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**Assessing Seasonal Asymmetric Price Transmission in Ghanaian Tomato Markets With the Johansen Estimation Method**

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# Assessing Seasonal Asymmetric Price Transmission in Ghanaian Tomato Markets With the Johansen Estimation Method

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**Abstract:** We assess market integration and price transmission of perishable agricultural produce in Sub-Saharan Africa by studying Ghanaian tomato markets which are characterized by pronounced seasonality in production and trade flows. We analyse the tomato markets of Ghana by simultaneously regarding its five most important markets, Navrongo, Techiman, Kumasi, Tamale and Accra, in a multivariate asymmetric price transmission framework. The estimation of the model is based on a unique dataset and on a modified version of the Johansen estimation procedure which is suitable for estimating such multivariate models. We estimate the price transmission parameters for four regimes which are a combination of the seasonal patterns in trade flows and asymmetries in the long-run price equilibrium between the most important production region (Techiman) and the most important consumption centre for tomatoes (Accra). We find strong evidence for integration of the five markets. In general, price transmission appears to be fast. Disequilibria mainly trigger price responses in the two production regions of Navrongo and Techiman. The regimes are found to matter for the whole system of tomato markets. Disequilibrium is shown to spillover between the price relationships. Consequently, tomato markets in Ghana appear to be integrated and function very well since price signals are rapidly passed through the country.

**Keywords:** asymmetric price transmission, cointegration, Ghana, regime-dependent model, seasonality, tomato, vector error-correction model.

**JEL:** C32, Q11, Q13, F14, F15



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**Assessing Seasonal Asymmetric Price Transmission in Ghanaian Tomato Markets With the Johansen Estimation Method**

## 1. Introduction

Ghana is one of the few countries in West Africa which pursues a liberal trade policy both domestically and internationally. Hence it represents a suitable case for studying market integration and price transmission in Sub-Saharan Africa. Tomatoes are one of the most important vegetables produced as well as consumed in the country. Its production shows a pronounced seasonal pattern and prices of fresh tomatoes in Ghana typically vary substantially even within a week. We thus study the structure of this system of markets in detail by focusing on the analysis of the dynamics and interdependencies of wholesale prices of selected major tomato markets of the country.

The literature on asymmetries in the transmission of price signals between markets suggests that asymmetries in this process might play an important role (see, e.g., Meyer and von Cramon-Taubadel, 2004). Hence, we suggest a model which not only accounts for the seasonality in production but also allows assessing asymmetric price transmission in this multivariate market framework. Such an analysis is important because it may inform current and future policy strategies aimed at improving market integration and price transmission. In addition, identifying how dynamics of intermarket price relationships deviate from season to season may be useful in formulating policy options for tackling seasonal gluts and price hikes in Ghana's tomato markets, and for strengthening the engagement of Ghana in the Doha Round of trade negotiations. In the long run, it may guide policies towards improving the competitiveness if the tomato markets and the welfare of tomato producers in Ghana.

Empirical research on spatial price relationships in agricultural markets examines the underlying factors likely to drive (asymmetric) spatial price dynamics. For example, von Cramon-Taubadel (1998), Abdulai (2000), Meyer and von Cramon-Taubadel (2004) study the implications of market power on asymmetric price transmission (APT). The recent literature of Jensen (2007) and others[3] sheds light on the importance of information flow on price formation and price dynamics. Little attention has been drawn to properties of the markets such as seasonality – a notable periodic variability of output, supply or prices of a commodity, due to changing weather patterns, for example. The production and supply of many

[3] For an overview of this literature, see Jensen (2009).

agricultural commodities exhibits more or less pronounced seasonality. This is especially the case for perishable commodities which permit only a short time lag between harvest and delivery such as fruits and vegetables. The impact of seasonality can be expected to be even more pronounced in developing countries where crop production is largely weather-dependent, and where storage in the form of mechanical refrigeration and processing facilities are lacking.

It is known that traders of perishable and seasonally produced commodities adjust their prices as the volume of the produce in storage or supply changes (Parrott et al., 2001). Moreover, there is a certain possibility that seasonal effects on the production of commodities may affect not only the quantity and quality of the commodity supplied, but also other fundamental variables of market performance such as market infrastructure, arbitrage decisions, and levels of transaction costs, prices and trade flows between spatially connected markets (Eduardo and Mario, 2001). Farm commodity prices may also reflect seasonal production patterns by being at their lowest at peak production and highest at lean seasons (Goodwin et al., 2002). Therefore, parameters quantifying the speed of price transmission might also vary by season. If these patterns are disregarded, the resulting estimates are weighted averages of the (hidden) regime-dependent parameters which might be negligible if seasonality does not play an important role. If, however, seasonality constitutes a major feature of the market studied, the information of the analysis is considerably extended by estimating seasonally dependent parameters. Such an approach is then both from a practical and an econometric perspective necessary since the model would be otherwise oversimplifying and parameter estimates would not reflect the major features of the market. Although such an analysis seems desirable from a number of viewpoints, data limitations, that is, incomplete or missing data on seasonal patterns, often do not allow for considering regime-dependence of this manner. We have, however, a unique dataset available which consists of both data on prices and seasons, so that such a complex model can be studied.

A number of publications study price transmission or market integration for markets of perishable commodities. For example, Parrott et al. (2001) or Padilla-Bernal et al. (2003) study tomato markets in the United States. These studies, unlike ours, however, focus on the markets of a temperate and industrialized country where impediments to storage (that is, mechanized refrigeration), processing and trade infrastructure are minimal. This setting is hardly comparable to the one at hand since prices are subject to a qualitatively different market system. Although not dealing with tomato markets, the article of Goodwin et al.

(2002) assessing perishable commodity markets appears to be very interesting in this respect since it focuses on the period from 1880 to 1911 when mechanical refrigeration was introduced in the United States. Furthermore, a few studies evaluate price transmission and structure of markets for perishable commodities in Sub-Saharan Africa. For example, Mabaya (2003) and Stephens et al. (2008) study the tomato market of Zimbabwe. Clottey et al. (2009) and Ihle et al. (2010) focus on the Ghanaian Tomato market.

The purpose of this paper is to consider information on seasonal patterns and on asymmetries in price transmission in order to develop an appropriate model of Ghana's fresh tomato market. It proposes a multivariate model of APT which is capable of accommodating a wide range of regimes in price transmission analysis which have to be exogenously determined by the researcher. Examples are asymmetries in price transmission, that is, the regimes are defined according to the size of the deviations from equilibrium relative to zero, or production seasons. The suggested model allows combining two or more of such regime categories in order to obtain sophisticated regime-dependent estimates. For this purpose, we adapt the Johansen estimation method for cointegration analysis (Johansen, 1988, 1991) by explaining in detail how parts of the approach have to be changed for the given purposes. This represents a methodological innovation since to date, to our knowledge, either the Engle-Granger or the Stock-Watson methodology is used for estimation (Frey and Manera, 2007). We however focus on the Johansen method since it was shown to have statistical properties which are superior to the usual approaches for most settings (Gonzalo, 1994).

## 2. Methodology

In this paper, we generalize the APT model suggest by von Cramon-Taubadel (1998) to a multivariate setting, that is we develop an estimation approach which allows to estimate multivariate APT models which may consist of more than two price series and more than one cointegration relationship. The suggested model not only generalizes the traditional APT model which models pairs of prices with one cointegration relationship but also offers a general framework for the estimation of multivariate regime-dependent models. We develop the estimation approach in detail and several examples of how it can be implemented.

The basic model we are concerned with is the vector error correction model (VECM) which takes the typical form:

$$\Delta p_t = \alpha\beta' p_{t-1} + \sum_{i=1}^{k} \Gamma_i \Delta p_{t-i} + \varepsilon_t = \alpha\, eqe_{t-1} + \sum_{i=1}^{k} \Gamma_i \Delta p_{t-i} + \varepsilon_t = \Pi p_{t-1} + \sum_{i=1}^{k} \Gamma_i \Delta p_{t-i} + \varepsilon_t . \qquad (1)$$

$p_t = \{p_t^1, \ldots, p_t^v\}'$ and $\varepsilon_t$ are *v*-dimensional vectors of prices and Gaussian white noise errors, respectively. $\Delta$ is the first difference operator so that $\Delta p_t = p_t - p_{t-1}$ and *k* denotes the lag length of the included price changes. The parameters of the model are $\alpha, \beta$ and $\Gamma = (\Gamma_1, \ldots, \Gamma_k)$ which have to be estimated. The $(v \times kv)$ dimensional matrix $\Gamma$ contains the partial influences of the lagged price differences on the current price changes $\Delta p_t$ (hence, they are also called *short-run parameters*). The $(v \times r)$ dimensional matrix $\beta$ contains the weights of the stationary long-run relationships (cointegration relationships) of the prices where *r* denotes the number of long-run relationships (cointegration matrix). The $(v \times r)$ dimensional matrix $\alpha$ is called the loading matrix and quantifies the partial influences of the deviations from the long-run equilibrium in the previous period on the current price movements $\Delta p_t$. The *r*-dimensional vector $eqe_{t-1}$ contains the equilibrium errors of the previous period, that is, the deviations from the equilibrium prices of the past period which are corrected by the price changes $\Delta p_t$ from period to period. The underlying functional relationship can thus be presented as

*current price movement = f(previous equilibrium errors)+g(past price movement).* (2)

The APT model is based on the VECM. As mentioned above, it typically models two prices, i.e., $p_t = \{p_t^1, p_t^2\}'$ and can be specified as[4]:

$$\Delta p_t = \alpha^+ \beta' p_{t-1} I_{t-1}^+ + \alpha^- \beta' p_{t-1} I_{t-1}^- + \sum_{i=1}^{k} \Gamma_i \Delta p_{t-i} + \varepsilon_t = \alpha^+ ect_{t-1}^+ + \alpha^- ect_{t-1}^- + \sum_{i=1}^{k} \Gamma_i \Delta p_{t-i} + \varepsilon_t . \quad (3)$$

The variables $I_{t-1}^+$ and $I_{t-1}^+$ are indicator functions for the sign of equilibrium error of the previous period, that is, $I_{t-1}^+ = 1$ if $ect_{t-1} \geq 0$ and zero otherwise and $I_{t-1}^- = 1 - I_{t-1}^+$. However, several publications address the issue of misspecification of such a relationship, see, e.g., Gonzalez-Rivera and Helfand (2001) or Ihle et al. (2010). In particular, the pairwise analysis of prices which are subject to complex multiple influences, that is, to a multivariate system of prices in space might not be an appropriate modelling approach since potentially relevant variables might be omitted. This regards either the omission of lagged differences of other exogenous or endogenous prices or of disequilibria which exert a significant influence.

[4] For details, see, e.g., Meyer and von Cramon-Taubadel (2004) or Frey and Manera (2007).

This touches the question of the identification of the relevant determinants of a set of prices. One can argue that this is a disputable issue per se since one can always discuss which variables to regard and which not, that is, where and based on what criteria (theoretical considerations, significance levels, data availability, interest of the research etc.) to draw the line between included and not regarded variables. Hence, even if more than one equilibrium relationship is regarded in an equation, one can certainly argue than this increased set of variables might not yet represent the relevant, i.e., the true set of determinants. However, this belongs to a different aspect of model building/ variable selection since this criticism applies in exactly the same way to bivariate models as in (2). The issue addressed here is the inconsistency regarding the set of prices of interest. The attention of empirical analysis is drawn to a set of prices of a homogenous commodity measured in more than two locations if the (potentially complex) interactions within this system of prices, that is, involving more than bivariate pairs, are to be assessed. If the modelling then focuses on bivariate price relationships, then the implicit assumption is made that all price series except the two under consideration are irrelevant[5] which contradicts the basic aim of the analysis of assessing complex interdependencies. Therefore, the model and the respective estimation method which we suggest allow for the consideration of all prices of the system (and all long-run equilibria between them).

The basic idea of the approach is simple since it is an adaptation of estimation procedure of Johansen (1988, 1990). The Johansen procedure is a three-step approach based on the so-called concentrated model which we call in line with Johansen (1995) and Juselius (2008) the **R-form**[6] of the VECM. It consists of the observed right- and left-hand side variables of a VECM, the so-called **X-form,** which are transformed in such a way so that the estimation of all three parameters of the VECM ($\alpha, \beta$ and $\Gamma$) become feasible. The transformation is based on the Frisch-Waugh-Lovell Theorem[7]. The left-hand side and the right-hand side variables are cleaned from the partial influence of the lagged price differences $\Delta p_{t-i}$ , $i = 1,\ldots,k$, that is:

$$\begin{aligned} R_{0t} &= \Delta p_t - \hat{B}_0'(\Delta p'_{t-i},\ldots,\Delta p'_{t-k})' \\ R_{1t} &= p_{t-1} - \hat{B}_1'(\Delta p'_{t-i},\ldots,\Delta p'_{t-k})' \end{aligned} \tag{4}$$

where $\hat{B}_0$ and $\hat{B}_1$ are OLS estimates.

[5] This is formalized by the fact that all other variables carry the coefficient zero or, alternatively, are dropped from the pairwise model.
[6] The "R" stands for *reduced*.
[7] For details, see, e.g., Davidson and MacKinnon (2004: 68).

The core of the Johansen approach is the *reduced rank regression*

$$R_{0t} = \alpha\beta' R_{1t} + u_t, \tag{5}$$

Where $u_t$ is normally distributed with mean vector 0 and covariance matrix $\Omega$ that is, model (2) becomes

*current 'purged' price movement = f('purged' previous equilibrium errors).* (6)

The approach estimates the parameters of (1) in the following three steps of which we modify the second step in order to model a multivariate APT model. First, the cointegration matrix $\beta$ is estimated as derived by Johansen:

$$\hat{\beta} = \arg\min |\hat{\Omega}(\beta)| \tag{7}$$

where $\hat{\Omega}(\beta)$ is the estimated covariance matrix dependent of $\beta$.[8]

The second step estimates the loading matrix $\alpha$ conditional on the obtained $\hat{\beta}$ from step one by postmultiplying (5) by $(\beta' R_{1t})' = R'_{1t}\beta$ so that one obtains:

$$R_{0t} R'_{1t}\beta = \alpha\beta' R_{1t} R'_{1t}\beta. \tag{8}$$

The final equation is then obtained by taking the average of time of the products of the time-dependent matrices in order to obtain the product moment matrices $S_{ij}$, $i, j = 1,2$:

$$\begin{aligned} &\left(T^{-1}\sum_{t=1}^{T} R_{0t} R'_{1t}\right)\beta = \alpha\beta'\left(T^{-1}\sum_{t=1}^{T} R_{1t} R'_{1t}\right)\beta \\ &S_{01}\beta = \alpha\beta' S_{11}\beta. \end{aligned} \tag{9}$$

The OLS estimate of the loading matrix (the adjustment speeds) is then

$$\hat{\alpha}(\beta) = S_{01}\beta(\beta' S_{11}\beta)^{-1}. \tag{10}$$

At this point, we modify Johansen's procedure in order to enable to obtain regime dependent estimates of the adjustment speeds $\alpha$. We reverse the order of operations in (9) by first multiplying by the cointegration vector and taking then averages over time. In particular, we first multiply $\beta'$ and $R_{1t}$ and obtain thus the estimated equilibrium errors of the **R-form** (the purged equilibrium errors)**.** Afterwards, we manipulate these quantities, calculate the products of all time-dependent variables and take the averages over time last.[9] The third step of the Johansen procedure is unchanged so that the short-run dynamics $\Gamma$ are estimated in the same way as suggested by Johansen.

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[8] For details, see, e.g. Juselius (2008).

[9] This procedure is equivalent to the one in (9). It, however, takes advantage of the reversed order since it allows the estimation of multivariate APT models. Details are given in Appendix I.

## 3. Data and Study Setting

We restrict the focus of this analysis to the five major tomato markets of Ghana. Among them are the most important net producer markets[10] Navrongo (Nav) and Techiman (Tec) which supply a substantial share of Ghana's fresh tomato in alternate seasons. Besides them, we also consider the three most important net consumer markets namely Tamale (Tam), Kumasi (Kum) and Accra (Acc) located in the three largest cities of Ghana (Figure 2 in Appendix I).

The analysis is based on a unique set of primary data available which consists of semi-weekly observations of wholesale tomato prices and trade flows of these five markets (Table 1). It was collected by continuous market surveys conducted from mid March 2007 until end of February 2010 consisting of 348 observations of each market (Figure 1). Hence, the dataset covers three years which is equivalent to seven tomato production seasons. The prices are quoted for the best quality of tomato available at the time of the survey in the given market. They are measured in New Ghana Cedis (GH¢) per normal crate[11] of fresh and ripped tomato since this is the basic quantity tomatoes are traded in Ghana.[12]

**Table 1: Descriptive Statistics of the Prices**

| | ***Navrongo*** | ***Techiman*** | ***Kumasi*** | ***Tamale*** | ***Accra*** |
|---|---|---|---|---|---|
| Number of obs. | 348 | 348 | 348 | 348 | 348 |
| Mean | 52 | 52 | 52 | 46 | 84 |
| Median | 42 | 40 | 50 | 40 | 70 |
| Stand. dev. | 35 | 29 | 25 | 29 | 51 |

Source: Authors' calculations.

Due primarily to differences in the weather conditions between the two producer markets, tomato production and supply is seasonal. The producer market Navrongo (and its satellite production areas), located in the northern savannah region of Ghana and dependent on irrigated production, is the main source of tomato supply in the dry season (December – May). Techiman and surrounding areas, located in the southern forest region and using a rain-

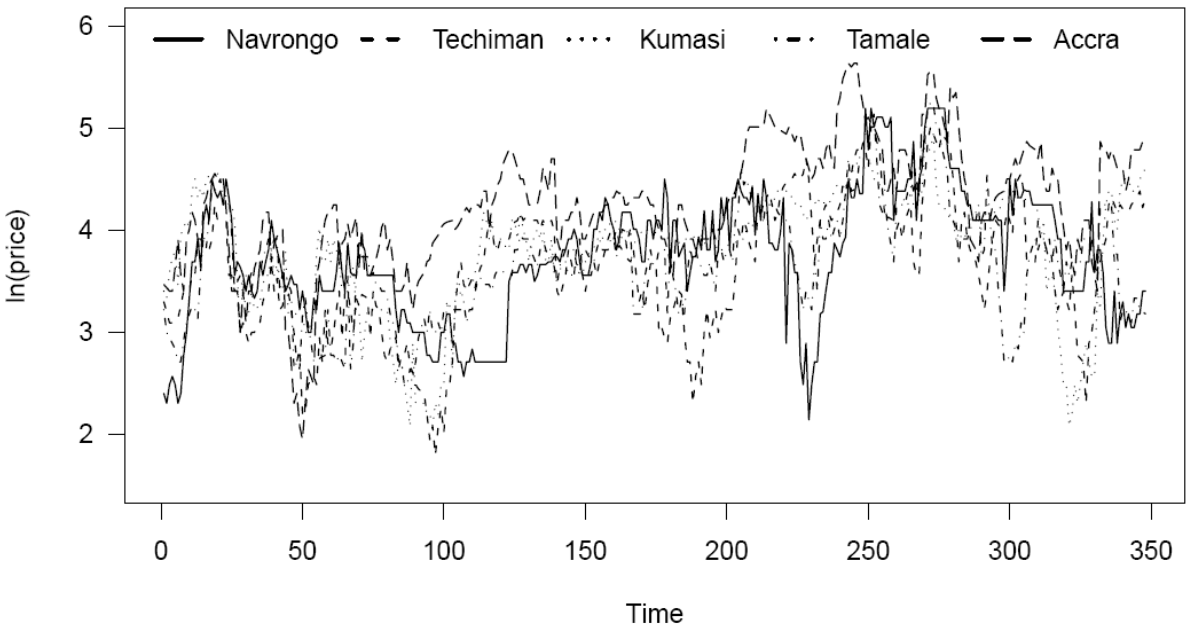
[10] We use the terms 'net producer' and 'net consumer' for regions which are characterized by a net production and a net consumption of tomatoes, respectively.

[11] The average weight of a normal crate is around 110 kg. The weight varies with the water content of the produce.

[12] We use logged prices in the analysis afterwards.

fed production system, supplies the national market with tomatoes in the rainy season (June-November). In-between the two main supply seasons is a short transitional period (April - June) within which much of the tomato supply in Ghana comprises imports from Burkina-Faso.[13]

**Figure 1: Prices of Fresh Tomato in Ghana in GH¢**




Source: Authors.

Hence, two main seasons can be identified in the system of Ghana's tomato markets in terms of supply and trade flows, namely the Navrongo and Techiman seasons.[14] Each of them possesses unique market characteristics. During the Navrongo season, the region in the north of Ghana supplies about 80%[15] of all fresh tomato traded in Ghana. About three months following the onset of tomato supply from Navrongo, the market's output levels begin to decline and its share of tomato in the markets gradually phases out while imports from Burkina-Faso into Ghana increases. The total average price per crate of fresh tomato from Navrongo (GH¢58) during this season is less than that from Burkina-Faso (GH¢68) due to trader preference for the latter. As supply of fresh tomatoes from Navrongo declines, the

[13] Since no tomato wholesale prices from Burkina Faso were available to us, we regard this period and the Navrongo season as one regime in the estimations because Navrongo is located close to the Ghanaian border to Burkina Faso and trade has thus to take the same way and similar distances (see Figure 2 in Appendix I).

[14] Note that the season associations are based on the patterns of supply from the production areas. Hence, the length of one regime varies with supply patterns, which in turn may be seasonally determined.

[15] Due to lack of reliable data on the quantities of production and supply, the stated percentages are only approximate market shares based on observations.

supply of tomato from Burkina-Faso increases, peaking at about 70% of the share of fresh tomato marketed in Ghana in April and May. High transaction costs due to the long distance to the huge consumer markets in Ghana's south and the "cross-border" location of Burkinabe tomato markets lead to high tomato prices in Ghana which tend to rise continuously from the start to the end of this period. Techiman (and nearby areas such as Tuobodom and Akomadan) is by far the largest supplier of Ghana's fresh tomatoes, supplying tomato for more than 6months of a year. Its production is rain-fed, and within a period of fair amounts of small-scale production by households in other parts of Ghana. Because of this, and due to the increased perishability of tomato with rainfall, the total average price of the commodity (GH¢49) is generally lowest during this season. On the other hand, because rainfall makes roads to farm gates less passable, transportation costs may be higher.

Based on the above thoughts and the market characteristics, we are interested in assessing multivariate APT in Ghanaian tomato markets. Although that the approach outlined in section 2 allows a highly complex multivariate structure we stick to a parsimonious model.[16] As mentioned above, Techiman and Accra are the most important producer and consumer markets, respectively. Thus, we hypothesize that the long-run equilibrium between these two markets plays a crucial role in Ghanaian tomato markets. Consequently, price disequilibria of this relationship may signal price shocks which are relevant for the whole system of markets. That is why, we analyse the impact of asymmetry in this price relationship on the entire Ghanaian tomato market. Furthermore, we take the seasonal structure of this market into account in the analysis because it represents a major feature of it which can be expected to shape price dynamics of the system.

Thus, we propose the following multivariate APT model:

$$\Delta p_t = \alpha^A eqe_{t-1}^A + \alpha^B eqe_{t-1}^B + \alpha^C eqe_{t-1}^C + \alpha^D eqe_{t-1}^D + \sum_{i=1}^{k} \Gamma_i \Delta p_{t-i} + \varepsilon_t . \qquad (11)$$

The indices $A$ to $D$ indicate the four regimes considered whose details are depicted in Table 2. Each of the vectors $eqe_{t-1}^i = \left(eqe_{t-1}^{i1} \quad eqe_{t-1}^{i2} \quad eqe_{t-1}^{i3} \quad eqe_{t-1}^{i4}\right)', i = A, B, C, D$ has four elements (that is, four equilibrium errors per regime where 1 denotes the equilibrium Nav-Acc, 2 Tec-Acc, 3 Kum-Acc and 4 Tam-Acc) so that each of the matrices $\alpha^i$ has five rows and four

[16] One might imagine a model assessing asymmetry in each of the four equilibrium errors. This would yield eight regimes leaving on average only less than 45 observations for each regime. We consider this number as too low to yield stable estimation results and thus stick to a model with only four regimes, that is, having on average 90 observations per regime.

columns. The resulting vector of deviations from equilibrium consisting of the four stacked equilibrium error vectors is thus of dimension $wr = 4 \cdot 4 = 16$ and the final loading matrix of regime-dependent adjustment speeds has $(v \times wr) = (5 \times 16)$ elements. The signs of the deviations from the equilibrium between Techiman and Accra have been obtained based on the first step of the Johansen procedure as outlined in Appendix I. The seasons were obtained from the trade flow observations of our dataset.

**Table 2: Regimes of Multivariate APT**

| ***Regime*** | ***Deviation from the Tec-Acc equilibrium*** | ***Season*** | ***Frequency*** |
|---|---|---|---|
| *A* | Positive | Techiman | 31% |
| *B* | Positive | Navrongo | 21% |
| *C* | Negative | Techiman | 29% |
| *D* | Negative | Navrongo | 19% |

Source: Authors.

## 4. Results

### *5.1 Time Series Properties*

Following the usual approach of time series analysis, we first test for a unit root in the individual price series. We choose the KPSS test developed by Kwiatkowski et al. (1992).[17] The test clearly suggests at the 5% level of significance that all five series have a unit root (Table 3).

[17] This test has the null hypothesis that the series is stationary. If the test statistic exceeds the critical value, then the null is rejected. We test for level stationarity for all series except Accra because it is the only series which shows, based on visual inspection, slight trending. In the selection of the lag length, we follow the recommendation of Kwiatkowski et al. (1992: 175) and use $8(348/100)^{0.25} \approx 11$ lags.

**Table 3: Results of the KPSS Unit Root Test**

| ***Series*** | ***Levels*** | | ***First differences*** | |
|---|---|---|---|---|
| | ***Test statistic*** | ***Critic. value 5%*** | ***Test statistic*** | ***Critic. value 5%*** |
| Navrongo | 0.793*** | 0.463 | 0.083 | 0.463 |
| Techiman | 1.046*** | 0.463 | 0.026 | 0.463 |
| Kumasi | 0.648** | 0.463 | 0.032 | 0.463 |
| Tamale | 0.915*** | 0.463 | 0.046 | 0.463 |
| Accra | 0.171** | 0.146 | 0.020 | 0.463 |

Source: Authors' calculations. Note: The asterisks *** and ** denote rejection of the null hypothesis at the 1% and 5% significance levels, respectively.

Having obtained evidence that all considered tomato price series have a unit root, we proceed to test for multivariate cointegration among the five series using the Johansen trace test (Table 4).[18] At the 5 % significance level, we obtain strong evidence for the conclusion that four cointegration relationships, that is, long-run price equilibria, among the five price series exist. In other words, the price system is driven by only one common stochastic trend. Since we obviously have trade flows between the five markets, we conclude that the markets are integrated as defined by, e.g., Gonzalez-Rivera and Helfand (2001). Hence, we obtain strong evidence for a common domestic tomato market in Ghana since the five most important regional markets are characterized by both the exchange of market information by ensuring stable long-run equilibria and physical commodities.

**Table 4: Results of the Johansen Trace Cointegration Test**

| ***Null hypothesis*** | $rank(\Pi) \leq 0$ | $rank(\Pi) \leq 1$ | $rank(\Pi) \leq 2$ | $rank(\Pi) \leq 3$ | $rank(\Pi) \leq 4$ |
|---|---|---|---|---|---|
| ***p value*** | <0.001 | <0.001 | 0.031 | 0.033 | 0.105 |

Source: Authors' calculations.

[18] The tests and estimations were performed using JMulTi (Lütkepohl and Krätzig, 2004), R (R Development Core Team, 2009) and the urca-Package for R (Pfaff, 2008).

### *5.1 Estimation Results*

We first estimate a multivariate VECM[19] and apply a number of restrictions on the cointegration relationships. We decided to estimate these equilibria with respect to Accra because it is the largest market in the country and obtain the following not regime-dependent relationships[20]:

$$\begin{aligned} \hat{eqe}_t^1 &= p_t^{Nav} - p_t^{Acc} + 0.462 \\ \hat{eqe}_t^2 &= p_t^{Tec} - 1.15\, p_t^{Acc} + 1.24 \\ \hat{eqe}_t^3 &= p_t^{Kum} - p_t^{Acc} + 0.435 \\ \hat{eqe}_t^4 &= p_t^{Tam} - p_t^{Acc} + 0.571. \end{aligned} \tag{12}$$

The signs of only the second equilibrium error $\hat{eqe}_t^2$ are used to create the sign indicator matrices as outlined in Appendix I which yields in combination with the season indicator vector the four regimes as outlined in Table 2. Table 5 displays the regime-dependent estimates of the adjustment speeds. It clearly suggests that the four hypothesized regimes matter for the price dynamics in the Ghanaian tomato market system. They appear to be particularly relevant for the two producer markets which are significantly impacted by multiple asymmetric and symmetric partial influences in all four regimes. In contrast, the three consumer markets only show very few significant reactions to disequilibria and appear to be weakly exogenous in most regimes.

First, we observe that the adjustment speeds in the first, fifth and ninth row of the Navrongo price and in the second, the tenth and the fourteenth row of the Techiman price are the price responses (the partial impacts) to deviations from the equilibria of each price with Accra all of them being significant at 5%. They are extraordinarily strong in magnitude and all of the correct sign. That is, disequilibria in the Nav-Acc and the Tec-Acc relationships are very quickly corrected by the prices of the producer markets. Significant price responses are even observed during off-season of the respective market, that is, in regimes *B* and *D* for the Techiman and regimes *A* and *C* for the Navrongo price. This appears to be a very plausible observation in the Ghanaian tomato market given the strong evidence for market integration as found above and the particular spatial structure of the markets (see Figure 2 in Appendix II).

[19] The results are not shown here, but can be obtained from the authors upon request.

[20] The Wald test for the adequacy of these restrictions yields a p-value of 0.12 so that the restrictions are not rejected at the 5% level.

**Table 5: Estimates of the Regime-dependent Adjustment Speeds $\alpha$**

| *Regime* | *Equilib. Error*[A] | *Navrongo* | *Techiman* | *Kumasi* | *Tamale* | *Accra* |
|---|---|---|---|---|---|---|
| *A* | Nav-Acc | -0.421*** | 0.009 | 0.039 | -0.02 | 0.106 |
| *A* | Tec-Acc | 0.293** | -0.336*** | 0.012 | 0.062 | -0.087 |
| *A* | Kum-Acc | 0.088 | 0.127** | -0.078 | -0.002 | 0.037 |
| *A* | Tam-Acc | 0.058 | 0.086* | -0.013 | -0.119** | -0.007 |
| *B* | Nav-Acc | -0.132** | -0.02 | 0.008 | 0.084 | 0.002 |
| *B* | Tec-Acc | -0.137 | -0.181* | 0.116 | 0.05 | 0.304*** |
| *B* | Kum-Acc | 0.266*** | 0.055 | -0.107 | 0.085 | -0.032 |
| *B* | Tam-Acc | 0.208** | 0.059 | -0.007 | -0.134 | 0.065 |
| *C* | Nav-Acc | -0.257*** | 0.089 | -0.088 | 0.063 | 0.034 |
| *C* | Tec-Acc | -0.112* | -0.124** | 0.035 | -0.063 | 0.071 |
| *C* | Kum-Acc | 0.12* | 0.100* | 0.041 | 0.022 | 0.086 |
| *C* | Tam-Acc | 0.136** | 0.007 | 0.115** | -0.111* | 0.057 |
| *D* | Nav-Acc | -0.126* | -0.129** | -0.039 | 0.039 | 0.016 |
| *D* | Tec-Acc | -0.225* | -0.448*** | 0.06 | -0.078 | -0.021 |
| *D* | Kum-Acc | 0.259** | 0.339*** | -0.133 | 0.085 | 0.035 |
| *D* | Tam-Acc | 0.084 | 0.202* | 0.036 | -0.169 | -0.02 |

Source: Authors' calculations.

[A] For clarity, we do not write here the symbols (such as $e\hat{q}e_t^{11}$ etc.) but instead the names of the markets of the respective equilibrium. Note: The asterisks ***, ** and * denote rejection of the null hypothesis at the 1%, 5% and 10% significance levels, respectively.

The magnitudes of the four significant reactions of the producer markets are also of correct sign. Very interesting appears the coefficient 0.304 in the sixth row of Accra which indicates that the price of the huge consumer market of Ghana's capital significantly responds to positive deviations from its equilibrium with Techiman during the Navrongo season (regime *B*). At the 5% level of significance, the Navrongo price shows five significant responses (rows 2, 7, 8, 12 and 15) to disequilibria additionally to the above-mentioned three responses to deviations from its own equilibrium. A similar pattern is shown by the Techiman price in rows 3, 13 and 15. Obviously, these deviations from equilibrium lead to an increase of the

Navrongo and Techiman price, respectively, and thus tend to push these prices away from their respective equilibrium with respect to Accra. They thus counteract the correction of equilibrium errors indicated by the strong adjustments in rows 1, 5 and 9 and in rows 2, 10 and 14 for the Navrongo and Techiman price, respectively. Since they increase the disequilibrium these coefficients show that disequilibrium spills over from one market to another in the system.

In general, the adjustment speeds are large in magnitude. This points to very fast adjustment of existing equilibria which is plausible before the background of the perishable nature of tomatoes on the one hand and the very good state of the arterial highway connecting the marketing centres. It suggests furthermore that networks of tomato traders are well evolved permitting a very quick response to price shocks in the country.

## 5. Conclusions

This article analyses the domestic tomato trade of Ghana by regarding its five most important markets: Navrongo, Techiman, Kumasi, Tamale and Accra. Since the dynamics and interdependencies of the system are potentially highly complex, we suggest a model which extends the usual bivariate analysis of asymmetric price transmission to a multivariate framework by enabling the multivariate analysis of regime-dependent behaviour of the price responses to disequilibria. We develop a modified version of the Johansen estimation procedure which allows estimating such a model benefitting from the superior statistical properties of this method.

We analyse a unique dataset consisting of semi-weekly observations on prices and trade flows in the five markets. Each price series consists of 348 observations between March 2007 and February 2010. Techiman and Accra represent by far the largest production and consumption regions, respectively. We thus hypothesize that asymmetries in price transmission (that is, whether the sign of deviations from equilibrium are positive or negative) between this market pair are relevant for the whole system of markets. Furthermore, the Ghanaian tomato market is characterized by pronounced seasonality, as supply switches depending on the time of the year between the two major production areas of Navrongo and Techiman. We thus study price transmission depending on four regimes which result from combining these two regime categories.

Using the KPSS test, we find all price series to have a unit root. The Johansen trace test provides clear evidence that four (bivariate) equilibria exist in the system of five prices. Therefore, we obtain strong evidence that the tomato markets of Ghana are integrated. The

estimation results of the multivariate regime-dependent asymmetric price transmission model show an interesting pattern. They confirm that the regimes matter for the whole system since the prices show pronounced regime-dependent adjustment behaviour. Strongest responsiveness to disequilibria, that is, error-correction, is shown by the two production regions of Navrongo and Techiman with the price of the smaller market showing manifold reactions on deviations from various equilibria in all regimes. The responses to disequilibria of both of the markets with Accra, respectively, are of the correct sign and large magnitude. However, the results suggest that disequilibria of other market pairs are spilling over to these two relationships and thus acting as a counterforce towards the error-correction behaviour. The large net consumption centres are weakly exogenous in almost all regimes showing only reaction on a few disequilibria which appears to be plausible given the structure of the Ghanaian tomato trade. The general picture is that Ghanaian tomato markets can be considered to be well integrated. The transmission of price shocks is regime-dependent and in general very strong with error-correction rates ranging from 10% to more than 40% per each period of three days.

This analysis provides an informative insight into the structure of tomato markets of Ghana. Although the primary observations might suffer from some measurement error, they constitute a unique setting for the analysis of price transmission of a perishable vegetable product in Sub-Saharan Africa. The general picture suggested by the analysis appears to be plausible given the structure of the country's tomato market. The analysis can be extended in various ways, for example, by performing a number of tests on the estimated regime-dependent adjustment speeds which straightforwardly can by done in the framework of the Johansen methodology. Furthermore, the estimation of regime-dependent impulse response functions or persistence profiles might supplement the presented estimation results.

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## Appendix I

In the following, we show how to 'blow up' the *r*-dimensional vector $\beta' R_{1t}$ of the purged equilibrium errors by a matrix of a particular form which is referred to as the *regime (indicator) matrix*. This matrix allows representing any number of regimes exogenously determined by the researcher by a (number of) decision rule(s).[21] For illustration, consider the case in which the researcher is interested in modelling APT depending on two seasons for a system of three prices connected by two long-run equilibria.[22] That is, she wants to obtain estimates for regime-dependent adjustment speeds for each of following eight regimes shown in Table 6.

**Table 6: Regime Characteristics**

| ***Regime*** | ***Season*** | $eqe^1$ | $eqe^2$ |
|---|---|---|---|
| A | 0 | >0 | >0 |
| B | 0 | >0 | <0 |
| C | 0 | <0 | >0 |
| D | 0 | <0 | <0 |
| E | 1 | >0 | >0 |
| F | 1 | >0 | <0 |
| G | 1 | <0 | >0 |
| H | 1 | <0 | <0 |

Source: Authors.

The regime indicator matrix $W$ is of dimension $(T \times w)$ where $w$ denotes the number of regimes regarded. In the following we outline the steps necessary for the creation of this matrix. First, indicator matrices for each of the regime categories have to be created which signal the occurrence of a particular regime for each period *t, t=1,…,T*. in this example, three categories exist which are the season, the sign of $eqe^1$ and the sign of $eqe^2$ all of which consist of two possible values, that is, season vs. no season and positive $(\geq 0)$ vs. negative. The season indicator vector $C$ of dimension $T$ indicating the seasons has thus the following form:

[21] Although the regime matrix can take any dimension, only a low number of regimes is meaningful in applied analysis, so that, one would typically employ two to four regimes.

[22] $\alpha$ and $\beta$ are thus $(3 \times 2)$ matrices.

$$C = \begin{pmatrix} 1 \\ 0 \\ \vdots \\ 1 \end{pmatrix} \tag{13}$$

where an element takes the value 1 if the observations belongs to the season and zero otherwise. Based on step one of the Johansen approach, the $(T \times R)$ matrix of the estimated equilibrium errors $e\hat{q}e = (\hat{\beta}' p) = p'\hat{\beta}$ can be calculated where $p = (p_1, \ldots, p_T)$ is a $(v \times T)$ matrix of observed prices and $\hat{\beta}$ was obtained in the first step. Hence, the sign indicator vectors $S^l, l = 1, \ldots, r$ signal for the $l^{th}$ column of this matrix the sign of its elements $e\hat{q}e_{t-1}^l$ for all periods *t*. They are also of dimension *T* and have the form:

$$S^l = \{s_t^l\}_{t=1,\ldots,T} \tag{14}$$

where

$$s_t^r = \begin{cases} 1 & if\ e\hat{q}e_t^r \geq 0 \\ 0 & otherwise \end{cases} . \tag{15}$$

For illustration, suppose that $e\hat{q}e = \begin{pmatrix} 1 & -1 \\ -2 & 2 \\ 3 & 0 \end{pmatrix}$. The corresponding sign indicator matrices are then

$$S^1 = \begin{pmatrix} 1 \\ 0 \\ 1 \end{pmatrix} \text{ and } S^2 = \begin{pmatrix} 0 \\ 1 \\ 1 \end{pmatrix}. \tag{16}$$

Since each regime consists of the combination of these categories all possible combinations have to be taken into account as depicted in Table 7 where $\circ$ denotes the Hadamard product, that is, the element-wise product of the vectors.

The final regime indicator matrix *W* classifying each observation into one of the eight regimes the researcher is interested in is then the horizontal concatenation of the eight vectors in Table 7. This matrix is of dimension $(T \times w)$ and has thus for the given example the form[23]:

---

[23] *w* denotes the number of regimes, that is, in the case the above example $w = \prod_{m=1}^{M} \text{no. of regimes of category } m = 2 \cdot 2 \cdot 2 = 8$ where *M* denotes the number of regime categories.

$$W = \begin{pmatrix} W^A & W^B & W^C & W^D & W^E & W^F & W^G & W^H \end{pmatrix} = \{w_t\}_{t=1,\ldots,T} \qquad (17)$$

where $w_t$ is a $(1 \times w)$ dimensional matrix (that is, a *w*-dimensional vector) signalling the occurrence of one of the regimes in period *t*.

**Table 7: Regime Matrices**[24]

| ***Regime*** | ***Season*** | $eqe^1$ | $eqe^2$ | ***Resulting indicator vector*** |
|---|---|---|---|---|
| A | 0 | >0 | >0 | $W^A = (I - C) \circ S^1 \circ S^2$ |
| B | 0 | >0 | <0 | $W^B = (I - C) \circ S^1 \circ (I - S^2)$ |
| C | 0 | <0 | >0 | $W^C = (I - C) \circ (I - S^1) \circ S^2$ |
| D | 0 | <0 | <0 | $W^D = (I - C) \circ (I - S^1) \circ (I -$ |
| E | 1 | >0 | >0 | $W^E = C \circ S^1 \circ S^2$ |
| F | 1 | >0 | <0 | $W^F = C \circ S^1 \circ (I - S^2)$ |
| G | 1 | <0 | >0 | $W^G = C \circ (I - S^1) \circ S^2$ |
| H | 1 | <0 | <0 | $W^H = C \circ (I - S^1) \circ (I - S^2)$ |

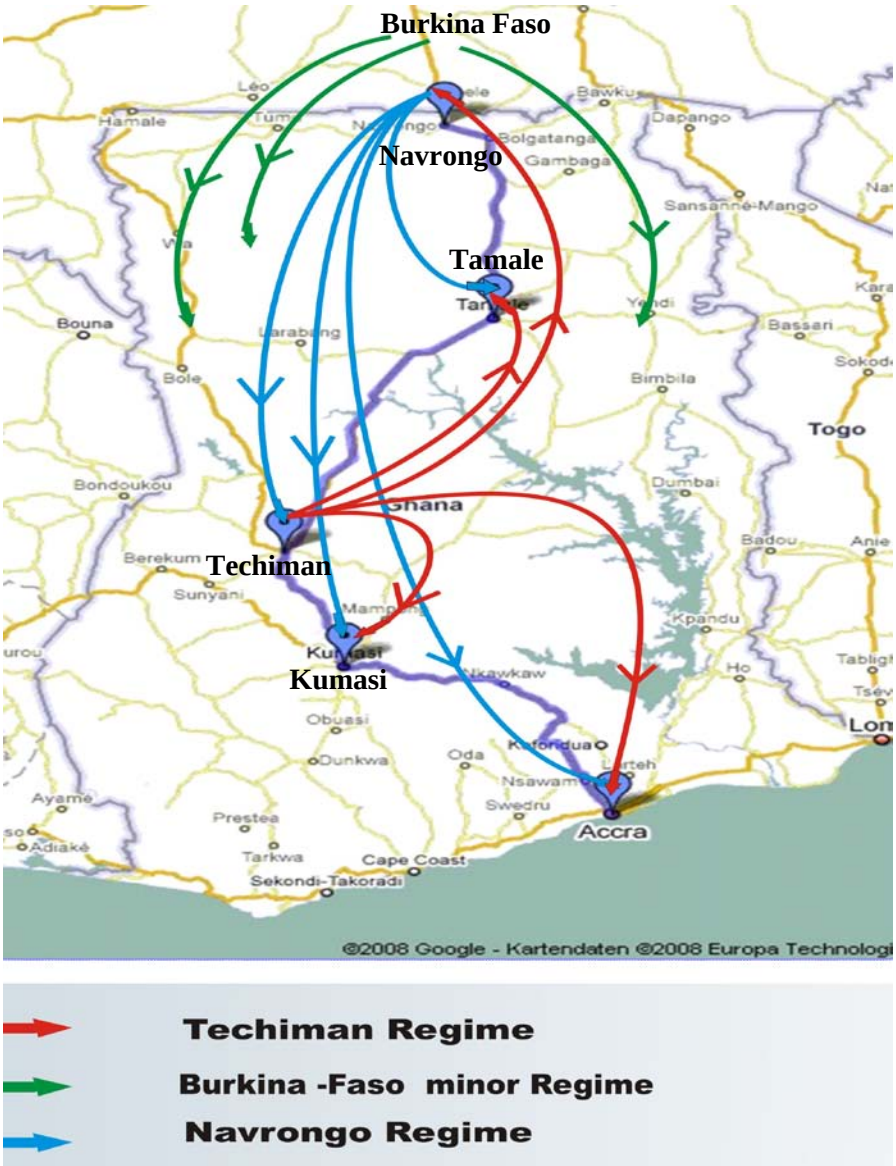
Source: Authors.

The purged equilibrium errors $\beta' R_{1t}$ of equation (9) are then 'blown up' by Kronecker multiplication from the left, that is, the regime-specific purged equilibrium errors $w'_t \otimes \beta' R_{1t}$ are of dimension $(wr \times 1)$. The matrix multiplication and the averaging over time are then done in the same way as in (9). The estimate of the matrix of adjustment speeds $\hat{\alpha}$ can then be performed identically as in (10) with the only difference that the resulting matrix is not of dimension $(v \times r)$ but of dimension $(v \times wr)$ instead. The standard errors of the regime-dependent estimates of the adjustment speeds are obtained in the usual way by only regarding the regime-dependent purged equilibrium errors $w'_t \otimes \beta' R_{1t}$ instead of the usual ones.

[24] *I* denotes a *T*-dimensional vector of ones.

## Appendix II

**Figure 2: The Pattern of Seasonal Tomato Trade Flows**




Source: Google maps and authors' depiction.

Note: The road highlighted in blue is a part of the West African Highway and thus the most important and best maintained transportation link between the major tomato markets of the country. The markets are lined up along the road so that tomato trade for example from Navrongo to Accra has to pass through all markets in between.