Price Transmission and Volatility Spillovers in Asian Rice Markets: Evidence from a Panel GARCH Model

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15 April 2015

Price Transmission and Volatility Spillovers in Asian Rice Markets: Evidence from a Panel GARCH Model

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This study examines world rice price transmission and volatility spillovers across major Asian rice markets over the period 2005-2013. In addition to the conventional GARCH models, we use a panel GARCH framework to estimate the spillover effects along with the consideration of heterogeneity and interdependence among six countries—Bangladesh, China, India, the Philippines, Thailand and Vietnam. Empirical results suggest that changes in the world price of rice and the 2007-2008 price shocks affected not only the price levels of domestic rice markets but also their conditional variances. Moreover, interdependence across those rice markets contributed to a strong spillover of a price shock in one country to another within the region.

KEYWORDS *Rice market, price transmission, volatility spillover, GARCH, food policy*

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1. Introduction

In an effort to maintain the welfare of domestic rice producers and consumers, policymakers in Asian developing countries must address the issues concerning volatility in rice prices and spillover effects from the world market. Surges in rice prices in 2007 and 2008 have renewed interest in the impact of both the levels and volatility of prices that the world rice market exerts on domestic markets.

An important aspect of the world's rice markets is the debate over the implications of government policies used to insulate local markets from price changes in the rest of the world. Minot (2011) and Baltzer (2013) show that trade barriers, such as export quotas and import tariffs, reduce price transmission across countries. However, Timmer (2010) argues that policy actions undertaken by countries to stabilize domestic prices often produce spillover effects that ultimately *increase* world price instability. If government interventions through short-term trade policy actions are not at all effective, then these actions may facilitate full price transmission from the world to domestic markets. As such, ineffective trade interventions would raise *both* the levels and volatility of world prices. Furthermore, world and domestic prices would become more correlated.

A large body of literature has highlighted the role of policies in the extent of price transmission and volatility spillovers between the world and domestic markets. Quiroz and Soto (1995), Baffes and Gardner (2003), Rapsomanikis et al. (2004), Imail et al. (2008), Dawe (2009) and Baltzer (2013) have provided evidence in support that government price stabilization policies lead to incomplete or low price transmission. However, Sharma (2002), Conforti (2004), Rapsomanikis (2011), Robles (2011), Goshray (2011), Alam et al. (2012), and John (2013) have also provided empirical support to a strong relationship between international and domestic agricultural commodity prices in the presence of government interventions.

A common feature of the above studies is that their empirical work is mostly confined to time-series data of individual countries. Empirical work on individual time-series data, however, ignores the possibility that changes in one country's rice price levels and their volatility could spill over to another country. Interdependence across Asian rice markets was evident during the 2007-08 rice "crisis" episode when trade policy actions by governments raised both the levels and volatility of world rice prices, which eventually affected their own markets. In particular, many observers believe that the rice export restrictions by India and Vietnam in 2007 and the Philippine National Food Authority's rice import tenders for Vietnamese rice imports in early 2008 all contributed to sharp increases and high volatility in the world rice prices during that period. Between October 2007 and April 2008, world market rice prices tripled, reaching the highest levels ever recorded in nominal terms.

Against the above background, the objective of this paper is to conduct an empirical investigation on recent price transmission and volatility spillovers across major rice markets in Asia, namely Bangladesh, China, India, the Philippines, Thailand and Vietnam. Those are among the world's largest rice producers, and the Philippines is also the world's largest rice importer. One distinction of our work is to capture possible interdependence across rice markets in those countries as well as their heterogeneity.

In the literature concerning developments in world rice markets, our work extends the recent studies of Ghoshray (2011), Rapsomanikis (2011) and John (2013). More specifically, instead of the conventional time-series framework found in those studies, we estimate both the mean and variance relationships between the world and domestic rice prices using the panel Generalized Autoregressive Conditional Heteroskedasticity (GARCH) framework recently advanced by Cermeño and Grier (2006), and Lee (2010). The GARCH approach allows us to shed light on historical changes in rice price uncertainty through the dynamics of the conditional variance and covariance processes. The extension of GARCH to the panel setting, which pools time-series and cross-section data together, enables us to evaluate both the nature and the size of rice price transmission and volatility spillovers while accounting for possible interdependence and heterogeneity across countries.

The rest of the paper is organized as follows. Section 2 outlines the conceptual framework for the empirical study. Section 3 presents the panel GARCH model and the data. Section 3 discusses the empirical results. Section 4 concludes and draws policy implications.

2. Conceptual Framework

In order to motivate our study concerning the recent price transmission from the world to domestic rice markets in Asia, we present a simplistic model of the law of one price (LOP). According to Fackler and Goodwin (2001), the LOP can be written in two alternative forms as

$$p_d = p_w + \tau \tag{1}$$
$$p_w - p_d \leq \tau \tag{2}$$

where p_d refers to the domestic price, p_w denotes the world price, and τ corresponds to transportation and transaction costs in trade. Equation (1) represents the strong form of the LOP which, if the commodity is freely traded, indicates an integrated relationship between prices in the world and domestic markets. The price gap between the two markets is represented by transportation and transaction costs τ (Baltzer, 2013). This case holds only in the long run when price changes in the world market are completely and instantaneously transmitted to prices in the domestic markets. Complete integration of markets and price transmission imply that the price effect arising from changes in one country's domestic supply and demand conditions will prompt trade with other countries. The implication is that domestic prices tend to equalize with the world price except for transport costs. In the short run, price transmission may be incomplete if the pass-through of price changes between the world and domestic markets is not immediate but occurs after some time.

Equation (2) represents the weak form of the LOP, which suggests that the price gap between the world and domestic prices of a commodity should be at most equal to the transactions costs. Let $p_w + \tau$ and $p_w - \tau$ represent, respectively, import parity and export parity price gap that is generated by the transportation and transactions costs. Based on this price gap, incentives for international arbitrage can occur in two ways (Baltzer, 2013). First, sufficiently large excess domestic supplies, which lower domestic prices below export parity, should ensure that domestic prices do not stay too far below export parity for too long. Second, if domestic supplies are tight relative to demand, which push domestic prices close to or above import parity, should invite importers to satisfy the excess demand at import parity. Consequently, the domestic price is determined by domestic supply and demand conditions, and it is unrelated to international prices if the domestic price is within the parity bounds and the commodity is non-traded.

The close relationship between the world price and domestic prices under LOP is relevant to our study because rice is traded globally, particularly for the rice produced in Asia. Although the strong form of LOP implies cointegration between the world price and domestic prices, empirically estimating equation (1) is important in order to determine the extent of price transmission from international to domestic markets. In this case, the implicit assumption is that the variations in τ over time only have a small impact on changes in domestic prices. Furthermore, the simplified relationship between the world and domestic prices under LOP in equation (1) provides a fundamental basis of understanding the volatility spillovers across domestic markets. Timmer and Falcon (1975) and Martinez et al. (1998) argue that the thin world trade of rice is the primary cause of instability in the world rice market. Accordingly, the volatility in world rice prices can also be assumed to be a function of the volatility in domestic rice prices. With this direction of volatility spillovers, volatility in world rice prices can also be tied to government rice trade policy, which also affects rice prices in levels.

3. Model Specification and Data

3.1 Panel Diagonal VECH Model

This section outlines the panel GARCH model that is used for our empirical work. More details can be found in Cermeño and Grier (2006), and Lee (2010). For N countries and T periods, the conditional mean equation for the rice prices can be expressed as a dynamic panel model with fixed effects:

$$p_{it} = \mu_i + \sum_{k=1}^{K} \phi_k p_{it-k} + \mathbf{x}_{it}\boldsymbol{\beta} + \varepsilon_{it}, \qquad i = 1,\dots, N;\ t = 1,\dots, T, \qquad (3)$$

where the subscript i refers to a specific country and the subscript t refers to a given time period. The term $\mathbf{x}_{it}$ contains exogenous variables with coefficients captured by the vector $\boldsymbol{\beta}$. The term μ_i captures possible time-invariant effects associated with domestic rice prices; and ε_{it} is a disturbance term with conditional moments as follows:

$$E[\varepsilon_{it}\varepsilon_{js}] = 0 \qquad \text{for } i \neq j \text{ and } t \neq s, \qquad (4)$$

$$E[\varepsilon_{it}\varepsilon_{js}] = 0 \qquad \text{for } i = j \text{ and } t \neq s, \qquad (5)$$

$$E[\varepsilon_{it}\varepsilon_{js}] = \sigma_{ij,t}^2 \qquad \text{for } i \neq j \text{ and } t = s, \qquad (6)$$

$$E[\varepsilon_{it}\varepsilon_{js}] = \sigma_{it}^2 \qquad \text{for } i = j \text{ and } t = s. \qquad (7)$$

Equation (4) essentially indicates the restriction of no non-contemporaneous cross-sectional correlation, and equation (5) reflects the restriction of no autocorrelation. Equations (6) and (7) define the general conditions of the conditional variance-covariance process. Those four conditions which makes it more feasible for estimation by reducing the total number of free parameters.

The conditional variance and covariance processes of ε_{it} are assumed to follow a GARCH (1,1) process:

$$\sigma_{it}^2 = \alpha_i + \delta\, \sigma_{i,t-1}^2 + \gamma \varepsilon_{i,t-1}^2 + \mathbf{x}_{it}\boldsymbol{\theta}, \quad (8)$$

$$\sigma_{ijt} = \eta_{ij} + \lambda \sigma_{ij,t-1} + \rho \varepsilon_{i,t-1}\varepsilon_{j,t-1} + \mathbf{x}_{it}\boldsymbol{\vartheta}, \qquad \forall\, i \neq j \quad (9)$$

This specific GARCH process is adopted for its popularity and parsimony. Equations (8) and (9) also show the inclusion of the exogenous variables as for conditional mean equation (3). This augmentation to the standard GARCH process allows us to test for the impact of world market prices on the volatility of domestic prices.

Using matrix notation, equation (3) can be written as:

$$\mathbf{y}_t = \boldsymbol{\mu} + \mathbf{z}_t \boldsymbol{B} + \boldsymbol{\varepsilon}_t, \quad (10)$$

where $\mathbf{y}_t$ and $\boldsymbol{\varepsilon}_t$ are $N \times 1$ vectors, $\boldsymbol{\mu}$ is the corresponding $N \times 1$ vector of individual-specific effects, and $\mathbf{z}_t = [p_{t-1} \ldots p_{t-k} \vdots \mathbf{x}_t]$ a matrix with corresponding coefficients in $\boldsymbol{B} = [\phi \vdots \boldsymbol{\beta}']'$. The disturbance term has a normal distribution $N(\mathbf{0}, \Omega_t)$. The disturbance term $\boldsymbol{\varepsilon}_t$ is conditional heteroskedastic and cross-sectionally correlated, such that the least-squares estimator is consistent but not efficient. For this reason, we follow Cermeño and Grier (2006) and Lee (2010), and apply the maximum-likelihood (ML) method, which maximizes the following log-likelihood function:

$$L = -\frac{1}{2}\{NTlog(2\pi) + \sum_{t=1}^{T} log|\boldsymbol{\Omega}_t| + \sum_{t=1}^{T}[(\mathbf{y}_t - \boldsymbol{\mu} - \mathbf{z}_t\boldsymbol{B})' \times \boldsymbol{\Omega}_t^{-1}((\mathbf{y}_t - \boldsymbol{\mu} - \mathbf{z}_t\boldsymbol{B})]\}. \quad (11)$$

3.2 Data

We conducted estimations using monthly observations on the world and domestic wholesale prices in real US dollars per ton covering the period between January 2005 and April 2013 (T = 100) for six Asian countries (N = 6). The data for Bangladesh, the Philippines, Thailand and Vietnam reflect national averages for the most widely traded rice quality, while the data for China and India apply to the prices in their capital cities. We use the price of Thailand 25%B FOB Bangkok as a proxy for the world rice price.[2] The real domestic wholesale and world prices are calculated by first dividing the nominal prices by the domestic consumer price index

[2] Instead of the Thai export price as a measure of the world price, we have also considered the export prices of the equivalent quality rice from Vietnam and Pakistan. Granger's weak exogeneity tests (with 6 lags) for the whole observation period support Granger-type causality running from the Thai price to the Vietnamese and Pakistani prices. There is no evidence to support the causal effect of either the Vietnamese or Pakistani rice price on the Thai rice price. It has also been argued that the Thai rice export price no longer dominated the world rice market after September 2011. Granger's weak exogeneity tests with data over the post-September 2011 period do not support this argument. Using the subsample period before September 2011 does not meaningfully alter the empirical results presented here.

(CPI), and then multiplying by the US CPI. Data on prices are sourced from *FAO GIEWS Food Price Data and Analysis Tool*, and CPI data are obtained from the *International Financial Statistics*.

Our empirical work began with data specification. Table 1 shows the unit-root test results for the price data series. The tests were conducted for the two alternative cases of a constant and a constant plus trend. Panel A shows the test results of the augmented Dickey-Fuller (1981) *t*-test for individual time-series data. In light of the Akaike Information Criterion (AIC), three autoregressive lags were included in regressions for all data series in log levels, and two lags were included for the first-differenced data. The ADF-*t* statistics show strong evidence of a unit root for the domestic and world prices are expressed in log levels. When first-differencing is applied to the data, the null hypothesis of stationarity cannot be rejected in all cases. Those findings, which support integration for all domestic rice price series, corroborate with those in Rapsomanikis (2011) for India and the Philippines, Alam et al. (2012) for Bangladesh, Chulaphan et al. (2013) for Thailand and Vietnam, and Imai et al. (2008) for China.

In addition to the univariate test results in panel A, panel B shows the corresponding unit-root tests for the panel data of domestic prices. For the Im-Pesaran-Chin (2003) and Levin-Lin-Chu (2002) tests, the null hypothesis is a unit root for the panel data. Both panel-based test statistics strongly reject the unit-root null in the case of first-differenced data, but not in the case of data in levels.

The bottom row of panel B in Table 1 shows the ADF statistics for Pedroni's (1999) test for cointegration between the levels of domestic prices and the world price in the panel setting. Both statistics show little evidence to support cointegration between domestic prices as a whole and the world price. The results in Table 1 provide little empirical support for either of the two forms of LOP, and thus perfect market integration does not occur for rice around the world. Furthermore, the linkage between the domestic and world prices can be examined through a first-differences model specification without the consideration of cointegration between the two variables. The first-differences specification allows us to measure the extent to which *changes* in the world price are transmitted into the Asian domestic rice markets.

Figure 1 displays the patterns of the price data, which are expressed as the 100 times the first difference of the log levels of the respective domestic and world prices. The domestic prices of China and the Philippines varied the least over time, while those of Thailand and Vietnam varied the most. In addition to the world price, the Vietnamese and Thai domestic prices showed a spike in early 2008 during the rice crisis episode. Both Thai and Vietnamese prices also appear to follow the world price the most.

Table 2 provides supporting evidence for the application of a GARCH-type model for understanding the volatility dynamics of rice prices. The table shows the Ljung-Box Q statistics for serial correlation and the results of an F-test of ARCH effects in the residuals of regressions of first-differenced price series on two autoregressive lags. For both tests, the statistics are generated with a fourth order autoregressive lag for the residuals. The Ljung-Box Q statistics show scant evidence of serial correlation, suggesting that the autoregressive model of two lags is appropriate for all price series. Furthermore, the ARCH test statistics provide strong evidence of conditional heteroskedasticity in the variances of the rice price data. Overall, the test statistics in Table 2 support the application of GARCH-type models for estimating the volatility dynamics of the Asian rice price series.

Given the objectives of this paper, the exogenous variables of interest in the $\mathbf{x}_t$ term in equation (1) include the lagged value of the change in the world rice price (p^*_{t-1}), and a dummy variable ($CRISIS_t$) capturing the effects of the 2007-08 Asian rice price shocks. The dummy variable takes on the value of one between October 2007 and May 2008, and zero otherwise.

4. Model estimation results

4.1 MGARCH Estimation Results

Before proceeding to the panel GARCH estimation, it is interesting to first look at results from corresponding GARCH model regressions for the six individual countries. The interactions between each of the six domestic prices and the world price is modeled using a popular MGARCH(1,1) process parallel to our panel model setting. The conditional mean equation can be expressed as a second order vector autoregression (VAR):

$$\mathbf{y}_{it} = \boldsymbol{\mu}_i + \boldsymbol{\phi}_{1i}\mathbf{y}_{it-1} + \boldsymbol{\phi}_{2i}\mathbf{y}_{it-2} + \boldsymbol{\beta}_i CRISIS_t + \mathbf{e}_{it}, \quad (12)$$

where $\mathbf{y}_{it} = (p_{it}, p^*_{it})$, and $\mathbf{CRISIS}_t = (CRISIS_t, CRISIS_t)$. The variables p_{it} and p^*_{it} correspond to the domestic and world rice prices, respectively. The term $CRISIS_t$ is the dummy variable that accounts for the sudden and exogenous change in the global rice market. The conditional variance-covariance equation is estimated with BEKK parameterization:

$$\mathbf{H}_{it} = \mathbf{C}_i'\mathbf{C}_i + \mathbf{A}_i'\mathbf{e}_{it}\mathbf{e}_{it}'\mathbf{A}_i + \mathbf{B}_i'\mathbf{H}_{it-1}\mathbf{B}_i + \mathbf{D}_i'\mathbf{CRISIS}_t\mathbf{D}_i. \quad (13)$$

The dummy variable in equation (13) captures the effect of the 2007-08 price shocks on price volatility.

Table 3 displays the MGARCH estimation results of the six countries in the sample. Panel A shows the estimation results of the conditional mean equation (12) for the alternative domestic prices as the dependent variable. About half of the estimates for the lagged dependent variables are statistically significant. The domestic prices for China and India do not appear to have been affected by changes in the world rice price. Such results are due to those two countries' strong export controls imposed prior to the surge in world rice prices (Fang, 2010; Gulati and Dutta, 2010). For other countries, the linkage between the domestic and world price is statistically meaningful. Particularly for Thailand and Vietnam, the coefficient estimates for the lagged world price are above 0.45. Such estimates reveal economically large spillover effects on the domestic markets, and domestic rice prices tend to react quickly to rice markets in the rest of the world.

Panel B of Table 3 shows the coefficient estimates for the variance-covariance equation (13). The element A_{21} in the **A** matrix captures the effects of a shock in the world price on individual domestic prices. Estimates are empirically meaningful for all countries except India. India has kept its domestic rice prices below international prices for most years using domestic price stabilization policies and export restrictions (Gulati and Dutta, 2010). The estimates for the element B_{21} in the **B** matrix reflect the extent to which volatility in the world price affects volatility in domestic prices. Estimates are statistically significant for the Philippines and Thailand, but not for the other Asian countries. The results for the Philippines are consistent with those reported by Rapsomanikis (2011), who argued that rice price instability arose from the government's imposition of export and import restrictions especially during the 2008 rice crisis. The estimate for Thailand reflects the uncertainty over the government's policy on selling its rice stocks from the paddy pledging program, which contributed to the greater price fluctuations (Poapongsakorn, 2010).

The elements A_{12} and B_{12} reflect the impacts of changes in the domestic markets on the world market. More specifically, A_{12} shows the extent to which a shock to a country's rice market affects the world rice price, and B_{12} shows how much volatility in domestic rice prices affects the volatility in the world rice price. The estimate for A_{12} is statistically significant for all countries except China. The positive sign of the associated coefficient estimates suggests that an unexpected increase in domestic prices in these countries raises the world price. For the Philippines, Thailand and Vietnam, the estimate for B_{12} is also statistically significant, further highlighting the significance of price volatility in those countries on the world rice market. Both coefficient estimates for those three countries also imply that when governments impose trade measures that result in higher world rice prices, volatility in the world rice market rises as well.

The coefficient estimates for the dummy variable reflect the importance of the Asian rice price crisis on the volatility dynamics of domestic and world prices (D_{11} and D_{22}), as well as their covariances (D_{21}). The estimates are statistically significant for all these coefficients in the cases of the Philippines, Thailand and Vietnam, highlighting again the close relationship between those major rice markets and the world market. The statistical significance and positive estimates for D_{21} highlights the positive volatility spillovers between the domestic and world markets.

The estimates for the element B_{11} reflect the varying levels of persistence in the volatility of rice prices. The estimate is the highest at 0.88 for Vietnam, and the lowest at 0.31 in the case of China. The sharp contrasts among those estimates are also evident in Figure 2, which plots the patterns of the conditional variance series for the six countries. Figure 2 also displays the patterns of the conditional covariances between the domestic prices and the world price. Interestingly, the patterns vary appreciably across countries, although most covariance series reach a peak during the 2007-08 rice crisis. The series for Bangladesh and China are relatively smaller than the series for other countries. The overall positive covariances indicate that the world rice price and domestic prices tended to change over time in the same direction.

Overall, the bivariate MGARCH model estimations in Table 3 show mixed findings for the linkage between the world price and domestic price across different Asian countries. Overall evidence of this relationship in either the conditional mean or the conditional variance equation is much stronger for the Philippines, Thailand and Vietnam, than for Bangladesh, India and China.

4.2 Panel GARCH Estimation Results

Given the equivocal findings in the preceding section, it is difficult to generalize the conclusion on the transmission of world rice prices and volatility spillovers across countries. This provides motivation for the application of a panel regression framework outlined in Section 2 above. As Cermeño and Grier (2006) and Lee (2010) pointed out, there is potential efficiency gain in the estimation of conditional variances and covariances when GARCH estimation also incorporates interdependence across different rice producing countries. Estimation results for the panel GARCH model are displayed in Tables 4 to 6. In addition to the lagged values of the domestic prices, the explanatory variables in the $\mathbf{x_t}$ term include the first lagged value of the change in the world price and the dummy variable controlling for the 2007-08 rice crisis. The second lagged value of the world price change variable does not enter this model because its estimates are not statistically significant for all countries in Table 3.

Table 4 lists the coefficient estimates for the conditional mean equation (3). In sharp contrast to their corresponding estimates for individual countries on the panel (Table 3), all coefficient estimates are statistically significant. In particular, the estimate for the lagged world price change implies that a 10-percent increase in the world price raises the overall domestic prices by 2.9 percent. The estimate for the dummy variable also highlights the impact of the 2007-08 rice crisis on the domestic rice markets. The bottom row of Table 4 shows the result of a Chow-type test for poolability of the panel data for the six countries. The null hypothesis of a pooled regression is tested against the alternative hypothesis of six fully separated regressions. The F statistic of 5.99 strongly supports the application of a panel model over individual regressions.

Table 5 shows the estimation results for the conditional variance equation (8). The estimate for the parameter δ at 0.69 reflects a fair amount of persistence in price volatility. By comparison, the estimate for the parameter γ is 0.24, indicating the positive effect of a price shock on the volatility of domestic prices. The estimate for θ_1 indicates the effect of changes in the world price on domestic prices, while the estimate for θ_2 captures the impact of the 2007-08 crisis on price volatility[3]. Both estimates are empirically meaningful. Moreover, the point estimate for θ_1 is near the average of the corresponding estimates in Table 3.

Table 6 shows the coefficient estimates for the conditional covariance equation (9). The majority of the estimates for η_{ij} ($i \neq j$) are statistically significant and positive, meaning that the variances of the six domestic rice prices vary in the same direction over time. The estimate for λ at 0.87 highlights a rather high persistence among the conditional covariances. Likewise, the estimate for ρ is also statistically significant, supporting the impact of a price shock on the conditional covariances. The estimates for ϑ_1 and ϑ_2 are also close to their counterparts in the conditional variance equation in Table 5 above. Those estimates reveal strong evidence about

[3] The coefficient estimates for both the conditional mean and conditional covariance equations are robust for the case of no crisis dummy. As a further robustness check, we have included policy variables such as export ban, import tenders and government stockpiling in the mean equation with and without the crisis dummy. The results suggest that those policy variables are not strong enough to affect the domestic prices in the panel setting. However, policy variables like the import tenders in the Philippines and export ban in Vietnam are statistically significant for their respective domestic markets.

the impact of changes in the world price and the 2007-08 price shocks on the covariances of Asian domestic rice markets.

Despite the finding of interdependence, we evaluate country-specific effects in the variance and covariance equations by applying likelihood ratio (*LR*) tests based on the log-likelihood values of the panel model estimated separately with and without individual effects. The *LR* statistic is 37.12 for conditional variance equation (8) and 61.34 for the conditional covariance equation (9). Both statistics are significant at the 1% level, suggesting the presence of individual effects and heterogeneity across countries.

The overall estimation results in Tables 4 to 6 underscore the extent of interdependence across the rice markets of Asian countries. Such interdependence has helped contribute to the spillover of a price shock in one country to another within the region. More importantly, the estimation results with the panel GARCH model confirm the role of changes in the world rice price on domestic rice markets.

5. Conclusions

This paper has examined the transmission and volatility spillover of the world price of rice to domestic rice markets based on a panel of six Asian countries over the period 2005-2013. Empirical results of conventional MGARCH models suggest an empirically meaningful relationship between the world rice price and the domestic price in either the conditional mean or the conditional variance equation for the Philippines, Thailand and Vietnam. Furthermore, strong levels of persistence in the volatility of domestic and world prices were observed in the cases of Vietnam and Thailand.

In a panel GARCH setting, regression results suggest that changes in world price of rice and the 2007-08 price shocks increased not only the domestic markets' overall price levels but also their rice volatility. There is also strong evidence of interdependence across different Asian rice markets, and the extent of interdependence contributes to the spillover of a price shock in one country to another within the region. Those results raise questions regarding the effect of government policies in the extent of price volatility spillovers, which were evident in the case of import tenders in the Philippines and export ban in Vietnam. Our empirical results also have direct bearing on the debate about the benefits of international policy coordination in the world rice market.

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Table 1 Unit Root and Cointegration Tests

	Log Levels		First Differences	
	Constant	Constant+Trend	Constant	Constant+Trend
A) Time-Series Data (ADF *t*-Test):				
Bangladesh	-2.27 *	-2.28 *	-10.61	-10.68
India	-1.92 *	-1.76 *	-14.23	-13.83
Philippines	-1.84 *	-2.77 *	-6.05	-5.27
Thailand	-1.68 *	-2.29 *	-6.44	-6.42
China	-0.77 *	-3.16 **	-6.25	-6.23
Vietnam	-3.31 ***	3.19 ***	-7.96	-5.85
World Price	-1.96 *	-2.97 *	-5.35	-5.33
B) Panel Data (Domestic Prices)				
Im-Pesaran-Shin	-1.30	-0.56	-7.44 *	-7.39 *
Levin-Lin-Chu	0.99	0.90	-5.28 *	-3.95 *
Pedroni ADF test	-0.82	-1.21		

Notes: For the augmented Dickey-Fuller (ADF) tests with individual time-series data, the null hypothesis is a stationary time series. For the panel data, the null hypothesis is a unit root. Regressions were run with 3 autoregressive lags for data in levels, and 2 autoregressive lags for first-differenced data. *, **, and *** indicate rejection of the null hypothesis at the 1%, 5% and *** statistical levels, respectively.

Table 2 Tests for Serial Correlation and Conditional Heteroskedasticity

	Ljung-Box Q (4)	ARCH (4)
Bangladesh	0.31	4.32 *
India	0.18	5.21 *
Philippines	0.61	18.63 *
Thailand	0.87	11.52 *
China	0.02	2.06 ***
Vietnam	0.43	2.78 **
World Price	0.90	2.81 **

Notes: *, **, and *** denote statistical significance at the 1%, 5%, and 10% levels, respectively.

Table 3 MGARCH Estimation Results

	Bangladesh	India	Philippines	Thailand	China	Vietnam
A) Conditional Mean Equation						
Intercept	-0.37 (0.63)	-0.12 (0.28)	0.23 (0.75)	-0.21 (0.33)	0.51 (1.94)**	-0.53 (0.87)
p_{it-1}	0.17 (1.56)	0.02 (0.21)	0.27 (2.52)*	0.47 (2.38)**	0.26 (2.63)*	0.36 (3.39)*
p_{it-2}	0.05 (0.47)	0.11 (1.07)	-0.15 (1.50)	-0.41 (2.10)**	-0.12 (1.25)	-0.15 (1.48)
p^*_{t-1}	-0.16 (1.36)	-0.10 (1.24)	0.12 (1.87)***	0.48 (2.73)*	0.09 (1.87)***	0.46 (3.52)*
p^*_{t-2}	0.11 (1.10)	0.07 (0.93)	0.14 (2.26)*	0.25 (1.25)	0.02 (0.47)	0.20 (1.63)
$CRISIS_t$	3.87 (1.78)***	2.29 (1.34)	1.34 (1.08)	9.00 (3.43)*	0.11 (0.11)	1.54 (0.62)
Std. error	5.38	3.88	2.86	5.94	2.32	5.73
B) Conditional Variance/Covariance Equation						
C_{11}	3.98 (8.55)*	2.68 (6.77)*	1.18 (3.25)*	1.18 (0.36)	2.09 (8.94)*	0.90 (2.28)
C_{21}	0.07 (0.21)	0.20 (0.51)	-0.29 (0.61)	-0.29 (0.35)	-0.22 (3.07)*	-0.57 (2.32)**
C_{22}	0.37 (0.42)	0.01 (0.01)	0.01 (0.01)	0.01 (0.12)	0.06 (0.89)	0.01 (0.12)
A_{11}	0.34 (2.49)*	0.30 (2.26)**	0.45 (1.78)***	0.31 (2.37)**	0.05 (2.27)**	0.36 (4.19)*
A_{12}	0.22 (3.60)*	0.12 (1.65)***	0.55 (2.47)*	0.35 (3.35)*	0.03 (1.62)	0.12 (2.40)**
A_{21}	0.59 (5.15)*	0.03 (0.65)	0.04 (0.43)	-0.47 (3.39)*	0.21 (9.94)*	0.25 (3.28)*
A_{22}	0.51 (4.46)*	0.41 (3.26)*	0.33 (2.11)**	-0.10 (0.76)	0.50 (5.76)*	-0.04 (0.45)
B_{11}	0.25 (1.11)	0.66 (5.64)*	0.46 (1.85)***	0.86 (9.54)*	0.31 (3.38)*	0.88 (8.70)*
B_{12}	-0.05 (0.34)	-0.10 (1.07)	0.43 (2.07)**	0.14 (1.98)**	0.26 (1.61)	0.08 (3.25)*
B_{21}	0.05 (0.37)	0.03 (1.51)	0.25 (4.70)*	0.13 (1.97)**	-0.03 (0.21)	0.01 (0.17)
B_{22}	0.76 (11.17)*	0.85 (9.30)*	0.87 (17.04)*	0.87 (9.16)*	0.83 (5.84)*	0.89 (28.57)*
D_{11}	0.69 (0.40)	2.17 (4.97)*	0.33 (2.40)**	5.45 (4.46)*	1.88 (1.32)	1.24 (2.48)**
D_{21}	2.98 (0.91)	5.02 (3.21)*	5.35 (3.75)*	2.79 (3.33)*	5.58 (11.25)*	5.03 (4.14)*
D_{22}	6.36 (2.58)*	-0.01 (0.95)	4.58 (3.61)*	1.18 (2.12)**	0.94 (4.38)*	0.02 (1.69)***

Notes: Estimates for the conditional mean equations are for the "domestic" price equations. Absolute values of *t*-statistics are in parentheses. *, **, and *** denote statistical significance at the 1%, 5%, and 10% levels, respectively.

Table 4 Panel GARCH-Conditional Mean Estimation Results

Variable	Estimate
μ_i	0.02 (0.15)
p_{it-1}	0.24 (5.69) *
p_{it-2}	0.06 (1.68) ***
p^*_{t-1}	0.29 (9.42) *
$CRISIS_t$	2.95 (4.09) *
Likelihood	-1782.59
Chow F	5.99 *

Notes: Absolute values of t-statistics are in parentheses. * and ** denote statistical significance at the 1% and 5% levels, respectively.

Table 5 Panel GARCH-Conditional Variance Estimation Results

Coefficient	Estimate
α_1	0.31 (0.85)
α_2	-0.08 (0.25)
α_3	0.16 (0.74)
α_4	0.31 (1.62)
α_5	-0.11 (0.42)
α_6	0.44 (0.19)
δ	0.69 (6.29) *
γ	0.24 (1.74) ***
θ_1	0.12 (2.65) *
θ_2	0.24 (2.76) *

Notes: Absolute values of t-statistics are in parentheses. * and ** denote statistical significance at the 1% and 5% levels, respectively.

Table 6 Panel GARCH-Conditional Covariance Estimation Results

Coefficient	Estimate
η_{11}	0.48 (1.81) ***
η_{21}	3.56 (8.24) *
η_{22}	0.03 (1.09)
η_{31}	1.77 (6.19) *
η_{32}	0.41 (3.22) *
η_{33}	0.32 (1.65) ***
η_{41}	0.67 (7.43) *
η_{42}	0.16 (9.15) *
η_{43}	0.05 (0.46)
η_{44}	0.44 (8.96) *
η_{51}	2.71 (31.62) *
η_{52}	0.04 (0.34)
η_{53}	0.20 (1.77) ***
η_{54}	-0.09 (1.31)
η_{55}	0.07 (1.38)
η_{61}	0.75 (5.93) *
η_{62}	0.36 (0.97)
η_{63}	-0.06 (0.11)
η_{64}	0.09 (0.69)
η_{65}	0.96 (5.35) *
η_{66}	0.05 (0.31)
λ	0.87 (8.24) *
ρ	0.35 (9.32) *
ϑ_1	0.20 (3.48) *
ϑ_2	6.88 (4.67) *

Notes: Absolute values of *t*-statistics are in parentheses. *, **, and *** denote statistical significance at the 1%, 5%, and 10% levels, respectively.

Figure 1 First-Differenced Rice Price Data

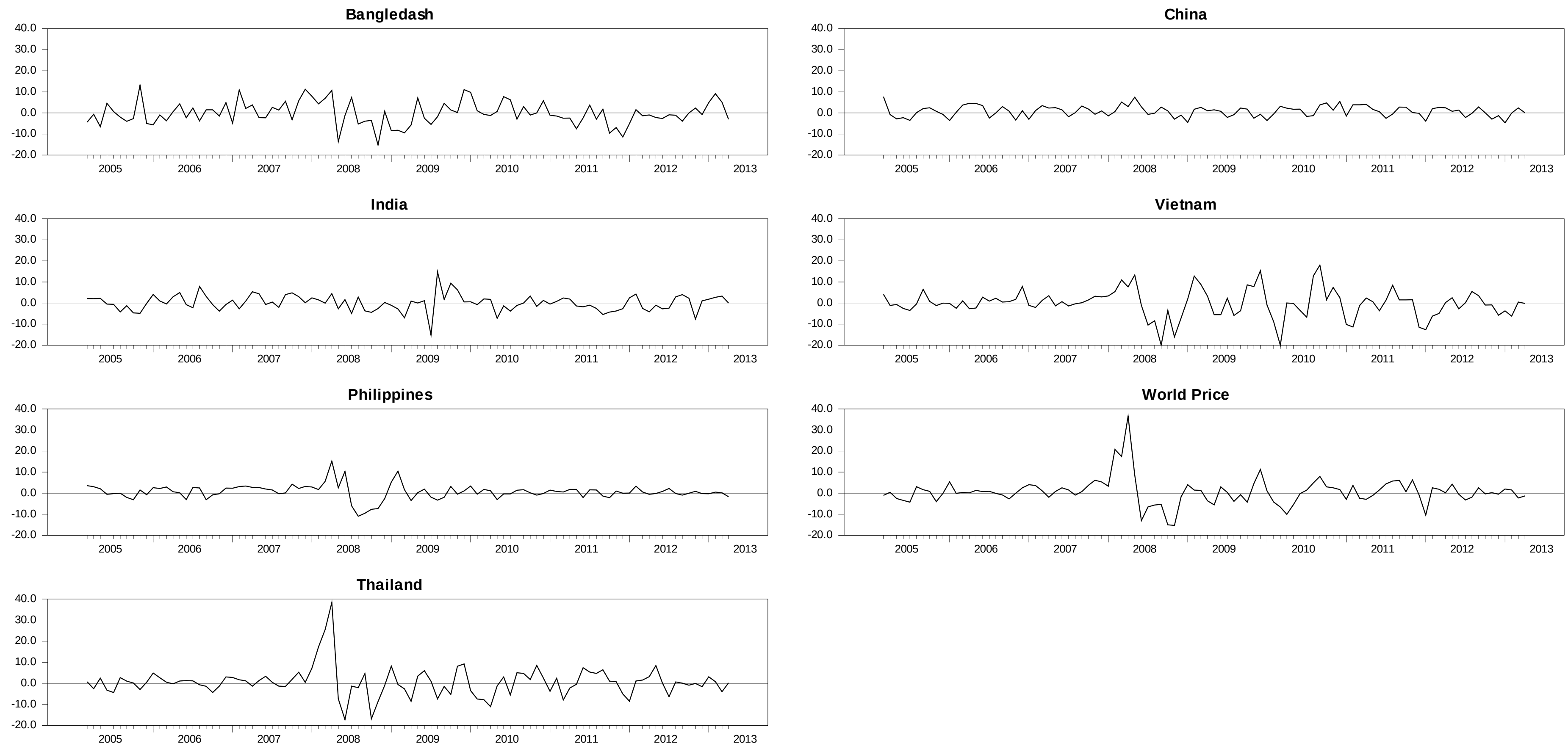

Figure 2 Variances and Covariances of Price Series