Analysis of Price Transmission along the Cambodian Rice Value Chain

S. Bairagi[1]; S. Mohanty[2]

1: International Rice Research Institute (IRRI), Agri-Food Policy Platform , Philippines, 2: International Potato Center (CIP), , Viet Nam

Corresponding author email: s.bairagi@irri.org

Abstract:

A threshold specification of the asymmetric error correction model is applied to estimate and test the threshold cointegrating relationship between the wholesale paddy price (farm price) and wholesale rice price, and the wholesale and retail price of rice in Cambodia. Based on our analysis, the threshold cointegration test suggests in favor of asymmetric cointegration. Further, the test of the symmetric adjustment process advocates the presence of asymmetric price transmission in both the short run and long run. The Granger causality test revealed a unidirectional causality from wholesale price to farm price, and a bidirectional causality between wholesale and retail price. Finally, we found that decreases in wholesale price are more quickly transmitted to farmers than price increases. Conversely, increases in wholesale price are more quickly transmitted to consumers than price decreases. For faster price transmission, improved market infrastructure, better market integration, and dispersion of marketing information are suggested.

Acknowledgement: We thank the Global Rice Science Partnership (GRiSP) project of the CGIAR for supporting this study. The contents and opinions expressed herein are those of the authors and do not necessarily reflect the views of the authors' institution, and shall not be used for advertising or product endorsement purposes. The usual disclaimer applies.

JEL Codes: C12, C24

#617

Analysis of Price Transmission along the Cambodian Rice Value Chain

Abstract

A threshold specification of the asymmetric error correction model is applied to estimate and test the threshold cointegrating relationship between the wholesale paddy price (farm price) and wholesale rice price, and the wholesale and retail price of rice in Cambodia. Based on our analysis, the threshold cointegration test suggests in favor of asymmetric cointegration. Further, the test of the symmetric adjustment process advocates the presence of asymmetric price transmission in both the short run and long run. The Granger causality test revealed a unidirectional causality from wholesale price to farm price, and a bidirectional causality between wholesale and retail price. Finally, we found that decreases in wholesale price are more quickly transmitted to farmers than price increases. Conversely, increases in wholesale price are more quickly transmitted to consumers than price decreases. For faster price transmission, improved market infrastructure, better market integration, and dispersion of marketing information are suggested.

Key words: error correction, asymmetric price transmission (APT), threshold autoregressive (TAR) model, threshold cointegration, and rice market.

JEL codes: C12, C24, Q13, L13, O53.

1. Introduction

Rice is the most important staple food for Cambodia, with per capita rice consumption of 170 kg per year. In terms of daily calorie intake, rice constitutes approximately 63% of total calorie intake (FAOSTAT 2016). On the supply side, on average 3.0 million hectares of land are cultivated for rice production, and 7.25 million metric tons of paddy are annually produced. In terms of trade, Cambodia has been a net rice-exporting country since 2005 (USDA 2016). The rice sector employs about 3 million people in rice production, processing, and marketing activities (IFC 2015). As a whole, the rice sector contributes approximately 25% to the country's agricultural gross domestic product (GDP), which accounts for 14% of the total national GDP.

In Cambodia, approximately 38% of total paddy production was marketed in 2014-15[1], of which only 12.8% was milled locally. The rest of the paddy was exported to Vietnam (19.1%) and Thailand (6.0%). Five main actors (intermediaries), involved in the rice value chain of Cambodia, perform domestic production, processing, and marketing activities: retailers, wholesalers/processors/exporters, paddy traders, farmers, and input suppliers. The likely structure of the Cambodian rice market is illustrated in Figure 1. Paddy farmers are at the bottom of the downstream market in the rice value chain. Cambodian farmers are subsistence farmers with less than 2 hectares of land (FAO 2014). Rice is grown twice a year (dry and wet seasons), most of which is in the wet season (FAO 2016). On average, farmers' return to their own input (land) is estimated to be around 59.2% of total revenue, while it was 48.8% in 2006 (Table 1).

Cambodian rice millers are one of the key actors in the rice supply chain. Three types of rice mills are present in Cambodia: (a) small home-based non-commercial mills, (b) small home-based commercial mills, and (c) large mills. Even though the Kingdom has around 50,000 rice mills (as of mid-2012), only 22 are large mills (WB 2015). Theoretically, the market structure of the rice mill industry can be defined as a bilateral oligopoly market. This implies that rice millers set the farm price (paddy price) at p^f when they buy it from farmers or paddy traders. They also set the price of rice, p^w, after adding their processing and relevant costs on top of their expected profit/margin when they sell it to retailers. In Figure 1, the equilibrium price is the point where the marginal outlay curve and marginal revenue curve intersect. The difference between p^w and p^f is profit. Because of any supply or demand shocks, wholesalers will pass on any deviation, σ, from p^w, implying $p^w \mp \sigma$, to retailers/consumers. Note that, if the rate is exactly the same as σ, implying $p^r \mp \sigma$, then the price transmission process is called symmetric. Rice millers' mark-up, $\vartheta^w = (\frac{p^w - MC^w}{p^w})$, is estimated to be about 20.8% over their marginal cost (row 3 and column 10 of Table 1). Furthermore, millers' share in the total margin is approximately 18.5% (row 3 and column 12 of Table 1).

Retailers are at the top of the upstream market of the value chain. The Cambodian rice retail market can be explained as an oligopoly market (Figure 1). Thus, retailers earn a certain percentage over their marginal cost. This can be expressed as $p^r > MC^r$, where p^r is the price they charge from consumers and MC^r is the marginal cost of rice that is a function of the price paid to wholesalers (rice millers), p^w, and other costs (i.e., transportation, capital). Retailers' mark-up, $\vartheta^r = (\frac{p^r - MC^r}{p^r})$, is estimated to be about 5.6%, implying that they earn about 5.6% over the marginal cost (row 6 and column 10 of Table 1). Based on the marketing margin analysis, retailers' share in the total margin (from farmer to retailer) is about 9.5% (row 6 and column 12 of Table 1).

Cambodian rice market structure is poor. Transaction costs between producers and consumers are high because of both poor market and poor state infrastructure (i.e., roads, transportation, ports, and electrical power) (Hang Chuon and Suzuki 2005; Naron 2012; Sophea 2012). In addition, market participants/actors do not have perfect knowledge about price information; in economics, this is called "information asymmetry," which causes markets to become inefficient. Naron (2012) noted that middlemen in Cambodia distort the transmission of consumers' price signals to growers because of problems of information asymmetry. These factors are the likely reasons for the presence of asymmetric price transmission (APT) in the rice market of Cambodia. APT can be defined as when any price deviation (positive or negative) in the downstream market (wholesale level) does not transmit at the same rate or in the same period of time to the upstream market (retail level).

1.1 Literature review on APT in the rice market

The concept of APT is not new; it has been researched since the 1980s. However, Meyer and von Cramon-Taubadel (2004) are the first who defined APT economically and classified it as centered on three criteria: (i) price transmission with regard to magnitude, speed, and speed and magnitude; (ii) positive and negative transmission; and (ii) vertical or spatial transmission. Several reasons are noted in the literature that may cause price transmission process asymmetry[2]: noncompetitive market structures, adjustment and menu costs, high transaction costs, asymmetric flow of information, government intervention, input substitution at the processing level, the existence of different qualities of an agricultural commodity, and "consumption inertia"[3].[4]

The presence of APT is evidence of market failure because its presence deviates the equilibrium point from a competitive equilibrium condition. This leads to an inefficient allocation of resources. Consequently, the welfare benefits of one group of people (consumers and producers in our case) are eroded if the conditions of symmetry are not satisfied. This would also lead to a different distribution of welfare because it changes the timing and/or the size of the welfare changes associated with price changes (Meyer and von Cramon-Taubadel 2004; Gedara *et al.* 2016). Moreover, the efficient movement of price signals may be hindered because of the presence of APT, which may influence decision making regarding resource allocation (Gedara *et al.* 2016). Therefore, it is very important to identify the presence of APT, which could help enable policy-makers to initiate new policies with regard to an efficient marketing system.

A vast literature already tested the hypothesis of whether or not price transmissions of agricultural commodities are asymmetric. If we concentrate only on rice, then a total of 15 studies can be found, based on our knowledge.[5] These studies considered 14 countries[6] that examined the movement of prices from wholesale to retail levels, international to domestic levels, international to international levels, and regional to regional levels. These studies found that price transmission processes of the reported countries (except Mali, the Philippines, and Senegal) are asymmetrically cointegrated. In other words, rice markets of these countries are inefficient. This finding has an important policy implication for the food security and poverty of the people of those countries whose primary diet is rice. Even though rice is an important item in the food basket for Cambodians, no study has been conducted to test the hypothesis of the adjustment process of price transmission. Thus, this paper attempts to examine the price transmission process of wholesale and retail prices of rice in Cambodia.

2. Methodology

2.1 Models for asymmetric price transmission (APT)

In the literature, three sets of models have dealt with APT of food markets: (i) estimations based on the classical specification developed in the 1970s (i.e., Wolffram 1971; Houck 1977; Heien 1980; Kinnucan and Forker 1987), (ii) estimations incorporating the nonstationary property of data along with linear cointegration (known as the error-correction model, and hereafter ECM) (i.e., Engle and Granger 1987; von Cramon-Taubadel, 1998), and (iii) estimations incorporating nonlinear relationships of price series, known as the regime switching model (i.e., Enders and Siklos 2001; Abdulai 2000; Hansen and Seo 2002). Combining (ii) and (iii), Enders and Granger (1998) introduced a specification of APT with regard to improving the traditional tests for nonstationary and cointegration in the presence of APT (Simioni *et al.* 2013), known as the error correction model with threshold cointegration (TECM). This model has recently become an increasingly popular tool to analyze price transmission of agricultural commodities.[7] Because, if the long-run relationship between any two price series is asymmetric, the test for cointegration may lead to misleading findings (Balke and Fomby 1997). This paper used the TECM to test for the presence of APT in the rice market of Cambodia.

2.2 Error correction model with threshold cointegration (TECM)

The development of TECM is described in the following section. This section is adopted from Meyer and von Cramon-Taubadel (2004), Grasso and Manera (2007), Sun (2011), Fiamohe *et al.* (2013), and Gedara *et al.* (2016).

The Engle-Granger (1987) two-step approach, known as the Granger theorem, states that, if all the price series are integrated of order one, then an error correction model can be estimated. The first step is to estimate the long-run relationship between any two price series, P^1 (farm price or retail price) and P^2 (wholesale price), and the relationship can be written as:

$$ln\, P_t^1 = \beta_0 + \beta_1 \ln P_t^2 + \xi_t \qquad (1)$$

where P_t^1 and P_t^2 are the retail and wholesale price of rice at time *t* (month) for example; β_0 is the constant; β_1 is the cointegrating parameters (elasticity here as series are in log form); and ξ is the random error term with constant variance that can be contemporaneously correlated; it needs to be constant over time to test a long-run relationship.

In the second step, the estimated long-run residuals from equation (1) are tested through the augmented Dickey-Fuller (ADF) test, which is as follows:

$$\Delta\hat{\xi}_t = \rho\hat{\xi}_{t-1} + \sum_{i=1}^{L} \gamma_i \Delta\,\hat{\xi}_{t-i} + \upsilon_t \quad (2)$$

where Δ denotes the first difference; ρ is the coefficient to be estimated for the ADF test; L is the number of lags that is accounted for by serially correlated residuals[8]; γ is the coefficient related to the lagged estimated residuals in difference, estimated from equation (1); and υ_t is the white noise term. If the null hypothesis of $\rho = 0$ is rejected, then the Granger theorem suggests that the price series are cointegrated. The representation of equations (1) and (2) is jointly known as ECM.

The ECM model assumes linearity and a symmetric adjustment process among the price series. As mentioned before, if the long-run relationship between these two price series is asymmetric, the test for cointegration is misspecified. To overcome this problem, there are two extensions of the Granger representation theorem. First, asymmetric adjustment is incorporated by Granger and Lee (1989), and then threshold conintegration along with asymmetric adjustment are incorporated by Enders and Granger (1998) and Enders and Siklos (2001).

To allow for asymmetries, Granger and Lee (1989) proposed this following specification of equations (1) and (2), dividing the error correction term into two components:

$$ln\, \Delta P_t^1 = \theta_{P_t^1} + \varphi_{P_t^1}^{+} \hat{\xi}_{t-1}^{+} + \varphi_{P_t^1}^{-} \hat{\xi}_{t-1}^{-} + \sum_{i=1}^{L} \alpha_{P_{ti}^1}^{+}\, ln\, \Delta P_{t-i}^{1+} + \sum_{i=1}^{L} \alpha_{P_{ti}^1}^{-}\, ln\, \Delta P_{t-i}^{1-} + \sum_{i=1}^{L} \beta_{P_{ti}^1}^{+}\, ln\, \Delta P_{t-i}^{2+} + \sum_{i=1}^{L} \beta_{P_{ti}^1}^{-}\, ln\, \Delta P_{t-i}^{2-} + u_{P_t^1} \qquad (3) \text{ and}$$

$$ln\, \Delta P_t^2 = \theta_{P_t^2} + \varphi_{P_t^2}^{+} \hat{\xi}_{t-1}^{+} + \varphi_{P_t^2}^{-} \hat{\xi}_{t-1}^{-} + \sum_{i=1}^{L} \alpha_{P_{ti}^2}^{+}\, ln\, \Delta P_{t-i}^{1+} + \sum_{i=1}^{L} \alpha_{P_{ti}^2}^{-}\, ln\, \Delta P_{t-i}^{1-} + \sum_{i=1}^{L} \beta_{P_{ti}^2}^{+}\, ln\, \Delta P_{t-i}^{2+} + \sum_{i=1}^{L} \beta_{P_{ti}^2}^{-}\, ln\, \Delta P_{t-i}^{2-} + u_{P_t^2} \qquad (4)$$

where the subscripts $_{P_t^1}$ and $_{P_t^2}$ are the coefficients that are related to the respective prices; θ is the constant term; φ^+ and φ^- are the coefficients to be estimated that measure long-run asymmetry; $\hat{\xi}_{t-1}^{+}$ and $\hat{\xi}_{t-1}^{-}$ are defined as, if the estimated residuals from equation (1) are strictly greater than 0, $\hat{\xi}_t > 0,$ then $\hat{\xi}_{t-1}^{+} = \hat{\xi}_t$ and zero otherwise; whereas $\hat{\xi}_{t-1}^{-} = \hat{\xi}_t$ when $\hat{\xi}_t < 0$ and zero otherwise. To capture the short-run asymmetries, similarly, all the lagged price variables in the first difference are decomposed into two components as $\Delta X_{t-i}^{+} = X_{t-i} - X_{t-i-1} > 0$ and $\Delta X_{t-i}^{-} = X_{t-i} - X_{t-i-1} < 0$, where $X = P_t^1$ and P_t^2 and $i = 0, \ldots, L$. The presence of asymmetric adjustment in the equilibrium can be detected by inspecting the sign, magnitude, and statistical significance of the coefficients of equations 3 and 4. However, single or joint hypotheses of the estimated coefficients are necessary to test through the conventional F test (Grasso and Manera, 2005).

The second extension of the standard Granger theorem by Enders and Granger (1998) and Enders and Siklos (2001) was to incorporate the threshold (nonlinear) adjustment process in equation 2:

$$\Delta\hat{\xi}_t = \rho_1 I_t \hat{\xi}_{t-1} + \rho_2(1 - I_t)\hat{\xi}_{t-1} + \sum_{i=1}^{L} \gamma_i \Delta\,\hat{\xi}_{t-i} + v_t \qquad (5)$$

where I_t is the Heaviside indicator. When $I_t = 1$ if $\hat{\xi}_{t-1} > \tau$, and 0 otherwise, then the model is referred to as TAR-ECM (threshold autoregressive error correction model), used in this study; when $I_t = 1$ if $\Delta\hat{\xi}_{t-1} > \tau$, and 0 otherwise, then the model is referred to as MTAR-ECM (momentum threshold autoregressive error correction model)[9] τ is the threshold or attractor that can be specified as 0, but it should not be restricted to 0. The threshold value can consistently be estimated by minimizing the sum of squared residuals (Chan 1993)[10]. Simioni *et al.* (2013) argued that a zero threshold may not be the most appropriate value in the case of modern distribution practices.

The presence of a threshold cointegration as well as asymmetric adjustment in the long-run equilibrium can be tested with equation (5). The necessary and sufficient conditions for the estimated adjustment coefficients are $\rho_1 < 0, \rho_2 < 0$, and $(1 + \rho_1)(1 + \rho_2) < 1$. The economic explanation of these adjustment coefficients is if $|\rho_2| > |\rho_1|$, then this relationship is called negative "deepness" of ECT (Sichel, 1993; Enders and Granger, 1998). This implies that decreases in price tend to revert quickly toward equilibrium, whereas increases in price tend to persist.

Finally, a threshold specification of the asymmetric error correction representation (equations 1 and 5) can be written as:

$$ln\,\Delta P_t^1 = \theta_{P_t^1} + \delta_{P_t^1}^{+}\hat{E}_{t-1}^{+} + \delta_{P_t^1}^{-}\hat{E}_{t-1}^{-} + \sum_{i=1}^{L}\alpha_{P_{ti}^1}^{+}\,ln\,\Delta P_{t-i}^{1+} + \sum_{i=1}^{L}\alpha_{P_{ti}^1}^{-}\,ln\,\Delta P_{t-i}^{1-} + \sum_{i=1}^{L}\beta_{P_{ti}^1}^{+}\,ln\,\Delta P_{t-i}^{2+} + \sum_{i=1}^{L}\beta_{P_{ti}^1}^{-}\,ln\,\Delta P_{t-i}^{2-} + \epsilon_{P_t^1} \qquad (6)$$

and

$$ln\,\Delta P_t^2 = \theta_{P_t^2} + \delta_{P_t^2}^{+}\hat{E}_{t-1}^{+} + \delta_{P_t^2}^{-}\hat{E}_{t-1}^{-} + \sum_{i=1}^{L}\alpha_{P_{ti}^2}^{+}\,ln\,\Delta P_{t-i}^{1+} + \sum_{i=1}^{L}\alpha_{P_{ti}^2}^{-}\,ln\,\Delta P_{t-i}^{1-} + \sum_{i=1}^{L}\beta_{P_{ti}^2}^{+}\,ln\,\Delta P_{t-i}^{2+} + \sum_{i=1}^{L}\beta_{P_{ti}^2}^{-}\,ln\,\Delta P_{t-i}^{2-} + \epsilon_{P_t^2} \qquad (7)$$

where E is the error correction term, defined as $\hat{E}_{t-1}^{+} = I\hat{\xi}_{t-1}$ and $\hat{E}_{t-1}^{-} = (1-I)\hat{\xi}_{t-1}$; ϵ is the error term; and all other variables are defined before. We estimate equation (1) and equations (5-7) with the "apt" package within R environment (Sun 2014).

3. Data and unit root test

This study used average monthly wholesale farm price (paddy price), wholesale rice price, and the retail price of rice from January 2007 to July 2016. Price series by variety and by provincial markets are collected from the Ministry of Agriculture, Forestry & Fisheries (MAFF) in Cambodia. However, the data reveal that only the price of mixed-rice variety[11] of five provinces (Battambang, Kampong Cham, Kampong Chhnang, Siem Reap, and Takeo) has a continuous series. We used the average of these five provincial prices for our analysis. Note that these five provinces account for approximately 42% of the total rice production in Cambodia (Sitha 2012).

The deflated farm, wholesale, and retail price series are shown in Figure 2. Figure illustrates that price series fluctuate significantly (are volatile) since the global cereal price crisis 2007-08 that started in the beginning of 2007. According to World Bank (2016) estimates, in Cambodia, rice price volatility was about 4.2 during 2007 to 2012. It was estimated to be around 1.6 during 2012 to 2015. Note that the higher the number, the more volatile the price is.

3.1 Unit root test

To deal with any time series data, the first step is to check whether the series is stationary (no unit root). A time series is termed to be stationary if the mean and variance are constant over time. This property is also referred to as $I(0)$, which denotes that the series is integrated of order 0. Least square estimators of time series data with unit roots may suffer from problems of spurious regression (Granger and Newbold 1974; Phillips 1986). Several methods can be employed for unit root testing (Stock, 1994; Maddala and Kim, 1998; Phillips and Xiao, 1998). The two most popular methods are augmented Dickey Fuller (ADF) (Dickey and Fuller, 1979) and Phillips-Pheron (PP) (Phillips and Perron, 1988) tests. We used the “urca” package within R program to perform this test. Our null hypothesis is that both the wholesale and retail price series are $I(1)$. A regression with drift and trend terms (equation 1 with a time index) is estimated, including a lag length of one, determined by AIC and BIC statistics. Note that all the price series are in logged form. The decision rule is that, if the null hypothesis can be rejected for the first-differenced series, then the time series is integrated of order one. The ADF and PP test statistics are shown in Table 2. We found that the calculated values of the test statistics of the levels of all price series are greater than the critical values. However, the calculated values of the test statistics of the first-differenced series of all the price series are less than the critical values.

Therefore, we fail to reject the null hypothesis and conclude that all the price series are integrated of order one.

4. Results and Discussion: test for asymmetric price transmission

4.1 Dynamics of Long-run Equilibrium: results from the TAR (equation 5)

4.1.1 Long-run price transmission elasticity

The long-run relationship between farm price (wholesale paddy price at the farmers' level) and wholesale price (rice price at the millers'/wholesalers' level), wholesale and retail price are respectively, $ln\hat{F}_t = \underset{(0.201)}{0.131} + \underset{(0.028)}{0.910}\, lnW_t$, and $ln\hat{R}_t = \underset{(0.192)}{1.537} + \underset{(0.026)}{0.804}\, lnW_t$. The transmission elasticity between farm and wholesale prices is about 0.910 and it is statistically significant at the 1% level. This coefficient can be interpreted as price transmission elasticity because both prices are in logged form. Thus, it can be explained if 10% wholesale price increase, the farm price would increase by 9.10%. Similarly, the estimated transmission elasticity between the retail and wholesale rice price is 0.804, implying that a 10% wholesale price increase resulted in an 8.04% increase in retail price. Therefore, we conclude that, in Cambodia, any change in wholesale rice price was almost fully transmitted in the long run to consumers and producers.

4.1.2 Long-run adjustment speed

Estimates of the price adjustment coefficients, ρ_1 and ρ_2, are reported in Table 3. We found that these coefficients satisfy all the necessary and sufficient conditions described before. Rows 2 and 3 of this table show that the adjustment coefficients are statistically significant, which is an indication of convergence with the long-run equilibrium. We also found that positive deviation is greater than negative deviation, $|\rho_1| > |\rho_2| (= 0.592 > 0.343)$, when farm price is a function of wholesale price (farm-miller relationship). This implies that decreases in wholesale price are more quickly transmitted to producers than increases. Conversely, when retail price is a function of wholesale price (miller-consumer relationship), we found $|\rho_2| > |\rho_1| (= 1.009 > 0.470)$, which implies that increases in wholesale price are more quickly transmitted to consumers than decreases. Similar findings were made by Alam *et al.* (2016) and Gedara *et al.* (2016) for wholesale and retail prices of rice in Bangladesh and Sri Lanka—increases in wholesale price are more quickly passed on to consumers than decreases.

The magnitudes of the adjustment coefficients tell us how fast it is converged (reverted or eliminated or persisted) to the equilibrium. The time to adjust positive and negative deviation from long-run equilibrium can be calculated dividing 1 by the adjustment coefficients, $\left({}^{1}/_{\rho_1} \text{ or } {}^{1}/_{\rho_2}\right)$. Because month is used as the unit of time in our study, the point estimates would illustrate the convergence time in terms of months. From the farm-miller relationship, we found that positive deviation takes about 1.70 months to adjust long-run equilibrium, whereas it takes 2.91 months to adjust negative deviation from the equilibrium. In the case of the price relationship between millers and retailers, negative and positive deviation take about 1.00 and 2.13 months, respectively, to adjust long-run equilibrium (Table 3).

4.1.3 Long-run nonlinear (threshold) cointegration test

The null hypothesis of no threshold cointegration in the long-run, $H_0: \rho_1 - \rho_2 = 0$, is tested using a test statistical value suggested by Enders (2004). Table 3 shows that all the p-values corresponding to the values of test statistics (15.35 and 23.21) are statistically significant at the 1% level. Therefore, we reject the null hypothesis and conclude that farm price and wholesale price as well as wholesale and retail price are cointegrated with threshold adjustment.

4.1.4 Long-run symmetric adjustment test

The significance of the price adjustment coefficients (described before) does not guarantee that the price transmission process is asymmetric in the long run. We used a standard F test to detect whether asymmetric price transmission (APT) is present in the farm and wholesale price, and in the wholesale and retail price of rice in Cambodia. Specifically, the null hypothesis of symmetric price adjustment in the long-run, $H_0: \rho_1 = \rho_2$, is tested (Table 3). The decision rule is that, if the calculated value is greater than the tabulated value, then we can reject the null. In other words, if the corresponding p-value is significant, we can reject the null hypothesis and conclude that the price adjustment process is asymmetric in the long run. Table 3 reveals the presence of APT in between the farm price and wholesale price. Moreover, APT is detected between the retail and wholesale price of rice.

4.2 Dynamics of Short-run Equilibrium: results from TAR-ECM (equations 5 and 6)

To find the short-run asymmetries, using F statistics, three types of hypotheses are tested based on the estimated coefficients. These tests are (a) the Granger causality test, (b) short-run asymmetric effect, and (c) equilibrium adjustment path asymmetric effect. Table 4 presents the estimated parameters along with the tests for short-run asymmetries.

4.2.1 Granger causality test

The hypothesis of Granger causality between price series is assessed with standard F tests. The relevant coefficients for this test are α_1^+, α_1^-, β_1^+, and β_1^-. The F-statistic and p-value of the hypothesis that retail price does not Granger-cause wholesale price, $H: \alpha_1^+ = \alpha_1^- = 0$, are found to be 4.091 and 0.02, respectively (Table 4). This indicates that changes in consumer price for any reason (e.g., demand-led) affect the wholesale price. Meanwhile, the F-statistic and p-value of the hypothesis that wholesale price does not Granger-cause retail price, $H: \beta_1^+ = \beta_1^- = 0$, are found to be marginally significant at the 10% level (2.228 and 0.11). Thus, we conclude that there is a bidirectional relationship between the wholesale and retail price of rice in the Cambodian market. Table 4 also reveals a unidirectional relationship between the wholesale price of paddy and the wholesale price of rice. This implies the changes in wholesale price affect the farm price (F-statistic and p-value, respectively, are 3.334 and 0.04), but not the reverse (0.067 and 0.94).

4.2.2 Short-run asymmetric effect

The hypotheses of short-run asymmetry are $H: \alpha_1^+ = \alpha_1^-$ and $H: \beta_1^+ = \beta_1^-$. The estimated F-statistics and respective p-values are presented in Table 4. This table reveals that two out of eight ρ-values are statistically significant. This implies that the null hypothesis cannot be rejected for all the cases. Therefore, we conclude that there might have been some asymmetric effects, as at least two p-values are significant.

4.2.3 Equilibrium adjustment path asymmetry

Equilibrium adjustment path asymmetry is also tested using the standard F-test. The relevant coefficients of this test are δ^+ and δ^-, and are presented in Table 4. The hypothesis is that the equilibrium adjustment path is symmetric: H: $\delta^+ = \delta^-$. We found that three out of four coefficients related to δ are statistically significant. Therefore, we reject the null hypothesis and conclude that the equilibrium adjustment path is asymmetric.

To sum up, the diagnostic tests of both the short-run and long-run models suggest that the price adjustment process between the farm paddy and wholesale price, and the wholesale and retail price in Cambodia, is asymmetric. In other words, the rice market in Cambodia is inefficient. To solve this problem, policy interventions are required that might help to change the direction of price transmission. Furthermore, the development of markets (i.e., supermarkets) and access to technology (i.e., cell phone, internet) may affect transmission speed. Finally, for faster price transmission between markets, improved market infrastructure, better market integration, and dispersion of marketing information are recommended.

5. Conclusions

This paper assessed market integration and the presence of asymmetric price transmission in the Cambodian rice market during January 2007 to July 2016. A threshold specification of the asymmetric error correction model is applied to estimate and test the threshold cointegrating relationship between the farm price (wholesale paddy price) and wholesale rice price, and the wholesale and retail price of rice. We found that the farm, wholesale, and retail rice markets in Cambodia are asymmetrically cointegrated. We also found that the price transmission process between the farm and wholesale, and wholesale and retail rice markets is asymmetric in both the short run and long run. Specifically, decreases in wholesale price are more quickly transmitted to farmers than price increases. Conversely, increases in wholesale price are more quickly transmitted to consumers than price decreases. Finally, we found that there is a unidirectional causality from the wholesale price to farm price, and a bidirectional causality between the wholesale and retail price. Thus, we conclude that the rice market in Cambodia is inefficient. For faster price transmission, improved market infrastructure, better market integration, and dispersion of marketing information are recommended.

References

Abdulai, A. (2000). Spatial Price Transmission and Asymmetry in the Ghanaian Maize Market. *Journal of Development Economics* 63, 327–349.

Acharya, S.S., Chand, R., Birthal, P.S., Kumar, S. and Negi, D.S. (2012). Market Integration and Price Transmission in India: A Case of Rice and Wheat with Special Reference to the World Food Crisis of 2007/08. Food and Agriculture Organization (FAO), Rome, Italy.

Agricultural Development International (ADI) (2010). Cambodia Rice Value Chain Study: Crop Year 2009-2010: Final Report. Prepared for Food and Agriculture Organization (FAO) Investment Center. Phnom Penh, Cambodia: Agricultural Development International (ADI).

Alam, M.J., McKenzie, A.M., Begum, I.A., Buysse, J., Wailes, E.J. and Huylenbroeck, G.V. (2016). Asymmetry Price Transmission in the Deregulated Rice Markets in Bangladesh: Asymmetric Error Correction Model. *Agribusiness*: 1–14. DOI: 10.1002/agr.21461.

Azzam, A. M. (1999). Asymmetry and Rigidity in Farm-Retail Price Transmission. *American Journal of Agricultural Economics* 81 (3), 525–533.

Balcombe, K., Bailey, A. and Brooks, J. (2007). Threshold Effects in Price Transmission: The Case of Brazilian Wheat, Maize, and Soya Prices. *American Journal of Agricultural Economics* 89(2), 308–323.

Balke, N.S. and Fomby, T.B. (1997). Threshold Cointegration. *International Economic Review* 38(3), 627–644.

Bettendort, L., van der Geest, S.A. and Varkevisser, M. (2003). Price Asymmetries in the Dutch Retail Gasoline Market. *Energy Economics* 25, 669–689.

Boyd, M.S. and Brorsen, B.W. (1988). Price Asymmetry in the US Pork Marketing Channel. *North Central Journal of Agricultural Economics* 10, 103–109.

Capps, O. and Sherwell, P. (2007). Alternative Approaches in Detecting Asymmetry in Farm-Retail Price Transmission of Fluid Milk. *Agribusiness* 23, 313–331.

Chalajour, M. and Feizabadi, Y. (2013). Marketing Price Transmission Analysis in the Iranian Rice Market. *African Journal of Agricultural Marketing* 1 (2), 41–46.

Chan, K.S. (1993). Consistency and Limiting Distribution of the Least Squares Estimator of a Threshold Autoregressive Model. *The Annals of Statistics* 21, 520–533.

Chavas, J.P. and Mehta, A. (2004). Price Dynamics in a Vertical Sector: The Case of Butter. *American Journal of Agricultural Economics* 86, 1078–1093.

Chen, B. and Saghaian, S. (2016). Market Integration and Price Transmission in the World Rice Export Markets. Prepared for Poster Presentation at the South Agricultural Economics Association (SAEA) Annual Meeting, San Antonio, Texas, 6-9 February 2016.

David, V. (2014). Challenges & Opportunities Cambodia Rice Sector. Presented at the 18th SSC-TDRI Meeting, Ministry of Commerce, the Government of Cambodia, 21 August 2014.

de Silva, S., Johnston, R. and Sellamuttu, S.S. (2014). Agriculture, Irrigation and Poverty Reduction in Cambodia: Policy Narratives and Ground Realities Compared. Accessed 10 August 2016, available at http://pubs.iclarm.net/resource_centre/AAS-2014-13.pdf.

Dickey, D.A. and Fuller, W.A. (1979). Distribution of the Estimators of Autoregressive Time Series With a Unit Root. *Journal of the American Statistical Association* 74(366), 427–431.

Enders, W. (2004). Applied Econometric Time Series. John Wiley & Sons, Inc., New York.

Enders, W. and Granger, C.W.J. (1998). Unit-Root Tests and Asymmetric Adjustment with an Example using the Term Structure of Interest Rates. *Journal of Business & Economic Statistics* 16, 304–311.

Enders, W. and Siklos, P.L. (2001). Cointegration and Threshold Adjustment. *Journal of Business & Economic Statistics* 19,166–167.

Engle, R.F. and Granger, C.W.J. (1987). Cointegration and Error Correction: Representation, Estimation, and Testing. *Econometria* 55, 251–276.

Falkowski, J. (2010). Price Transmission and Market Power in a Transmission Context: Evidence from the Polish Fluid Milk Sector. *Post-Communist Economies* 22, 513–529.

Food and Agriculture Organization (FAO) (2014). Socioeconomic Context and Role of Agriculture in Cambodia. Country Fact Sheet on Food and Agriculture Policy Trends, FAPDA (Food and Agriculture Policy Decision Analysis), April 2014, Food and Agriculture Organization (FAO), Rome, Italy.

Food and Agriculture Organization (FAO) (2016). GIEWS Country Brief Cambodia. The Global Information and Early Warning System (GIEWS) of Food and Agriculture Organization (FAO), Rome, Italy.

FAOSTAT (2016). FAOSTAT data. Food and Agriculture Organization of the United Nations Statistical Division. Accessed 10 August 2016, Available at http://faostat3.fao.org/home/E.

Fiamohe, R., Seck, P.A., Alia, D.Y. and Diagne, A. (2013). Price Transmission Analysis Using Threshold Models: An Application to Local Rice Markets in Benin and Mali. *Food Security*, 5, 427–438.

Fiamohe, R., Alia, D.Y., Bamba, I., Diagne, A. and Amovin-Assagbaa, E. (2015). Transmission of Rice Prices from Thailand into West African Markets: The Case of Benin, Mali, and Senegal. *Journal of African Business* 16(1-2), 128–143.

Frey, G. and Manera, M. (2007). Econometric Models of Asymmetric Price Transmission. *Journal of Economic Surveys* 21, 349–415.

Gedara, P.M.K., Ratnasiri, S. and Bandara, J.S. (2016). Does Asymmetry in Price Transmission Exist in the Rice Market in Sri Lanka? *Applied Economics* 48(27), 2491–2505.

Gergely, N., Baris, P. and Meas, C. (2010). An Economic Survey of Rice Sector in Cambodia. Accessed 20 September 2016, available at https://www.scribd.com/document/111879201/An-Economic-Survey-of-Rice-Sector-in-Cambodia.

Ghoshray, A. (2008). Asymmetric Adjustment of Rice Export Prices: The Case of Thailand and Vietnam. *International Journal of Applied Economics* 5, 81–90.

Granger, C.W.J. and Lee, T.H. (1989). Investigation of Production, Sales and Inventory Relationships using Multicointegration and Non-Symmetric Error Correction Models. *Journal of Applied Econometrics* 4, 135–159.

Granger, C. W. J. and Newbold, P. (1974). Spurious Regressions in Econometrics, *Journal of Econometrics* 2, 111-120.

Grasso, M. and Manera, M. (2007). Asymmetric Error Correction Models for the Oil-Gasoline Price Relationship. *Energy Policy* 35(1), 156–177.

Griffith, G.R. and Piggott, N. (1994). Asymmetry in Beef, Lamb and Pork Farm-Retail Price Transmission in Australia. *Agricultural Economics* 10, 307–316.

Hang Chuon, C. and Suzuki, N. (2005). Characteristics of the Rice Marketing System in Cambodia. *Journal-Faculty of Agriculture Kyushu University* 50(2), 693–714.

Hansen, B.E. and Seo, B. (2002). Testing for Two-Regime Threshold Cointegration in Vector Error Correction Models. *Journal of Econometrics* 110, 293–318.

Hassanzoy, N., Ito, S., Isoda, H. and Amekawa, Y. (2016). A Comparison of Asymmetric Price Transmission from Global to Domestic Markets between High and Low Quality Grains: A Case of Afghan Rice Markets. *Economics Bulletin* 36(1), 537–552.

Heien, D.M. (1980). Markup Pricing in a Dynamic Model of Food Industry. *American Journal of Agricultural Economics* 62, 10–18.

Houck, J.P. (1977). An Approach to Specifying and Estimating Nonreversible Functions. *American Journal of Agricultural Economics* 59, 570–572.

International Finance Corporation (IFC) (2015). Transforming Cambodia's Rice Industry. Rice Sector Support Project Brochure, International Finance Corporation (IFC), World Bank Group, Washington, D.C.

International Rice Research Institute (IRRI) (2015). World Rice Statistics Online Query Facility. International Rice Research Institute, Los Baños, Laguna, Philippines. Accessed 31 July 2016, available at http://ricestat.irri.org:8080/wrsv3/entrypoint.htm.

Jamora, N. and von Cramon-Taubadel, S. (2016). Transaction Cost Thresholds in International Rice Markets. *Journal of Agricultural Economics* 67(2), 292–307.

Kann, S., San, T., Touch, P., Sinet, H. and Vicheka, P. (2008). Training Course on Grain Post–harvest Technology: Country Paper of Cambodia, Pathumtani, Thailand. June 29-July 12, 2008.

Keho, Y. and Camara, A.S. (2012). Vertical Price Transmission in Local Rice Markets in Côte d'Ivoire: Are Consumers Really Right? *Asian Journal of Agriculture and Rural Development* 2(4), 552–564.

Kinnucan, H.W. and Forker, O.D. (1987). Asymmetry in Farm-Retail Price Transmission for Major Dairy Products. *American Journal of Agricultural Economics* 69, 285–292.

Kula, O. and Turner, C. (2015). An Analysis of Three Commodity Value Chains in Cambodia: Rice, Horticulture, and Aquaculture. Presentation Produced for Review by the USAID.

Maddala, G.S. and Kim, M. (1998). Unit Roots, Cointegration, and Structural Change. Cambridge University Press.

Martiz, M.J.R. (2008). Price Transmission Mechanism in the Philippines Rice Industry. MS Thesis, Submitted to the University of Delaware.

Meyer, J. and von Cramon-Taubadel, S. (2004). Asymmetric Price Transmission: A Survey. *Journal of Agricultural Economics* 55, 581–611.

Naron, H.C. (2012). Cambodian Economy: Charting the Course of a Brighter Future, A Survey of Progress, Problems and Prospects. Institute of Southeast Asian Studies (ISEAS), Singapore.

Pede, V.O., Valera, H.G.A., Alam, M.J. and McKenzie, A.M. (2013). Nonlinearities in Regional Rice Prices in the Philippines: Evidence from a Smooth Transition Autoregressive (STAR) Approach. Paper Prepared for Presentation at the 2013 AAEA & CAES Joint Annual Meeting, Washington, DC, 4-6 August 2013.

Peltzman, S. (2000). Prices Rise Faster Than They Fall. *Journal of Political Economy* 108, 466–502.

Phillips, P.C.B. (1986). Understanding Spurious Regressions in Econometrics. *Journal of Econometrics* 33, 311–340.

Phillips, P.C.B. and Perron, P. (1988). Testing for a Unit Root in Time Series Regression. *Biometrika* 75(2), 335–346.

Phillips, P.C.B. and Xiao, Z. (1998). A Primer on Unit Root Testing. *Journal of Economic Surveys* 12, 423–470.

Reeder, M. (2000). Asymmetric Prices: Implications on Traders' Market Power in Philippine Rice. *Journal of Philippine Development* 27, 59–69.

Sambour, J. (2010). Introducing Fortified Rice in Cambodia and Vietnam. PATH Fortified Rice Feasibility Study 2010. Accessed 10 August 2016, available at http://www.gainhealth.org/wp-content/uploads/2015/05/Introducting-Fortified-Rice-in-Cambodia-and-Vietnam.pdf.

Sanogo, I. and Amadou, M.M. (2010). Rice Market Integration and Food Security in Nepal: The Role of Cross-Border Trade with India. *Food Policy* 35, 312–322.

Serra, T. and Goodwin, B.K. (2003). Price Transmission and Asymmetric Adjustment in the Spanish Dairy Sector. *Applied Economics* 35, 1889–1899.

Sichel, D. (1993). Business Cycles Asymmetry: A Deeper Look. *Economic Enquiry* 31, 224–236.

Simioni, M., Gonzales, F., Guillotreau, P. and Le Grel, L. (2013). Detecting Asymmetric Price Transmission with Consistent Threshold along the Fish Supply Chain. *Canadian Journal of Agricultural Economics* 61, 37–60.

Singh, S.P., Ekanem, E., Tegegne, F. and Muhammad, S. (2007). The Rice Industry in Cambodia: Production, Marketing System, and Impediments to Improvements. *Journal of Food Distribution Research* 38(I), 141–147.

Sitha, A. (2012). National Assessment of Cambodia's Main Crop and Fodder Resources. Project Report. Accessed 23 September 2016, available at https://are.berkeley.edu/~dwrh/FAO_ECTAD_FMD_Cambodia/Documents/AS2012.pdf.

Sophea, K. (2012). The Rice Situation in Cambodia. Technical Assistance Consultant's Report, No. TA 7495-REG, Asian Development Bank (ADB), Philippines.

Stock, J.H. (1994). “Unit Roots, Structural Breaks, and Trends”, in R.F. Engle and D.L. McFadden (eds.), Handbook of Econometrics, Volume IV. North Holland, New York.

Sun, C. (2011). Price Dynamics in the Import Wooden Bed Market of the United States. *Forest Policy and Economics* 12, 479–487.

Sun, C. (2014). Asymmetric Price Transmission with R Package “apt”. Accessed 7 July 2016, available at https://cran.r-project.org/web/packages/apt/vignettes/apt.pdf.

United States Department of Agriculture (USDA) (2016). Production, Supply and Distribution Online Database. Foreign Agriculture Service, United States Department of Agriculture. Available at: https://apps.fas.usda.gov/psdonline.

von Cramon-Taubadel, S. (1998). Estimating Asymmetric Price Transmission with the Error Correction Representation: An Application to the German Pork Market. *European Review of Agricultural Economics* 25, 1–18.

World Bank (WB) (2015). Cambodia Rice Sector Overview: Turning Cambodian Rice into White Gold. Technical Working Paper No. 98835, The World Bank, Washington, D.C.

World Bank (WB) (2016). Agriculture, Value Added (% of GDP). The World Bank, Washington, D.C. Accessed 24 June 2016, available at http://data.worldbank.org/indicator/NV.AGR.TOTL.ZS.

Wolffram, R. (1971). Positivistic Measures of Aggregate Supply Elasticities: Some New Approaches - Some Critical Notes. *American Journal of Agricultural Economics*, 53, 356–359.

Xia, T. and Li., X. (2010). Consumption Inertia and Asymmetric Price Transmission. *Journal of Agricultural and Resource Economics* 35, 209–227.

Tables

Table 1. Net margin (riel/kg) of rice value chain actors in Cambodia[¶]

	2006[‡]						2015 (Estimated)					
	Cost	Selling price	Price spread[‡‡]	Mark-up[§§]	Profit	% of total profit	Cost	Selling price	Price spread[‡‡]	Mark-up[§§]	Profit	% of total profit
Farmer	256	500		48.8	244	49.9	536[§]	1316[§]		59.2	779.5	68.5
Collector	25	530	30	5.7	5	1.0	25	1355	39	3.0	14.1	1.2
Miller	50	676	146	21.6	96	19.7	146[⊥]	1712[††]	357	20.8	211.0	18.5
Transporter	60	750	74	9.9	14	2.9	64[¶¶]	1790	78	4.4	14.2	1.2
Wholesaler	16	832	82	9.9	66	13.5	16	1817	27	1.5	10.6	1.0
Retailer	-	896	64	7.1	64	13.1	-	1925[††]	108	5.6	108.2	9.5
Total			396		489	100.0			609		1138	100.0

Notes: [¶] This estimate is based on 1 kg of milled-rice. – indicates not available. The marketing costs for collector's and wholesaler's in 2015 were unavailable, so we considered it same as 2006.

[‡] Agrifood Consulting International and CamConsult (2006) cited in Sophea (2012). The values of byproducts at farmer's and miller's level were not reported.

[§] The Rice Value Chain Survey (2015) by the International Rice Research Institute (IRRI).

[⊥] Miller's processing cost and margin are from WB (2015).

[††] Average price of mixed rice in 2015, gathered from Ministry of Agriculture, Forestry and Fisheries, the Government of Cambodia.

[‡‡] Price spread is calculated as for example collector's selling price minus farmer's selling price

[§§] The mark-up is defined as: (price spread/selling price)×100.

[¶¶] David (2014)

Table 2. Tests for the order of integration

Unit root test†††	ADF	Decision	PP	Decision
Log of wholesale price of paddy (ln F_t)	-2.57	I(1)	-2.18	I(1)
First difference of logged wholesale price of paddy (ln ΔF_t)	-7.50	I(0)	-10.03	I(0)
Log of wholesale price of rice (ln W_t)	-2.70	I(1)	-2.18	I(1)
First difference of logged wholesale price of rice (ln ΔW_t)	-7.73	I(0)	-11.02	I(0)
Log of retail price of rice (ln R_t)	-2.95	I(1)	-3.49	I(1)
First difference of logged retail price (ln ΔR_t)	-7.85	I(0)	-11.64	I(0)

Source: Authors' calculation based on data illustrated in Figure 2.

††† The following model is estimated: $y_t = \tau y_{t-1} + \emptyset_0 + \emptyset_t t + u_t$, where, $y = lnF, \Delta lnF, lnW, \Delta lnW, lnR, and\ \Delta lnR$. One lag is considered based on Akaike information criterion (AIC) and Bayesian information criterion (BIC). The null hypothesis is $H_0 =$ the series is I(1) or $H_0 =$ unit root (nonstationary). Critical values for the ADF test are -3.99, -3.43, and -3.13 at the 1%, 5%, and 10% level, respectively, whereas for the PP test these are -4.04, -3.45, and -3.15, respectively.

Table 3. Test for threshold cointegration (TAR model)

Item	Farm-miller	Miller-consumer
Estimate		
Threshold, τ	0.039	-0.044
$\rho_1(\Delta\hat{\xi}_{t-1} > \tau)$	-0.592***	-0.470***
	(-4.736)	(-3.777)
ρ_2 $(\Delta\hat{\xi}_{t-1} \leq \tau$	-0.343***	-1.009***
	(-3.371)	(-6.243)
Time to adjust long-run equilibrium (months)$^{\surd}$		
From positive deviation	1.70	2.13
From negative deviation	2.91	1.00
Diagnostics		
No threshold CI: $\emptyset$ $(H_0: \rho_1 = \rho_2 = 0)$	15.351***	23.206***
	[0]	[0]
No APT: F $(H_0: \rho_1 = \rho_2)$	2.667*	8.411***
	[0.100]	[0.005]
Sample size	115	115

Notes: $\emptyset$ is the cointegration test with TAR threshold adjustment; critical values at 1% and 5% are 8.910 and 6.560, respectively, which are from Enders (2004). Values within parentheses are t-statistics, whereas *p*-values are within brackets. *** and *, respectively, denote significance at the 1% and 10% level. CI stands for cointegration; APT denotes asymmetric price transmission. Farm-miller: farm price is a function of wholesale price. Miller-consumer: retail price is a function of wholesale price.

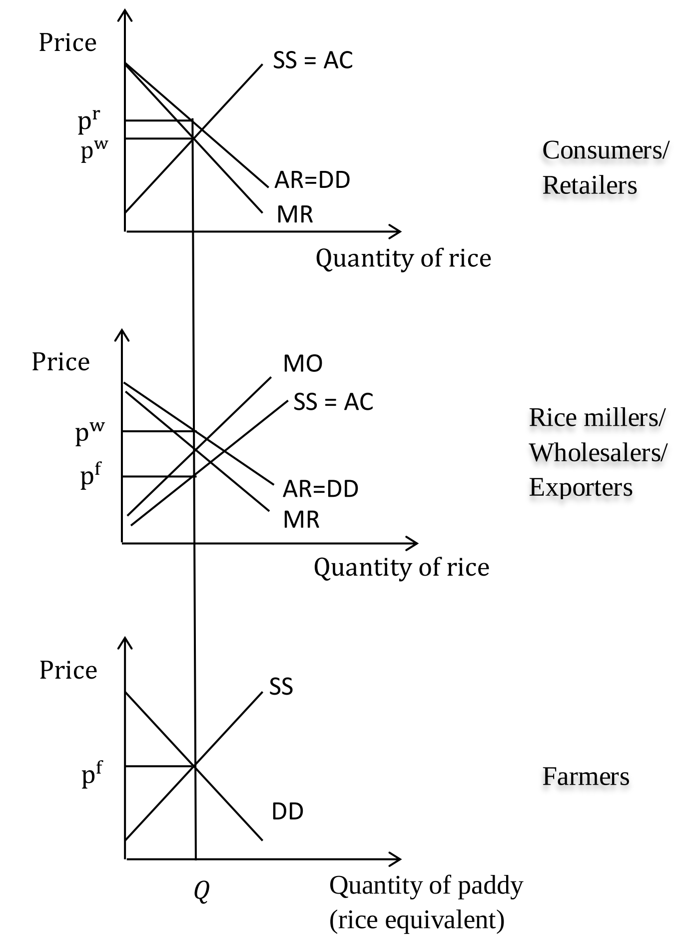
Table 4. Parameter estimates from the asymmetric error correction model with threshold cointegration (ECM-MTAR)

Items	Farm-miller		Miller-consumer	
	Wholesale paddy price	Wholesale rice price	Wholesale rice price	Retail rice price
Parameters				
θ (intercept)	0.006	0.015**	0.002	0.002
	(0.916)	(2.087)	(0.307)	(0.354)
α_1^+	-0.029	-0.179	0.152	0.255*
	(-0.139)	(-0.847)	(0.893)	(1.717)
α_1^-	0.078	0.060	0.532***	0.247
	(0.338)	(0.258)	(2.627)	(1.400)
β_1^+	0.113	0.068	0.145	0.210.
	(0.500)	(0.300)	(0.887)	(-1.468)
β_1^-	0.496**	0.647***	-0.011	0.306*
	(2.498)	(3.228)	(-0.055)	(1.676)
δ^+	0.633*	-0.120	0.308*	-0.167
	(1.766)	(-0.333)	(1.709)	(-1.063)
δ^-	-0.190.	-0.608***	-0.211	-1.317***
	(-1.501)	(-4.753)	(-0.877)	(-6.282)
Diagnostic				
AIC	-350.851	-348.846	-331.400	-362.512
BIC	-329.032	-327.026	-309.580	-340.693
$H_{01}: \alpha_1^+ = \alpha_1^- = 0$	0.067	0.395	4.091**	2.688*
	[0.94]	[0.68]	[0.02]	[0.07]
$H_{02}: \beta_1^+ = \beta_1^- = 0$	3.334**	5.332***	0.395	2.228
	[0.04]	[0.01]	[0.68]	[0.11]
$H_{03}: \alpha_1^+ = \alpha_1^-$	0.119	0.583	1.899	0.001
	[0.73]	[0.45]	[0.17]	[0.98]
$H_{04}: \beta_1^+ = \beta_1^-$	1.542	3.448*	0.313	4.452**
	[0.22]	[0.07]	[0.58]	[0.04]
$H_{05}: \delta^+ = \delta^-$	5.176**	1.785	3.253*	21.075***
	[0.02]	[0.18]	[0.07]	[0]

Notes: Values within parentheses are t-statistics, whereas *p*-values are within brackets. ***, **, and * denote significance at the 1%, 5%, and 10% level, respectively. For the hypotheses, H_{01} and H_{02} are Granger causality tests; H_{03} and H_{04} are related to short-run asymmetric effect; and H_{05} is the equilibrium (long-run) adjustment path asymmetric effect.

Figures

Figure 1. Market structures of the rice supply chain in Cambodia

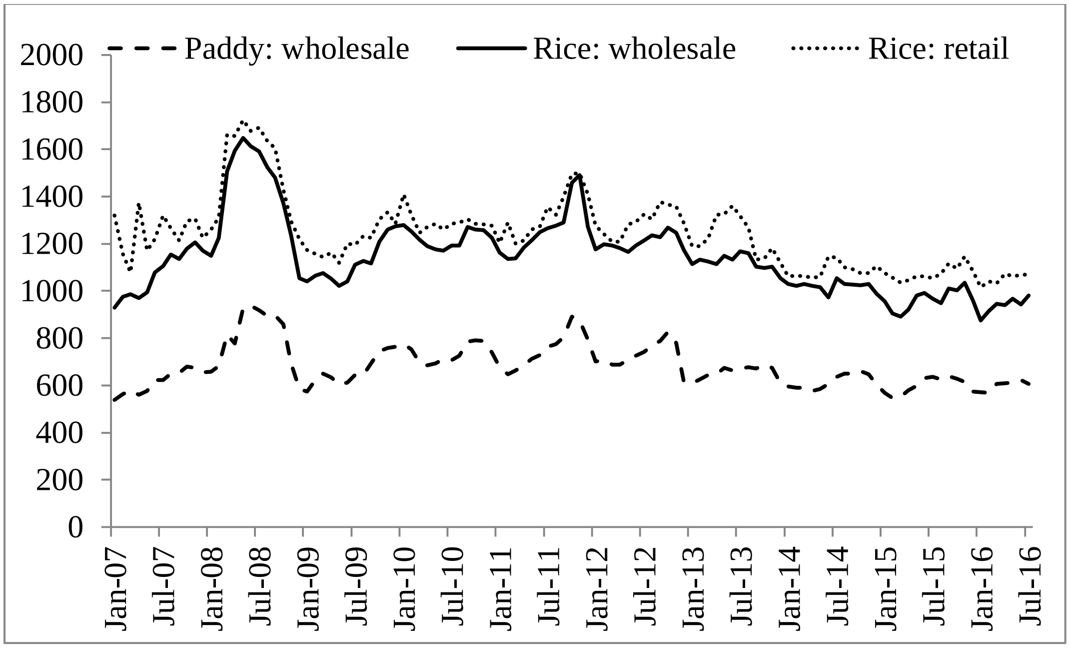


Legend:

- p^f, p^w, and p^r are the farm-gate (producer), wholesale, and retail price, respectively.
- DD and SS stand for demand and supply schedules, respectively.
- MR and AR denote marginal and average revenue curves, respectively.
- MO represents the marginal outlay curve.

Notes: Input providers to all the vertical stages of production are not shown for simplicity. Also, no distinctions are made between rice millers, exporters, and wholesalers because it is evident that rice millers are engaging in export and wholesale activities in addition to rice processing (IRRI, 2015). Furthermore, paddy traders act as a commission agent so they are not included in the main market structure. A detailed value chain map including all actors can be found in Kula and Turner (2015), Singh *et al.* (2007), and Hang Chuon and Suzuki (2005).

Figure 2. Evolution of real price of rice and paddy in Cambodia: Jan 2007 to July 2016 (2006 = 100)



Notes: The prices of mixed-rice varieties are considered, collected from the MAFF in Cambodia. Prices are in real values, which are deflated using the consumer price index, gathered from the different issues of the annual reports published by the National Bank of Cambodia. Paddy is referred to un-milled-rice, and rice is milled-rice. Paddy is referred to un-milled rice at the farmers' level, while rice is milled-rice.

[1] Post-harvest loss, seed, and animal feed account for approximately 24% of total paddy production, whereas about 38% is used for farmers' self-consumption. Estimations are based on FAOSTAT (2016), USDA (2016), de Silva *et al.* (2014), Kann *et al.* (2008), and ADI (2010) cited in Sambour (2010).

[2] Definitions of these different types of APT and a detailed literature review on potential causes of APT can be found in Meyer and von Cramon-Taubadel (2004) and Frey and Manera (2007).

[3] If the price elasticity of demand for rice is very inelastic, then consumers may not adjust their quantity of purchase in response to price changes. Thus, retailers might be reluctant to reduce the price (Xia and Li, 2010; Gedara *et al.* 2016) because of a negative price deviation at the downstream level.

[4] Kinnucan and Forker 1987; Boyd and Brorsen 1988; Griffith and Piggott 1994; Balke and Fomby 1997; Azzam 1999; Peltzman 2000; Abdulai 2000; Bettendort *et al*. 2003; Serra and Goodwin 2003; Meyer and von Cramon-Taubadel 2004; Chavas and Mehta 2004; Capps and Sherwell 2007; Balcombe *et al.* 2007; Ghoshray 2008; Falkowski 2010; Xia and Li 2010.

[5] Reeder 2000; Martiz 2008; Ghoshray 2008; Sanogo and Amadou 2010; Keho and Camara 2012; Acharya *et al.* 2012; Fiamohe *et al.* 2013; Pede *et al.* 2013; Chalajour and Feizabadi 2013; Fiamohe *et al.* 2015; Gedara *et al.* 2016; Hassanzoy *et al.* 2016; Chen and Saghaian 2016; Alam *et al.* 2016; Jamora and von Cramon-Taubadel 2016.

[6] Afghanistan, Bangladesh, Benin, Côte d'Ivoire, India, Iran, Mali, Nepal, the Philippines, Senegal, Sri Lanka, Thailand, the U.S., and Vietnam. Note that Jamora and von Cramon-Taubadel (2016) investigated the relationships between international prices and 221 domestic prices in 47 rice-importing countries that are not listed here.

[7] A detailed survey can be found in Grasso and Manera (2007) and Gedara *et al.* (2016).

[8] To address possible serial correlation in the residual series, it is necessary to select an optimal number of lags. This can be done with several selection criteria (i.e., AIC, BIC, Ljung-Box Q statistics). The two most popular criteria, the Akaike information criterion (AIC) and Schwarz Bayesian information criterion (SIC/BIC/SBIC), are used in this study. Based on these rules, lag length, j, is chosen to minimize $\log\left(\frac{SSR_j}{n}\right) + \frac{(j+1)C(n)}{n}$, where SSR_j is the sum of squared residuals with j lags and n is the number of observations; $C(n) = 2$ for AIC and $C(n) = \log(n)$ for BIC.

[9] The TAR model is designed to capture potential asymmetric deep movements in the residuals, whereas MTAR is used to capture steep variations in the residuals (Enders and Granger, 1998; Enders and Siklos, 2001). There is no rule to choose either the TAR-ECM or MTAR-ECM; however, Enders and Siklos (2001) recommended using AIC and BIC to select the best model. The lower the values of AIC or BIC, the better the model is.

[10] Chan's (1993) search method to obtain a consistent estimate of threshold value, τ, is to (a) sort the observations on the threshold variable, $\Delta\hat{\xi}_{t-1}$, in ascending order; (ii) trim the top and bottom 15% quantile values; (iii) use each potential value (70% of the sorted threshold variable) to estimate the sum of squared errors (SSE) from the model and examine the relationship between the SSE and the threshold value; and (iv) choose the threshold value that minimizes the SSE.

[11] Many traditional varieties mostly grown in the wet season collected from different small farmers and mixed together to sell further are called mixed varieties (Sophea, 2012). These varieties constitute approximately two-thirds of the total rice production; their price is comparatively lower than that of fragrant varieties, mostly consumed in rural areas (Gergely *et al.* 2010).