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Price Dynamics and Market integration of Sorghum and Millet Markets in Ghana

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Abstract

This present study was conducted to examine the price dynamics (volatility), market integration and price transmission dynamics of sorghum and millet markets in Ghana. We sampled six major markets for each of the selected crops, comprising of Techiman, Tamale, Bolgatanga, Wa, Kumasi, Accra for the analysis with Tamale as the reference markets for both crops. The dataset for the analysis was monthly average secondary prices from January 2006 to December 2013. The estimations were performed using momentum threshold autoregressive model and threshold vector error correction model. The results of the consistent momentum threshold autoregressive (CMTAR) model revealed co integration and asymmetric adjustment. In both sorghum and millet commodities markets, the markets in relation to the reference market exhibited asymmetric adjustment in the long-run with little adjustment for positive deviations as compared to the substantial decay for a negative deviation. This implies that intermediaries' response quickly to price movements that squeeze the profit margin than movements that stretches margin. Tamale was found to be the market leader as the market does not responds to perturbation from the other markets. Finally, there were higher levels of price instability indices and price risk in all markets for the commodities under study in the country accompanied by typically periods of higher persistent and explosive volatility levels.

Keywords: Market integration, price volatility, tvecm and consistent m-tar.

Introduction

Millet and Sorghum are important staple food for many Ghanaians accounting for 11 percent of total domestic food consumption in 2013[1]. Millet and Sorghum continue to be baseline stability in food security conditions in Ghana especially the three northern parts of the country where majority of localities own-produced millet and sorghum remain the primary sources of food for meeting households' needs. Food prices in Ghana have been much higher than average over the past 12 months characterized by high inflation. These high food prices affect households differently depending on whether they are net buyers or net sellers. In Ghana, poorer households spend a larger share of their expenditures on food and are therefore more influenced by rising food prices[2]. Price fluctuations have significant effect on area, productivity and the production of agricultural commodities. This uncertainty in agricultural commodities prices makes it difficult for producers to allocate resources efficiently, limits their access to credit for productivity enhancing inputs, and leads to adopt low-yield, low risk production technologies, thereby lowering average incomes[3]. The overall performance of agriculture depends, not only on efficiency of production or supply, but also on marketing efficiency, particularly the agricultural markets and price signal. The differences in prices that prevail across the country require investigation in to price integration and dynamics among the spatially separated markets. Market integration and price dynamics play significant fundamental role in managing risk associated with demand and supply shocks as well-integrated markets facilitate adjustment in net export flows across space, thereby reducing price variability faced by consumers and producers. In view of this background, the present study was conducted to study the price dynamics, price integration and transmission of sorghum and millet of major regional markets in Ghana.

Methodology

Study area and data source: The present study of analyzing the price dynamics and price transmission of sorghum and millet markets in Ghana employed secondary monthly wholesale average prices data published on the statistical database of food and agriculture organization[1] spanning from January 2006 to December 2013 making a total of 96 observations. The markets under study were Techiman, Kumasi, Tamale, Accra, Bolgatanga, and Wa. Techiman. Tamale was taken as the central/reference market for both millet and sorghum. The estimations of the econometric models were based on the logarithm transformation of the dataset.

Econometric approach: In this study, ADF, Philip-Perron (PP), KPSS were employed to examine the unit root properties of data generating process (DGP). Prices of many agricultural products exhibit definite seasonal patterns which reflect the various marketing practices of farmers and market intermediaries as well as the natural biological lag processes that govern production. In an attempt to model such phenomenon (seasonality) in the study, the seasonal unit root test often called HEGY for monthly data was employed[4]. The model for monthly data can expressed as

$$\Delta_{12}y_t = \pi_1 z_{1,t-1} + \pi_2 z_{2,t-1} + \pi_3 z_{3,t-1} + \pi_4 z_{3,t-2} + \pi_5 z_{4,t-1} + \pi_6 z_{4,t-2} + \pi_7 z_{5,t-1} + \pi_8 z_{5,t-2} + \pi_9 z_{6,t-1} + \pi_{10} z_{6,t-2} + \pi_{11} z_{7,t-1} + \pi_{12} z_{7t-2} + \sum_{j=1}^{p} \alpha_j^* \Delta_{12} + \mu_t \quad (1)$$

The null hypotheses H_0: $\pi_1 = 0$, H_0: $\pi_2 = 0$ and H_0 : $\pi_1 = \pi_2 = 0$ correspond to tests for regular, semiannual and annual unit roots, respectively. These hypotheses can be tested by estimating the model by OLS and considering the relevant't-' and '*F*-tests'.

Cointegration Analysis: The cointegration approach of Johansen and Engle and Granger implicitly assume a linear and symmetric adjustment mechanism toward equilibrium. These models have low power in measuring market integration in the presence of asymmetric adjustment[5,6]. This led to the application of new model such as the threshold autoregressive model developed by Enders and Siklo[5]. This model permits different speed of adjustment depending on the value of the error correction term. The threshold autoregressive model can be expressed as

$$\Delta\mu_t = I_t \rho_1 \mu_t + (1 - I_t)\rho_2 \mu_{t-1} + \sum_{i=1}^{p} \gamma \Delta\mu_{t-1} + \omega_t \quad (2)$$

Where I_t is the Heaviside indicator function such that

$$I_t = \begin{cases} 1 \text{ if } \mu_{t-1} \geq \tau \\ 0 \text{ if } \mu_{t-1} < \tau \end{cases} \quad (3)$$

and τ is the value of the threshold, ρ_1 *and* ρ_2 are the speed of adjustment, $\omega_t$is a sequence of zero-mean. The null hypothesis tested in the model was no cointegration ($\rho_1 = \rho_2 = 0$) which is based on nonstandard joint F-test. The test statistic Φ_i was compared to critical values provided by Enders and Siklos[5]. When the null hypothesis of no cointegration is rejected, then the standard F-test for symmetric adjustment ($\rho_1 = \rho_2$) can be performed. The value of the critical threshold is usually unknown to the researcher and needs to be estimated as reported by Podo V.F.[7]. In the estimation of the consistent MTAR, Chan's methodology was adopted[8]. Hansen and Seo test was conducted to complements the results of M-TAR model to test for the presence of significant threshold effect[9]. Following the Hansen and Seo test for threshold effect, if the null hypothesis is rejected, threshold error correction model (TVECM) will be adopted. The threshold vector error correction model can be expressed as:

$$\Delta P_t = \begin{cases} \rho_1 \gamma' P_{t-1} + \theta_1 + \sum_{m=1}^{M} \circledast_1 \Delta P_{t-m} + \varepsilon_t, \gamma' P_{t-1} \leq \Psi \text{ (Regime 1)} \\ \rho_2 \gamma' P_{t-1} + \theta_2 + \sum_{m=1}^{M} \circledast_{2m} \Delta P_{t-m} + \varepsilon_t, \Psi < \gamma' P_{t-1} \text{(Regime 2)} \end{cases} \quad (4)$$

The TVECM explains price adjustments in both short term and long term, but depends conditionally on the magnitude of the deviation from the long term equilibrium. If we fail to reject the null hypothesis, then transmission follows the standard linear VEC model. The specification of standard VECM is given below

$$\Delta y_t = \alpha_1 + p_1 e_1 + \sum_{i=0}^{n} \beta_1 \Delta y_{t-i} + \sum_{i=0}^{n} \delta_1 \Delta X_{t-1} + \sum_{i=0}^{n} \gamma_i Z_{t-i} \quad (5)$$

$$\Delta X_t = \alpha_2 + p_2 e_{i-1} \sum_{i=0}^{n} \beta_1 Y_{t-i} + \sum_{i=0}^{n} \delta_i \Delta X_{t-i} + \sum_{i=0}^{n} \gamma_i Z_{t-i} \quad (6)$$

The error correction representation highlights more on the adjustment process in both short-run and long-run responsiveness to price changes which generally reflects arbitrage and market efficiency[10].

Risk and Volatility Measurement: Price risk is one of the most important components of risk in agriculture as it affects farmers, market intermediaries' decision and government policies. To examine this phenomenon, the Cuddy-Della Valle instability and the GARCH-M models were adopted to examine the instability and the risk of the prices of the selected markets of the commodities. The Cuddy-Della Valle index can be given as:

$$CDV = CV^* \times \sqrt{1 - R^2} \quad (7)$$

Where: CDV is the Cuddy-Della Valle Index, CV* is the simple estimate of the CV (%), R^2 is the coefficient of determination from time trend regression adjusted by the number of degrees of freedom. The GARCH-M has the specification as:

$$y_t = \mu + \lambda\sigma_t + \alpha_t \quad (8)$$

$$\sigma_t^2 = \alpha_0 + \sum_{i=1}^{p} \alpha_i a_{t-i}^2 + \sum_{j=1}^{q} \beta_j \sigma_{t-j}^2 \quad (9)$$

Where: y_t is the time series value at time t, μ is the mean of GARCH model. λ is the volatility coefficient (risk premium) for the mean, σ_t is the conditional standard deviation (i.e. volatility) at time t, P is the order of the ARCH Component model. α_i is the parameters of the the ARCH component model. β_j are the parameters of the the GARCH component model[11].

Results and Discussion

Unit Root and Seasonality Test: The results of HEGY test is presented in table-1, which revealed that it was not possible to reject a unit root at zero frequency at conventional levels of significance in all the price series. This suggests that the series may possess a stochastic trend. For some of the rest of the frequencies, it was possible to reject unit roots in all series with the exception of Kumasi sorghum market series which exhibited seasonal unit root at all frequencies. In summary, there was an indication of unit root at zero frequency (regular unit root). Hence it was best to treat seasonality as a deterministic component in the subsequent regressions. Thus, the price series were seasonally adjusted for further analysis and that all the remaining econometric estimations were based on the seasonally adjusted data of all the prices on the various markets under study.

The results of the ADF and PP test considering the appropriate lag lengths suggested by BIC revealed that at 5%significance level, the null hypothesis of unit root cannot be rejected for all four price series in their levels. As expected, the null hypothesis is rejected after taking the first difference of all series and testing for stationarity. The KPSS results confirmed those of the ADF test. We strongly reject the null hypothesis of no unit roots (i.e. the series is stationary) at level for all the prices series at 5% significance levels, but cannot reject the null hypothesis at the first difference of the price series. Thus, the series under the study are first difference stationary processes indicating integration of the same order I (1).

Cointegration: Since cointegration approach of Johansen implicitly assumes a linear and symmetric adjustment mechanism and fails to reject the absence of cointegration in the presence of asymmetric adjustment and threshold effect, the consistent MTAR was estimated to examine the integration relationships between the markets. The results of Consistent MTAR model are displayed in table-3, which indicated that the null hypotheses of no cointegration ($\rho_1 = \rho_2 = 0$) can be rejected t 5 percent significance level for all the relationships. The results also revealed that Tamale-Kumasi and Tamale-Techiman exhibited symmetric adjustment while Tamale-Accra, Tamale-Bolgatanga and Tamale- Wa exhibited asymmetric price adjustment for sorghum markets and Tamale-Kumasi and Tamale-Bolgatanga exhibited symmetric price adjustment and Tamale-Accra, Tamale-Techiman and Tamale-Wa exhibited asymmetric price adjustment for millet markets relationships. The point estimates indicate that the market intermediaries response more quickly to price differentials that tend to squeeze profit margin. For instance, the point estimate of $\rho_1 = -0.099$ and $\rho_2 = -0.3295$ for Tamale and Accra sorghum markets pair indicate that approximately 10 percent of positive deviation and 32.95 percent of negative deviation while 47.21 and 91.22 percent of positive and negative deviation respectively for Tamale-Accra millet markets pair from the equilibrium were eliminated within one month.

Table-1
HEGY test for Seasonal Unit Root for Sorghum and Millet

Variable	Accra		Bolgatanga		Kumasi		Tamale		Techiman		WA		Freq
	Sorghum	Millet	Sorghum	Millet	Sorghum	Millet	Sorghum	Millet	Sorghum	Millet	Sorghum	Millet	
π_1	2.894	2.802	2.331	1.671	2.132	2.105	1.862	1.565	2.274	1.547	1.453	0.350	0
π_2	0.503	1.872	2.783	0.857	2.095	1.029	2.436	1.232	0.791	1.821	2.387	0.788	π
$\pi_3 = \pi_4$	4.599	4.191	0.300	4.290	2.597	2.933	1.943	8.075**	1.338	6.552**	3.186	7.065**	π/2
$\pi_5 = \pi_6$	9.721**	10.194**	11.875**	8.190**	4.997	12.46**	6.566**	5.654	4.445	9.935**	3.547	3.479	2π/3
$\pi_7 = \pi_8$	3.106	11.698**	4.217	1.428	2.606	2.079	3.561	7.032**	4.169	7.017	9.140**	7.757**	π/3
$\pi_9 = \pi_{10}$	15.306**	8.780**	11.048**	5.607	5.982	9.117**	2.544	6.462**	7.954**	4.494	15.93**	12.73**	5π/6
$\pi_{11} = \pi_{12}$	3.1959	9.610**	8.0938	2.186	5.873	4.412	3.582	7.859**	6.321	7.045**	8.401**	5.022	π/6
T(Lags)	72(12)	91(5)	91(5)	72(12)	91(5)	91(5)	95(1)	72(12)	95(1)	91(5)	96(0)		

Note: ** indicates significance at 5 percent probability

Table-2
ADF, PP and KPSS Unit Root for Sorghum and Millet

	ADF TEST		**PP TEST**		**KPSS TEST**	
	Level	First Diff	Level	First Diff	Level	First Diff
Accra	-2.305	-8.475**	-2.389	-8.489**	2.882	0.1002**
Kumasi	-3.140	-12.293**	-3.141	-12.292**	0.7912	0.0391**
Techiman	-2.697	-11.016**	-2.700	-11.015**	2.160	0.0550**
Bolgatanga	-2.693	-11.814**	-2.693	-11.814**	3.139	0.0375**
Tamale	-2.081	-11.676**	-2.082	-11.676**	6.724	0.0673**
Wa	-1.957	-8.425**	-1.960	-8.425**	5.607	0.1198**
Millet						
Accra	-2.625	-11.039**	-2.62	-11.04**	2.079	0.079**
Kumasi	-3.327	-14.232**	-3.42	-14.23**	0.889	0.033**
Techiman	-2.229	-11.073**	-2.23	-11.07**	2.443	0.065**
Bolgatanga	-2.301	-9.362**	-2.30	-9.36**	2.042	0.057**
Tamale	-2.580	-10.129**	-2.58	-10.13**	2.121	0.0496**
Wa	-2.626	-11.039**	-2.62	-11.04**	2.079	0.0787**

Table-3
Result of MTAR and Consistent MTAR for Sorghum

	Consistent MTAR for Sorghum					**Consistent MTAR for Millet**				
Items/market	**TA**	**TK**	**TT**	**TB**	**TW**	**TA**	**TK**	**TT**	**TB**	**TW**
τ	-0.109	0.109	0.060	0.083	-0.095	-0.099	-0.075	-0.057	-0.059	-0.098
ρ_1	-0.099 (0.066)	-0.3915 (0.1471)	-0.6453 (0.1603)	-0.0587 (0.153)	-0.2312 (0.097)	-0.4721 (0.1213)	-0.3522 (0.1213)	-0.5545 (0.1336)	-0.2292 (0.1733)	-0.4721 (0.1213)
ρ_2	-0.3295 (0.1039)	-0.1258 (0.0757)	-0.3384 (0.0994)	-0.6301 (0.094)	-0.6463 (0.1341)	-0.9122 (0.1520)	-0.5838 (0.1820)	-1.1010 (0.1438)	-0.5411 (0.1005)	-0.9122 (0.1520)
$\Phi(\rho_1 = \rho_2 = 0)^1$	6.1637***	4.6173*	13.904***	22.575***	14.439***	25.58***	7.8799**	37.946***	15.381***	27.58***
$\rho_1 = \rho_2$	3.4822*	2.7483	2.6495	14.702***	6.277*	5.1199**	1.3572	7.7556**	2.423	6.6362*
P. Value	0.0652	0.1008	0.107	0.00023	0.0140	0.026	0.2471	0.0065	0.123	0.01159
Lag	0	1	0	0	0	1	1	0	0	0
ρ_1	-123.825	-66.919	-76.908	-87.492	-143.868	-160.939	-171.013	-170.822	-140.469	-157.640
ρ_2	0.597	0.913	0.594	0.870	0.980	0.869	0.656	0.991	0.881	0.691
$\Phi(\rho_1 = \rho_2 = 0)^1$	0.109	0.561	0.712	0.811	0.957	0.771	0.909	0.521	0.639	0.869
$\rho_1 = \rho_2$	17.852*	16.566*	15.858	8.448	14.497	12.68	15.624	14.190	9.756	12.680
P. Value	0.063	0.089	0.14	0.379	0.222	0.488	0.127	0.282	0.879	0.448

Hansen and Seo test was employed to examine whether the markets exhibit significant threshold effect. The results of the Hansen and Seo (HS) test for both sorghum and millet markets pairs are presented in table-3 above as Sup-LM statistics. The null hypothesis of no significant threshold effect was failed to be rejected at 5 and 10 percent significance level for all markets pairs for both sorghum and millet except Tamale-Accra and Tamale-Kumasi sorghum markets pairs.

Transmission Dynamics: The results of the TVECM model to examine the price transmission dynamics of sorghum and millet markets prices under study based on the HS test and Consistent MTAR results are presented table-4. The results revealed that an increment in the prices of Tamale market brings about approximately 9 percent increment in the Accra sorghum market prices as indicated by the cointegrating parameter. The coefficients in Tamale model are statistically significant while those of Accra are positive and insignificant suggesting that in the long-run, Accra price Granger –cause Tamale prices. The estimated critical threshold value is -0.2062 which distinguishes two regimes, an extreme and typical regime, with 20.4 and 79.6 percent of the data observation respectively. The parameter -0.4887 for Tamale price spread indicating a faster adjustment to the long-run equilibrium below the threshold value implying market players' response to negative deviation. The market adjustments to eliminate 26.46 percent of positive deviation (shock). This is two times slower than negative deviation. The threshold value signifies that adjustment is faster when tamale prices spread lies 21 percent below its long equilibrium as determined by the spread in the Accra prices. The estimated cointegrating parameter 0.9197 for Tamale –Kumasi prices relationship indicates that 10 percent in the Tamale prices leads to approximately 10 percent increase in the Kumasi prices. The estimated threshold parameter is -0.0983, with an extreme regime accounting for 21.5 percent of the total observation and the typical regime accounting for 78.5 percent of the observation. The threshold values of -0.2062 and -0.0983 for Tamale-Accra and Tamale-Kumasi relationship respectively may suggest the presence of non-linearity and asymmetric relationship between the markets pairs allowing the prices to adjust differently depending on whether the disequilibria are negative or positive.

To further explore the how the market response to positive and negative perturbations, an asymmetric test was conducted to examine whether the market relationships exhibit long-run asymmetry. The results are presented in table-5. In Tamale-Accra relationship, the point estimates for Accra market imply that in the long-run the market will respond to approximately 9.81 for positive deviation and 1.033 for the negative. The negative adjustment is not significant at conventional level (the corresponding p-value is 0.9297). Therefore, it seems that in the long-run the price of Accra responds to only positive deviations but, the transmission is weak. This implies that the market intermediaries' response to only deviation that stretches profit margin and any price reduction takes long time to be transmitted. This result is expected as Accra serves as the capital of the country where major consumption takes place and market intermediaries form group under the influence of market queen and will not respond to quickly to commodities prices reduction. The F-statistic of 2.156 indicates that the price of Accra Grange cause the price of Tamale. Accra had significant lagged impacts on its own price.

Table-4
TVECM for TA and TK Sorghum Market Pairs

Variable	**Regime 1**		**Regime 2**			**Regime 1**		**Regime 2**	
TA	ΔP_{Tamale}	ΔP_{Accra}	ΔP_{Tamale}	ΔP_{Accra}	**TK**	ΔP_{Tamale}	ΔP_{Kumasi}	ΔP_{Tamale}	ΔP_{Kumasi}
Ect	-0.4887 (0.157)	0.1674 (0.379)	-0.2646 (0.0107)*	0.1073 (0.059)*	**Ect**	-0.4707 (0.0063)**	0.0381 (0.8006)	-0.3187 (0.0130)*	0.0827 (0.4653)
Constant	-0.2386 (0.079)	0.0441 (0.556)	0.0674 (0.0022)**	-0.0041 (0.732)	**Constant**	-0.2154 (0.0077)**	-0.0259 (0.716)	0.0974 (0.0044)**	0.0344 (0.2531)
ΔT_{t-1}	-0.0093 (0.976)	0.0932 (0.582)	0.0148 (0.914)	0.1881 (0.015)*	ΔT_{t-1}	-0.0370 (0.7867)	0.3589 (0.0043)**	-0.0370 (0.7867)	0.3589 (0.0043)**
ΔT_{t-2}	0.3464 (0.098)	0.1756 (0.129)	0.2308 (0.095)*	0.1513 (0.049)*	ΔT_{t-2}	0.1235 (0.2271)	-0.0638 (0.6868)	0.1484 (0.2658)	0.3246 (0.0078)**
ΔA_{t-1}	-1.2593 (0.003)**	-0.4267 (0.068)*	0.0951 (0.6642)	-0.0179 (0.883)	ΔK_{t-1}	-0.5945 (0.0078)**	-0.0448 (0.8193)	-0.2655 (0.0617)*	-0.597 (0.00008)***
ΔA_{t-2}	-1.2154 (0.0039)**	-0.2954 (0.196)	-0.0571 (0.775)	-0.1566 (0.1595)	ΔK_{t-2}	-0.3969 (0.1452)	-0.3021 (0.2161)	0.0208 (0.8801)	-0.1007 (0.4208)
Threshold Value = - 0.2062, Cointegrating Vector = (-1, 0.8776). Percentage of observation in each Regime = 20%, 79.6%, AIC = -943.7891 BIC = -880.4742 SSR = 1.0998, Log likelihood = 232.972					Threshold Value = - 0.0983, Cointegrating Vector = (-1, 0.91968) Percentage of observation in each Regime = 21.5%, 78.5%, AIC = -855.187, BIC = -791.872 SSR = 1.44103 Log likelihood = 188.6709				

In Tamale-Kumasi relationship; the F-statistics of 2.646 and 2.602 are significant implying bidirectional causality between the markets pair indicating market interdependence. Tamale had significant distributed and cumulative asymmetric lag effect on its own price at lag two and asymmetric effects on Kumasi at lag two. The final type of asymmetry examined was the long-run equilibrium asymmetric path to adjustment. In Tamale-Accra relationship, Accra with F-statistic of 0.630 with a p-value of 0.430 implies symmetric path of adjustment toward equilibrium in the long-run due to price spread created by price changes in Tamale market. In contrast, for Tamale, the F-statistic was 11.920 with a p-value of 0.001 indicates an asymmetric momentum equilibrium adjustment which adjust to eliminate 8.18 percent for positive deviation and 65.38 percentfor negative deviation in the long-run. The magnitude suggests that in the long term the price of Tamale responds more to negative deviation in a month. This result is also expected because Tamale serves as main production area for the commodities and farmers will respond more quickly to price differentials that tend to squeeze their profit margin. Measured in time response, positive deviations take about full year to be fully converge while negative deviations take one and Half months only in the production area. In summary, the price of Tamale exhibit positive asymmetric adjustment and thus response fully to price movement that squeezes the profit margin whiles Accra and Kumasi exhibited negative asymmetry and therefore response fully to price movements that stretches the profit margin.

Focusing on the consistent MTAR model and HS test, linear asymmetric and symmetric error correction model were estimated to examine the price transmission dynamics for the markets that exhibited linear asymmetric and symmetric cointegration respectively as depicted in table-6. The results revealed that in Tamale- Bolgatanga markets pair, Bolgatanga market response faster to adjustment of positive deviations from the equilibrium compared to negative deviations creates by price changes in Tamale market while Tamale market exhibit positive asymmetry indicating faster speed of adjustment to negative deviation from equibrium as created by the spread in Bolgatanga market.

Table-5
Results of Asymmetric Test

	ΔP_{Tamale}	ΔP_{Accra}	ΔP_{Tamale}	ΔP_{Kumasi}
δ^+	0.0818 [0.2159]	0.0981 [0.005]**	0.0978 [0.1002]	0.1721 [0.0010]**
δ^-	-0.6538 [0.004]**	0.01033 [0.9297]	-0.2464 [0.0318]*	0.0717 [0.4611]
$H_{01}: \alpha_I^+ = \alpha_I^- = 0\ for\ all\ lags$	0.141[0.966]	0.761[0.554]	3.557[0.010]***	2.646[0.039]**
$H_{02}: \beta_I^+ = \beta_I^- = 0\ for\ all\ lags$	2.156[0.081]*	2.538[0.046]**	2.602[0.042]**	0.967[0.430]
$H_{03}: \alpha_1^+ = \alpha_1^-$	0.049[0.825]	0.390[0.534]	3.219[0.076]*	0.497[0.483]
$H_{03}: \alpha_2^+ = \alpha_2^-$	0.318[0.574]	0.003[0.957]	5.197[0.025]**	3.743[0.056]*
$H_{04}: \beta_1^+ = \beta_1^-$	1.389[0.242]	0.519[0.473]	2.865[0.094]*	3.146[0.080]*
$H_{04}: \beta_2^+ = \beta_2^-$	1.840[0.179]	0.891[0.348]	4.641[0.034]**	0.035[0.852]
$H_{05}: \sum_{i=1}^{2} \alpha_i^+ = \sum_{i}^{2} \alpha_i^-$	0.334 [0.565]	0.260 [0.612]	11.996*** [0.001]	4.982** [0.028]
$H_{06}: \sum_{i=1}^{2} \beta_i^+ = \sum_{i}^{2} \beta_i^-$	0.010 [0.919]	0.021 [0.884]	0.037 [0.848]	1.814 [0.182]
$H_{07}: \delta^+ = \delta^-$	11.920 [0.001]***	0.630 [0.430]	8.591*** [0.004]	0.995 [0.322]
R^2	0.220	0.326	0.296	0.338
LB(4)	0.971	0.968	0.982	0.940
LB(8)	0.983	0.937	0.460	0.893
LB(12)[1]	0.893	0.973	0.874	0.549

Tamale market had one period lagged significant effect at conventional level on error correction term of Bolgatanga market for positive deviation from the equilibrium. The point estimates of the adjustment parameters indicate that Bolgatanga prices adjusted to eliminate about 36 percent of a unit positive deviation from the equilibrium created by changes in the price spread of Tamale market while Tamale market response to Bolgatanga market to eliminate 34 percent of a unit negative change in the deviation from the equilibrium created by Bolgatanga market prices.

The F-statistics of 2.316 with p-value of 0.064 implies that the prices of tamale granger-cause the prices in Bolgatanga market implying unidirectional causality between the market pair. The F-stat of 3.769 and 4.504 implies tamale had significant asymmetric distributed lag effects its own price and Bolgatanga at conventional level.

The results of linear cointegration asymmetric and symmetric error correction for millet markets are reported in Table-6 and 7. The result provides mixed output for the markets pair. Accra and Techiman market significantly responded to both positive and negative deviations from the equilibrium relationship induced by changes in Tamale market prices. Accra market responses faster to positive deviations from the equilibrium relationship compared to negative deviations; indicating negative asymmetry.

The point of adjustment parameters indicates that Accra market adjusted to eliminate 84.19 percent and 28.29 percent of the positive and negative deviations respectively from equilibrium as a result of innovation (shock) in the prices of Tamale market. In time period wise, positive deviation requires 1.18 months to fully converge to equilibrium while 3.53 months. The F-statistic of 8.440 indicates that the price of Accra Grange-cause the price of Tamale. Tamale had distributed lag asymmetric effect for its own price and symmetric effect on Accra market.

The results revealed that Accra market exhibits symmetric path of adjustment to equilibrium in the long-run to price changes created by Tamale prices. In Tamale-Techiman markets pair, Techiman market adjusted to converge to both negative (17.75 percent) and positive (38.05 percent) deviations from equilibrium createdbyprice changes in Tamale market. Tamale market does not respond by adjusting to eliminate negative and positive deviations from the equilibrium relationship created by price changes in Techiman market as evident by the insignificance of the adjustment parameters at conventional levels. The positive sign for both adjustment parameters imply that Tamale is the market leader among the markets pair.

The results revealed that Techiman exhibited both short-run and long-run symmetric lag effect on Tamale market as well as its own price series and the vice-versa. Similarly, Techiman market exhibited symmetric path of adjustment to equilibrium in the long-run due to price changes created by Tamale market. In Tamale – Kumasi market pair, the results from the error correction term show there is speed of adjustment of about 27 percent running from Tamale to Kumasi towards long run equilibrium implying that 27 percent of the disequilibrium corrected for each month in Kumasi market is by changes in Tamale prices while Tamale market does not respond to changes in Kumasi as evident by the positive and insignificant error correction term.

The results of the long run relationship between Tamale and Kumasi revealed by the cointegrating vector in the period of 2006-2013 suggest that 10% appreciation of the market prices in Tamale is likely to increase prices in Kumasi by 9.65%. The wald test results (F-Stat = 0.0372, Prob. = 0.9635) revealed no short-run casuality running from Tamale to Kumasi, but Kumasi in the short-run had short-run causality for its own price, thus implies that Tamale is independence on Kumasi prices.

However, the speed of adjustment of 27.08% for Kumasi is relatively weak as relate[12] who found 27.73% and summed up that there is weak integration among the markets.

Price Instability and Volatility: The stability indices revealed highest instability (7% and 5.53%) for Sorghum and Millet prices respectively for the reference market (Tamale) for the period under study. It was noted that during the period considered for the study the instability indices were comparatively higher for the Sorghum markets than Millet markets. Instability in domestic market especially in the reference market (area of higher production) will have considerable impact on the domestic market since the price movements as well as the production levels of commodity in the country which may induce food and nutritional insecurity as majority of poor population spend their income on food. In most of the markets, we observe that the estimated coefficients of the model does not obey the assumption of $(\alpha + \beta) < 1$, which implies that the mean does not revert thus, exhibit high persistence and explosive volatility.

The results revealed that in most of the markets the estimated coefficients for the variance equation of the model (the ω, α and β coefficients) are statistically significant at the 90%, 95% and 99% confidence level indicating that the volatility in the market prices is influenced by the market's own internal perturbation (shock) as evident from the significant ARCH and GARCH terms.

Finally, we can conclude that the market intermediaries are exposed to high level of risk as evident by the estimated coefficient values of λ . The λ coefficients are statistically significant for most of the markets implying a correlation between risk and expected return. In summary, the results of the GARCH-M estimation clearly signify that the volatility in the current day depends on volatility in the preceding day's market price information and the previous day's price volatility as evident from the significant ARCH and GARCH terms.

Table-6
Results of Linear Cointegration and Asymmetric Error Correction Model for Sorghum and Millet

Variables	ΔP_{Wa}	ΔP_{Bolga}	ΔP_{Accra}	$\Delta P_{Techiman}$	ΔP_{Wa}
Constant	-0.0247 (0.015)	-0.0415 (0.030)	0.0139 (0.019)	0.0103 (0.020)	0.0245 (0.022)
ΔT_{t-1}^{+}	0.0446 (0.112)	-0.3616 (0.198)*	-0.2610 (0.141)**	-0.319 (0.169)*	0.1161 (0.190)
ΔT_{t-2}^{+}	0.0574 (0.097)	0.3162 (0.194)	-0.0706 (0.108)	-0.0222 (0.134)	-0.0295 (0.175)
ΔT_{t-1}^{-}	0.0499 (0.138)	0.2859 (0.242)	-0.1745 (0.102)*	-0.1046 (0.130)	0.0077 (0.155)
ΔT_{t-2}^{-}	0.1044 (0.137)	-0.3853 (0.222)	-0.0676 (0.117)	-0.251 (0.142)*	0.0914 (0.140)
ΔA_{t-1}^{+}	-	-	0.6010 (0.262)**	-	-
ΔA_{t-2}^{+}	-	-	0.1213(0.166)	-	-
ΔA_{t-1}^{-}	-	-	0.1198(0.221)	-	-
ΔA_{t-2}^{-}	-	-	0.3787(0.169)0**	-	-
ΔB_{t-1}^{+}	-	0.2712 (0.192)	-	-	-
ΔB_{t-2}^{+}	-	0.0476 (0.181)	-	-	-
ΔB_{t-1}^{-}	-	-0.2547 (0.219)	-	-	-
ΔB_{t-2}^{-}	-	-0.0569 (0.224)	-	-	-
ΔTE_{t-1}^{+}	-	-	-	0.177(0.257)	-
ΔTE_{t-2}^{+}	-	-	-	0.274(0.181)	-
ΔTE_{t-1}^{-}	-	-	-	0.392 (0.228)*	-
ΔTE_{t-2}^{-}	-	-	-	0.130(0.178)	-
ΔW_{t-1}^{+}	0.2040 (0.156)	-	-	-	-0.0712 (0.221)
ΔW_{t-2}^{+}	0.2218 (0156)	-	-	-	0.0558 (0.197)
ΔW_{t-1}^{-}	-0.2826 (0.244)	-	-	-	-0.2035 (0.229)
ΔW_{t-2}^{-}	-0.587 (0.255)*	-	-	-	-0.0613 (0.224)
δ^{+}	0.0943 [0.4296]	0.3571* [0.0803]	-0.8419 [0.0004]***	-0.3805 [0.00014]***	-0.35146 [0.104]
δ^{-}	-0.3199** [0.0234]	-0.0496 [0.6714]	-0.2829 [0.006]***	-0.1775 [0.00039]***	0.05687 [0.772]
$H_{01}: \alpha_I^{+} = \alpha_I^{-} = 0\ for\ all\ lags$	0.337 [0.852]	2.316 [0.064]*	1.594 [0.184]	0.962 [0.433]	0.178 [0.949]
$H_{02}: \beta_I^{+} = \beta_I^{-} = 0\ for\ all\ lags$	2.250 [0.071]*	00840 [0.504]	1.926 [0.114]	1.3111 [0.273]	0.337 [0.852]
$H_{03}: \alpha_1^{+} = \alpha_1^{-}$	0.001 [0.979]	3.769[0.056]*	0.230[0.633]	0.898 [0.346]	0.202 [0.654]

Variables	ΔP_{Wa}	ΔP_{Bolga}	ΔP_{Accra}	$\Delta P_{Techiman}$	ΔP_{Wa}
$H_{03}: \alpha_2^+ = \alpha_2^-$	0.061 [0.805]	4.504 [0.037]**	0.001[0.9986]	1.185 [0.280]	0.258 [0.613]
$H_{04}: \beta_1^+ = \beta_1^-$	2.242 [0.138]+	2.533 [0.115]+	2.662 [0.107]+	0.449 [0.505]	0.153 [0.696]
$H_{04}: \beta_2^+ = \beta_2^-$	5.710 [0.019]**	0.095 [0.759]	1.287 [0.260]	0.301[0.585]	0.127 [0.722]
$H_{05}: \sum_{i=1}^{2} \alpha_i^+ = \sum_{i}^{2} \alpha_i^-$	0.053 [0.818]	0.014 [0.905]	0.247 [0.620]	0.003 [0.953]	0.002 [0.968]
$H_{06}: \sum_{i=1}^{2} \beta_i^+ = \sum_{i}^{2} \beta_i^-$	8.111*** [0.006]	2.330 [0.131]+	0.515 [0.475]	0.046 [0.830]	0.324 [0.571]
$H_{07}: \delta^+ = \delta^-$	1.145 [0.288]	2.523 [0.116]+	1.603 [0.209]	0.179 [0.674]	1.634 [0.205]
R^2	0.228	0.183	0.616	0.519	0.087
AIC	-238.374	-130.362	-172.337	-137.865	-171.402
BIC	-207.983	-99.971	-142.076	-107.604	-141.011
LB(4)	0.996	0.228	0.917	0.995	0.861
LB(8)	0.222	0.376	0.989	0.826	0.988
LB(12)	0.179	0.595	0.700	0.614	0.637

Table-7
Results of Linear Cointegration and Symmetric Error Correction Model for Millet Markets

Variables	ΔP_{Tamale}	ΔP_{Kumasi}	ΔP_{Tamale}	ΔP_{Bolga}
Constant	0.0125 [0.2929]	0.0153 [0.093]*	0.0148 [0.1408]	0.0142 [0.2091]
Ect_{t-1}	0.1970 [0.1815]	-0.27008 [0.0172]**	0.4404 [0.0001]***	0.0441 [0.7147]
ΔT_{t-1}	-0.0353 [0.7941]	0.0143 [0.8892]	-0.1336 [0.2420]	0.0088 [0.9447]
ΔT_{t-2}	-0.0368 [0.7513]	0.0237 [0.7885]	-	-0.1082 [0.3025]
ΔK_{t-1}	0.2799 [0.098]*	-0.3123 [0.0164]**	-	-
ΔK_{t-2}	-0.0516 [0.7380]	-0.0988 [0.4005]	-	-
ΔB_{t-1}	-	-	-0.1260 [0.1791]	-0.0159 [0.9182]
ΔB_{t-2}	-	-	0.1819 [0.7905]	-0.0164 [0.9087]
ΔT_{t-1}= $\Delta T_{t-2} = 0$	0.0628 [0.9391] df= (2,87)	0.0372 [0.9635] df=(2,87)	1.2734 [0.2850] df= (2,87)	0.6037 [0.5468] df = (2,87)
ΔK_{t-1}= ΔK_{t-2} =0	2.3456 [0.1018] Df= (2,87)	3.1068 [0.0497]** Df= (2,87)	-	-
ΔB_{t-1}= $\Delta B_{t-2} = 0$	-	-	0.9196 [0.4025] df = (2,87)	0.00848 [0.9915] df = (2,87)
R^2	0.2319	0.1318	0.374	0.160
AIC	-204.37	-149.56	-167.469	-146.810
Loglike	101.0298	75.5455	80.4511	91.118

Table-8
Results of CDV and GARCH-M for Sorghum and Millet Markets

		Sorghum				
Markets/Variables	**CDV (%)**	μ	λ	ω	α	β
Accra	3.76	0.0364*** (0.0101)	-0.3625*** (0.121)	0.0005** (0.0002)	-0.0676*** (0.0196)	0.9269*** (0.0486)
Kumasi	4.00	-0.0051 (0.0113)	0.0959** (0.0479)	0.0019*** (0.0006)	1.4124*** (0.2711)	0.0599 (0.0676)
Techiman	5.09	-0.1297** (0.066)	0.6387*** (0.1856)	-0.0225*** (0.0029)	0.5726*** (0.0005)	1.2207*** (0.0005)
Tamale	7.00	0.0605 (0.1460)	0.0231* (0.0135)	0.01375*** (0.0029)	0.24694** (0.0862)	0.40867** (0.0204)
Bolgatanga	5.50	0.3792*** (0.0867)	-0.0293 (0.0924)	0.00211 (0.0025)	0.11027* (0.0583)	0.7371** (0.2849)
Wa	4.78	-0.1733*** (0.0062)	1.6897*** (0.0931)	-0.0026*** (0.00007)	0.3395*** (0.0335)	0.8210*** (0.1062)
		Millet				
Accra	4.52	0.1636 (0.2802)	0.3063* (0.1621)	0.01005 (0.0082)	0.3455* (0.0203)	0.8603*** (0.1874)
Kumasi	3.33	-0.2344* (0.1398)	-0.4718*** (0.0278)	0.0036** (0.0013)	0.3334* (0.1828)	0.1928 (0.2074)
Techiman	5.19	0.0392*** (0.0078)	-0.3531** (0.1319)	0.00619*** (0.0017)	0.5777** (0.2662)	-0.1518 (0.1405)
Tamale	5.53	-0.0862 (0.1799)	0.6246*** (0.1561)	0.057*** (0.0119)	0.5622*** (0.1148)	0.1846*** (0.2399)
Bolgatanga	4.46	0.0661*** (0.0161)	-0.7174*** (0.2406)	0.0031*** (0.00096)	0.9439*** (0.3170)	-0.0160 (0.0624)
Wa	4.52	-0.0109 (0.0379)	0.2488 (0.4568)	0.0081** (0.0036)	0.2974*** (0.1082)	-0.3571** (0.1794)

Conclusion

This study was conducted to investigate price dynamics and market integration of Ghanaian's sorghum and millet markets during the period of January 2006 to December 2013. We employed the consistent MTAR model and its extension and GARCH-M model to examine the degree of market integration as well the price volatility of sorghum and millet markets in Ghana. The price transmission dynamics were analyzed through an asymmetric error correction model with threshold cointegration incorporated. The price series for all commodities considered for study in the various markets were found to be highly integrated as evident by the cointegrating parameters (i.e0.8776 and 0.91968). Considering the error correction coefficients from the standard and extended MTAR models we observed a mixed pattern on the performance of markets of commodities with some markets exhibiting higher adjustment for positive deviation than negative deviations and vice versa. The price transmission between reference and the other regional selected markets under consideration appears to be asymmetric in the sense that increases in wholesale prices in the reference market are passed on more rapidly to the other regional markets, while price reduction takes somewhat longer period to transmit through the other markets. Finally, we recommend that the government should support the Agricultural Market Information System (AMIS) in the country to enhance food market information and transparency, regulation and supervision of agricultural derivative markets.

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