}$. A sufficient condition for the conditional variance to be positive is $a_0 > 0$, $a_i \geq 0$, $i = 1, 2, ..., q$. $b_j \geq 0$, $j = 1, 2, ..., p$. Some applications of GARCH model can be found in Paul *et al*. (2009; 2014) and Paul (2015).

Exponential GARCH (EGARCH) Model

The EGARCH model was developed by Nelson (1991) to allow for asymmetric effects between positive and negative shocks on the conditional variance of future observations. As pointed out by Nelson and Cao (1992), the advantage of EGARCH model is that there are no restrictions on the coefficient of volatility equation, since it is logarithm of conditional variance. In the EGARCH model, the conditional variance, h_t, is an asymmetric function of lagged disturbances. The EGARCH model can be represented by specifying the logarithm of conditional variance as per Equation (1):

$$\ln(h_t) = a_0 + \sum_{i=1}^{p} \beta_i \ln(h_{t-i}) + \sum_{j=1}^{q} \alpha_j \left| \frac{\varepsilon_{t-j}}{\sqrt{h_{t-j}}} \right| + \sum_{k=1}^{r} \gamma_k \frac{\varepsilon_{t-k}}{\sqrt{h_{t-k}}} \qquad \ldots(1)$$

Here, represents the asymmetric coefficient in the model. In most cases, if the association between variance and returns are negative, then its value must be negative and significant. Also, the difference between andcan be expressed as the impact of shock on conditional volatility. Here, coefficient represents the measure of persistency, mostly less than one but as its value approaches unity, the persistence of shock increases. To facilitate the sudden shifts in variance, we can introduce dummy variable in the specification of the model (2):

$$\ln(h_t) = a_0 + \sum_{i=1}^{p} \beta_i \ln(h_{t-i}) + \sum_{j=1}^{q} \alpha_j \left| \frac{\varepsilon_{t-j}}{\sqrt{h_{t-j}}} \right| + \sum_{k=1}^{r} \gamma_k \frac{\varepsilon_{t-k}}{\sqrt{h_{t-k}}} + \sum_{l=1}^{n_c} \phi_l \, DUM_{l,t} \qquad \ldots(2)$$

In this model, n_c are the total number of date-wise shifts, DUM indicates dummy variable considering value 1 as the sudden shift appears in conditional volatility onwards, otherwise it takes the value 0.

Stationarity Test

The first step in the times series analysis, before testing for cointegration and Granger causality, is to examine the stationarity for each individual time series. A series is said to be stationary if the mean and variance of the series are time invariant. If the series are not tested for stationarity, the situation might lead to the problem of spurious regression between variables generated by a non-stationary process. Therefore, stationarity (unit root) test should be carried out to test for the order of integration. In literature, several tests for testing the presence of unit root are available. Among them, Augmented Dickey-Fuller (ADF) unit root test (Dickey and Fuller, 1979) and Philips Perron (PP) test (Philips and Perron, 1988) are most widely used.

Cointegration test

The cointegration depicts the long-term relationship between the variables. It means that even if two or more series are non-stationary, they are said to be co-integrating if there exists a stationary linear combination of them. The Johansen method of cointegration was applied to find the linkages between domestic markets and export prices and also across the domestic markets.

Vector Error Correction Model

Once the series are found to be cointegrated, the next step is to find the short-run relationship along with the speed of adjustment towards equilibrium using error correction model, modified by Engle and Granger (1987). The error correction model may be represented by Equations (3) and (4):

$$\Delta \ln X_t = \alpha_0 + \Sigma\beta_{1i}\Delta \ln Y_{t-1} + \Sigma\beta_{2i}\Delta \ln X_{t-1} + \gamma ECT_{t-1} \quad \ldots(3)$$

$$\Delta \ln Y_t = \beta_0 + \Sigma\alpha_{1i}\Delta \ln X_{t-1} + \Sigma\alpha_{2i}\Delta \ln Y_{t-1} + \gamma ECT_{t-1} \quad \ldots(4)$$

where, ECT_{t-1} is the error correction term lagged one period generated by the error correction model; and γ is the error correction coefficient that measures the response of the regressors in each period to departures from equilibrium.

Negative and statistically significant values of γ depict the speed of adjustment in restoring equilibrium after disequilibria. The presence of ECT_{t-1} reflects the presumption that dependent variable does not adjust instantaneously to its long-run determinants. Therefore, in the short-run an adjustment is made to correct any disequilibrium in the long-run. Hence, the error-correction model shows how system converges to the long-run equilibrium. The lagged explanatory variables represent short- run impact and the long-run impact is given by the error correction term.

Granger Causality

The standard Granger causality test (Granger, 1988) examines how one variable explains the latest value of another variable. It says that if a variable Y is Granger caused by another variable X, then the variable X can be used in predicting the values of Y variable and vice-versa. The null hypothesis (H_0) tested in this case was that the X variable did not Granger cause variable Y and variable Y did not Granger cause variable X. If a variable Granger causes another variable, it means that the lagged value of one variable helps in forecasting the value of another variable and vice-versa.

Impulse Response Function

Mostly, Granger causality tests do not seem to determine the relative strength of causality effects beyond the selected time span. In such circumstances, causality tests are inappropriate because these tests are unable to indicate how much feedback exists from one variable to other beyond the selected sample period (Rahman and Shahbaz, 2013). Perhaps the best way to interpret the implications of the models for patterns of price transmission, causality, and adjustment are to consider the time paths of prices after exogenous shocks; in other words, impulse responses (Vavra and Goodwin, 2005). The impulse response function traces the effect of one standard deviation or one unit shock to one of the variables on the current and future values of all the endogenous variables in a system over various time horizons (Rahman and Shahbaz, 2013). The impulse response functions are applied to examine the extent one standard deviation shock in one of the markets affects the current as well as the future values of other markets.

Results and Discussion

Trends in Onion Exports

India contributes significantly to the world onion trade; it exported 1.2 Mt of fresh onions to the world for ₹ 2,300 crores in the year 2014-15 (APEDA). The share of onions & shallots exports (HS code 070310) in the global exports hovered between 10 and 20 per cent during 2005-2014. Both, world and Indian onion exports have witnessed increasing trends during 2000-2014; with India showing an exponential growth. The

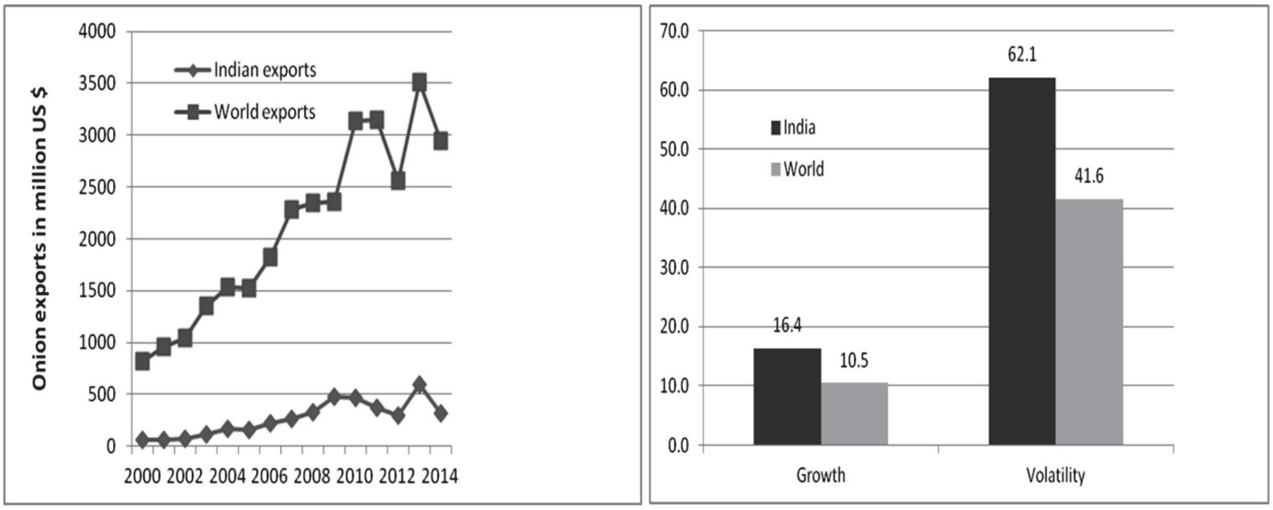

Figure 2. Trends and volatility in onion exports from world and India

Table 1. Export of onion from India and unit value realized, 2010-11 to 2014-15

Particulars	2010-11	2011-12	2012-13	2013-14	2014-15
Value of Indian onion exports (US $ million)	390.4	359.4	361.8	525.0	460.3
Share of onion exports to Indian onion production	7.8	7.5	9.9	7.5	8.4
Share of importing countries					
Bangladesh PR	32.2	22.4	22.2	27.7	31.2
Malaysia	27.6	25.7	25.0	20.1	18.0
Sri Lanka DSR	10.0	10.1	10.4	12.4	12.6
United Arab Emirates	9.3	12.9	12.1	10.4	11.3
Nepal	1.4	2.5	2.0	2.1	5.5
Indonesia	5.3	5.1	3.4	7.6	2.8
Others	14.2	21.2	24.8	19.7	18.5
Unit value realized (US$/t)					
Bangladesh PR	321	257	164	359	260
Malaysia	384	307	235	438	291
Sri Lanka DSR	325	238	252	291	291
United Arab Emirates	286	259	207	319	287
Nepal	185	260	418	280	304
Indonesia	464	375	255	509	182
All countries	330	274	217	354	282

Indian exports have registered the growth of 16.4 per cent per year during 2000 to 2014, whereas the world exports grew @ 10.5 per cent per year (Figure 2). However, the Indian exports of onion were much more volatile, with a coefficient of variation of 62 per cent, whereas the overall world onion exports were quite stable.

The onion exports from India have risen at a much faster rate in recent years due to surge in onion production in the country. The country has exported around 7.5 to 10 per cent of the domestic onion production, largely to the South Asian countries, including Bangladesh, Sri Lanka and Nepal. Bangladesh is the most important destination and captured close to one-third share of the total onion exports from India (Table 1)

Table 1 also provides the unit value realized (UVR) from the exports of onions to various destinations and reveals wide variations in UVR from different countries. Despite Bangladesh being a major importing nation, the UVR was quite low as compared to other importing countries for all the years studied, except in 2013-14. The UVRs from Malaysia and Indonesia have usually been higher than from other importing destinations.

Volatility and Structural Break in Onion Prices

On applying several models, it was found that the onion export price has both seasonal and non-seasonal unit roots. Accordingly, seasonal and non-seasonal differencing was applied to make the series stationary. At the first step, the best seasonal linear time series model was fitted to the onion export data and it was found that SARIMA (3,1,0)(0,1,0) model had the minimum value of Scquartz Bayesian Criteria (SBC). Therefore, SARIMA (3,1,0)(0,1,0) model was selected for modelling the onion export. After fitting the model, the residuals were checked for the presence of autocorrelations and ARCH effect. The ARCH LM test was applied to test the presence of conditional heteroscedasticity. A significant presence of conditional heteroscedasticity was seen at different lags. To accommodate the conditional heteroscedasticity in the model, an important extension of GARCH family of models, viz. Exponential GARCH (EGARCH) model was applied. The parameter estimates of SARIMA (3,1,0) (0,1,0)–EGARCH(1,1) model along with the standard error, t-statistics and probability values are reported in Table 2. The presence of single structural break in the volatility of onion price export was found out using AMOC method. It was observed that during April, 2013, there was a significant presence of structural break in the variance of export price as the Indian economy had witnessed the most violent onion price crises during 2013.

A perusal of Table 2 reveals a difference in the parameter estimates between the EGARCH models without structural break and with structural break. For visual inspection, the observed and predicted prices of onion export by SARIMA-EGARCH model have been depicted in Figure 3. The plots of actual and predicted values of export prices exhibit that the model had clearly captured the volatility in export prices and may further be used for forecasting of UVR.

To find multiple change points in the variance of domestic and export prices of onion, PELT method was used. The location of structural breaks for all the series under consideration is depicted in Figure 4. The number of breaks has been found maximum in the onion price of Solapur market (13), whereas Delhi has shown the minimum (7) number of breaks. The number of structural breaks in the volatility of onion price at Bangalore, Hubli, Lasalgaon, Pune markets and of the

Table 2. Results of SARIMA (3,1,0)(0,1,0) –EGARCH (1,1) model for estimating volatility in onion export prices

Variable	DF	Estimate	Standard error	t-Value	Pr > |t|
Mean equation					
Intercept	1	0.007	0.021	0.356	0.722
AR1	1	0.508	0.066	7.647	<0.001
AR2	1	-0.278	0.062	-4.488	<0.001
AR3	1	-0.147	0.047	-3.124	0.002
Variance equation without structural break					
a_0	1	-5.671	0.296	-19.182	<0.001
β_1	1	0.820	0.217	3.778	<0.001
α_1	1	-0.721	0.087	-8.303	<0.001
γ_1	1	-0.072	0.013	-5.538	<0.001
Variance equation with structural break at April, 2013					
a_0	1	-5.852	0.317	-18.461	<0.001
β_1	1	0.827	0.219	3.776	<0.001
α_1	1	-0.740	0.085	-8.706	<0.001
γ_1	1	-0.076	0.016	-4.750	<0.001

Table 3. Major break points in variance in domestic and export prices of onion in different markets

Year	Markets						
	Delhi	Bangalore	Hubli	Lasalgaon	Pune	Solapur	Export
2007	Oct 2007	Oct 2007	Sep 2007	Oct 2007	Nov 2007	Oct 2007	Nov 2007
2010	Oct 2010	Oct 2010	Aug 2010	Nov 2010	Aug 2010	Aug 2010	Sep 2010
2011	Feb 2011	Feb 2011	Feb 2011	Jan 2011	Feb 2011	Feb 2011	Feb 2011
2013	Dec 2013	Dec 2013	Nov 2013	–	Nov 2013	Dec 2013	Oct 2013

onion export price has been observed as 10, 12, 10, 12 and 8, respectively. The major break points which were common across all the markets along with the export price are reported in Table 3.

A perusal of Table 3 indicates that there was a break during September to November in 2007. Another price shock situation was created in 2010, when the structural breaks were observed during August to November. The most explosive kind of situation was experienced in price rise of onion in 2013 and the breaks were found during October to December. The analysis of structural breaks reveals that the prices in different markets move together. Sometimes, the shocks in prices are transferred to other markets with some lags. Even the export prices follow the situation of shocks in the domestic markets. The causality among the prices in these markets has been discussed later.

Stationarity in Price Series of Onion

The results of the stationarity test are presented in Table 4. According to both ADF and PP tests, series

Table 4. Testing stationarity of seasonally adjusted log prices of onion in different markets

Markets	Level series		I[st] differenced series	
	ADF	PP	ADF	PP
Delhi	-2.251	-2.806	-7.748	-6.974
Bangalore	-2.488	-2.846	-6.719	-7.148
Hubli	-2.258	-2.722	-6.435	-7.022
Lasalgaon	-2.493	-2.805	-7.241	-7.617
Pune	-2.419	-2.823	-7.099	-6.507
Solapur	-2.359	-2.610	-6.452	-7.403
Export price	-2.170	-2.621	-7.142	-6.706

Note: 1 per cent and 5 per cent critical values for ADF test were -3.490 and -2.884; 1 per cent and 5 per cent critical values for PP test were -3.480 and -2.886, respectively

for all markets were found non-stationary at level as the null hypothesis was not rejected at 1 per cent and 5 per cent levels of significance. After the first difference, these series became stationary. So, all the series were

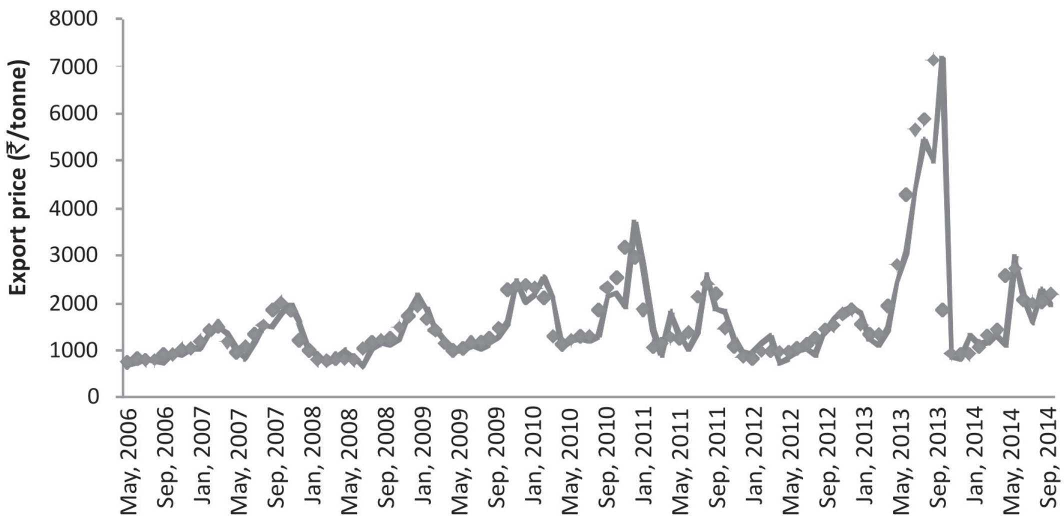

Figure 3. The observed and fitted values of monthly onion exports from India by SARIMA-EGARCH model, May, 2006 to Sept., 2014

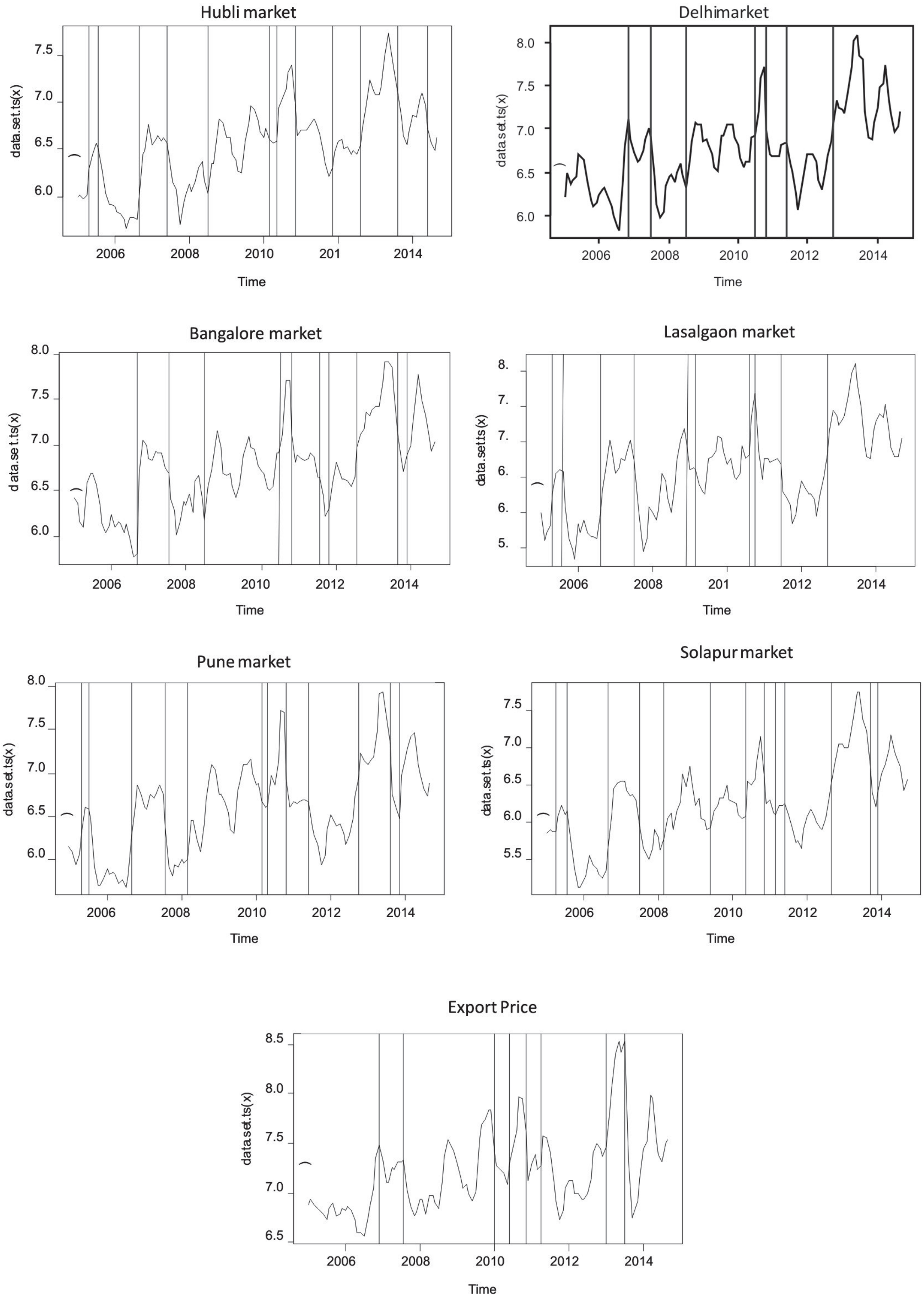

Figure 4. Detection of structural breaks in domestic and export prices of onion: Change points in variance
Note: **The Y axes in all the graphs present the log of prices in ₹/tonne in the respective markets.**

integrated of order 1 and therefore, these can be tested for cointegration.

Examining Cointegration in Onion Prices

The results of Johansen's co-integration test are presented in Table 5. The likelihood ratio (L.R.) indicates that, except for Bangalore and Hubli, there exists one cointegration vector between combinations of two markets each. The first null hypothesis (r=0) is rejected at 5 per cent level of significance. The results have detected at least one cointegration relationship between the prices of domestic markets. Based on trace

Table 5. Cointegration and speed of adjustment among major domestic onion markets

H_0: Rank=r	H_1: Rank>r	Eigen value	Likelihood ratio	Trace test	Speed of adjustment	
Delhi and Bangalore markets					Delhi market	Bangalore market
0	0	0.122	20.386	41.112	14.21	35.12
1	1	0.051	5.845	6.175		
Delhi and Hubli markets					Delhi market	Hubli market
0	0	0.152	27.477	21.906	32.42	12.62
1	1	0.071	8.508	5.343		
Delhi and Lasalgaon markets					Delhi market	Lasalgaon market
0	0	0.190	28.667	37.341	30.49	15.20
1	1	0.044	5.013	6.221		
Delhi and Pune markets					Delhi market	Pune market
0	0	0.059	11.439	28.142	3.3	26.6
1	1	0.041	4.641	6.128		
Delhi and Solapur markets					Delhi market	Solapur market
0	0	0.239	37.431	31.284	58.81	18.17
1	1	0.060	6.897	4.368		
Bangalore and Hubli markets					Bangalore market	Hubli market
0	0	0.197	35.602	28.091	55.01	20.41
1	1	0.086	10.369	5.664		
Bangalore and Lasalgaon markets					Bangalore market	Lasalgaon market
0	0	0.169	26.938	31.402	33.18	12.2
1	1	0.054	6.176	6.340		
Bangalore and Pune markets					Bangalore market	Pune market
0	0	0.135	25.085	28.916	21.72	10.95
1	1	0.072	8.518	6.667		
Bangalore and Solapur markets					Bangalore market	Solapur market
0	0	0.133	21.836	37.358	74.72	22.56
1	1	0.051	5.834	4.422		
Hubli and Lasalgaon markets					Hubli market	Lasalgaon market
0	0	0.149	27.197	24.305	10.62	36.17
1	1	0.072	8.586	5.378		
Hubli and Pune markets					Hubli market	Pune market
0	0	0.171	30.436	25.024	16.51	43.96
1	1	0.075	8.936	5.230		
Hubli and Solapur markets					Hubli market	Solapur market
0	0	0.105	20.292	18.874	20.82	7.01
1	1	0.063	7.511	4.302		

Contd...

Table 5. Cointegration and speed of adjustment among major domestic onion markets — *Contd.*

H_0: Rank=r	H_1: Rank>r	Eigen value	Likelihood ratio	Trace test	Speed of adjustment	
Lasalgaon and Pune markets					Lasalgaon market	Pune market
0	0	0.126	20.534	33.596	17.21	24.68
1	1	0.048	5.467	5.865		
Lasalgaon and Solapur markets					Lasalgaon market	Solapur market
0	0	0.252	38.452	27.607	53.85	11.09
1	1	0.052	5.934	4.394		
Pune and Solapur markets					Pune market	Solapur market
0	0	0.113	20.083	22.662	45.91	13.42
1	1	0.058	6.699	4.458		

Note: 5 per cent critical value of likelihood ratio at rank 1 is 9.24 and 5 per cent critical value of trace at rank 1 is 9.13.

Table 6. Cointegration across the selected onion markets

H_0: Rank=r	H_1: Rank>r	Eigen value	Likelihood ratio	5% critical value	Trace test	5% critical value
0	0	0.416	214.414	131.700	193.736	132.000
1	1	0.373	152.604	102.140	140.729	101.840
2	2	0.286	98.846	76.070	97.389	75.740
3	3	0.210	60.089	53.120	65.747	53.420
4	4	0.131	32.950	34.910	33.295	34.800
5	5	0.078	16.786	19.960	17.102	19.990
6	6	0.063	7.472	9.240	4.968	9.130

statistics, it was observed that there existed 1 co-integration vector between combinations of each pair of markets. The results have detected at least one co-integration relationship between prices of domestic. The acceptance of co-integration between two series implies that there exists a long-run relationship between them and this means that an error-correction model (ECM) exists which combines the long-run relationship with the short-run dynamics of the model. The speed of adjustment reflects the efficiency of the markets in bringing prices to equilibrium. The markets at Delhi, Bangalore, Pune and Lasalgaon have shown a higher speed of adjustment as compared to other markets. This might depend on the inter-linkages across the markets, backward linkages within the value chain, infrastructural condition and also linkages with global markets.

The cointegration analysis has inferred that one series would be helpful in predicting the other series. In a way, it indicates price transmission from one market to the other market. The cointegration has also been investigated among the domestic markets and export price considering all the markets at a time. It has been found that there are 4 cointegrating vectors based on both the trace statistics as well as Likelihood Ratio, as reported in Table 6. Subsequently, vector error correction model (VECM) was applied to compute the short-run relationship and error correction coefficients or speed of adjustment. The speed of adjustment towards equilibrium varied from 7.1 per cent to 26.2 per cent every month.

The short-run equations emerging out from the VECM are given below, where SAPd, SAPb, SAPh, SAPl, SAPp, SAPs stand for seasonally adjusted price in Delhi, Bangalore, Hubli, Lasalgaon, Pune and Solapur markets in current and lag periods converted into natural logarithm. The ECT stands for error correction term. The coefficient of ECT measures the

Table 7. Cointegration and speed of adjustment between major domestic onion markets and export prices of onion

H0: Rank=r	H1: Rank>r	Eigen value	Likelihood ratio	Trace test	Speed of adjustment	
Delhi market and Export price					Delhi market	Export price
0	0	0.181	27.004	31.956	4.6	41.21
1	1	0.041	4.702	6.002		
Bangalore market and Export price					Bangalore market	Export price
0	0	0.217	33.254	30.040	5.67	40.06
1	1	0.050	5.795	6.030		
Hubli market and Export price					Hubli market	Export price
0	0	0.217	32.483	25.873	5.81	46.70
1	1	0.044	5.091	5.234		
Lasalgaon market and Export price					Lasalgaon market	Export price
0	0	0.268	40.806	29.966	03.70	40.65
1	1	0.051	5.840	5.982		
Pune market and Export price					Pune market	Export price
0	0	0.245	36.552	31.443	07.02	47.32
1	1	0.044	5.021	5.660		
Solapur market and Export price					Solapur market	Export price
0	0	0.260	43.489	26.272	3.06	43.27
1	1	0.074	8.832	4.332		

Note: 5 per cent critical value of likelihood ratio at rank 1 is 9.24 and 5 per cent critical value of trace at rank 1 is 9.13.

speed of adjustment in the selected markets which ranged from 7 per cent in Solapur market to 26 % in Bangalore market.

$$\Delta \ln SAPd_t = -0.181ECT_{t-1} - 0.212\Delta \ln SAPd_{t-1} + 0.239\Delta \ln SAPb_{t-1} + 0.054\Delta \ln SAPh_{t-1} - 0.110\Delta \ln SAPl_{t-1} + 0.563\Delta \ln SAPp_{t-1} - 0.058\Delta \ln SAPs_{t-1} \quad \ldots(5)$$

$$\Delta \ln SAPb_t = -0.262ECT_{t-1} + 0.019\Delta \ln SAPd_{t-1} + 0.342\Delta \ln SAPb_{t-1} - 0.173\Delta \ln SAPh_{t-1} - 0.350\Delta \ln SAPl_{t-1} + 0.728\Delta \ln SAPp_{t-1} - 0.052\Delta \ln SAPs_{t-1} \quad \ldots(6)$$

$$\Delta \ln SAPh_t = -0.106ECT_{t-1} + 0.054\Delta \ln SAPd_{t-1} + 0.119\Delta \ln SAPb_{t-1} - 0.217\Delta \ln SAPh_{t-1} - 0.095\Delta \ln SAPl_{t-1} + 0.466\Delta \ln SAPp_{t-1} + 0.032\Delta \ln SAPs_{t-1} \quad \ldots(7)$$

$$\Delta \ln SAPl_t = -0.154ECT_{t-1} - 0.117\Delta \ln SAPd_{t-1} + 0.172\Delta \ln SAPb_{t-1} + 0.037\Delta \ln SAPh_{t-1} - 0.339\Delta \ln SAPl_{t-1} + 0.873\Delta \ln SAPp_{t-1} - 0.067\Delta \ln SAPs_{t-1} \quad \ldots(8)$$

$$\Delta \ln SAPp_t = -0.221ECT_{t-1} - 0.149\Delta \ln SAPd_{t-1} + 0.279\Delta \ln SAPb_{t-1} - 0.034\Delta \ln SAPh_{t-1} - 0.065\Delta \ln SAPl_{t-1} + 0.567\Delta \ln SAPp_{t-1} - 0.160\Delta \ln SAPs_{t-1} \quad \ldots(9)$$

$$\Delta \ln SAPs_t = -0.071ECT_{t-1} + 0.008\Delta \ln SAPd_{t-1} + 0.145\Delta \ln SAPb_{t-1} + 0.238\Delta \ln SAPh_{t-1} - 0.173\Delta \ln SAPl_{t-1} + 0.494\Delta \ln SAPp_{t-1} - 0.169\Delta \ln SAPs_{t-1} \quad \ldots(10)$$

Causality and Impulse Response across Domestic Markets and Export Prices

The Granger causality helps in establishing the direction of causation (if any) between the variables and thus helps in predicting the value of one variable on the basis of other variable. In the present analysis, optimum lag length was selected based on the minimum AIC and SBC criteria. The null hypotheses of the Granger-Causality test are:

H_0: X does not Granger- cause Y

H_1: X does Granger-cause Y

The results of pair-wise Granger causality test are presented in Table 8. If null hypothesis is rejected, then the results are significant. In the case of Delhi with

Table 8. Granger causality testing between domestic market price of onion

Null hypothesis	Lags	F-statistic	Probability
Bangalore does not Granger cause Delhi	2	1.358	0.261
Delhi does not Granger cause Bangalore	2	7.627	0.001
Hubli does not Granger cause Delhi	3	6.043	0.003
Delhi does not Granger cause Hubli	3	8.219	0.000
Lasalgaon does not Granger cause Delhi	2	3.450	0.035
Delhi does not Granger cause Lasalgaon	2	3.245	0.043
Pune does not Granger cause Delhi	2	5.265	0.007
Delhi does not Granger cause Pune	2	0.029	0.972
Solapur does not Granger cause Delhi	3	8.538	0.000
Delhi does not Granger cause Solapur	3	6.296	0.003
Delhi does not Granger cause export price	2	9.543	0.000
Hubli does not Granger cause Bangalore	2	7.221	0.001
Bangalore does not Granger cause Hubli	2	2.633	0.076
Lasalgaon does not Granger cause Bangalore	2	3.336	0.039
Bangalore does not Granger cause Lasalgaon	3	1.751	0.178
Pune does not Granger cause Bangalore	3	8.590	0.000
Bangalore does not Granger cause Pune	3	0.082	0.922
Solapur does not Granger cause Bangalore	3	13.680	0.000
Bangalore does not Granger cause Solapur	2	6.270	0.003
Bangalore does not Granger cause export price	2	5.512	0.005
Lasalgaon does not Granger cause Hubli	2	2.950	0.056
Hubli does not Granger cause Lasalgaon	2	4.314	0.016
Pune does not Granger cause Hubli	2	10.005	0.000
Hubli does not Granger cause Pune	2	2.831	0.063
Solapur does not Granger cause Hubli	2	3.600	0.031
Hubli does not Granger cause Solapur	2	7.102	0.001
Hubli does not Granger cause export price	3	9.975	0.000
Pune does not Granger cause Lasalgaon	3	9.241	0.000
Lasalgaon does not Granger cause Pune	3	0.956	0.388
Solapur does not Granger cause Lasalgaon	3	5.974	0.003
Lasalgaon does not Granger cause Solapur	3	2.579	0.080
Lasalgaon does not Granger cause export price	3	9.596	0.000
Solapur does not Granger cause Pune	2	4.317	0.016
Pune does not Granger cause Solapur	2	9.744	0.000
Pune does not Granger cause export price	2	11.775	0.000
Solapur does not Granger cause export price	2	10.541	0.000

other markets, there was bidirectional causality between Delhi and Hubli markets; Delhi and Lasalgaon markets; Delhi and Solapur markets. It means that Delhi market Granger causes Hubli, Lasalgaon and Solapur markets and Hubli, Lasalgaon and Solapur markets also Granger cause Delhi market. However, there was unidirectional causality between Delhi and Pune markets and Delhi and Bangalore markets. The causality runs from Pune market to Delhi market, whereas Delhi market does not Granger causes Pune market. Also, causality runs from Delhi market to Bangalore market but not the vice-versa.

In the case of Bangalore with other markets, there was bidirectional causality only between Bangalore and Solapur markets. However, there was unidirectional causality between Bangalore and Pune markets;

Table 9. Granger causality testing between export and domestic market prices of onion

Null hypothesis	Lags	F-Statistic	Probability
Export price does not Granger cause Delhi	3	9.247	0.000
Export price does not Granger cause Bangalore	3	3.749	0.027
Export price does not Granger cause Hubli	3	3.379	0.038
Export price does not Granger cause Lasalgaon	3	2.866	0.061
Export price does not Granger cause Pune	3	1.954	0.147
Export price does not Granger cause Solapur	3	7.122	0.001

Bangalore and Delhi markets; Bangalore and Hubli markets and Bangalore and Lasalgaon market. The causality runs from Hubli, Lasalgaon, Pune and Delhi markets to Bangalore markets whereas Bangalore market does not Granger cause Hubli, Lasalgaon, Pune and Delhi markets. In the case of causality between Lasalgaon and other markets, there was bidirectional causality only between Delhi market and Lasalgaon market. However, there was unidirectional causality between Lasalgaon and Pune markets; Lasalgaon and Bangalore markets; Lasalgaon and Hubli markets; and Lasalgaon and Solapur markets. The causality runs from Hubli, Pune and Solapur markets to Lasalgaon market, whereas Lasalgaon market does not Granger cause Hubli, Pune and Solapur markets. Lasalgaon market Granger cause Bangalore market but not the vice-versa.

In the case of Hubli with other markets, there was bidirectional causality between Hubli and Solapur markets and; Hubli and Delhi markets. However, there was unidirectional causality between Hubli and Pune markets; Hubli and Bangalore markets and Hubli and Lasalgaon markets. The causality runs from Pune market to Hubli market but not the vice-versa. In the case of Pune with other market, there was bidirectional causality between Pune and Solapur markets and Pune and Delhi markets. However, there was unidirectional causality between Pune and Hubli markets; Pune and Bangalore markets and Pune and Lasalgaon markets. In case of Solapur with other markets, there was bidirectional causality between Solapur and Pune markets; Solapur and Delhi markets; Solapur and Hubli markets and Solapur and Bangalore markets. However, there was unidirectional causality between Solapur and Lasalgaon markets.

A look at the causality relationship between domestic market and export, reveals the results to be significant. It means that markets at Delhi, Bangalore, Hubli, Lasalgaon, Pune and Solapur Granger cause export. The causality between export prices and domestic markets was also been explored and the results are reported in Table 9. The results, except for Pune and Lasalgaon markets, are significant for all other markets. It means null hypothesis that export does not Granger cause domestic market is rejected in the case of all markets, except for Pune and Lasalgaon markets.

The impulse response functions in terms of Cholesky one standard deviation innovations have clearly shown how and to what extent a one standard deviation shock in one of the markets affects the current as well as the future prices in the other markets. The prices seemed to be transmitted to other markets till 3 lags when a one standard deviation shock was given. After that the response of market to the given shocks seemed to be stabilizing. Although, the response curves, as shown in Figure 5, depict a similar pattern throughout the time horizon, the magnitude of responses has found been to be relatively poor in some market pairs.

Conclusions

This paper has investigated the long-run and short-run relationships between export price and domestic prices of onion. The study on the price transmission and export volatility using SARIMA-EGARCH model has captured the volatility in onion export quite satisfactorily. The analysis of structural breaks in volatility has revealed the situations of price shocks in the years 2007, 2010, 2011 and 2013, when onion prices went abnormally high and created disturbances in the markets. The ADF and PP unit root tests have suggested that the domestic market price series and export price series are integrated of the order one.

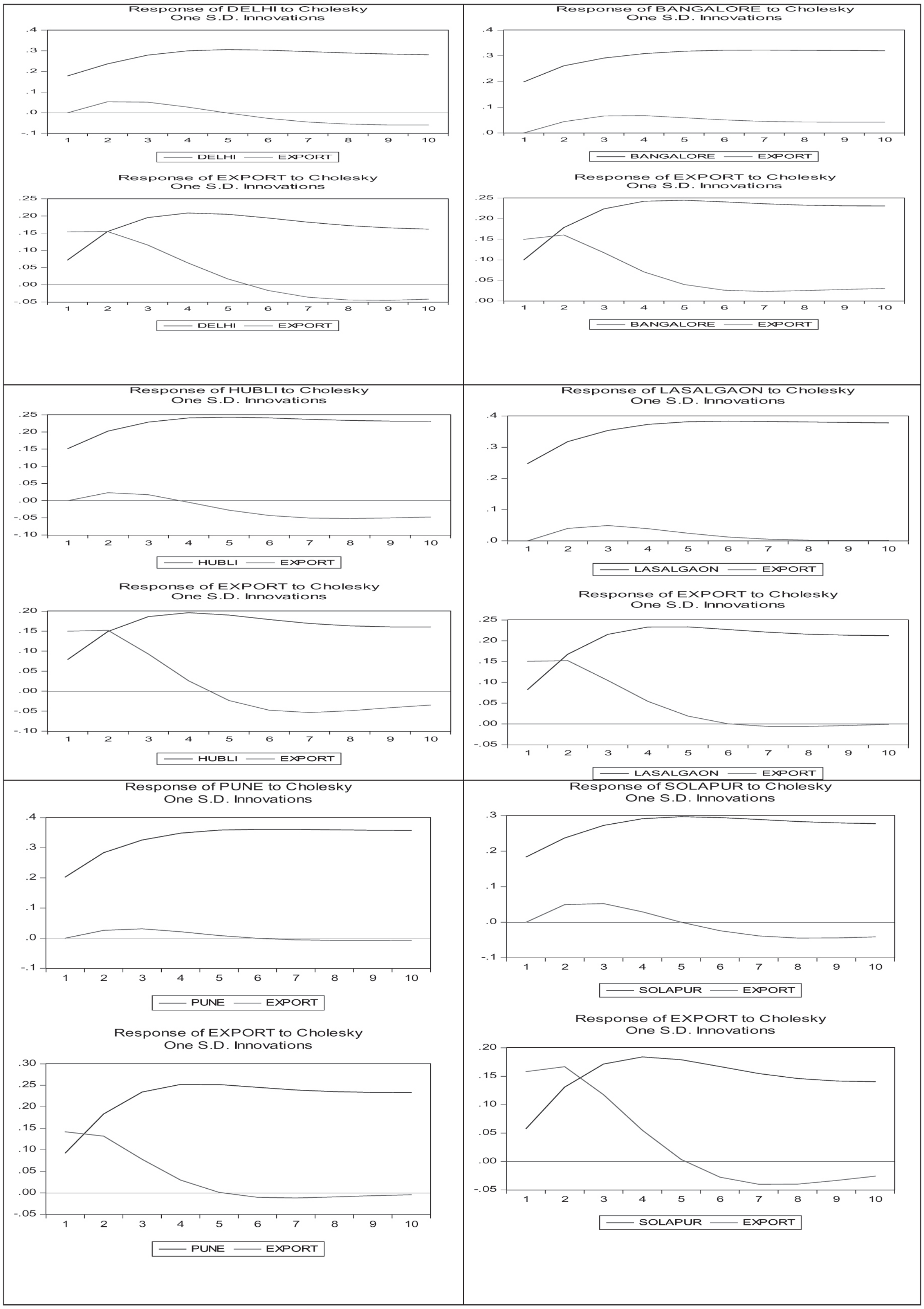

Figure 5. Impulse response curve

After establishing stationarity results, Johansen cointegration test has established the long-term relationships across domestic market prices and also between domestic market prices and exports prices. The Granger causality test has revealed bidirectional causality between the markets at Delhi and Hubli, Delhi and Lasalgaon, Delhi and Solapur, Hubli and Solapur, Pune and Solapur, and Bangalore and Solapur. The remaining markets have been found to share unidirectional causality amongst them. Also, the export prices share bidirectional causality with the markets at Delhi, Bangalore, Hubli and Solapur and unidirectional causality with Pune and Lasalgaon markets. The error correction model has confirmed that the domestic market prices have long- term relationship amongst them and with export prices. Also, they share the short-term relationship. The markets at Delhi, Bangalore, Pune and Lasalgaon have shown higher speed of adjustment as compared to other markets. This might depend upon the inter-linkages among markets, backward linkages within the value chain, infrastructural development and also linkages with global markets. The prices seem to be transmitted to other markets till 3 lags when a one standard deviation shock was given. After that the response of market to the given shocks seems to be stabilizing. Although, the response curves depict a similar pattern throughout the time horizon, the magnitude of responses has been found relatively poor in some market pairs.

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