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# Spatial Differences in Rice Price Volatility: A Case Study of Pakistan 1994–2011

BURHAN AHMAD, OLE GJØLBERG, and MUBASHIR MEHDI

Prices of agricultural commodities tend to be more volatile in comparison to other commodities. Volatility can result in inefficient allocation of the resources by the farmers, traders and consumers. Rice is the second major staple and export item of Pakistan. This study presents the trends in volatility of regional rice markets of Pakistan and analyses spatial differences in volatility across regional rice markets in Pakistan from 1994 to 2011, and also draws comparison of volatility with the international market. ARCH-LM tests are applied to check the presence of volatility and volatility clustering is found in all the markets. Tests for equality of variance and dynamic conditional correlations (DCC) GARCH model are employed to analyse the spatial differences across the regional rice markets of Pakistan. The results indicate the presence of spatial differences in volatility. Positive conditional correlations in the dynamic conditional correlations (DCC) GARCH model are found which indicate positive association of volatility across markets. Spatial differences in volatility and its persistence reflect the differences in market forces, infrastructure and information flow which leads to varying degree of risk across markets and some regions are exposed to higher risk. The study found out that Hyderabad and Sukkur are the most volatile markets and their volatility levels are highly persistent and require highest time to return to its long-term mean which makes them the riskiest rice markets. Investments in infrastructure, particularly in transportation and controlling the market power of middlemen may reduce price risk across markets particularly in the most risky markets.

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*Keywords:* Rice Prices Volatility, Regional Markets, Pakistan. DCC-GARCH-models

## 1. INTRODUCTION

Commodity prices are generally volatile and agricultural commodity prices are typically more volatile than those for example, of metals [Deaton and Laroque (1992); Pindyck (2004); Newbery (1989)]. High volatility poses difficulties in the prediction of agricultural commodity price changes which might exert large impacts on developing economies relying on the agricultural production, export and import of food commodities. Price risk raises problems for the macroeconomic as well as the microeconomic policy [Deaton and Laroque (1992); Stigler (2011)]. The prolonged periods of high volatility raise concerns for the governments, traders, producers and

Burhan Ahmad <burhan_uaf@hotmail.com; burhan_uaf@yahoo.com> is Assistant Professor, Institute of Business Management Sciences (IBMS), Universality of Agriculture Faisalabad, Faisalabad. Ole Gjølberg <ole.gjolberg@nmbu.no> is Professor, NMBU School of Economics and Business, Norwegian University of Life Sciences (NMBU), Norway. Mubashir Mehdi <mubashir_mehdi@hotmail.com> is Assistant Professor, Institute of Business Management Sciences (IBMS), University of Agriculture Faisalabad, Faisalabad.

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consumers [Kroner, *et al.* (1995)]. Persistent high price volatility can increase economic inequality and strengthen poverty traps, particularly in the presence of inadequate liquidity and asset resources [Zimmerman and Carter (2003) in Rapsomanikis ( 2011)].

High food price volatility became a hot issue during and after the 2007-08 food crises, claiming an extra attention of researchers and policy-makers. The World Bank [World Bank (2009)] stated that "*high volatility in the food prices combined with the impact of financial crisis, threatens to further increase food insecurity*". In times of crisis, volatility may be self-leading, i.e., generating cascades of volatility. Such a phenomenon can lead to "herd-like" behaviour where market agents make decisions, following the price trends instead of sticking to market fundamentals [Rapsomanikis (2011)]. Hence, a better understanding of the price volatility is a prerequisite for developing strategies to reduce the negative effects from high volatility and also to devise policies aiming at stabilising commodity prices.

In this article, we analyse price volatility in Pakistan's rice markets, focusing on the regional differences. These differences may convey important information to decision makers at political levels. Bottlenecks in the distribution of goods may be one of the major factors behind spatial differences in price volatility. Hence, the information on price volatility, in general, and on the regional differences in volatility, in particular, can be an important input in view of the political decisions on interventions in transportation and trading infrastructure and policies aiming at the improved functioning of markets.

In Pakistan, rice production is an important part of agriculture, rice being the second largest staple food after wheat and the second largest export item after cotton and cotton products. Rice production covers about 20 percent of the total cropped area under food grains in the country and the rice crop accounts for almost 3.1 percent of the value added in agriculture, contributing to 0.7 percent of GDP [Pakistan (2014); Pakistan (2013)]. Pakistan is a net exporter of rice and earns about 15 percent of its foreign exchange from rice exports [Siddique (2008)]. Paddy rice production in Pakistan contributes 1.3 percent to the global production volume entailing Pakistan to have an 11 percent share of exports of milled rice in the world rice export levels [UN FAO (2010)].

Given the economic importance of the rice sector in Pakistan's economy, it is important to understand the way the rice markets are functioning and the behaviour of prices. In particular, we seek the answers for the following questions:

(1) What is the general trend in rice price volatility in Pakistan's domestic (regional) markets?
(2) Are there any spatial differences in volatility in rice markets across Pakistan?
(3) Are volatilities among the markets correlated?

Two main varieties of rice i.e. Basmati and IRRI are produced in Pakistan. Basmati rice is a long grain fine rice variety having nice aroma and it is produced is mainly in the Punjab province of Pakistan. On the other hand, IRRI rice is a coarse grain variety which is mainly produced in Sindh province of Pakistan [Abdullah, *et al.* (2015)]. Domestic consumption of Basmati rice is higher than IRRI rice while yield, production and exports of IRRI[1] rice are higher than that of Basmati rice [Ahmad and Gjølberg

[1]IRRI6 and IRRI9 coarse rice varieties were developed at the International Rice Research Institute (IRRI) in the Philippines. IRRI9 was developed by crossing the IRRI6 and Basmati rice.

(2015); Pakistan (2013); FAO (2010)]. This study employs monthly wholesale price data from 1994 to 2011 of six major wholesale markets of IRRI rice in Pakistan. In order to enable us to draw international comparisons, the price of Thai 5 percent broken rice is also included in the analysis. Thai 5 percent broken rice is a coarse grain variety similar to IRRI rice and is a close substitute to IRRI rice. Its price has been used as a benchmark price in many studies [Ahmad and Gjølberg (2015)].

There are eight major domestic wholesale rice markets in Pakistan; i.e. Karachi, Lahore, Rawalpindi, Multan, Sukkur, Hyderabad, Peshawar and Quetta. Six of these markets are included in this study. Karachi and Lahore are not included due to lacking of access to data on complete price series. However, the markets included can be considered a representative sample of the four provinces and are situated close to surplus as well as in deficit production regions. Moreover, some of these markets are also involved in exports. Hyderabad, included in the sample, lies close to Karachi with a port from which rice is shipped to other countries. Rice is also exported from Quetta and Peshawar to Iran and Afghanistan which, both regions included in our sample as is Rawalpindi close to Lahore in the Punjab province which is a deficit region of IRRI.

For several reasons, the behaviour of prices in these regions may differ, which may lead to spatial differences in the volatility. For instance, Fang and Sanogo (2014) described that the rise in prices of IRRI rice in the Lahore market was higher than in other markets during October 2006–April 2007. This may result in more variation of volatility in the Lahore market, which may lead to a higher difference in the spatial volatility in IRRI rice markets of Pakistan. The present study focuses on finding these differences. The results of the study indicate that spatial differences in volatility exist across regional markets of rice in Pakistan. However, there are high expectations that including these markets could strengthen the findings of this study. The greatest impediment to cover these markets for the time being has already been mentioned above that there is a lack of access to data on complete price series in both these markets. Moreover, these markets, given their cosmopolitan dimensions hold so great an attraction for people that they prefer, sometimes, to ignore their neighbouring markets in view of greater business prospects in these markets. However, equally neutralising argument to this market trend is that markets like Lahore and Rawalpindi, being equally attractive options for the people provide a good case of comparison, as the generalisations regarding volatility, for instance drawn from the study of one market can easily be applied to the other market. The same argument applies in the case of Hyderabad-Karachi markets. So, for their relative relevance or conversely for disadvantage, either of these markets were considered to be left out of purview in this project. Future studies can take up these markets also.

Earlier studies on rice markets in Pakistan, such as by Mushtaq, *et al.* (2006) and Ghafoor and Aslam (2012), focused mainly on measuring market integration of Basmati rice markets in the Punjab province, whereas Ahmad and Gjølberg (2015) measured market integration of IRRI rice markets in the four provinces of Pakistan through employing co-integration techniques of time series econometrics. Fang and Sanogo (2014) focused on measuring the effects of price and climate shocks on household wheat and rice consumption. In the first place, they identified the areas and corresponding livelihood groups, that were relatively more vulnerable to potential shocks. In the second place, they identified the most vulnerable markets of wheat and rice to domestic and international price shocks through a market integration analysis by employing co-integration technique. Finally, they performed simulations to investigate the effects of shocks on household consumption through shock impact modelling system (SISMOD). Abdullah, *et al.* (2015) analysed the marketing system of Basmati and non-Basmati rice in Pakistan not only to identify marketing problems faced by different market players but also to determine the marketing margins. However, all of the above research endeavours have left an important research gap to examine the trends in price volatility and spatial difference in volatility among rice markets of Pakistan. Therefore, present study has been specifically designed to identify spatial differences in regional rice markets of Pakistan. For the said purpose, pair wise tests of equality of variances, ARCH-LM tests and multivariate dynamic conditional correlations (DCC) GARCH models are applied. Moreover, conditional correlations across markets are also determined through DCC-GARCH model.

## 2. RICE PRODUCTION AND VALUE CHAIN SYSTEM IN PAKISTAN

Production area and volume, annual percentage changes in area and volume, and yield per hectare of both varieties of rice, Basmati and IRRI, are presented in Table 1. The Punjab province is a major producer of Basmati rice, while Sindh of IRRI rice.[2] Punjab shares about 90 percent of total Basmati production and Sindh about 65 percent of total IRRI production in Pakistan. Until 2008, there was no area under production of Basmati in the province of Sindh, and a very small area was allocated afterwards. The

Table 1

*Production Area, Volume and Yield of Rice Crop in Pakistan*

| | Area (000, Hectares) | | | | Production (000, Tons) | | | | Yield (Kg/ha) | |
|---|---|---|---|---|---|---|---|---|---|---|
| Year | Basmati | % Change | IRRI | % Change | Basmati | % Change | IRRI | % Change | Basmati | IRRI |
| 93-94 | 1104 | | 961 | | 1267 | | 2524 | | 1148 | 2627 |
| 94-95 | 1145 | 3.8 | 865 | –10.0 | 1352 | 6.7 | 1927 | –23.7 | 1180 | 2226 |
| 95-96 | 1148 | 0.2 | 895 | 3.4 | 1488 | 10.1 | 2282 | 18.4 | 1296 | 2550 |
| 96-97 | 1174 | 2.3 | 952 | 6.4 | 1564 | 5.1 | 2528 | 10.8 | 1372 | 2656 |
| 97-98 | 1106 | –5.8 | 952 | 0.1 | 1439 | –8.0 | 2468 | –2.4 | 1302 | 2592 |
| 98-99 | 1216 | 10.0 | 989 | 3.8 | 1687 | 17.2 | 2593 | 5.1 | 1387 | 2623 |
| 99-00 | 1296 | 6.5 | 1016 | 2.7 | 1871 | 10.9 | 2912 | 12.3 | 1444 | 2867 |
| 00-01 | 1158 | –10.6 | 927 | –8.8 | 1701 | –9.1 | 2556 | –12.2 | 1468 | 2759 |
| 01-02 | 1332 | 15.0 | 667 | –28.0 | 1999 | 17.6 | 1695 | –33.7 | 1501 | 2539 |
| 02-03 | 1377 | 3.4 | 722 | 8.2 | 2304 | 15.3 | 1942 | 14.6 | 1673 | 2690 |
| 03-04 | 1521 | 10.4 | 718 | –0.6 | 2522 | 9.4 | 1901 | –2.1 | 1659 | 2648 |
| 04-05 | 1558 | 2.5 | 678 | –5.6 | 2555 | 1.3 | 1908 | 0.4 | 1639 | 2816 |
| 05-06 | 1659 | 6.4 | 750 | 10.7 | 2920 | 14.3 | 2214 | 16.0 | 1761 | 2952 |
| 06-07 | 1589 | –4.2 | 757 | 0.9 | 2736 | –6.3 | 2238 | 1.1 | 1721 | 2958 |
| 07-08 | 1467 | –7.7 | 747 | –1.3 | 2643 | –3.4 | 2284 | 2.1 | 1801 | 3058 |
| 08-09 | 1697 | 15.7 | 915 | 22.5 | 2901 | 9.8 | 2984 | 30.6 | 1710 | 3261 |
| 09-10 | 1544 | –9.0 | 894 | –2.3 | 2732 | –5.8 | 2790 | –6.5 | 1770 | 3120 |
| 10-11 | 1413 | –8.5 | 617 | –30.9 | 2445 | –10.5 | 1490 | –46.6 | 1731 | 2413 |

*Source: Agricultural Statistics of Pakistan 2011-12.*

[2]A table with detailed data on province wise and period wise area and production of rice is provided in Appendix.

area of Basmati rice varied between 1.3 and 1.7 million hectares while its production fluctuated between 1.2 and 3.1 million tons. The variation in the area and production of IRRI rice ranged from 0.6 to 9.2 million hectares and from 0.3 to 3.0 million tons, respectively [Pakistan (2013)]. The fluctuations in area and production primarily depend on timely availability of fertiliser and pesticides, water availability, access to credit, weather conditions, price fluctuations, market power of the middlemen and the effect that unstable farm income has on the timing of sowing, the purchase of inputs and the ability to respond to external shocks [Abdullah (2015); Iqbal, *et al.* (2009)]. More details on rice economy of Pakistan can be found in Salam (2009), Ahmad and Garcia (2012) and Ahmad and Gjølberg (2015).

Over time, Pakistan has been enacting a wide range of government policies and regulations influencing the domestic and export rice markets. These include privatisation of exports in 1988-89; export subsidies during 2002-04; minimum export price policy during 2007-08; decreasing import tariffs and a price support policy until 2001-02 [Salam (2009); REAP (2010); WTO (2011)]. After 2002, the government occasionally and irregularly announced an indicative support price [Salam (2009)]. This essentially is often intended to generate a floor price during the period of abundant supply, but is not a proper substitute of market-determined prices and is intended to correct shortcomings in the marketing system [Anwar (2004)], such as controlling the market power of middlemen. Moreover, there have been no government purchases of rice since 1996. The situation before that procurement, level of government procurement, was too low to affect the prices in the wholesale markets as well as decisions making of the producers and other stakeholder. Farooq, *et al.* (2001) and Mushtaq and Dawson (2001) found a low level of responsiveness from the farmers to the support prices and suggested its discontinuity.

The data for total rice exports as well as exports of Basmati and non-Basmati (mainly IRRI6 and IRRI9) from Pakistan for the period 2001-11 are given in Table 2. During this period, the total exports varied between 2.7 million tons and 4.2 million tons for IRRI, while such variations for Basmati rice are 0.8–1.2 million tons and 1.7–3.2 million tons, respectively. For the last few years, however, exports of non-Basmati rice that mainly consist of IRRI6 and IRRI9 varieties have been greater than that of Basmati

Table 2

*Variety Wise and Total Rice Exports from Pakistan during 2001-11*

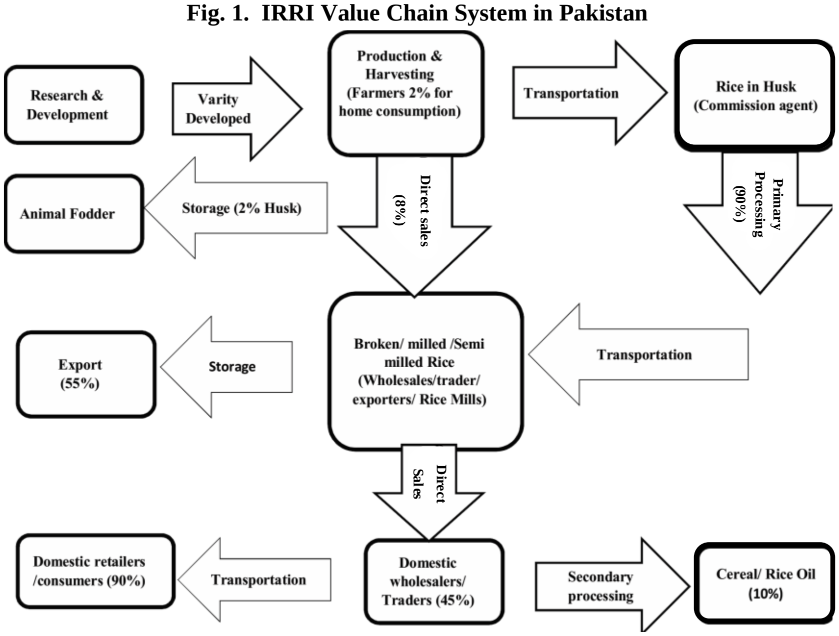
| Year | Rice (all) M. tons | Rice (all) Billion Rs | Basmati M. tons | Basmati Billion Rs | Non-Basmati M. tons | Non-Basmati Billion Rs |
|---|---|---|---|---|---|---|
| 2001-02 | 1.68 | 27.51 | 0.55 | 15.86 | 1.13 | 11.65 |
| 2002-03 | 1.82 | 32.43 | 0.72 | 21.08 | 1.10 | 11.36 |
| 2003-04 | 1.82 | 36.53 | 0.82 | 24.28 | 1.01 | 12.25 |
| 2004-05 | 2.89 | 55.39 | 0.81 | 26.07 | 2.08 | 29.32 |
| 2005-06 | 3.69 | 69.33 | 0.84 | 28.71 | 2.85 | 40.61 |
| 2006-07 | 3.13 | 68.29 | 0.91 | 33.73 | 2.22 | 34.55 |
| 2007-08 | 2.81 | 117.09 | 1.14 | 68.23 | 1.67 | 48.86 |
| 2008-09 | 2.73 | 154.76 | 0.97 | 83.25 | 1.76 | 71.51 |
| 2009-10 | 4.18 | 183.37 | 1.03 | 71.77 | 3.15 | 111.60 |
| 2010-11 | 3.67 | 184.67 | 1.17 | 82.31 | 2.50 | 102.36 |

*Source: Agricultural statistics of Pakistan* (Various Issues).

rice and this changing trend reflects the increasing importance of IRRI rice for export purposes. Exports of both the varieties decreased during the food crisis of 2007-08, probably due to the minimum export price policy during this period. After the crisis period and withdrawal of the policy, exports of both varieties increased. The increase in non-Basmati rice exports was larger than in Basmati.

Mapping of the IRRI rice value chain system in Pakistan is presented in Figure 1. Mapping of the Rice value chain comprises of the fundamentals of product flow system which takes into account various players and the subsequent key activities they performed at their specific level. For example Research and Development (R&D) Institutions such as Rice Research Institute and Ayub Agriculture Research Institute (AARI) are responsible to introduce varieties which are compatible to the existing production system and generate a substantial yield for the farmers. Rice producing farmers are mainly located into two provinces, Sindh and the Punjab. However, IRRI rice is mainly grown in the Sindh that is about 65 percent of its total produce in the country. Majority of the farmers possess small and medium size holdings and mainly depend on the middlemen for marketing of their produce. The Middlemen, located in the main grain markets, control the supplies through village dealers/contractors. An estimated proportion of 10-15 percent of husk is generated from the overall produce that is used as fodder for animals and sometime is also procured by the paper making industry. Rice after husk removal is called brown rice, a stage referred to as primary processing. The husk so obtained is procured by wholesalers/rice mills from the farmers/contractors [Pakistan (2013); TDAP (2016); Abdullah, *et al.* (2015) and Rehman, *et al.* (2012)].

**Fig. 1. IRRI Value Chain System in Pakistan**




*Source:* TDAP (2016), Abdullah, *et al.* (2015), Pakistan (2013) and author's intuition.

Milling is a very important step in the post-production phase of rice wherein edible white rice is produced after completely removing the husk and bran layers. Broken rice is also produced during the milling process; however, depending upon the demand of the customers its quantity should be minimum broken kernel. In the rice processing industry usually rice mills are privately owned enterprises, owned by rice exporters. However, some rice growers also have established their rice mills in the vicinity. Total milled rice contains whole grains or head rice, and broken rice while rice hull, rice germ and bran layer and fine broken rice are the by-products which are mainly procured by oil and cereal making companies. In IRRI rice, 65-70 percent white rice is produced which is transported to consumers in both the domestic and export market. About 90 percent IRRI exports are directed to Middle East, Africa and South and Central Asia. The whole value chain is dominantly handled the Middle men and in this case the mill owners are the key chain player [Pakistan (2013); TDAP (2016); Abdullah, *et al.* (2015); Rehman, *et al.* (2012)].

Regarding domestic markets, another issue is that a traditional marketing system is still in practice in which traders, wholesalers and distributors are the main stakeholders, hence their interests determine the market mechanism. They assert their own terms and conditions for the growers. Therefore, strict hold of the middle men and less price of rice in markets is perceived as the major problem in the overall IRRI rice value chain system. In addition, some of the marketing factors such as extra commission, high market committee fee, high carriage and other handling charges, late payment by dealers, high storage cost and lack of storage facilities create a lot of wattage which affects the overall value of the produce. Distant markets, shortage of transport and improper roads were also rated as the major product flow barriers in the IRRI rice value chain system which may lead to price volatility and spatial difference in volatility across regions [Pakistan (2013); TDAP (2016); Abdullah, *et al.* (2015); Rehman, *et al.* (2012)].

Market intermediaries such as traders and commission agents are based in the grain markets and are involved in the wholesale trade. Grain markets exist in most of the cities, however, eight markets are mentioned in the introduction section and six of them are selected for the present study. The distances between the selected markets in this study are given in the Table 3. Among the selected markets for the present study, Peshawar and Quetta are the provincial capitals of Khyber Pakhtunkhwa and Balochistan provinces, respectively. The distance between the two is roughly 850km. Quetta and Peshawar are relatively far from the production regions, with populations of about 0.84 and 1.3 million, respectively. Peshawar is situated close to the border of Afghanistan while Quetta is located close to the borders of Iran and Afghanistan. Rawalpindi is the neighbouring city of Islamabad, the capital of Pakistan, and is situated 183km away from Peshawar. Rawalpindi has about 1.83 million inhabitants and it lies between Peshawar and Multan. Multan is located in South Punjab at a distance of 549 km from Rawalpindi and has a population of about 1.55 million. Sukkur is located in Sindh province and it is 468km from Multan. Hyderabad is located close to Karachi, the provincial capital of Sindh and it is a port city. Hyderabad and Sukkur are 323km apart from each other with populations of about 10.4 and 0.40 million, respectively. These are located relatively closer to the production regions as Sindh is the largest producing province of IRRI rice. The respective distance of Quetta from Sukkur is 400km and from Hyderabad 722km.

Table 3

*Equality of Variance Test and Distance between Domestic Market Pairs*

| Market Pairs | Equality of Variance /SD (1994-2011) | Distance (Km) |
|---|---|---|
| Rawalpindi – Peshawar | Yes | 183 |
| Hyderabad –Sukkur | No | 323 |
| Quetta – Sukkur | No | 399 |
| Sukkur – Multan | Yes | 468 |
| Multan – Rawalpindi | No | 548 |
| Quetta – Multan | Yes | 625 |
| Multan – Peshawar | No | 689 |
| Quetta– Hyderabad | No | 721 |
| Hyderabad –Multan | No | 781 |
| Quetta – Peshawar | No | 846 |
| Sukkur – Peshawar | No | 884 |
| Quetta – Rawalpindi | Yes | 902 |
| Sukkur – Rawalpindi | No | 1012 |
| Hyderabad – Peshawar | No | 1206 |
| Hyderabad – Rawalpindi | No | 1325 |
| Average–International Market | No | 7595[a] |

[a] Sea distance between Karachi and Bangkok.

Logistics or distances from the production area to the market are characterised as critical operational or supply chain strategic planning components which involve ensuring product delivery to the right place, at the right time, and at the right price [Christopher (2005); Ballou (2004)]. Dunne (2010) identified that an effective logistic planning can improve the overall efficiency of the marketing system. Therefore, selection of the mode of transport, rout, product handling and storage provisions can also enhance the product value at the market place. An important consideration to mark here is that all of the above identified markets in Pakistan are connected with motorways, highways or railways. Cargo transportation is carried out mostly through highways. Infrastructure, in general, is relatively more developed in the Punjab province compared with other provinces. National highway and motorway network spans around 9600km, forming about 3.7 percent of total road network, accounting for about 95 percent of freight of all goods. So, road transport is the backbone of the transport sector of Pakistan. Road infrastructure has improved in Pakistan as percentage of paved roads increased from about 53 percent of total roads in 1991 to about 72 percent in 2010. This percentage is greater than in China, India, Indonesia, and Vietnam but lesser than in Thailand and Malaysia. However, about half of Pakistan's national highways are in a poor condition and poor road safety is a major concern along with low productivity of the transportation system. Trucks usually travel at a speed of less than 50km per hour mainly because of being overloaded and in poor quality. Railway freight accounts for only 5 percent of the total freight services. Pakistan's railways freight productivity is considered to be significantly inferior and lower than the productivity of railways in India and Thailand. Moreover, the storage system of Pakistan railways has been so sub-standard that it cannot ensure the product quality at the desired level. Low productivity can result in it being uncompetitive when compared with the road network [World Bank (2013)]. Another problem is the high cost of transportation which is mainly dependent on the prices of fuel. Fuel is one of the major import items of Pakistan and its imports are levied high tax which provides an important source of revenue to the government [Afia (2008)]. Imposition of tariff on oil imports is one of the reasons for increase in the domestic prices of oil and ultimately in the cost of transportation. However, for the last one to two years, oil prices have experienced a declining trend because of the decline in prices in the international market. Overall, poor logistic management system in Pakistan has endangered the rice value chain efficiency and effectiveness, and this situation is likely to affect the prices and its volatility in different markets.

## 3. DATA AND METHODS

The data for monthly IRRI rice prices in the six domestic markets: Rawalpindi, Multan, Peshawar, Hyderabad, Sukkur and Quetta, were taken from the agricultural statistics of Pakistan [Pakistan (2013)]. Staff members of PBS collect data on wholesale prices of 463 items, rice being one of them, included in wholesale price index (WPI) from the wholesale markets in 21 cities regularly on monthly basis. One Statistical Officer in every Regional/Field office is responsible for the technical supervision of work done by the price collectors. He is required to ensure that the technical aspects of price collection are clearly understood and the laid down instructions are generally followed by the price collectors. For this purpose, he is required to visit the markets for random checking of the prices. The Chief Statistical Officers of Regional offices also undertake field checking of the price data collected by the price collectors. Senior Officers from the Head Office also carryout surprise field inspections/visits to ensure authenticity of data. Collected data are entered in computers located at 34 Regional/Field Offices. Price data are checked and scrutinised at the headquarters to ensure its accuracy. In case of any doubt or abnormal variations, the concerned price reporting centres are contacted immediately for clarifications and necessary corrections [Pakistan (2013a)]. The data for Thai prices are downloaded from World Bank's pink sheet [World Bank (2012)]. Thai prices are converted to Pakistan rupees for comparison with the domestic markets using exchange rate from Oanda (2012) web page.

The present study employs the dynamic conditional correlation generalised autoregressive conditionally heteroskedastic (DCC)-GARCH approach of multivariate GARCH models developed by Engle (2002) to examine the spatial differences in volatilities of prices among the six major markets of IRRI rice of Pakistan. Multivariate GARCH models are employed very often in the studies examining the volatilities in prices in time series data analysis and their transmission across markets. DCC-GARCH, in particular, is designed to analyse the dynamics of volatility of a time series under analysis and measures conditional correlations among the various time series under study and transmissions among them. In DCC-GARCH model, the conditional variances are modelled as univariate generalised autoregressive conditionally heteroskedastic (GARCH) models and the conditional co-variances are modelled as nonlinear functions of the conditional variances. The conditional quasi correlation parameters that weight the nonlinear combinations of the conditional variances follow the GARCH-like process specified in Engle (2002). The (DCC) GARCH model is about as flexible as the closely related varying conditional correlation (VCC) GARCH model, rather more flexible than the constant conditional correlation (CCC) GARCH model and similarly more parsimonious than the diagonal (VECH) GARCH model [Engle (2002); Göt, *et al.* (2013)].

The mean equation in the DCC GARCH model for domestic rice market of Pakistan can be written as:

$$Y_t = a_0 + \sum_{i=1}^{p} a_i Y_{t-1} + \varepsilon_t \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (1)$$

Where $Y_t$ is a 6x1 vector of prices in the six domestic markets, $\alpha_0$ is a 6x1 vector of drifts, and $\varepsilon_t$ is a 6x1 vector of error terms. Error term ($\varepsilon_t$) has the following conditional variance-covariance matrix:

$$H = D_t R_t D_t \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (2)$$

Where $D_t$ is a diagonal 6x6 matrix of conditional variances ($\sigma_{it}^2$) in which each $\sigma_{it}^2$ is generated according to a univariate GARCH model of the following form for each price series.

$$\sigma_t^2 = \alpha_0 + \sum_l^m \alpha_l \mu_{t-l}^2 + \sum_k^s \beta_k \sigma_{t-j}^2 \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (3)$$

A typical GARCH (1,1) can be written as follows:

$$\sigma_{t|}^2 = \alpha_0 + \alpha_1 \mu_{t-1}^2 + \beta_1 \sigma_{t-1}^2 \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (4)$$

Where $\sigma^2$ is the conditional variance from the conditional mean equation, $\mu_t^2$ is the squared error term from the equation for conditional mean, *i* indexes markets and t indexes time periods. The lambda ($\lambda$) denotes the sum of alphas and betas and for GARCH (*m*,*s*) can be written as $\lambda = \sum_l^m \alpha_l + \sum_k^s \beta_k$ and for GARCH(1,1) it can be written as $\lambda = \alpha_1 + \beta_1$. Lambda $\lambda$ is termed as persistence parameter and measures the persistence in volatility. A close to 1 value of Lambda indicates that it will take longer time for the conditional variance to revert to its long-term mean. If $\lambda = 1$ then the conditional variance can increase with no bounds and no tendency to revert to its long-term value of the mean. The greater than one value lambda ($\lambda > 1$) exhibits an explosive growth. Theoretical support for the last two cases is lacking, hence value of the lambda is presented as less than 1. Moreover, the speed with which the conditional mean return to the value of its long term mean can be calculated by measuring the time required for conditional mean to fill half of the gap between the value of the long term mean and the present value of the conditional mean. This time period is called half-life and can be represented by *K* which is computed as $K = \frac{\ln(0.5)}{\ln(\lambda)}$. For instance, 0.8 value of $\lambda$ calculates as $K = 3.1$, indicating that the initial gap between the current value of the conditional variance and the value of its long-term mean is covered in about 3 time periods. If $\lambda = 1$, then the value $K$ will be infinity, meaning the existence of the gap for an infinitely long time periods. In other words conditional mean will not revert to its long term mean [Bloznelis (2016)].

$R_t$ represents a 6x6 symmetric dynamic correlations matrix that is defined in the following form:

$$R_t = (\text{diag}(Q_t))^{-1/2}\,\bar{Q}_t\,(\text{diag}(Q_t))^{-1/2} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (5)$$

Where

$$Q_t = \{q_{ij,t}\} = (1-\alpha-\beta)\,\bar{Q}_t + \beta\, Q_{t-1} + \alpha\,(\mu_{t-1}\,\mu'_{t-1}) \quad \ldots \quad \ldots \quad \ldots \quad (6)$$

GARCH-DCC model primarily focuses on obtaining conditional correlations in $R_t$ written as follows:

$$\rho_{ij,t} = \frac{q_{ij,t}}{\sqrt{q_{ii,t}}\sqrt{q_{jj,t}}}$$

In the above Equation 6, $Q_t = \{q_{ij,t}\}$ is the time varying covariance matrix of standardised residuals from (1), $\bar{Q}_t$ is unconditional variance-covariance matrix obtained by estimating a univariate GARCH in Equation (3), and α and β are vectors of non-negative adjustment parameters satisfying $\alpha + \beta < 1$. Parameter α indicates the impact of the lagged error term (or, in other words, the role of the previous shocks) on the series' volatility in the current period. Parameter β represents the effect of price volatility in the previous period on volatility in the current period [Bloznelis (2016); Got, *et al.* (2013)].

These models are widely applied on financial data series such as stock prices, exchange rate and interest rate, etc. A number of applications of these models on the monthly prices data on agricultural commodities do exist also. Valadkhani, *et al.* (2005) investigated Australia's export price volatility by employing GARCH models and presented the evidence that Australia's export prices significantly vary with world prices. Fredy, *et al.* (2008) investigated the effects of policies of market reforms on maize price volatility in Tanzania and identified the factors responsible for spatial price volatility using an autoregressive conditional heteroskedasticity in mean (ARCH-M) model. They found that the reforms resulted in an increase in the farm-gate prices and volatility. They also found higher volatility in the less developed regions; surplus areas of maize; and the regions not having the borders with the neighbouring countries. They suggested investments for improving transportation infrastructure and communication to reduce the spatial price volatility in the long run. Baharom, *et al.* (2009) found that Thailand's rice export price had been volatile during 1961–2008. They also found asymmetry in volatility, indicating that positive shocks lead to larger increases in volatility than the negative shocks. Apergis and Rezitis (2003) in their study of volatility transmission the markets of Greece discovered that the agricultural input and retail food prices wield positive and highly significant effects on the volatility of agricultural output prices by employing multivariate GARCH models. They also illustrated that output prices exert significant positive effects on their own volatility. Rapsomanikis (2011), employing multivariate GARCH models, found that wheat market in Peru and maize markets in Mexico were not showing an increasing trend in price volatility while the world wheat and maize markets showed increasing price volatility. He also found volatility clustering in all the markets during 2008 on account of food crises. He added that domestic price volatilities are more responsive to domestic shocks compared with shocks in the international market prices. He also found that India's power in the international rice market led to bidirectional causality between Indian and international market prices. A similar relationship existed between the volatilities in Indian and international market prices. However, Indian price stabilisation policies such as restrictions on exports on account of the price surge during 2007-08 reduced the volatilities in the domestic markets and raised volatility in the international market.

## 4. SALIENT FEATURES OF REGIONAL RICE PRICES VOLATILITY

To visualise price volatility, monthly percentage price changes in domestic price (average of all markets) and international market prices are plotted in Figure 3. Large fluctuations reflecting high volatility can be viewed particularly after 2008. As an alternative measure of volatility, rolling 48-month standard deviations of logarithmic prices returns are depicted in Figure 4. Increases in rolling standard deviations have been observed since 2008, falling in line with the preceding argument. The argument was further validated by Gilbert and Morgan (2010) found that rice price volatility was higher compared with other food grains during and after the food crisis period 2007-08. They also added that evidence was weak for the perception of increasing grain price volatility.

**Fig. 2. Logarithmic Price Returns in Pakistan's Domestic (Average) and International Rice Markets**

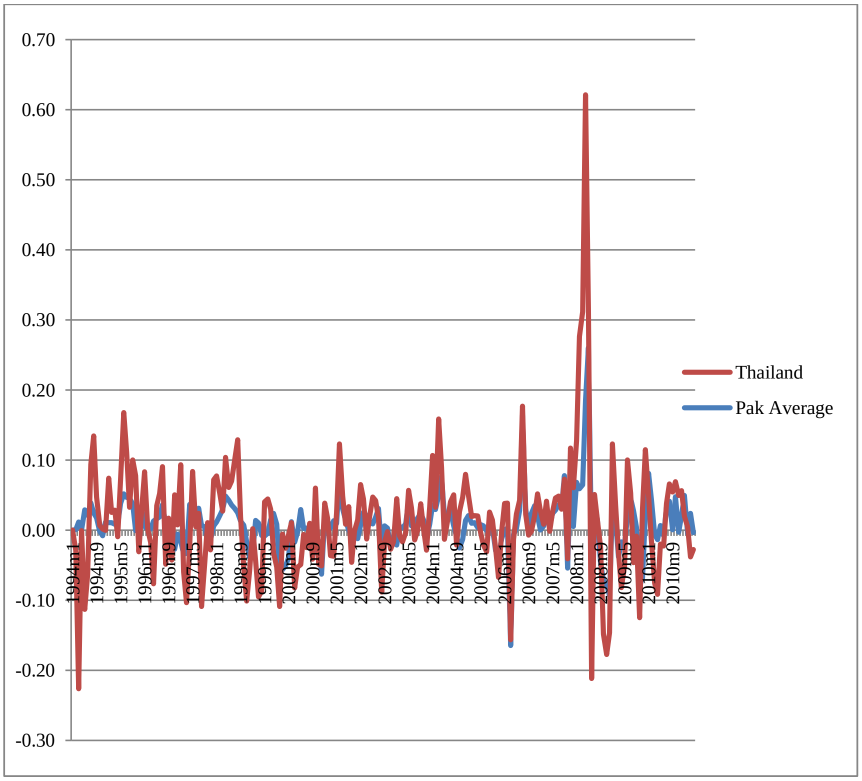
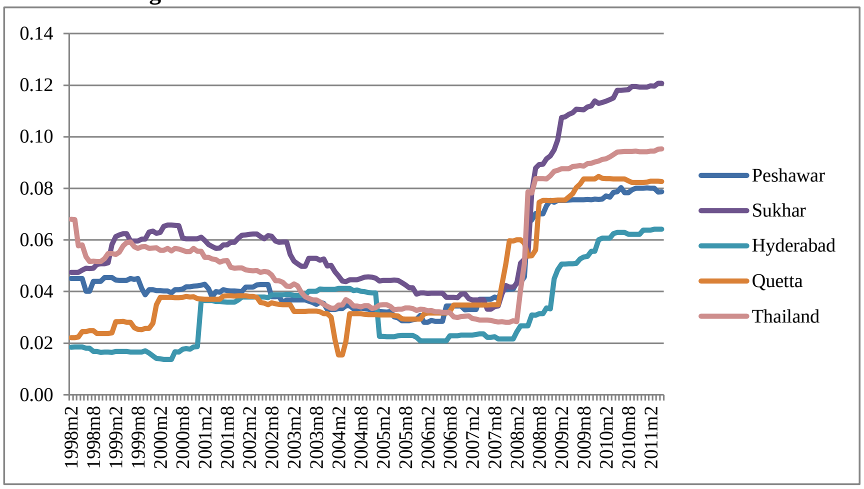
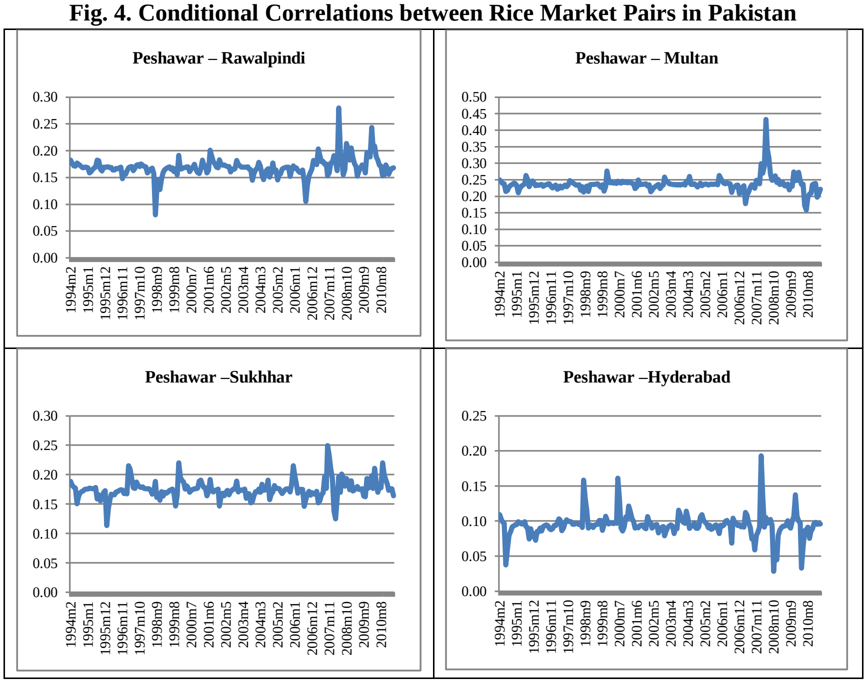


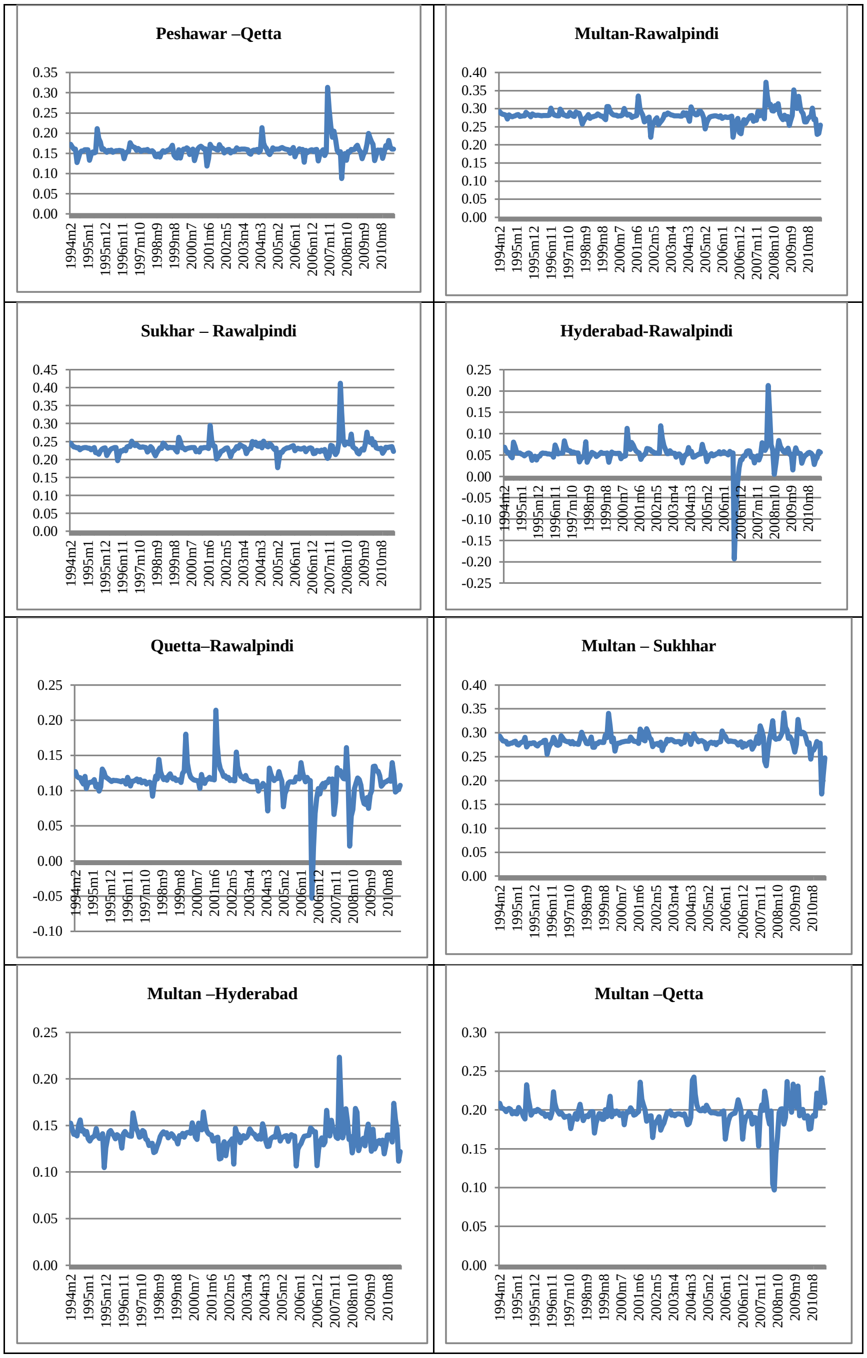
**Fig. 3. Standard Deviations of Logarithmic Price Returns in Pakistan's Domestic and International Rice Markets Over 48-Month Rolling Windows during 1994–2011**

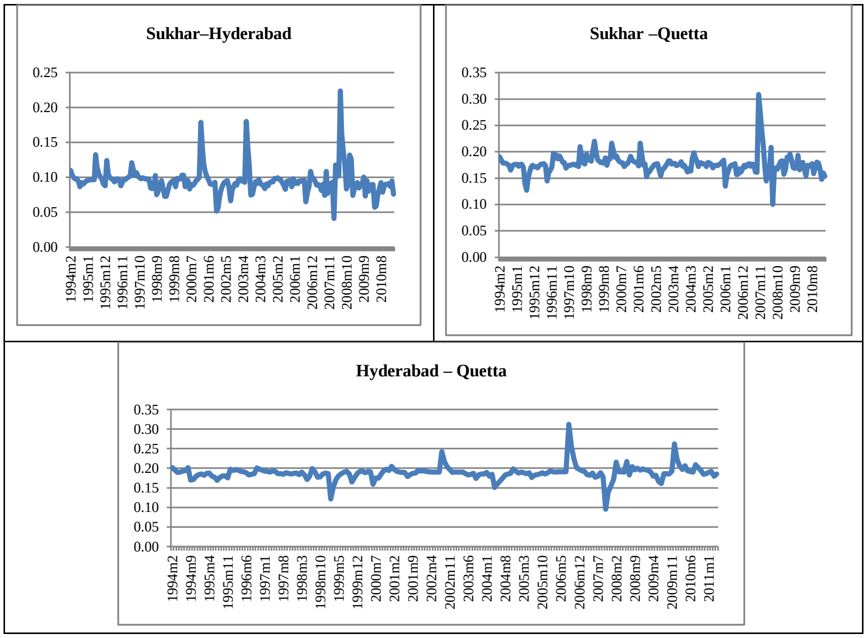



*Note:* Thailand's prices were converted into Pakistan's rupees before estimations of rolling standard deviations.

**Fig. 4. Conditional Correlations between Rice Market Pairs in Pakistan**




Peshawar –Qetta
Multan-Rawalpindi
Sukhar – Rawalpindi
Hyderabad-Rawalpindi
Quetta–Rawalpindi
Multan – Sukhhar
Multan –Hyderabad
Multan –Qetta




In view of answering the second research question in the study i.e. to visualise the spatial differences in the volatility among rice among pairs of markets, F-tests of equal variances are performed and the results are given in Table 3. Pair-wise test results show mixed picture demonstrating that some market pairs possess statistically equal volatility while other pairs exhibit differences in volatility. Volatilities of average domestic and international market price are also found to be different. Among domestic markets, markets that are located far from each other possess statistically different volatilities while volatility in neighbouring markets is similar with few exceptions. For instance the results for Sukkur and Hyderabad markets pair show dissimilar volatility despite the fact that these markets are not far from each other. A possible reason for this difference could be the exposure of these markets to the production area and international market as they are located in the surplus production region which is a source of supply to both the domestic and international markets. Hyderabad is located close to the Karachi port and therefore exposed to the international markets while Sukkur is located close to the production areas and act as a source of supply to both the domestic as well as international markets. Quetta and Peshawar are located far from each other and possibly, though there is no direct flow between them, they show a similar behaviour of volatility, again possibly due to their exposure to international markets. Peshawar is located close to the border of Afghanistan while Quetta is situated close to the borders of Afghanistan and Iran. Peshawar may also have been affected by the war against terrorism after the 9/11 incident, while Quetta has poor law and order situation. Quetta and Rawalpindi are also situated far from each other but possess statistically equal variance, which can be attributed to the fact that they are deficit regions as situated far from the production areas.

Although there is no direct trade between Quetta and Rawalpindi, their geographical location with respect to the supply area may lead to similarities in the operations of market forces and resulting behaviour of price volatility. Quetta-Sukkur and Multan-Peshawar market pairs, situated relatively far from each other, also showed statistically similar variance which, possibly, is because of expected higher trade between them. The actual data for trade is not available; however, we can expect this result as Sukkur and Multan are located relatively close to the production regions and product moves from Sukkur and Multan.

The volatility in all the regions and in the international market, measured by moving window of standard deviations of logarithmic price returns over 48 months (Figure 3) shows a rising trend in particular after the boom-and-bust period 2007-08. To further visualise the trends in volatility, the data set is divided into three sub-sets, 1994-1999; 2000-2005 and 2006-2011. Volatility is measured in terms of standard deviations of logarithmic price returns over the selected period. Results are shown in Table 4. These results, in general, support a rising trend in volatility. The highest level of volatility occurred in 2006-2011. During this period, volatility almost doubled in all the regions and even more than doubled in some markets. However, the level of volatility differs across markets during these sub-periods. Three markets, i.e. Rawalpindi, Multan and Hyderabad, showed an increase in volatility from 1994-1999 to 2000-2005 while Sukkur, Peshawar and Quetta showed a decrease in volatility during the same sub-periods.

Table 4

*Standard Deviations of Logarithmic Price Changes*

| Years | Peshawar | Rawalpindi | Multan | Sukkur | Hyderabad | Quetta |
|---|---|---|---|---|---|---|
| 1994-1999 | 0.044 | 0.034 | 0.043 | 0.056 | 0.017 | 0.033 |
| 2000-2005 | 0.033 | 0.039 | 0.049 | 0.043 | 0.035 | 0.028 |
| 2006-2011 | 0.072 | 0.081 | 0.092 | 0.104 | 0.057 | 0.073 |
| 1994-2011 | 0.052 | 0.051 | 0.064 | 0.071 | 0.039 | 0.048 |

## 5. ECONOMETRIC RESULTS

Augmented Dickey-Fuller and Phillips-Perron unit root tests applied on the logarithmic prices indicated non-stationarity while the test results on first-difference of log prices (i.e. logarithmic price returns) show that these are stationary. The results of unit root tests are reported in Appendix. ARCH-LM tests were applied on the logarithmic price returns to examine the presence of volatility clustering, or ARCH effects. The results (Table 5) support the hypothesis of presence of ARCH effects in the domestic as well as in the international markets. This evidence is weak for Rawalpindi and Hyderabad, where the test statistic is significant at 10 percent level. The results of univariate[3] part of DCC- GARCH models are reported in Table 6. All models included a first-order autoregressive term (lagged logarithmic price returns) in the conditional mean equation to control for the predictability of conditional mean. The coefficients on AR (1)

[3]Prices for Thai rice are not included in the DCC-estimations as the focus of the present study is to identify the spatial differences across domestic markets and estimating conditional correlations among them. However, separate univariate GARCH model is estimated for Thai prices for comparison.

in all the markets are positive and statistically significant at 1 percent level suggesting that specification of GARCH models without its AR term in any model for conditional mean would not be appropriate. Ljung-Box test for autocorrelation and ARCH-LM test for remaining ARCH effects were applied on standardised model residuals as diagnostics tests after the estimation of DCC-GARCH. The results show that the residuals do not have autocorrelation and conditional heteroskedasticity.

Table 5

*ARCH-LM Test on Price Returns in the Domestic Rice Markets in Pakistan*

| Year | Thailand | Peshawar | Rawalpindi | Multan | Sukkur | Hyderabad | Quetta |
|---|---|---|---|---|---|---|---|
| Skewness | 1.0 | 0.9 | 7.6 | 0.8 | 0.6 | 0.4 | 0.8 |
| Kurtosis | 2.9 | 2.6 | 2.6 | 2.8 | 2.5 | 2.2 | 2.8 |
| ARCH- LM[a] | 15.3 | 5.5 | 2.9 | 30.1 | 26.0 | 2.6 | 12.9 |

*Source:* Author's calculations.

*Notes:* [a] All the coefficients are significant at 1 percent level of significance except for Rawalpindi and Hyderabad which are significant at 10 percent level of significance

Table 6

*Univariate Part of DCC-GARCH Model*

| DlnP | Thailand | Hyderabad | Sukkur | Multan | Rawalpindi | Peshawar | Quetta |
|---|---|---|---|---|---|---|---|
| Constant | 0.005 | 0.009[a] | 0.01[a] | 0.009[b] | 0.01[a] | 0.009[b] | 0.01[a] |
| AR(1) | 0.33[a] | 0.23[a] | 0.21[a] | 0.38[a] | 0.48[a] | 0.29[a] | 0.23[a] |
| ARCH (1) | 0.15 | 0.17[c] | 0.20[b] | 0.32 | 0.72[c] | 0.21 | 0.97[a] |
| GARCH(1) | 0.43[b] | 0.81[a] | 0.72[c] | – | – | 0.51[a] | – |
| Lambda | 0.58 | 0.98 | 0.92 | | | 0.72 | |
| K | 1.27 | 34.31 | 8.31 | | | 2.11 | |
| Constant | 0.0003 | 0.00006[c] | 0.0004[b] | 0.003[a] | 0.001[a] | 0.0006[a] | 0.0006[a] |
| ARCH(2) | 0.28[b] | | | | | | |
| [d]Ljung-Box(3) | 4.95[c] | 1.22 | 0.96 | 2.62 | 2.19 | 0.06 | 3.00 |
| ARCH-LM(3) | 4.25 | 0.49 | 0.77 | 1.20 | 0.13 | 1.12 | 0.90 |

*Notes:* [a]/[b]/[c] statistically significant at the 1 percent, 5 percent, and 10 percent levels, respectively.

[d] Ljung-Box (3 lags) and ARCH-LM (3 lags) tests' statistics for standardised model residuals.

The ARCH coefficients in domestic markets are positive and statistically significant, except for Multan and Peshawar. These coefficients are significant at 10 percent level in Hyderabad and Multan while at 5 percent and 1 percent in Sukkur and Quetta, respectively. Their magnitudes range from around 0.2 in Hyderabad and Sukkur to around 0.7 in Rawalpindi and almost 1.0 in Quetta. In the international market, ARCH (1) coefficient is not significant while ARCH (2) coefficient is significant at 5 percent level; the sum of the two is 0.4. Significant ARCH (1) coefficients imply that the most recent shock to logarithmic price returns significantly affects the current volatility in the prices of rice markets. A relatively large ARCH coefficient (e.g. in Rawalpindi and Quetta) implies that the most recent shock has a sizeable impact of increasing the current period's volatility. A relatively small ARCH coefficient (as in Hyderabad and Sukkur) indicates that shocks to logarithmic price returns have a little impact on subsequent period's volatility.

The GARCH coefficients are not significant in Multan, Rawalpindi and Quetta markets while these are significant in Sukkur, Hyderabad and Quetta at 1 percent level of significance. The GARCH coefficient in the international market is significant at 5 percent level. Significant GARCH coefficients indicate autoregressive memory in conditional variance, that is, current conditional variance depends on past conditional variances. In other words, volatility in the past periods affects the current period's volatility of prices in the market. A relatively large GARCH coefficient implies that current volatility tends to remain close to its most recent value rather than at its basic level. Such a pattern is the strongest in Hyderabad and Sukkur (GARCH coefficient values of around 0.8 and 0.7 respectively) and less pronounced in Peshawar (around 0.5). The international market has the least pronounced autoregressive memory in conditional variance with a GARCH coefficient of around 0.4, indicating relatively smaller effects of past period's volatility on current period's volatility.

**Comment [T1]:** basic ?

Significant GARCH effects together with significant ARCH effects indicate that volatility depends on both previous shocks and previous volatility. The sum of the ARCH and GARCH coefficient value measures the persistence in volatility, and values close to unity reflect high persistence [Verbeek (2008)]. This sum for international market is 0.86, which is relatively high. Persistence in Hyderabad and Sukkur amounts to 0.98 and 0.89, respectively, even higher than that of the international market. The value of K, half-life, is also the highest in Hyderabad and Sukkur markets which are 34 and 8 respectively. This indicates that the initial gap between current volatility and its long-term mean would be covered in 34 periods in Hyderabad and 8 periods in Sukkur. Differences in the significance and magnitude of ARCH and GARCH coefficients reflect spatial differences in behaviour of the volatility across the regional rice markets in Pakistan. Hyderabad and Sukkur are the only two markets in Pakistan having both significant ARCH and GARCH effects and high values of K. Hence both of these can be regarded as the riskiest markets.

The results of the equality of variance tests, volatility trends measured by rolling window of the standard deviations and 5-years standard deviations of differenced logarithmic prices and ARCH/GARCH models reveal spatial differences in volatility across the regional markets in Pakistan. It is reasonable to assume that these spatial differences reflect the differences in infrastructure such as the cost of transportation and communication services, storages and possibly also the existence of market power by the market intermediaries. In particular, the domestic value chain where the intermediaries drive the whole chain, commission agents have inter-regional wholesale market contacts and they possess accurate market information. Therefore, they hold an important position in the market to influence prices. Moreover, the price surge during the 2007-08 food crises also affected the volatility in the regional markets. Inventory holders would intend to store more in a volatile environment resulting in increase in the inventories. Buildup in inventories can create shortage in domestic supply that in turn can increase the demand and ultimately prices. Increased price could negatively affect the food security. Differences in the volatility across markets can result in regional differences in decision making by the inventory holders, generating increased volatility. This is similar to the power structure of the middlemen in the existing supply chain system, generally in developing countries and particularly in Pakistan that govern the whole system according their vested interest [Dunne (2010)].

Other part of the DCC-Model is comprised of time-varying conditional correlations between market pairs which are presented in Figure 4. Figure 4 depicts that each market has a different correlation with the other market and over-time values of the conditional correlations vary across markets pairs. In general, these conditional correlations are low. These facts reflect that spatial differences exist across markets and market pairs which can also be explained by poor logistic and supply chain system that increases the information gap among the trading partners. The average dynamic conditional correlations during 1994-2011 are given in Table 7. The highest conditional correlation exists between Multan and Sukkur, 0.29. This is as was expected given the fact that these two markets are relatively close. Multan and Rawalpindi possess the second highest conditional correlation, 0.28, which are located in the same province. Both these markets have a relatively better road infrastructure and more trade can be expected from Multan to Rawalpindi as Multan is relatively closer to production/supply areas.

Table 7

*Time-varying Conditional Correlations from DCC-GARCH Model in Domestic Rice Markets of Pakistan*

| Market Pairs | Average Conditional Correlation | Distance (km) |
|---|---|---|
| Rawalpindi – Peshawar | 0.17 | 183 |
| Hyderabad –Sukkur | 0.09 | 323 |
| Quetta – Sukkur | 0.18 | 399 |
| Sukkur – Multan | 0.29 | 468 |
| Multan – Rawalpindi | 0.28 | 548 |
| Quetta – Multan | 0.20 | 625 |
| Multan – Peshawar | 0.24 | 689 |
| Quetta– Hyderabad | 0.19 | 721 |
| Hyderabad –Multan | 0.14 | 781 |
| Quetta – Peshawar | 0.16 | 846 |
| Sukkur – Peshawar | 0.18 | 884 |
| Quetta – Rawalpindi | 0.11 | 902 |
| Sukkur – Rawalpindi | 0.23 | 1012 |
| Hyderabad – Peshawar | 0.09 | 1206 |
| Hyderabad – Rawalpindi | 0.05 | 1325 |

Average conditional correlation between Rawalpindi and Sukkur is 0.23 which reflects the fact that there is direct trade between Sukkur and Rawalpindi as the former is located closer to the supply areas. However, this trade proportion seems lower than between Multan and Rawalpindi possibly due to larger distance. Average conditional correlation between Peshawar and Rawalpindi is relatively lower, 0.17, in spite of the fact that they are located closer, although in different provinces, and have good infrastructure. This reflects that there is more direct trade between Peshawar and Multan, having higher average conditional correlation, 0.33, as it is of a little difference to travel between Multan and Peshawar or Multan and Rawalpindi. This also suggests that good infrastructure and information flow promotes direct trade between the different markets. The conditional correlation between Hyderabad-Sukkur markets pair is relatively low, which is somewhat counterintuitive since these markets are situated close to each other. The test of equality of variance also showed a difference in price volatility between the two markets as described earlier. Relatively low correlation can be attributed to the differences in the demand structure in both the markets. Both have effects of derived demand from the other markets. In Hyderabad market effects of derived demand are from the Karachi which in turn has the demand from international market.

In general, it can be said that there is a higher degree of association in volatility between closer markets than between distant markets although exceptions exist. Distance is a proxy measure of infrastructure such as roads, transportation, communication and geopolitical conditions of the markets and operations of market forces differ across markets. These can be the possible reasons for differences in volatility and the varying degrees of conditional correlations across rice markets in Pakistan. Hence, investments on infrastructure and transportation can reduce the spatial differences in volatility across markets in Pakistan. Improving the efficiency of the railways would reduce the transportation cost and possibly price uncertainty across markets.

## 6. SUMMARY AND CONCLUSIONS

In the introduction, we presented three research questions on the general trend in rice price volatility in Pakistan's domestic markets, possible presence of spatial differences in volatility and presence of correlation between volatilities in different markets. To answer these questions, we analysed volatility trends and patterns by applying standard tests for equality of variance and GARCH-DCC models.

We found a rising trend in rice price volatility in regional markets of Pakistan as well as in the international market during the period 1994-2011. As for producers, higher volatility can result in inefficient allocation of resource. Inventory holders most likely tend to store more in a volatile environment resulting in an increase in inventory costs. Inventories can contribute to reduced price volatility. However, this depends on inventory holders being good at forecasting future prices. If not, building up inventory volumes may actually contribute to larger price variations.

Furthermore, we found differences in volatility across regional markets. In general, markets situated far from each other show statistically significant differences in variances while the markets located relatively closer to each other possess statistically equal variance, although exceptions exist. ARCH-LM tests on logarithmic price returns in individual markets show the presence of ARCH effects in all domestic markets and the international market. The significance and magnitude of ARCH and GARCH coefficients vary across markets reflecting spatial differences in volatility. The highest persistence in volatility is found in Sukkur and Hyderabad. Coupled with its high unconditional variance, Sukkur can be regarded as the most risky domestic market.

Analysis of conditional correlations using DCC model reveals positive association of volatility across markets. It also elucidates spatial differences since correlations are inversely related to distance between markets. Differences in volatile behaviour across markets reflect differences in infrastructure, transportation and communication services, and possibly the market power exercised by the market intermediaries. Given the poor quality of national highways, slow driving freight vehicles and inefficient railway freight, investments in infrastructure and particularly in transportation may reduce the price risk across markets. Hyderabad and Sukkur are found to be the risky markets and Sukkur the riskiest, hence, infrastructural investments in this region should be prioritised.

Improving the way markets function generally reduces price volatility. Such improvements can be achieved by investments in physical infrastructure, i.e. roads, railroads and telecommunications. But perhaps even more important, the open access of market information to both producers and consumers can balance the power structure in the existing chain and will possibly improve the overall supply chain profitability. The econometric results presented in this paper suggest that investments aiming at improving the way Pakistan's rice markets are functioning may yield good returns.

## APPENDIX

*Unit Root Tests*

| | Levels | | | | First Difference | |
|---|---|---|---|---|---|---|
| | Augmented Dickey Fuller (ADF) | | Phillips-Perron (Pperron) | | ADF | Pperron |
| Variables | No Rend | With Trend | No Trend | With Trend | No Trend | No Trend |
| Thailand fob | –1.15 | –1.70 | –1.27 | –1.98 | –7.06 | –2.88 |
| Avg. Dom. Price | –0.88 | –1.71 | –0.48 | –1.32 | –6.65 | –9.00 |
| **IRRI Rice** | | | | | | |
| Hyderabad | –0.45 | –2.82 | –0.30 | –2.50 | –7.39 | –10.39 |
| Sukkur | –0.52 | –2.35 | –0.46 | –2.31 | –8.08 | –13.26 |
| Multan | –0.83 | –2.40 | –0.77 | –2.22 | –7.32 | –9.97 |
| Rawalpindi | –0.59 | –2.27 | –0.48 | –2.03 | –7.31 | –9.33 |
| Peshawar | –0.56 | –1.73 | –0.43 | –1.60 | –7.10 | –10.89 |
| Quetta | –0.31 | –1.88 | –0.03 | –1.43 | –7.34 | –12.14 |

*Source:* Author's calculations.

Appendix Table 1

*Area, Production and Yield of Rice Crop in Pakistan*

| | | Area (000, hectares) | | | Production (000, tons) | | | Yield (Kg / ha) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Year | Prov. | Basmati | IRRI | Total | Basmati | IRRI | Total | Basmati | IRRI | Total |
| 93-94 | Punjab | 1074.0 | 218.5 | 1300.6 | 1215.9 | 361.5 | 1588.2 | 1132.0 | 1654.0 | 1221.0 |
| | Sindh | – | 630.1 | 702.9 | – | 1840.6 | 1954.9 | – | 2921.0 | 2781.0 |
| | Total | 1103.5 | 961.0 | 2187.1 | 1266.7 | 2524.3 | 3994.7 | 1148.0 | 2627.0 | 1826.0 |
| 94-95 | Punjab | 1107.6 | 222.6 | 1338.7 | 1295.9 | 376.3 | 1684.0 | 1170.0 | 1690.0 | 1257.0 |
| | Sindh | – | 535.6 | 598.3 | – | 1324.7 | 1406.7 | – | 2473.0 | 2351.0 |
| | Total | 1145.4 | 865.3 | 2124.6 | 1351.6 | 1926.6 | 3446.5 | 1180.0 | 2226.0 | 1622.0 |
| 95-96 | Punjab | 1109.2 | 214.5 | 1327.7 | 1415.1 | 381.9 | 1803.0 | 1276.0 | 1780.0 | 1358.0 |
| | Sindh | – | 570.9 | 642.3 | – | 1592.9 | 1697.2 | – | 2790.0 | 2642.0 |
| | Total | 1147.8 | 894.9 | 2161.7 | 1487.5 | 2281.9 | 3966.5 | 1296.0 | 2550.0 | 1835.0 |
| 96-97 | Punjab | 1133.1 | 216.5 | 1354.5 | 1486.6 | 369.8 | 1864.0 | 1312.0 | 1708.0 | 1376.0 |
| | Sindh | – | 625.5 | 701.8 | – | 1846.8 | 1961.5 | – | 2953.0 | 2794.0 |
| | Total | 1173.9 | 951.8 | 2251.1 | 1563.7 | 2527.9 | 4304.8 | 1372.0 | 2656.0 | 1912.0 |
| 97-98 | Punjab | 1055.0 | 221.4 | 1409.9 | 1342.9 | 396.9 | 1948.0 | 1273.0 | 1793.0 | 1382.0 |
| | Sindh | – | 614.4 | 689.3 | – | 1733.6 | 1840.9 | – | 2822.0 | 2671.0 |
| | Total | 1105.8 | 952.3 | 2317.3 | 1439.3 | 2468.0 | 4333.0 | 1302.0 | 2592.0 | 1870.0 |
| 98-99 | Punjab | 1162.2 | 236.8 | 1492.9 | 1584.3 | 422.2 | 2176.0 | 1363.0 | 1783.0 | 1458.0 |
| | Sindh | – | 628.7 | 704.1 | – | 1813.6 | 1930.3 | – | 2885.0 | 2742.0 |
| | Total | 1216.0 | 988.5 | 2423.6 | 1687.1 | 2593.3 | 4673.8 | 1387.0 | 2623.0 | 1928.0 |
| 99-00 | Punjab | 1246.8 | 266.7 | 1609.4 | 1764.0 | 534.8 | 2481.0 | 1415.0 | 2005.0 | 1541.0 |
| | Sindh | – | 616.9 | 690.4 | – | 1994.9 | 2123.0 | – | 3234.0 | 3075.0 |
| | Total | 1295.5 | 1015.5 | 2515.4 | 1870.8 | 2911.7 | 5155.6 | 1444.0 | 2867.0 | 2050.0 |
| 00-01 | Punjab | 1113.7 | 313.2 | 1627.2 | 1601.0 | 592.4 | 2577.0 | 1438.0 | 1891.0 | 1584.0 |
| | Sindh | – | 481.4 | 540.1 | – | 1580.3 | 1682.3 | – | 3283.0 | 3115.0 |
| | Total | 1158.2 | 926.5 | 2376.6 | 1700.6 | 2555.9 | 4802.6 | 1468.0 | 2759.0 | 2021.0 |
| 01-02 | Punjab | 1293.8 | 147.7 | 1475.9 | 1913.8 | 284.8 | 2266.0 | 1479.0 | 1928.0 | 1535.0 |
| | Sindh | – | 413.6 | 461.1 | – | 1102.1 | 1159.1 | – | 2665.0 | 2514.0 |
| | Total | 1331.8 | 667.3 | 2114.2 | 1999.3 | 1694.5 | 3882.0 | 1501.0 | 2539.0 | 1836.0 |
| 02-03 | Punjab | 1316.8 | 146.5 | 1512.3 | 2175.5 | 289.7 | 2579.7 | 1652.0 | 1977.0 | 1706.0 |
| | Sindh | – | 438.3 | 488.3 | – | 1240.6 | 1299.7 | –.0 | 2830.0 | 2662.0 |
| | Total | 1377.3 | 721.9 | 2225.2 | 2304.2 | 1941.9 | 4478.5 | 1673.0 | 2690.0 | 2013.0 |
| 03-04 | Punjab | 1426.1 | 138.0 | 1687.9 | 2309.2 | 287.6 | 2871.4 | 1619.0 | 2084.0 | 1701.0 |
| | Sindh | – | 495.3 | 551.2 | – | 1368.7 | 1432.8 | – | 2763.0 | 2599.0 |
| | Total | 1520.5 | 717.8 | 2460.6 | 2521.9 | 1900.5 | 4847.6 | 1659.0 | 2648.0 | 1970.0 |
| 04-05 | Punjab | 1466.5 | 108.1 | 1754.3 | 2347.9 | 236.4 | 2980.3 | 1601.0 | 2187.0 | 1699.0 |
| | Sindh | – | 484.9 | 543.9 | – | 1428.4 | 1499.7 | – | 2946.0 | 2757.0 |
| | Total | 1558.4 | 677.7 | 2519.6 | 2554.6 | 1908.1 | 5024.8 | 1639.0 | 2816.0 | 1994.0 |
| 05-06 | Punjab | 1535.0 | 131.9 | 1762.4 | 2641.8 | 314.8 | 3179.6 | 1721.0 | 2387.0 | 1804.0 |
| | Sindh | – | 527.4 | 593.2 | – | 1639.5 | 1721.0 | – | 3109.0 | 2901.0 |
| | Total | 1658.5 | 750.0 | 2621.4 | 2920.4 | 2214.1 | 5547.2 | 1761.0 | 2952.0 | 2116.0 |
| 06-07 | Punjab | 1474.3 | 138.8 | 1728.4 | 2493.6 | 334.4 | 3075.5 | 1691.0 | 2409.0 | 1779.0 |
| | Sindh | – | 534.3 | 598.1 | – | 1667.7 | 1761.8 | – | 3121.0 | 2946.0 |
| | Total | 1589.2 | 756.5 | 2581.2 | 2735.7 | 2238.0 | 5438.4 | 1721.0 | 2958.0 | 2107.0 |
| 07-08 | Punjab | 1377.1 | 159.8 | 1723.5 | 2453.1 | 414.4 | 3286.0 | 1781.0 | 2593.0 | 1907.0 |
| | Sindh | – | 531.1 | 594.0 | – | 1716.5 | 1817.7 | – | 3232.0 | 3060.0 |
| | Total | 1467.0 | 746.8 | 2515.4 | 2642.7 | 2283.9 | 5563.4 | 1801.0 | 3058.0 | 2212.0 |
| 08-09 | Punjab | 1548.3 | 202.3 | 1977.7 | 2601.7 | 517.7 | 3643.0 | 1680.0 | 2558.0 | 1842.0 |
| | Sindh | 88.8 | 560.3 | 733.5 | 133.3 | 1949.3 | 2537.1 | – | 3479.0 | 3459.0 |
| | Total | 1696.8 | 915.1 | 2962.6 | 2900.8 | 2983.9 | 6952.0 | 1710.0 | 3261.0 | 2347.0 |
| 09-10 | Punjab | 1414.0 | 218.9 | 1931.5 | 2475.4 | 532.2 | 3713.0 | 1751.0 | 2431.0 | 1922.0 |
| | Sindh | 74.3.0 | 518.9 | 707.7 | 103.2 | 1728.2 | 2422.4 | 1389.0 | 3331.0 | 3423.0 |
| | Total | 1543.5 | 894.0 | 2883.1 | 2731.7 | 2789.6 | 6882.8 | 1770.0 | 3120.0 | 2387.0 |
| 10-11 | Punjab | 1333.8 | 182.5 | 1766.8 | 2365.2 | 445.8 | 3384.0 | 1773.0 | 2443.0 | 1915.0 |
| | Sindh | 28.0 | 274.6 | 361.1 | 42.5 | 919.4 | 1230.3 | 1517.9 | 3348.1 | 3407.0 |
| | Total | 1412.6 | 617.4 | 2365.2 | 2445.1 | 1490.0 | 4803.5 | 1731.0 | 2413.0 | 2031.0 |

*Source*: Agricultural statistics of Pakistan 2011.

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