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A Spatial Price Analysis

Noah Larvoe

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Abstract

World food price hikes in 2007/2008 and 2012 plunged several people into hunger and poverty in developing countries. The situation stimulated responses from policy makers in some of these countries by trying to boost local production of crops in which they are self-sufficient. Integrated agricultural marketing systems are needed in the process in order to ensure efficient distribution and improvement in welfare of all actors involved in the consumption and production chain. The food balance sheet for Ghana shows that the country is self-sufficient in root and tuber crops such as cassava and yam. The main objective of the study is to determine the extent to which regional yam markets are integrated. Using monthly wholesale price series from 2006 to 2013, the study assesses the integration dynamics between five regional yam markets in Ghana. From the consistent threshold autoregressive model of cointegration, the study found that regional yam markets in Ghana are integrated. Thus, prices between local markets (Kumasi, Tamale, Techiman and Wa) and the reference market (Accra) are interdependent on each other both in the long-run and short-run, although there were some evidences of unidirectional interdependence. The Kumasi-Accra, Tamale-Accra and Techiman-Accra market pairs exhibited asymmetric adjustments whiles Wa-Accra market pair exhibited a symmetric adjustment. From the impulse response estimations, we found that different time periods are required for equilibrium to be restored when there is a shock in one pair of the four market combinations considered. The speed of adjustments was also dependent on the direction (positive or negative) of the shock or deviation. Overall, adjustment periods range between 8 months to 27months with the minimum adjustment time occurring between Techiman-Accra. In some cases, price shocks were persistent and required a long time to adjust. The integration found between regional markets could be attributed to improvement in ICT tools, such as mobile phones, as has been noted in some reviewed studies. The high and persistent adjustment times recorded between some market pairs may however, be attributed to comparatively low value-to-volume ratio of yam compared to other market commodities. This makes the cost of transportation a major portion of its price setting.

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List of abbreviations

AC	Accra market
ADF	Augmented Dickey-Fuller test
AEG	Augmented Engel-Granger test
AIC	Ackaike Information Criterion
ARCH	Autoregressive Conditional Heteroscedasticity
BIC	Bayesian Information Criterion
FAOSTAT	Food and Agriculture Organization Statistics
FASDEP	Food and Agricultural Sector Development Policy
GSS	Ghana Statistical Service
ICT	Information Communication Technology
IFAD	International Fund for Agriculture
IMC	Index of Market Connectedness
KU	Kumasi market
LOP	Law of One Price
PP	Philips Perron
RTIMP	Root and Tuber Improvement and Marketing Programme
TA	Tamale market
TAR	Threshold Autoregressive
TE	Techiman Market
SRID-MoFA	Statistics Research and Information Directorate of Ministry of Food and Agriculture
M-TAR	Momentum Threshold Autoregressive
PBM	Parity Bound Model
VAR	Vector Autoregressive
VECM	Vector Error Correction Model
WA	Wa market
USAID	United States Agency for International Development

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I dedicate this work to the entire family of Rev. M. B. Agyekum. I believe aside one's biological parents, everyone on earth needs people who will support, care and stand by them at a point in time. That is what I found in this wonderful family. God richly bless you all.

Chapter 1- Introduction

1.1 Background

The Agricultural sector in Ghana continues to be one of the most important sectors despite presently being overtaken by the services and the industrial sectors in terms of their contribution to Gross Domestic Product. The sector is currently ranked third and contributes 22% of the country's Gross Domestic Product (GSS, 2014) with crops accounting for about 77% of this figure. Agriculture also employs an estimated 42% of Ghana's overall working population and 76% of total rural households (GSS, 2010).

Root and tuber crops form part of many staple foods and account for major calorie intake in Ghana. According to SRID-MoFA (2013), the estimated levels of per capita consumption of cassava and yam are 154 and 50 kg/head/year respectively. Cassava accounts for about 22% (Nti & Sackitey, 2010) while yam accounts for about 16% (Anaadumba, 2013) of the total agricultural Gross Domestic Product.

Yam is therefore, second to cassava in terms of root crop production in Ghana and accounts for about 24 percent of total roots and tubers production in the country (MoFA, 2010). Yam is produced in seven out of the ten regions in the country. The Brong Ahafo, Northern and Eastern regions are the major producers. The combined share of these regions make up about 76% of the countrywide production with the remaining 24% distributed among the remaining 4 regions. See the regional map of Ghana below.

Figure 1.1 Regional map of Ghana

The crop takes approximately 8 months to mature and requires about 5 months of rainfall during its growing period. There are several varieties of yam produced in Ghana, but the most preferred one for both the domestic and the export markets is the white yam (also known as Pona in Ghana). Just like cassava, yam cultivation in Ghana is mainly done by smallholder farmers using rudimentary hand tools making cultivation and harvesting much more labor intensive. According to SRID-MoFA (2013), the annual production of yam is estimated at 6.7 million metric tons in Ghana with main harvesting periods starting from August to December. There are, however, lean seasons (period of low harvest activities) which occur between May and July. As noted by Anaadumba (2013), in many cases, yam producers are persuaded by traders to harvest their crop early in the season, when prices are very high. Nevertheless, immature yams are more perishable, which may partly explain why many producers experience high post-harvest losses.

Although yam is consumed in all parts of Ghana, Aidoo (2009) indicates that yam consumption tends to be higher in urban areas. He found that boiled yam (known in the local language as ampesi) is the most preferred yam product in Ghanaian urban centers, followed by pounded yam (fufu). Nonetheless, depending on the type of yam, it could also be used in variety of ways which includes roasted and fried yams.

Unlike cassava, Ghana exports a significant amount of yam and it is the leading exporter in the world as reported by Anaadumba (2013). Data from FAOSTAT shows that export during the 2008 food crisis was very high indicating its importance to consumers abroad especially many African migrants. Data from the millennium development authority, as reported by Anaadumba (2013), shows that the United Kingdom, the USA and the Netherlands are the major destination of yam exports from Ghana. The three countries together imports 90% of Ghana’s total yam export. Yet, yam exports like other crops, faces many quality problems arising from poor road network, harvesting and storage processes. This sometimes results in the spoilage of many tubers before they arrive at their export destination. According to Bancroft (2000), yam in Ghana is marketed in its original state without any special package or treatments including those exported. Thus, small restaurants and individual consumers buy the unprocessed yam and prepare them for consumers and consumption respectively.

Although there have been various forms of support to yam farmers, Anaadumba (2013) asserts that the value chain remains weak and less developed compared to commodities such as maize or rice. The marketing chain shows that yam harvested in the Northern Region is mostly transported to Accra through the Eastern Corridor; either through Hohoe and Akosombo or through Kete Krachi in the Volta region. Some yams from the Northern region are also transported to Kumasi through Yeji, Atebubu and Ejura using ferries or to Tamale by road (Anaadumba, (2013). Yams from the Brong Ahafo Region mainly go to Techiman, Kumasi or Accra. Figure 3.1 shows the various routes described above. Yam exporters normally purchase their commodities directly from farmers or wholesale shops in Accra, but increasing competition among exporters means most of them are forced to go to production areas as reported by USAID (2005).

With steadily increasing growth and development in Ghana, the consumption pattern is expected to shift towards more protein diet, but root and tuber crops will continue to be important, since they form part of staple foods of major ethnic groups in Ghana. For instance, Anaadumba (2013) highlighted yam as an important staple food for many Ghanaians, accounting for 11% of total consumption in 2007. The country is also the leading exporter of yam in West Africa accounting for about 94 % total yam export in the West Africa region.

Although Ghana is a net importer of food products, the country has a comparative advantage in the production of roots and tubers which could be built on to enhance food security and increase agricultural trade. The annual food balance sheet shows that the country has an excess of 6.2 million and 2.1 million metric tons of cassava and yam respectively (SRID-MoFA, 2013). According to the same report, the mean annual production growth rate of cassava and yam are estimated at 12.56% and 11.31% respectively between 2007 and 2012.

Ghana's agricultural sector specifically, the crop sector, is dominated by smallholder farmers with 90% of farm holdings being less than 2 hectares in size. However, due to the different climatic conditions in the country, agricultural production is not evenly distributed. Production of yam is mainly centered in the northern and central part of Ghana, although they are consumed in all parts of the country. It is therefore necessary that there is a smooth flow of these crops across the different regions in order to ensure food sufficiency to all households. To achieve this goal, the country relies heavily on the market system to transfer food from surplus producing regions to deficit regions. This has been the situation since the abolition of the state's involvement in production and distribution in 1990 through liberalization of the market system. The 2010 population census shows that the urban population has increased to 51% from 44% in 2000 (GSS, 2010). With this increasing rate of urbanization, the market system will continue to be relevant in the course of food distribution in Ghana and more so since the majority of the population spends significant portion of their budget on food.

Following the 2007/2008 and 2012 food price hikes, there have been major concerns about food security especially in developing countries (Godfray *et al.,* 2010). The rise of world grain, livestock and dairy product prices, which impacts were heavily felt in many developing countries, means developing countries cannot continue to rely on world markets. This is because the transmission of these high world grain market prices into the domestic markets of developing countries plunged several people into hunger and poverty (Mittal, 2009).

It is therefore imperative for countries such as Ghana to put in place appropriate policies to boost production and distribution especially, traditional crops which have long been touted as food security crops. The main challenge of food distribution remains lack of efficient market system in many countries (Godfray *et al.,* 2010). In event of price hikes such as the 2007/2008, crops as cassava and yam will be heavily counted upon to serve many Ghanaians especially the poor households. Nevertheless, the marketing system in Ghana faces many challenges which include lack of proper road network, inadequate product development for effective utilization of farm produce, and generally weak commodity value chains.

As major staples in Ghana, root crops have been the targets of several government policy frameworks in order to boost production and market access. The recent of such policies is the Root and Tuber Improvement and Marketing Programme (RTIMP) funded by International Fund for Agriculture (IFAD) which covered a period of 8 years between 2007 and 2014. The program sought to support root and tuber production and increase market linkages between regions. All these efforts are geared towards ensuring that the country maintains a high level of production to meet local consumption requirements and in some cases export as well as industrial use especially cassava.

1.2 Problem statement

Although production of food to meet local demand remains a major challenge in many developing countries, the issue of distribution through the market system poses a greater challenge to attaining food security in these countries (Godfray *et al.,* 2010). The issue is not different in Ghana. In trying to achieve food security status in Ghana, the Ministry of Food and Agriculture has pursued several policies over the years.

As highlighted by the FASDEP II (2008), the broad strategy for the attainment of food security is to focus on the development of five staple crops (maize, rice, yam, cassava and cowpea) on national and agro-ecological levels. The ministry however, identified lack of efficient market systems in the sector and has since been pursuing various policies to attain this efficiency through the FASDEP II since 2008. Under this programme, one of the main objectives has been to increase competitiveness and enhance integration between domestic markets and also with international markets. Thus, improving accessibility from farm to market centers and between regions is clearly a major priority in Ghana. But how have these policies improved the situation of especially root and tuber markets integration? This is an important question because one of the main challenges identified in the marketing of agricultural products during the drafting of FASDEPII were challenges such as poor nature of roads to production centers, inadequate market information, leading to weak market integration between local, districts, regional markets. Poor rural road infrastructure limits the effective distribution of food and lowers producer prices.

According to Acquah *et al*. (2012), integrated markets are important avenues of raising the income level of farmers and promoting the economic development of a country. They also asserted that in the state of well integrated markets, farmers allocate their resources according to their comparative advantage and invest in modern farm inputs to obtain enhanced productivity and production. Also, food becomes available and affordable thereby improving the food security status of households. This is very necessary in Ghana since almost all families supplement their food requirements with significant amounts of purchased staple crops. A well-integrated market is therefore needed to efficiently supply all households in order to achieve food security status in all parts of the county. Investigation of root and tuber crops integration is therefore vital since these crops are considered as food security crops in Ghana. Thus, integration can be regarded as a way of assessing efficiency of the root and tuber markets and for that matter a way of assessing the disparity between welfare of producers and consumers of the commodity in the different regions in Ghana.

This study therefore seeks to analyze comprehensively the extent of regional yam market integration by answering the following questions: To what extents do price shocks of yam in one regional market in Ghana affect other regional markets both in the short run and the long run? Are these shock transfers symmetric or asymmetric? At what speed are these shocks transmitted?

1.3 Study objectives

The main objective of this study is to assess the extent of integration of regional yam markets in Ghana. This will be achieved by the following specific objectives:

i. To determine short and long-run price co-movement of regional yam market in Ghana
ii. To determine the type of adjustment between regional market prices after price shocks and,
iii. To determine the speed of price shock transmission from one regional market to another.

1.4 Research hypothesis and relevance of study

Following several government interventions and policies in the root and tuber sector in pursuance of food security status as part of the Millennium Development Goal One in Ghana, the regional yam markets are expected to be spatially integrated. This means a price shock in one regional market will be transmitted into all other markets eventually. However, due to infrastructural bottlenecks such as bad road network and bulky nature of root and tuber crops, price shock adjustment is expected to be somewhat slow. The study therefore seeks to test the hypothesis that:

Regional yam markets are perfectly integrated with symmetric response since these regions are interdependent on each other. This means even though short-run prices may drift apart, long-run price between regional markets will exhibit similar trends. We also predict slow adjustment to equilibrium between markets infrastructural bottlenecks.

The relevance of this study is summarized by the statement below quoted and acknowledged as such: *Market integration is a central issue in many contemporary debates concerning market liberalization. It is perceived as a precondition for effective market reform in developing countries: "Without spatial integration of markets, price signals will not be transmitted from urban food deficit to rural food surplus areas, prices will be more volatile, agricultural producers will fail to specialize according to long term comparative advantage and gains from trade will not be realized" (Baulch 1997, p. 477). The knowledge of price mechanisms reduces uncertainty for policy-makers and the risk of duplication of interventions in two markets (Goletti et al., 1995)*

To add to this argument in Ghana, studies on spatial market integration have mostly focused on the cereal sector especially rice and maize. The root crop sector specifically, yam is chosen because the country is self-sufficient and this means such commodities will be heavily relied upon in the event of escalating world prices of grain and dairy products as occurred in 2008 and 2012. Many previous studies have also not explored the causes and determinants of market integration. In addition, the concept of market integration also needs to be updated frequently in order to inform policy makers the current trend and for that matter how producers and consumer welfare can be improved through national and regional market policies. The study will also add up to the already existing pool of literature on spatial market integration.

The study is structured into five chapters. The first chapter above presents the background, research problem and objectives of the study as already seen. The next chapter (chapter two) reviews various market integration studies by analyzing the different models and their applications. Similar studies in Ghana and other countries are also reviewed with emphasis on their results and how they differ from this study. Chapter three details out the research methodology used to achieve the study objectives whereas we present the results and discussion in chapter four. The last chapter summarizes the whole study and gives conclusions.

Chapter 2-Literature review

2.1 Concepts of market integration and its application to spatial markets

According to Hopcraft (1987), an indirect method of analyzing market efficiency is to test for market integration. In some cases market integration has been used in the same context as market efficiency. Some spatial price literatures have however distinguished between the two terms, though they agree the two are related to some extent (Barret and Li, 2002; Barrett, 2005; Fackler and Goodwin, 2001). Although there has been no formal definition of the term, Fackler and Goodwin (2001) suggest market integration as a measure of degree to which demand and supply shocks arising in one region are transmitted to another region. Market integration is therefore a measure of extent rather than a specific relationship. Thus, two markets are said to be integrated when a particular shock which shifts for instance, excess demand and for that matter prices in one market causes some changes in prices in another market.

The extent of integration depends on the price transmission ratio between the two markets. This definition according to Fackler and Goodwin (2001) clarifies the use of the term in early literature studies which simply portrayed market integration as commodity price co-movement in different regions. They argue that price co-movement between different regions could occur for some reasons, although the regions might not necessarily be linked by any trading network. Barret and Li (2002) also define market integration as tradability or contestability between markets. The authors describe the phenomenon as the transfer of Walrasian excess demand from one market to another, they manifest in physical flow of a commodity and the transmission of price shock from one market to another or both. Thus from this definition, physical movement of commodity between two markets is a sufficient but not a necessary condition to demonstrate "tradability" which according to Barret (2005) is the main focus of market integration in macroeconomics and international trade. He defines tradability as a notion that a good is traded between two economies, or that market intermediaries are indifferent between exporting from one nation to another and not doing so. This means positive trade flows are sufficient to illustrate trade market integration under tradability condition, and prices need not equilibrate between markets. Based on this, Barrett (2005) pointed out differences between two criteria for conceptualizing market integration: tradability-based in which trade is a sufficient condition and efficiency-based where trade is neither a necessary nor sufficient requirement.

Barrett (2005) therefore thinks that market integration conceptualized as tradability is consistent with Pareto inefficiency. Contestability as a concept of market integration in the absence of trade is when arbitrageurs face zero marginal returns leaving them indifferent about trading (Barrett and Li, 2002). The contestability idea therefore focuses on maximal exploitation of arbitrage rent and for that matter a competitive market.

In trying to analyze spatial market, many terms have been used to introduce different concepts in different literature which need to be highlighted. Terms such as price transmission, volatility and seasonality are constantly used in spatial price analysis. Spatial arbitrage mentioned earlier in this review is one common term in such studies.

Spatial arbitrage is a condition in spatial market analysis where prices of a commodity between two different locations differ exactly by the cost of moving the commodity from the region of lower price to the region of higher price. This cost is referred to as the transaction cost and it includes all costs such as transport cost and information costs that are involved in getting the commodity from one location to another. The spatial arbitrage condition is therefore regarded as a starting point of any model of spatial price behavior. However, this is an equilibrium condition as asserted by Fackler and Goodwin, (2001) and hence actual market prices may not follow the condition, but action of arbitrageurs will tend to move price differences towards the transaction cost in a well-functioning market.
Efficiency of spatially distant markets is therefore based on how potential profitable arbitrage opportunities are exploited. According to Negassa *et al.* (2003), when a spatial price differential is less than the transfer cost in the absence of trade, the efficiency condition holds. There is however, inefficiency when spatial price differentials are greater than transfer cost in the presence of trade or not. Market efficiency as asserted by Fackler and Goodwin (2001) is therefore used to motivate empirical studies of market integration.

Another fundamental concept in spatial market analysis is the Law of One Price (LOP). This is a unique concept of arbitrage which holds when regional markets that are linked together by trade have a common unique price abstracting for transaction cost (Fackler and Goodwin, 2001). Yet, Fackler and Goodwin (2001) noted that there are several versions of the Law of one price. They refer to a situation where some authors fail to distinguish between LOP and spatial arbitrage as weak LOP. The strong version is where spatial arbitrage condition holds as equality, thus price between two regions differing only by the transaction cost.

Market integration should therefore be expected when we observe a strong form of LOP. However, according to Fackler and Godwin (2001), the term is often used for both strong LOP where there is perfect market integration and even the weak form of LOP where we have the spatial arbitrage condition.

LOP is one reason why market integration cannot be defined simply as price co-movement. This is because prices that satisfy strong form of LOP may not move together if transport costs are large and volatile as noted by Fackler and Godwin (2001).

Analysis of spatial market integration of agricultural products is an important concept in many literatures in Agricultural economics. Agricultural commodities are normally produced in areas where there is surplus and hence must be moved to areas where there is deficit in supply. Sexton *et al.* (1991) highlighted the relevance of spatial market integration as agricultural products are always bulky and/or perishable and production is mostly concentrated in one location whereas consumption in the other. This may imply an expensive transportation cost which may cause price not to move together even if a strong form of LOP is satisfied as noted above. Spatial agricultural commodity markets therefore require careful and dynamic analysis to establish whether or not they are integrated.

The analysis of market integration in most literature is based on the Enke-Samuelson-Takayama and Judge (ESTJ) spatial equilibrium model (Barret, 2005). In the ESTJ model, the dispersion of prices in two locations for identical goods is bounded from above the cost of arbitrage between the markets when the trade volumes are unrestricted and from below when trade volumes are restricted for example with quota. Thus, the model assumes that price relationships between spatially competitive markets depend on the size of the transaction costs. If the difference between prices of two markets is exactly equal to the transaction cost for a homogenous good, then the two markets are considered very competitive (Barret, 2005). However, if price difference exceeds the transaction costs, then arbitrage condition is created and profit seeking agents will purchase the commodity from low price surplus markets and sell them in high price deficit markets as noted by Katengeza (2009).

To illustrate the spatial market integration, consider two spatially distinct markets, market one (M1) and market two (M2) with prices P^1 and P^2 respectively and τ^{12} as the transaction cost involved in moving a homogenous commodity from M1 to M2. Following (Fackler and Goodwin, 2001; Barret, 2005; Ankamah, 2012), two markets are said to be integrated when $\mathbf{P^1 = P^2 + \tau^{12}}$. Thus, the price in the two markets should equal each other accounting for the cost of transaction. As implied by the ESTJ model, this does not mean trade occurs between the two markets. In other words trade is neither a necessary nor sufficient condition for the attainment of such equilibrium condition. Trade will however occur when $|\mathbf{P^1 - P^2} > \boldsymbol{\tau^{12}}|$ thus, when the differences in prices exceeds the cost of transaction involved in moving the commodity between the two markets.

One important term worth highlighting is the issue of central or reference market. In many studies (Alderman 1991; Shively 1996; Amikuzuno 2009, 2010) the choice of the reference markets is based on which market has net surplus or net deficit of the commodity in question. In most of these studies the net surplus or producing region is chosen as the reference market. In other studies however, the net consumption market is used as the reference market as shown in Mensah Bonsu *et al*. (2011). Regardless of whether a net consumption or production market is used, the main idea behind the central/reference market is that it is the shock originating market. Thus, it should have the features such that it is able to influence other local or regional markets when there is a shock in that market.

2.2 Models of spatial price analysis

Spatial prices analysis models have evolved over the years from simple correlation analysis to presently more sophisticated models. As researchers identify various problems associated with spatial price analysis, different models have been used to empirically examine integration of spatial markets in an attempt to solve some of these problems. This section reviews some of the past techniques that have been used to address spatial market integration.

Simple correlation or regression techniques

Earlier studies on market integration focused on testing for the Law of One Price using static simple regression/correlation analysis. In many early empirical studies, authors assumed that spatially integrated markets share common price linkages. By such an assumption, researchers used simple regression or correlation analysis to determine the extent to which markets were integrated. Although the interpretations in regression and correlation differ, the mechanisms involved in their implementation are similar. According to Hossain and Verbeke (2010), regression analysis of market integration involves estimating bivariate correlation or regression coefficients between the time series of spot prices of homogenous good at distinct market places. The technique is based on the equation:

$$\boldsymbol{P_{1t} = \alpha_{\circ} + \alpha_1 P_{2t} + \varepsilon_t} \qquad \textbf{(2.1)}$$

where P_{1t} and P_{2t} are price series between two markets, α_o and α_1 are parameters to be estimated and ε_t is the error term. The LOP is then tested based on the necessary condition that $|\alpha_o = 0, \alpha_1 = 1|$. This is a test for the strong form of LOP. However, since this form of LOP rarely occurs, a necessary restriction is sometimes imposed on equation (2.1) to test the weak form of LOP that $|\alpha_o \neq 0,\ \alpha_1 = 1|$. This equation is normally evaluated at first differenced or in logarithmic form[1].

Markets are assumed to be integrated when coefficients obtained from regressions/correlation are statistically significant or exhibit high correlation. The intuition is that integrated markets exhibit price co-movements. Thus, highly significant regression coefficients or regression coefficients signify markets are integrated otherwise, the markets are assumed to be isolated.

As reported by Fackler and Goodwin (2001), Mohendru (1937) and Jasdanwalla (1966) were some of the first authors to study spatial price behavior using correlation analysis. Mohendru (1937) analyzed Punjab semi-monthly wheat prices with correlation analysis and realized pairwise correlation coefficients were high between four Punjab market markets. Jasdanwalla (1966) also used monthly prices to ascertain the linkages between terminal and local markets in India. He found that correlation between terminal markets was much stronger than correlation between terminal markets and local markets.

Although the use of correlation approach is simple and straightforward in analyzing market integration, many weaknesses have been identified with it. It is highly susceptible to influences of common factors such as inflation, population growth or even changes in the climate conditions that affect all markets under study (Fackler and Goodwin, 2001). This could lead to spurious correlations since the common components can create linkages between markets even though markets for a particular commodity may not be linked in terms of trade. Another shortcoming is influences of monopoly procurements at fixed prices in different markets. This could lead to a correlation coefficient of 1.0 regardless of interaction between regional markets as noted by Harriss (1979). Further weaknesses include: correlation does also imply causality (Cirera and Arndt, 2006) and the failure of these models to take into account transaction costs and heteroskedasticity in common price data (Fackler and Goodwin, 2001).

Another static model of spatial price analysis is the Variance Decomposition model developed by Delgado (1986) which tests integration of whole marketing system other than pair-wise tests. This approach involves treatment of price series to take care of seasonality while assuming a constant transaction cost in its implementation. The basis of this approach is to establish equality of spatial price spreads between market pairs for a particular season. The equality of the spatial price spreads is taken as a condition for market integration. This method is however based on contemporaneous price relationships

[1] For first-differenced α_1 is interpreted as marginal change in P_{1t} due to a marginal change in P_{2t}, for logarithmic function α_1 is interpreted in percentage terms.

and does not take care of dynamic relationships between a given pair of individual markets (Ankamah, 2012).

Dynamic models

Many studies have therefore resorted to the use of dynamic models due to the nature of price data used in market integration analysis to address the above problems. The use of dynamic models is also more important considering the dynamic nature of interregional marketing of especially agricultural commodities which have large transport costs due to their bulky and perishable nature. This may lead to significant delivery lags and slow shocks adjustment processes and hence making shocks persistent according to Fackler and Goodwin (2001). Commonly used dynamic regression models are reviewed below:

Granger causality test

Ganger causality test is one of the approaches which use a reduced form model to test for spatial market efficiency. According to Fackler (1996), many spatial models suffer from identification problems because they involve the use of simultaneous equations. This model however does not require identification. The model is implemented within a vector auto-correlation regression framework. The regional market price of one market is regressed on the lagged values of price in another regional market as:

$$P_t = \sum_{k=1}^{m} R_k P_{t-k} + \tilde{B} X_t + u_t$$
$$= \sum_{k-1}^{m} A_0^{-1} A_k P_{t-k} + A_0^{-1} B x_t + A_0^{-1} e_t \quad (2.2)$$

where P_t is a vector of prices, X_t is a vector exogenous factors affecting prices, A_i is a matrix of coefficients, u_t and e_t are vector of serially independent error terms (Fackler and Goodwin, 2001).

The model then tests the null hypothesis of no ganger-causality which is a restriction that the off-diagonal elements of R_k matrix are all zero. Thus, price *i* fails to ganger-cause price *j* if the ij^{th} elements of all R_k *(k>0)* are all zero statistically (Fackler, 1996). Significant coefficients however imply that price shock in one regional market stimulates response from another regional market but with a lag. Significant coefficients may therefore be interpreted as inefficient or unintegrated markets. Fackler (1996) and Granger (1980, 1988) however warn against such interpretations since instantaneous causality for most variables are unlikely due to delivery lags.

The test is therefore an inference of lead/lag relationship between prices of markets but has nothing to do with actual causality as the name suggests. The test reveals only whether the lead/lag relationships between two markets are statistically significant, but fails to point out the actual relationship or nature between prices of different markets. This is a major weakness of this approach since no valid conclusion can be made without other inferential tests. Interpretations of results should therefore be made with cautions in order to avoid inconsistent inferences. Other shortfalls of this model include lack of treatment of transaction cost and its sensitivity to omitted variable biases (Fackler and Goodwin, 2001).

The Ravalllion/Timmer model

The Ravallion (1986) and Timmer (1987) models are another dynamic regression method proposed to test for market integration. As noted by Fackler and Goodwin (2001), their models can be interpreted as a vector autoregressive with test of restrictions on the reduced-form parameters. These models are therefore regarded as a more dynamic version of the standard regression and the Granger causality tests of market integration as discussed above.

As indicated by Negassa *et al*. (2003) the Ravallion model became the most prominent technique for measuring market integration which distinguishes between short and long run market integration and segmentation after controlling for seasonality, common trend and autocorrelation. The Ravallion model is motivated on the background that adjustment of shocks in agricultural markets are slow and for that matter a considerable time lag may be required even if markets are integrated. The model assumes a constant inter-market transfer cost and rules out the possibility of inter-seasonal flow reversals. It tests the null hypothesis of segmented markets and as reported by Barrett (1996), Cirera and Arndt (2006), inference could be biased in favor of accepting this hypothesis if transfer cost are complex or time varying. The Ravallion model is based on the regression of the form:

$$\boldsymbol{P_{it} = \sum_{s=1}^{n} a_{is} P_{it-s} + \sum_{s=0}^{n} b_{is} P_{1t-s} + X_{it}c_i + e_{it}} \qquad (\boldsymbol{2.3})$$

where P_{it} and P_{1t} represent prices in a regional market *i* and central markets at time *t* respectively while X_{it} represents the constant and vector of characteristics influencing regional markets such as seasonality, time and policy variables. This test method is done in a radial spatial market structure between a group of regional and a central market where price formation is dominated by the central market (Ankamah, 2012; Fackler and Goodwin, 2001). From the dynamic above, Ravallion outlines many criteria of where markets are considered integrated. Firstly, the regional market *i* and the central market are integrated in the short-run if $b_{i0} = 1$ and if $a_{is} = b_{is} = 0$ (for all s = 1,…, *n*). This means a price shock in the central markets it is quickly passed to a regional market *i*. A weaker form of short-run integration also exists in a situation where the lag effects decay on average which only require that $b_{i0} = 0$ and $\sum_{s=1}^{n} a_{is} + b_{is} = 0$. With sometimes sluggish adjustment of spatially distinct markets especially with agricultural markets in mind,

Ravallion also proposed a test for long-run market equilibrium which requires that the condition $\sum_{s=1}^{n} a_{is} + \sum_{s=0}^{n} b_{is} = 1$ is satisfied. This means a price shock in the central market takes a longer time period to be transmitted to the regional markets *i*. A short-run integrated markets therefore implies long-run integration but not the vice versa as can be seen from the conditions stated above.
A test of market isolations is also proposed by Ravallion where prices are expected to be equal to the autarky prices (a_i in the regression above).

Timmer's (1987) dynamic approach however made a different assumption that central market prices are predetermined relative to other regional market prices and that the first order condition is sufficient to capture the spatial price dynamics. Timmer specified the relationship between regional markets and central market *i* as

$$\boldsymbol{P_{it} = c_0(P_{1t} - P_{1t-1}) + (c_0 + c_{1i})P_{1t-1} + c_{11}P_{it-1}} \qquad \textbf{(2.4)}$$

where P_{it} and P_{1t} are the prices in regional market *i* and central reference market 1 respectively. Based on equation (2d), Timmer proposed market integration measurement by what he referred to an index of market connectedness (IMC) by

$$\boldsymbol{IMCi = \frac{c_{11}}{c_0 + c_{1i}}} \qquad (\mathbf{2.5})$$

Timmer's approach is based on the argument that, in highly integrated markets, the lagged effects of the regional shocks should be small relative to current and lagged central reference market shocks. This implies for a highly integrated market the IMC should be close to zero. On the other hand, if the two markets are segmented or isolated, the reference price has no effects on the other market and in that case the IMC has large values. As argued out in Fackler and Goodwin (2001), the values of IMC cannot give a clear indication of how integrated markets. For instance large values of IMC show that market are isolated, but this could also mean transport costs between the markets exhibit high level persistence. Low IMC values only shows that markets are not isolated but reveals little about how integrated they are. Ravallion and Timmer's approaches to measuring market integration are therefore useful only if one can justify that transport rates are white noise processes (Fackler and Goodwin, 2001).

Parity bound model

As can be seen in the models reviewed above, transport cost had not been modelled explicitly in attempt to measure market integration. Most of these models confront the issue of market integration indirectly.

Rather than examining transportation systems, interviewing tracking shipments and looking for unexploited arbitrage, most researchers use time series econometrics applied to observed food prices (Baulch, 1997). The parity bound model developed in studies of Spiller and Haung (1986), spiller and wood (1996) and consequently used by Baulch (1997), Barrett and Li (2002) is one that attempts to address the problem of transfer cost. The parity bound model therefore tries to utilize all available market data i.e. prices, transfer cost, trade flows and volumes in its implementation.

The parity bound model (PBM), uses explicit information on transfer cost together with other market data to assess efficiency of inter-regional markets. The model assumes that transfer cost plays a critical role in determining price efficiency bounds (parity bound). The transfer costs determine the parity bounds within which prices of a homogenous commodity in two geographically distinct markets can vary independently. It is then expected that trade will cause prices in two markets to move on one for one basis when transfer costs equal the inter-market price differential and there are no impediments to trade between the markets (Baulch, 1997). This means spatial arbitrage conditions are binding. Trade will however, not occur when the inter-market price differential is lower than the transfer cost. In this case the arbitrage condition will not be binding which means lack of market integration.

The PBM therefore tries to assess the extent of market integration by distinguishing among three possible trade regimes: regime I at the parity bounds in which spatial price differentials exactly equal the transfer cost; regime II inside the parity bound s in which price differentials are less than transfer costs and finally regime III outside the parity bounds in which price differentials exceed the transfer cost (Baulch, 1996).

The aim of the model is therefore to determine the probability of an observation falling under any of the three regimes. This means it starts with the determination of the lower and the upper parity bounds for which the spatial arbitrage condition occurs between the markets being considered. Establishing this parity bounds is therefore a key requirement in the PBM and since transfer costs rarely exist, the task could be quite complicated (Barrett, 1996). The PBM therefore relies on exogenous transaction data to estimate the probability of achieving inter-market arbitrage conditions. The use of maximum likelihood based estimators is noted to cope well with trade discontinuities and time varying transaction costs as reported by Barrett (1996).

To formally carry out this approach, the deviation of the inter-market price spreads which is an extrapolated transfer cost in any period may be decomposed into three: a symmetric error term with zero mean (e_t) applying to transfer costs plus two error terms truncated from above at zero (u_t and v_t) which are subtracted or added depending on whether price differentials are inside or outside the parity bounds. The first error term e_t, allows transfer costs to vary between two period in response to seasonality or other changes that occur through changes in the transport sector. The error term u_t captures the extent to which price differentials fall short of the parity bounds when there is no incentive to trade while the error term v_t measures how much price differentials exceed transfer cost which arbitrage conditions are violated. The likelihood function for the PDM utilizing results derived by Weinston for the density of a normal plus half normal distribution as specified by Baulch (1997) is:

$$\boldsymbol{L} = \prod_{t=1}^{T} \left[\boldsymbol{\theta_1 f_t^1 + \theta_2 f_t^2 + (1 - \theta_1 - \theta_2) f_t^3}\right] \qquad (\mathbf{2.6})$$

where regime I : at the parity bounds

$$f_t^1 = \frac{1}{\sigma_e} \emptyset \left[\frac{Y_t - K_t}{\sigma_e}\right] \qquad (2.6a)$$

Regime II: inside the parity bounds

$$f_t^2 = \left[\frac{2}{\left(\sigma_e^2+\sigma_u^2\right)^{1/2}}\right] \emptyset \left[\frac{Y_t-K_t}{\left(\sigma_e^2+\sigma_u\right)^{1/2}}\right] \left[1 - \Phi\left[\frac{-(Y_t-K_t)\sigma_e/\sigma_v}{\left(\sigma_e^2+\sigma_u^2\right)^{1/2}}\right]\right] \qquad (2.6b\ )$$

and Regime III: outside the parity bounds

$$f_t^3 = \left[\frac{2}{(\sigma_e^2 + \sigma_v^2)^{1/2}}\right] \emptyset \left[\frac{Y_t - K_t}{(\sigma_e^2 + \sigma_v^2)^{1/2}}\right] \left[1 - \Phi\left[\frac{(Y_t - K_t)\, \sigma_e/\sigma_v}{(\sigma_e^2 + \sigma_v^2)^{1/2}}\right]\right] \qquad (2.6c)$$

In the above equations, ρ_1 and ρ_2 represent the probabilities for regime I and II, Y_t, the absolute value of the natural logarithm of the price spread between markets *i* and *j* at period *t [*i.e., $Y_t = \ln(/P_t^i - P_t^j/)$], σ_e,σ_u, and σ_v are the standard deviations of the errors terms e_t, u_t and v_t respectively; K_t is the logarithm of nominal transfer costs in period *t*, while $\emptyset(.)$ and $\Phi(.)$ represent the normal standard and distribution functions respectively. The probability estimates are obtained for the three regimes, the logarithm of the function is maximized with respect to $\rho_{1,}$ ρ_2 σ_e,σ_u, and σ_v using David-Fletcher-Powell algorithm. Although this model differs from PBM found in other studies, the basic idea of modelling transfer cost explicitly still remains.

The weakness of the PBM model becomes obvious considering the fact that transaction costs embody several unobservable components which may be difficult to capture. This makes studies including data on transfer costs quite tricky since some hidden components of transfer cost may be difficult obtain. The PBM also does not give causes of why markets are integrated or not, it shows only that spatial arbitrage condition are obeyed or violated (Barrett, 1996).

Impulse response analysis

The bound model is another dynamic technique that has been used to analyze market integration. It involves application of exogenous shocks to variables in terms of a moving average representation of Variable Autocorrelation (VAR) systems. In most market integration studies, causality tests are inappropriate as pointed out by Rahman and Shahbaz, (2013). This is because, such tests fail to indicate how much feedback exists from one variable to the other beyond the time period considered. To interpret the implications of the models for patterns of price transmissions, causality and adjustments therefore require consideration of the time path of prices after exogenous shock (Vavra and Goodwin, 2005).

The Impulse response function traces the effect of one standard deviation or one unit shock to one of the variables on current and future values of all endogenous variables in a system over time and horizon (Rahman and Shahbaz, 2013). Impulse response functions, expresses prices of regional markets as function of current and lagged shocks (impulse). Studies that use this approach in analysis of market integration argue it makes richer inferences in terms the dynamics of price adjustment compared to the standard regression analyses since it evaluates dynamic time path of responses to market shocks (Goodwin *et al.* 1999). Mathematically, the IRF for a system of *n* regional market prices with a set of responses reflecting the effects of exogenous shocks on prices in each of the *n* markets' price is given by:

$$p_t = \sum_{k=0}^{\infty} M_k \, e_{t-k} \qquad (2.7)$$

Thus, the IRF traces the impacts of a shock j over time on price *i* and the ijth element of M_k is expressed as a function of *k*. There are therefore n^2 of the function above for *n* regional prices (Fackler and Goodwin, 2001). The IRF therefore gives how and the extent to which a deviation of shock in one regional market affect the current as well as the future prices of all other integrated markets. Impulse response analysis gives better alternative to other tests of market integration which results are described as "all-or-nothing" since it allows examination of extent of eventual price adjustment over time (Goodwin *et al*. 1999). The shortcoming of impulse response studies remains the alternative interpretations which are sometimes based on strong assumptions of serially uncorrelated shock.

Cointegration model

The concept of co-integration for testing market has been used extensively in present studies following its introduction by Engle and Granger (1987) and Engle and Yoo (1987). This approach is more useful because most price series, especially nominal ones, used in the studies of market integration turn to behave as nonstationary. This renders most of the conventional tests for market integration particularly, those using simple regression invalid since the standard errors from such studies maybe inconsistent. Recent studies have therefore made significant advances in attempt to solve such problems by exploring current advances in econometrics. Cointegration in econometrics basically means different price series have long-run relation. The idea helps to analyze the relationship that exists between two spatial markets using price series from each market. Lack of cointegration between market price series is taken as market segmentation or isolation. The Cointegration test of market integration is done through determination of the order of integration of price series using unit root tests. A cointegration regression is then constructed when prices are found to be integrated of the same order and then testing the stationarity of the residuals from the cointegration regression. The cointegration test of market integration therefore involves evaluation of the equilibrium parity bound implied by spatial arbitrage condition. For two spatial markets with prices P_{1t} and P_{2t}, estimates of standard errors on parameters α and β from the equation:

$$\boldsymbol{P_{1t} = \alpha + \beta P_{2t} + \varepsilon_t} \qquad (\mathbf{2.8}\boldsymbol{a})$$

will be inconsistent if P_{1t} and P_{2t} are nonstationary. From the equation above, cointegration test analyzes the time series properties of the residual:

$$\boldsymbol{\varepsilon_t = P_{1t} - \alpha - \beta P_{2t}} \qquad (\mathbf{2.8}\boldsymbol{b})$$

If the residual is stationary or has no stochastic trend, then it means P_{1t} and P_{2t} are linked in a long-run stable equilibrium even though they may wander on their own in the short-run.

The early concept of spatial market analysis introduced by Engel and Granger were bivariate in nature but later approach by Johansen (1998) and Johansen and Juselius (1990) introduced multivariate version which allows for testing of all possible cointegrating vectors using maximum likelihood approach. Cointegration based tests however, reveal only long-run tendencies rather than period-by-period equilibria (Fackler and Goodwin, 2001). Engel and Granger suggested the use of error correction model after showing that there is a long run relationship using cointegration to analyze the short-run dynamics between price series. As reported in Ankamah (2012), the use of cointegration and error correction model enable researchers to explore further dynamics such as completeness, speed and asymmetry of price relationships as well as the direction of causality between two markets.

The use of cointegration test makes implicit assumption that transport costs are stationary or proportional to prices in case of logarithmic transformations. This is sometimes regarded as a weakness because if transport costs are non-stationary, then prices that are not integrated may not represent spatial arbitrage in any case. Thus, as indicated by Barrett (1996) and Negassa *et al*. (2003) it may be completely consistent with market integration even though one fails to find cointegration between two market price series if transaction costs are non-stationary. Cointegration test alone is not sufficient to draw any meaningful conclusion on market integration since the magnitude of cointegration coefficient may be far from unity, a basic intuition behind market integration. The strength of the model remains its ability to allow for consistent inferences in situations where individual market prices are non-stationary.

Switching regime (threshold autoregressive) models

The use of dynamic regression models in the test of market integration lack clearly articulated alternative to the null hypothesis that market are integrated as argued by Fackler and Goodwin (2001). This according to the authors is a problem when markets are imperfectly integrated because the network of trading linkages may be changing over time due to factors such as seasonality. The switching regime regression model is therefore designed to take care of such changes.

The model designed by Spiller and Wood (1998) suggest three possible regimes between two-location markets M_1 and M_2: regime I where M_1 ships to M_2; regime II where and M_2 ships to M_1 and regime III where there is trade between the two markets. The direction of trade depends on the transport rate from one market to the other with positive supply region having the less net transport rate. Trade will however not occur when there is equality in the transport rates involved in shipping from M_1 to M_2 and from M_2 to M_1. The model provides estimate of probability of being in each regime conditional on the size of observed price spread both ex ante and ex post. Integration between the two markets is tested with the hypothesis that a particular regime's probability equals one and all the others are zero. The Switching regime model therefore uses price spreads as an indicator of market connectedness which maybe be wrong since two markets may be connected simply because they both have a common trading partner.

Threshold Autoregressive (TAR) is a variation of the switching regime model used by Obstfeld and Taylor (1997). In the TAR, a fixed but unknown transport cost is assumed to act as a threshold beyond which price adjustment will take place and hence lead to market integration. When the price spread exceeds the threshold, it reverse toward the threshold and when it is within the transaction cost band, it is taken to behave in a serially independent ways (Fackler and Goodwin, 2001). This study approach therefore recognizes the important role of transaction cost which are not dealt with in many models reviewed above. However, as noted by Abdulai (2007), the assumption of fixed transaction cost which implies fixed neutral band over the period under study could be too strong and hence a weakness of the this model.

2.3 Review of similar studies

Analyses of market integration or market efficiency especially in the cereal sector have not been short in literature over the years in Ghana. The first of such studies are those carried out by Alderman (`1992), Shively (1996) and Badiane and Shively (1998). Alderman (1992) builds on the dynamic model used by Ravallion (1986) described above to assess the efficiency of markets by investigating how information flows across commodities. This study investigates the flow of information within a single market and then the relationships between prices in other spatially distant markets. The aim of the study was to find out whether prices of different agricultural commodities in Ghana are linked. In that case, policies could concentrate on a single commodity's price to achieve a broad base target in all other food commodities especially, grains which are much consumed in Ghana. Alderman (1992) used maize as his reference commodity and found that maize price movements are fully transmitted to other grains with three months lags. He shows that in the long-run markets are integrated but his investigations reveal imperfections with how markets process information. The possible explanation for lack of efficiency in terms of information processing was given as, action of traders who may set prices of other grains in response to information about maize prices which may require supply changes to bring the market to equilibrium. Another explanation given was that some traders may not be dealing with all the grains considered and for that matter, the cost of getting information may differ for different traders. His dynamic model therefore realized that the grain market in Ghana was properly functioning but however lacks perfect information flow in the marketing system.

This is however a reasonable finding considering the time the study was carried out, where Ghana's structural adjustment was still at its infant stages and communication technology such as mobile phones and internet were nearly non-existent. Although our study looks at the root crop markets, it does not look at intercommodity price transmission. The current penetration of Information Communication Technology (ICT) tools are also expected to make information less difficult to access and hence improve the imperfection regarding information processing

Shively (1996) is another study which looks at behavior of food commodity market prices in Ghana. Shively used an Autoregressive Conditional Heteroskedasticity (ARCH) regression analysis to investigate variability of monthly wholesale prices of maize in two markets in Ghana. Although this study differs in terms of the motivation behind, it gives important information on how volatile maize prices are and helps to understand how production, storage and trade influence changes in prices. This gives an idea of how commodities prices have been formed as well as the dynamics of price variation in the Ghanaian markets after structural adjustment which involved market liberalization, fiscal austerity and monetary reforms. His results show that prices of maize were more variable and higher in the years when economic reforms were adopted compared to years before and after. The results also suggest that the variations of prices are different in the different markets considered. For instance the years subsequent to the economic reforms saw Bolgatanga market's price volatility reduced compared to the Cape Coast market. Reduction in price volatility was attributed to storage during the reforms and possibly trade with the southern part of Burkina Faso. Again, this brings into mind the role of trade on prices as we see Ghana export yam.

Badiane and Shively (1998) build on the earlier spatial studies above and investigate the roles played by market integration and transport costs in explaining changes in prices in Ghana. This study examines both theoretically and empirically, how price formation is influenced by transport costs and market integration using a dynamic model. They argue that the link between prices and stockholding behavior provides a mechanism for both intertemporal and spatial arbitrage and for that matter central market price history could explain price levels in hinterland markets. In analyzing the market integration, the authors used the Ravallion (1986) approach above. Their model investigated the relationship between local and a central market of maize in the short-run and long-run. They defined the central market as the net exporting market whereas local markets represent the net importing markets. The authors investigated the link between market integration and price volatility by regressing the variance of local market price on central market price history. This was based on the model by Deaton and Laroque (1992) which shows that the link between prices and stockholding behavior creates a link between current period price volatility and past prices. Thus, the current price in a local market is believed to depend on its previous price, central market prices and harvest if there is positive storage and the markets are believed to be connected. Given an initial price shock in the central market, Badiane and Shively (1998) developed a dynamic price adjustment equation to compute the effects of this initial shocks originating from the central market on outlying markets. Using maize wholesale prices covering the period of 1980-1993, they showed that the price adjustment process in a particular market is determined by the degree of its interdependence on the central market where the shock originates.

The price reductions in various local markets in Ghana following the 1983 economic reforms were therefore attributed forces arising from both the local and the central markets. They however, acknowledge the important role of transport cost in both the speed of the adjustment and the degree of market connectedness and pointed out that changes in transport cost can be expected to lead to a different pattern of responses of local markets to central market's price shock. The path of a local market's price at a particular period after initial shock in a central market was consequently expressed as a function of the long-run multiplier between local/central market pairs, changes in the transport cost, prices in the local market prior to shocks in the central market and local market price level after shock has been fully transmitted to the local market. Thus, local prices also respond to transport cost as they adjust to volumes traded between two market pairs. In summary, Badiane and Shively (1988) produced results which confirm Alderman (1992) that the Ghanaian maize markets are fairly well integrated with strong connection between Techiman-Makola market pairs than the Techiman-Bolgatanga. Yet, time required for price shocks to be transmitted between both market pairs are the same. There was a weak link in terms contribution of price fall in the Bolgatanga market arising from a price fall in the central market, the Techiman. Thus, prices in local markets are determined primarily on their own past values and other local factors but not the central market's price due to poor integration between markets. The importance of market integration in price transmission was shown with evidence from the Makola market which is well connected with the Techiman market and shows strong responses. The authors also used simulation to show the importance of transport cost in determining how sensitive local market prices are to central market by increasing the estimated transport cost. The results show that large transport costs dampen the effect of the central market's price shocks on local prices. This study has been examined extensively because it does not only look at market integration but also how the integration affects price formation in local markets. It also deals with the issue of transport cost which much spatial price literature are silent on. It therefore gives important background to this study and helps to understand why some of the results may be obtained particularly, with yam which transport costs cannot be overlooked in its marketing process.

Following these early studies on spatial prices in Ghana, several authors have looked at different commodities or markets and found interesting results. Abdulai (2000) used a cointegration test that allows for symmetric price adjustment towards long-run equilibrium relationships to examine linkages between principal maize markets in Ghana. His approach differs from the previous studies in that, he assumes economic agents act to restore equilibrium when deviation from equilibrium exceeds a critical threshold in which case the benefit of the adjustment exceeds the cost. Also his study disagrees that price responses are always symmetric .This implies that a shock from a central market will elicit similar response in local markets, but is of the view that certain features associated with market imperfections may lead to asymmetric responses. He argues that effort of market participants to exploit arbitrage opportunities can result in the maintenance of equilibrium relationships among commodity prices in distant markets. Abdulai (2000) therefore employed threshold cointegration analysis models developed by Enders and

Granger (1998) to examine the relationships between wholesale prices of maize in Techiman (central market) and two local markets (Accra and Bolgatanga) with the objective of determining whether transmission between these markets is symmetric or asymmetric. The study results show that local markets response to central market prices is asymmetric in the sense that the response to falling central market prices is not the same as the response to increasing central market prices. For instance his results show that while prices in the Accra market adjust to eliminate about 40% of a unit negative change in the deviation from the equilibrium relationship created by the Techiman market, it adjust to eliminate only 13% of a unit positive change in the central market. In other words, increase in maize prices in the Techiman market is quickly passed to the Accra market while a decrease takes longer time to be passed to the Accra market. Again the study focuses on the grain sector as well as using the Techiman market as its central market. The root and tuber crops which form part of major staples however, remain less studied and this makes our study an important one by filling the gap between the extensively studied grain sector and the root and tuber sector which provide food security for many households in Ghana.

In further studies about the grain sector, Ankamah (2012) used regional monthly prices of maize from 2002 to 2010 to assess the linkages between regional markets in Ghana. Using the threshold autoregressive model, he shows that regional markets of maize are integrated, but characterized by asymmetry in terms of the price adjustment. His results also show that there is either a bidirectional market interdependence or causality to price changes in both the short-run and long-run. There is however, heterogeneity in terms of responses towards positive and negative deviations in the long run. The adjustment processes of all markets were not the same. For instance, whiles adjustment between the Greater Accra-Brong Ahafo market pair exhibited positive asymmetry, the adjustment between of the Brong Ahafo and the Northern, Ashanti, and Central regional markets exhibited negative asymmetry. The study also found the time required for adjustment after a shock in the central market to be ranging from 7 months to 26 months with the adjustments between Greater Accra and the Brong Ahafo markets requiring the least time. The author attributed the integration of regional markets to improvement in communication infrastructures which allows for easy access to information by market agents.

The improvement in communication infrastructure raised here has been noted to play a very important role in market integration. A similar study by Chowa (2014) in the Malawian maize markets shows that ICT based market interventions have positively influenced market integration and price transmission. They asserted that modern ICT tools have contributed to the reduction in information search cost leading to complete market efficiency in Malawi. Nevertheless, earlier studies (Alderman, 1992; Shively, 1996; Badiane and Shively 1998) have found similar results in the maize market in Ghana when there was low ICT development. Studies with different commodities other than the maize are needed to understand whether improvement in communication infrastructures have aided integration of all commodity markets or just some selected commodities.

In a more recent study, Adom (2014) examined spatial market integration of domestically imported rice markets and the extent of substitution between locally produced rice and imported rice. Based on current monthly wholesale prices from January 2006 to December 2013, the author used Johansen multivariate and cointegration models to show that the foreign rice markets in Ghana are well integrated, although there are some imperfections, indicating that foreign rice market in Ghana provides opportunities for arbitrage condition. He discovered the Accra market as the dominant market leader among the markets considered. His analysis of the effect of government policies during the 2007/2008 periods reveals that the policies somewhat succeeded in moderating the price fluctuations during the period, even though various local markets differed in their responses to central market price shocks. The results of regional substitution between the imported rice and the local rice suggest that there are evidences to that effect in the long-run but no clear evidence in the short-run indicating that the two products are not perfect substitutes. Hence, the author believes that government policy to limit importation of foreign rice in order to raise producer prices of locally produced rice will only have a mild effect on producers but slam a heavy burden on household's budget.

In another spatial price analysis studies in Ghana, Amikuzuno (2010) used Johansen's estimation method to analyze the seasonal asymmetric price transmission in the Ghanaian tomato market. The tomato market in Ghana shows significant seasonal patterns due to weekly price variations as noted by the study. The author analyzed the dynamics and interdependence of wholesale prices of five major markets: Accra, Kumasi, Techiman, Tamale, and Navrongo. Using semi-monthly data from March 2007 to February 2010 in a multivariate form of the Johansen's estimation procedure, the author found strong evidence of market integration with fast price transmission between markets. The study also found that any shock to the tomato market equilibrium also triggers responses from the production regions which are the Tamale and the Navrongo markets. The transmission of tomato price shocks were found to exhibit regime-dependent adjustment with generally strong error-correction rates ranging from 10% to more than 40% per each three days. This study gives important dimension to price transmission of highly perishable commodities which are difficult to store. It also gives important dimension to the frequency of data which are required for spatial prices. Although yam is different in terms of their features, their perishable natures make this study interesting to compare with Amikuzuno (2010). As highlighted by Meyer and von Cramon-Taubadel (2004), perishability plays a role in causing asymmetry in price transmission of products. They think traders might hesitate to raise prices for perishable products for fear of spoilage which would lead to negative asymmetry. However, Heien (1980) has rather opposite view that changing prices is more of problem for products with longer shelf life rather than perishables since price change for the former brings about higher cost and loss of goodwill. This study will contribute to such line of reasoning.

In a similar study, Mensah Bonsu *et al.* (2011) used the Johansen's cointegration approach to analyze the efficiency of plantain market system. They categorized the plantain markets in Ghana into central consumption, assembling and producing markets and shows that arbitrage in the plantain marketing system is working. Thus, there were both short-run and long-run relationships between the central market (Accra), the assembling markets (Kumasi, Koforidua, and Sunyani) and the production markets (Goaso, Begoro and Obogo). However, they realized the speed of price transmission between the central market and the assembling and production markets was relatively weak at 27.7% compared to the 100% threshold. Hence, they suggested the need for improvement in the market information in production areas. With significant penetration of mobiles phones which Egyir *et al.* (2011) noted as facilitating speedy transmission of market information, continuous studies are required to assess how the speed of transmission has evolved in various commodity markets. This study aims to throw more light on the matter.

Narrowing down on the root and tuber sectors, it is realized that not much has been done in terms of spatial price analysis. This is because less attention has been given to the sector due to less trading activity unlike the cereal sector. However, Acquah *et al.* (2012) analyzed price transmission in the cassava market in Ghana using the Johansen cointegration, Granger causality and autoregressive distributed lag models. They used weekly prices from 2008 to 2010 for six major markets in Ghana. They showed that the price series of cassava markets were integrated of order one which means that there is a unit root for market prices of cassava. They realized that there are no long-run relationships between market prices of cassava. This shows there is poor price transmission between the different cassava markets considered. There was also no causality between the reference market (Techiman) and the other markets showing independence of the various markets. However, their results are not surprising because cassava is not much traded in Ghana due to its low value-to-volume ratio. The costs of transportation are therefore high which limits trade between regions. Comparing cassava and yam, the latter is much traded and even exported. This study seeks to add to the sector's investigation of market efficiency.

Away from Ghana, spatially price studies have been carried out in different regions including intra-regional and inter-regional studies. To highlight a few studies, Muyatwa (2001) used the cointegration analysis and the error correction models to examine the integration of regional markets in Zambia following the liberalization of the maize markets. Using monthly wholesale prices from 1993 to 1997, the study found that both the magnitude and speed of price transmission between regional markets are much limited. The results also show that even though there has been rapid emergence of the private sector, the rate at which they are filling the gap left by the state has been slow due to various constraints such as lack of access to information and poor transportation infrastructures. Using a different framework from cointegration models, Negassa and Myers (2007) applied an extension of the parity bound model which allows dynamic shifts in regime probabilities in response to marketing policy to study the maize and wheat markets in Ethiopia. Their results show a dynamic adjustment path in the grain markets and, also the grain marketing reforms have improved efficiency in some markets but worsened it in others. They pointed out misallocation of resources in the two markets as the cause of inefficiency. They suggest different policy responses for the two commodities to improve efficiency, since there were asymmetries in terms of profit made by maize and wheat traders.

In more recent studies, Serebrennikov *et al.* (2014) examined the spatial integration of the Russian domestic wheat markets. Their study was based on the fact that the Russian Government always intervened in the wheat market during periods of shortage in domestic supply. They therefore used the threshold autoregressive model to understand whether the magnitude of transaction cost is high enough to cause a break in the short-run linkages between the Russian wheat markets. Their results show that the domestic markets became more active during restriction of export. In some cases, they found evidence of trade between domestic markets even though transaction costs were higher than potential returns from trade. They attributed this to other forces for instance, information flow which may determine trade behaviors apart from the arbitrage condition. Mengel and von Cramon-Taubadel (2014) analyzed the distance and border effects on price transmission of cereals which they believe are relatively more homogenous in terms of marketable qualities. The authors therefore used the price transmission estimates for 1189 cereal markets pairs from 57 studies to test the effects of border distance on price transmission using meta-analysis. Their findings suggest that distance and border have effects on price transmission as well as long-run price relationship between market pairs. Thus, both border and distance reduces probability of price cointegration and consequently find that speed of price adjustment between international markets is slower on the average than intra-national markets pairs.

2.4 Lessons and conclusion from review

There have been several models developed to empirically examine the behavior of spatial prices over the past decades. They range from simple correlation tests to more sophisticated cointegration because of recent advances in econometrics. Different tests make different assumptions and formulate different hypothesis to achieve their objectives. Based on these assumptions and hypothesis, some of these tests could lead to invalid conclusions. However, there is no single test which has been declared best among these several models since each test has its limitations and strengths. Many of these limitations have been pointed out above but one serious concern with most of these tests has been the assumption made about transaction costs. It can be seen that most of these tests do not explicitly consider transaction costs. Few of the models which take into account the critical role of transaction costs, do so by assumption due to lack of data and also the inability to capture the different components of transaction costs. It is therefore necessary that one understands the institutional mechanism and dynamics of a particular market in order to make meaningful interpretations of spatial tests. For instance as indicated by Fackler and Goodwin (2001), knowledge of continuous flow of commodities between two markets, direction of commodity flow and the pattern of seasonality could be very useful in interpretation of tests of market integration. The various tests therefore provide information on simple relationships between prices and it is necessary that results are interpreted in the context of more realistic and factual behavior of the markets under consideration. In some case, a single test may not be enough, but aggregation of different tests could give a better situation of market integration.

On empirical studies, the use of cointegration analysis seems to dominate current studies. Most studies however augment results from this test with other inferential techniques such as the threshold autoregressive model, the Granger causality tests and impulse responses in order to draw more concrete conclusions.

About the study area, spatial price studies to assess efficiency of commodity markets have not been lacking in Ghana just as in other countries. However, dynamic change in behaviors of market agents and with improvement in technology and somewhat infrastructure means continuous assessment is required in order to keep policy makers informed and updated. Most of the studies have also focused on the cereal sector, especially maize and rice, leaving a gap between the cereal and the root crop sector. Also as noted by many researchers (Shively 1996, Badiane and Shively 1998 and Amikuzuno 2010), Ghana’s economy is one of the economies that has experienced trade liberalization both domestically and to some extent internationally. This makes the various commodity markets worth studying in order to understand how similar economies which have liberalized market system and major economic reforms in the region evolved over the years.

Chapter 3- Research methodology

4.1 Study area and data collection

The study is carried out in Ghana which is made up of ten administrative regions out of which yam production takes place in seven of them. Production is mainly in the Northern and Eastern part of the country with distribution routes to consumption markets shown on the figure 3.1 below. Due to the widespread of yam consumption in Ghana, there are different marketing centers which can be categorized into production and consumption markets. The markets chosen for this study are the markets of Accra, Kumasi, Techiman, Tamale and Wa. These markets are chosen based on the major marketing routes and data availability. It can be seen that most of the marketing routes lead to the Accra market which is a main consumption market. The Accra market also serves as the main center where exporters compete for yam for export though recent competition has forced some exporters to go to other production and rural markets. The Accra market is therefore chosen as the central market for this study with all other markets analyzed in reference to this market.

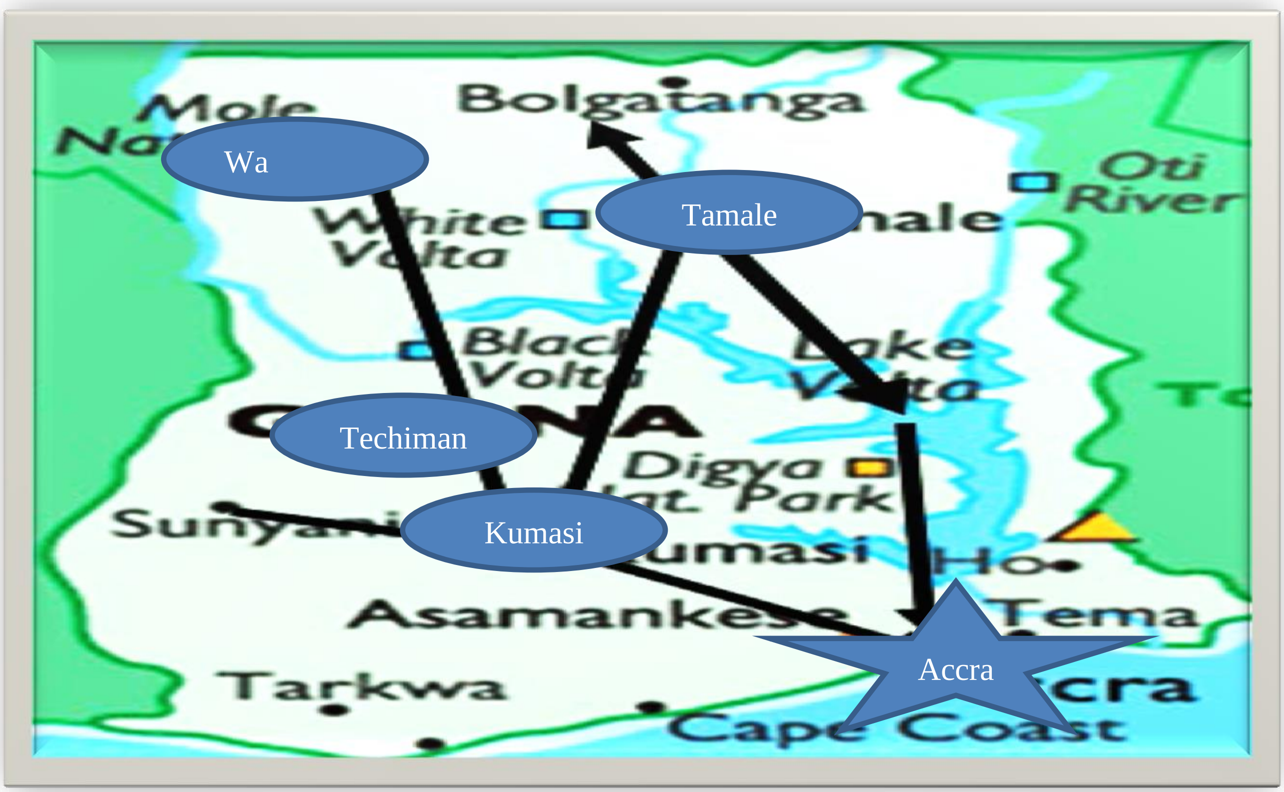

Figure 3.1 Marketing routes of yam in Ghana. Source: Adopted from Anaadumba (2013)

The data for this study is obtained from Statistical Research and Information Directorate (SRID) of the Ministry of Food and Agriculture (MoFA) in Ghana. The data is cross-checked with a similar set of data from FAOSTAT to iron out differences that arise. This data are collected by District Agricultural Development Units in Ghana on weekly basis. The weekly data are used to compute monthly prices by taking the average of the weekly prices. One key consideration in market integration analysis is the frequency of the data. As noted by Amikuzuno (2010), high frequency data such as weekly data are believed to capture precisely price transmission mechanisms better than low frequency data. However, as noted by Mensah-Bonsu *et al.* (2010), high frequency data such as weekly series are noted to have several long-run periods in which prices are constant. This could invalidate the statistical assumption of independent and identically distributed of the error term that follows a continuous distribution. Weekly prices could also pose greater challenges due to several missing figures which must be interpolated. This study therefore uses monthly wholesale prices from 2006 to 2013, a total of 96 observations for each market. Markets with missing figures are interpolated with previous monthly averages. The Tamale and Wa markets are located in the northern part of Ghana while Techiman and Kumasi markets are more central. The Accra market is located in the southern part of the country. The locations of the selected markets give a good spatial spread for this study. The prices are in nominal terms and the currency unit is Ghana Cedi (GHC). The prices are recorded per 250kg units. In order to interpret the econometric results in terms of elasticity or percentage change, the various price series are log-transformed during various empirical analyses.

3.2 Analytical methods

The concept of market integration has been presently dealt with in a cointegration framework as has been shown in the literature review section. The rationale behind the use of cointegration models is the fact that different variables may wander around in the short round but possess long-run equilibrium relationships. This means that the variables may move together in the long-run. The model is therefore used to achieve the first objective of this study which seeks to determine relationships between prices of regional yam markets in Ghana. The use of this method in market integration studies has been welcomed since most economic series have been found to be non-stationary. The use of cointegration involves several adjustments and tests processes of the data in order to ensure price series exhibit the right characteristics such as stationarity. The analysis starts with a unit root test of each series in order to ensure series do not exhibit random walk and in some cases with a drift. Estimating ordinary least square from data with random walk could lead to spurious regression and this may invalidate the hypotheses being tested as indicated by Granger and Newbold (1974). As indicated by Alemu and Van Schalkwyk (2008) price data collected over several periods must be adjusted for seasonality in order to avoid inconsistent and inaccurate results. This seasonality in price data could be stable or variable due to natural phenomena such as weather or behavior of economic agents respectively. Seasonality could be deterministic where similar trends are observed year after year, random or both (Hylleberg *et al*. 1990). Depending on the type of seasonality observed, different filtering approaches are used in order to correct for the problem. For instance if a series is found to be deterministic as mostly assumed by researchers, a seasonal dummy can be introduced in the model. To take care of seasonality in the price data, this study employs the HEGY seasonal unit root tests developed for quarterly data by Hylleberg *et al.* (1990) and later extended by Beaulieu and Miron (1993) for monthly data. This framework of analyses allows for examination of seasonal and non-seasonal unit root processes in the data. The null hypothesis of unit root at zero is tested against the alternate of stationarity for the model:

$$\Delta_{12} \boldsymbol{y_{it}} = \boldsymbol{\beta_{\circ}} + \boldsymbol{\gamma t} + \sum_{i=1}^{11} \boldsymbol{\beta_i D_{it}} + \sum_{k=1}^{12} \boldsymbol{\pi_k z_{k,t-1}} + \sum_{j=1}^{p} \boldsymbol{\delta_j} \Delta_{12} \boldsymbol{y_{it-j}} + \boldsymbol{\varepsilon_{it}} \tag{3.1}$$

where β_0, β_i, π_k and δ_j are parameters to be estimated. The D_{it} is a seasonal dummy which is equal to 1 for month i and 0 if otherwise, t is a trend variable, $z_{k,t-1}$ are non-singular linear transformations of lagged values of y_{it}, ε_{it} is the error term and p is the lag value selected automatically with the Ackaike Information Criteria (AIC). From the above equation, the null hypothesis involves testing $H_{ko}: \pi_k = 0$ for k = 1, 2 as against the alternative of $H_{k1}: \pi_k < 0$ using t-statistics. Also using F-statistics, the complex unit root is tested with the joint null hypothesis $H_{k0}: \pi_{k-1} = \pi_k = 0$ for k = 4,6,8,10,12 as against the alternative of $H_{k1}: \pi_{k-1} \neq 0 \; or \; \pi_k \neq 0$. The above test is augmented with the Canova and Hanson (1995) Lagrangian multiplier type which tests null hypothesis of stationarity, implying that the seasonal pattern is deterministic against the alternative of seasonal unit root for the individual or joint frequencies. From equation 3.2, the Canova and Hanson approach investigates the instability of the parameter β_{it} by testing $\beta_{it} = \beta_{it-1} + \varepsilon_t$ and $Var(\mu_t) = 0$. A rejection of the null hypothesis means seasonality in the data is not constant. This implies the null hypothesis should not be rejected for this test after adjusting for seasonality using seasonal dummy.

Based on the conclusion from this seasonality test, the data is adjusted with an appropriate treatment method. The most common treatment or filtering method in case of non-constant seasonality is the introduction of seasonal dummy but in case of deterministic seasonality, the OLS estimation is the same whether the data is treated or not as noted by Brendstrup *et al.* (2001).

3.2.1 Test for Unit roots in the presence of structural breaks

After the seasonal adjustment the conventional unit root test, called the Augmented Dickey-Fuller (ADF) test, is used to examine the price series in order to find out if they are stationary or possess unit roots. The ADF regression for a deseasonalized series P_{it} (i=1,2,..) is

$$\Delta P_{it} = \alpha_{\circ} + \gamma t + \delta P_{it-1} + \alpha_j \sum_{j=1}^{m} \Delta P_{it-j} + \mu_{it} \qquad (3.3)$$

where $\alpha_{\circ}$, γ, δ, and α_j are parameters to be estimated, t is the trend variable while $j = 1, 2, \ldots$ is the lag length which is determined by AIC or BIC, and μ_{it} is the error term. The null hypothesis that P_{it} has a unit root involves testing $H_0: \delta = 0$ against the alternative that P_{it} is stationary i.e. $H_1: \delta < 0$. A Conclusion is drawn by comparing the t-statics of the parameters with the critical values of Dickey and Fuller (1981) to see whether the series exhibits a deterministic trend ($\gamma \neq 0$), random walk ($\delta = 0$) and with a drift ($\alpha_{\circ} \neq 0$). Failing to reject the null hypothesis means the series is non-stationary and hence must be treated by first differencing and the test has to be conducted again. The procedure is repeated until a d^{th} difference gives stationary results. It should however be noted that stationarity is more important when the Vector Autoregressive (VAR) system is to be used. If the test shows $\gamma = 0$, and $\alpha_{\circ} = 0$), the model is subsequently estimated without trend and the constant (the drift term) respectively.

Since the ADF test is noted for its low power, the Philips-Peron test which is more robust will be used to confirm the results from the ADF. In testing for unit root of a series, it is important that structural breaks are considered since failure to do so may lead to bias conclusion as noted by Perron (1989). The ADF lacks the capacity to identify structural breaks and this may lead to non-rejection of the null hypothesis in case of structural breaks. According to Baum (2001), there could be a potential confusion of taking structural breaks in series as evidence of non-stationarity. Several authors (Zivot and Andrews 1992 Perron 1997; Montañés and Reyes 1998) have therefore proposed tests that allow for structural breaks following the test proposed by Perron (1989). The Zivot and Andrews (1992) test which allows for single structural breaks in the intercept and/or a trend of the series determined by a grid search over possible break points is adopted in this study to verify the behavior of the series. Their model tests the null hypothesis that P_{it} contains unit root with drift that excludes structural breaks against the alternative hypothesis that P_{it} exhibits trend stationary process, with a single period break occurring at an unknown time. The equation for Zivot and Andrews (1992) test allowing for breaks in both trend and the intercept is specified as:

$$\Delta P_{it} = \alpha_0 + \gamma t + \delta P_{it-1} + \theta_1 DT_t + \theta_2 DU_t + \alpha_j \sum_{j=1}^{m} \Delta P_{it-j} + \mu_{it} \qquad (3.4)$$

where $\theta_1$and θ_2 are the parameters to be estimated in addition to α_0 , γ, α_j from the ADF equation. The variable DU_t is a dummy with value **1** if t > TB (break date) and **0** otherwise. It is an indicator for a shift in mean at each possible break date. DT_t is the corresponding trend shift variable and takes values of $t - TB$ if t > TB and 0 if otherwise. According to Glyn *et al.* (2007), the TB is selected where the t-statistics from the ADF unit root test is at a minimum or most negative. When the value $\theta_1$is restricted to zero i.e. $\theta_1 = 0$ it means the model shift in the intercept while $\theta_2 = 0$ means shift in the trend.

3.2.2 Modelling long run relationship between regional markets

Cointegration Analysis

The use of cointegration in market integration has gained prominence in the literature recently. The rationale behind this model is that if price series are integrated of the same order, then a linear combination of the series is expected to produce a stationary series. This is used as an indication of long run market integration. Hence to determine the long-run relationships between regional markets, this study adopts the Engel-Granger (EG) cointegration test approach proposed by Engel and Granger (1987). This approach is a symmetric two step-residual based test of cointegration between non-stationary variables. Given a non-stationary reference regional market price, P_t^r and a non-stationary local regional market price P_t^l, the EG model is expressed as:

$$P_t^l = \beta_\circ + \beta_1 P_t^r + \mu_t \qquad (3.5)$$

where $\beta_\circ$ is the arbitrary constant accounting for price differentials (transfer and quality differences), β_1 is the price transmission or cointegration parameter and μ_t is the stochastic error term with zero mean and constant variance. To verify whether the two markets are integrated, the model tests whether a stable relationship exists between the two market price series with the null hypothesis that P_t^l and P_t^r are not integrated. This means the error term should be non-stationary for the null hypothesis to be accepted. Rejecting the null hypothesis therefore means the error term is stationary and hence the price series are cointegrated. From the equation above, long-run market integration is tested by estimating the coefficient of adjustment ρ which captures the rate of adjustment towards long-run equilibrium. This involves estimation of the equation:

$$\Delta\mu_t = \rho\mu_{t-1} + \varepsilon_t \qquad (3.6)$$

where ε_t is the white noise residual term. The null hypothesis of no cointegaration ($\rho = 0$) is tested by comparing the t-statistics with the Dickey-Fuller statistics for unit root test. A rejection of the null hypothesis means the error term is stationary $(-2 < \rho < O)$ with zero mean. One important assumption made for the validity of this test is that the error terms are uncorrelated or serially independent. In a situation where this assumption is violated, the lags of the dependent variable can be included in the equation relying on an information criterion in order to make ε_t a white noise process. This version of the test is usually known as the Augmented Engel-Granger test (AEG).

Although the EG and AEG tests are robust tests of cointegration relationships, they do not allow to test for multiple cointegration relationships at the same time. It has also been established that their conclusions are based on the choice of the dependent variable (Goodwin and Schroeder, 1990). The Johansen test is another alternative which resolves these problems. The Johansen procedure involves estimation of the equation of the form:

$$\Delta x_t = \pi x_{t-1} + \epsilon_t \qquad (3.7)$$

where $x_t$is [nx1] a vector of random variables integrated of some order say degree 1, π is [nxn] coefficient matrix and ϵ_t is [nx1] a vector of normally distributed error terms. Depending on the characteristics of the data, the equation can also be improved with deterministic independent variables, lags of the dependent variable (Δx_t) and also allowing for various orders of integration of x_t. The main intuition behind the Johansen test is determining the rank (r) of the estimated coefficient π. If the $\pi \neq 0$ then the system is believed to exhibit symmetric adjustment around $x_t = 0$ such that for any $x_t \neq 0$, Δx_{t+1} is always πx_t. The test uses the Trace Eigen and the maximum Eigen value statistics for its inference and in situations where the two lead to different inferences, Johansen and Jeslius (1990) suggest the use of the later.

3.2.3 Test for asymmetry

The implicit assumption by the EG and the Johansen cointegration test is that price adjustments are symmetric. This could be problematic in the sense that prices could be sticky in one direction more than the other implying asymmetry in the adjustment process. This could lead to misspecification of the above mentioned cointegration tests (Enders and Granger 1998; Enders and Siklos, 2001). In this case, the two regime Threshold Autoregressive (TAR) model introduced by Enders and Granger (1998); Enders and Siklos (2001), which recognizes transaction costs and allows for asymmetric adjustment is used. The TAR model is expressed as:

$$\Delta \mu_t = \rho_1 H_t \mu_t + \rho_2 (1 - H_t) \mu_{t-1} + \varepsilon_t \qquad (3.8)$$

where μ_t is the residual from equation (3.5) and H_t is the Heaviside indicator such that:

$$H_t = \begin{cases} 1 \text{ if } \mu_{t-1} \geq \tau \\ 0 \text{ if } \mu_{t-1} < \tau \end{cases} \qquad (3.9)$$

τ is the threshold value, ε_t is the independent and identically distributed error term which is uncorrelated with μ_j, j <*t* and ρ_1, ρ_2 are speed adjustment coefficients. The adjustment is symmetric when $\rho_1 = \rho_2$ in which case the test is regarded as a special case of the EG cointegration test. For any value of τ, the necessary and sufficient condition for convergence and stationarity of μ_t is $\rho_1 < 0$, $\rho_2 < 0$ and $(1 + \rho_1)(1 + \rho_2) < 1$ (Enders and Siklos, 2001). Convergence of the system implies that the long run equilibrium value of the sequence is given by $\mu_t = \tau$. In such circumstances, the adjustment is $\rho_1 \mu_{t-1}$ if

μ_{t-1} is above long-run equilibrium value and $\rho_2\ \mu_{t-1}$ if μ_{t-1} is below long-run equilibrium. Thus, if for instance, $-1 < \rho_1 < \rho_2 < 0$, then the negative phase of μ_t series will tend to be more persistent than the positive. The model is called Threshold Autoregressive (TAR) if the Heaviside indicator function depends on μ_{t-1} as shown in equation (3.9). On the other hand, if the Heaviside indicator depends on the change in previous period, μ_{t-1} as shown below:

$$H_t = \begin{cases} 1 \text{ if } \Delta\mu_{t-1} \geq \tau \\ 0 \text{ if } \Delta\mu_{t-1} < \tau \end{cases}$$

then equation (3.8) is termed as the Momentum-Threshold Autoregression (M-TAR) models. For the M-TAR, the adjustment to the long-run equilibrium margin between prices does not depend on the size of the margin at a given point but rather on the magnitude and direction of its change in the previous period. This means the M-TAR model exhibits a "momentum" in one direction more than the other (Enders and Siklos, 2001). Thus, with the M-TAR model, if $|\rho_1| < |\rho_2|$, the model exhibits relatively less decay for values of $\Delta\mu_{t-1}$ above the threshold than for values of $\Delta\mu_{t-1}$ below the threshold. In other words, positive changes from equilibrium tend to persist but negative changes are quickly reverted back to equilibrium. The M-TAR therefore allows the degree of autoregressive decay to depend on the first differences of the variable while the TAR allows for the degree of decay to depend on the state of the variable of interest. There is however, no rule of thumb as to which of the two is more appropriate for the adjustment process but rather selection is based on model selection criteria such as AIC or BIC. To ensure that ε_t in equation (3.8) is a white noise process i.e. no serial correlation, the Ljung-Box Q diagnostic test will be conducted under both TAR and M-TAR to rectify the problem.

As indicated by Enders and Siklos (2001), equation (3.8) may not be enough to capture the dynamics adjustment towards a long-run equilibrium value and hence must be augmented with lagged value of $\Delta\mu_t$ to become *p-th* order process as shown as:

$$\Delta\mu_t = \rho_1 H\mu_t + \rho_2(1 - H_t)\mu_{t-1} + \sum_{i=1}^{p-1} \gamma_i \Delta\mu_{t-i} + \varepsilon_t \qquad (\mathbf{3.10})$$

The inclusion of the lagged variable of $\Delta\mu_t$ also corrects the problem of serial correlation in case the problem is identified in equation (3.8). The lag length in equation (3.10) is determined by using a model selection criterion such as the AIC.

The null hypothesis for the TAR and M-TAR models is no cointegration which is tested based on joint a F-test of $\rho_1 = \rho_2 = 0$. The test statistics are compared with appropriate critical values provided by Enders and Siklos (2001), see table in appendix. A standard F-test of symmetry is performed by testing $\rho_1 = \rho_2$ when the null hypothesis is rejected. A rejection of both $\rho_1 = \rho_2 = 0$ and $\rho_1 = \rho_2$ means existence of threshold cointegration. This means there exist asymmetric or nonlinear adjustment between price pairs.

In general, the threshold value (τ) is unknown in the estimation of TAR and M-TAR and hence needs to be estimated with the values of ρ_1 and ρ_2. However, according to Enders and Siklos (2001), τ is normally set to zero in most economic applications so that the cointegrating vector coincides with the attractor. Following Otoo (2012), the threshold value in this study is initially set to zero in TAR and M-TAR and afterwards estimated using the method proposed by Chan (1993).This methodology involves a grid search over potential threshold values that minimize the sum of square residuals from the fitted TAR or M-TAR. It is implemented by sorting all the lagged values of $\mu_t$in series from equation (3.5) and the first difference of the lagged μ_t series in ascending order for both TAR and M-TAR respectively i.e. $\mu_1 < \mu_2 < \cdots < \mu_T$ for TAR and $\Delta\mu_1 < \Delta\mu_2 < \cdots < \Delta\mu_T$ for M-TAR where T represents the number of observations used. The largest and smallest 15% of the values are discarded and each of the remaining 70% of the values is considered as a potential threshold value which is used to individually estimate equation (3.10). The value that yields the lowest residual sum of square is chosen as the threshold value and it is used to estimate either the consistent TAR or M-TAR model.

3.2.4 Modelling short-run dynamics of price linkages

Threshold Vector Error Correction Models

The above models deal with long-run price relationships and after they have been used to establish that price series are linked or cointegrated, the vector error correction model (VECM) is used to analyze the short-run dynamics (Enders and Granger, 1998). This study will therefore use the VECM to achieve the objective of investigating the short-run dynamics between the reference market and the other regional markets in Ghana. The VECM helps to estimate the speed at which a deviation of prices from equilibrium is restored. The estimation of the error correction model depends on which of the symmetric or asymmetric model is accepted from the cointegration analysis. Given that price adjustment is asymmetric, then the asymmetric error correction model with local market price as dependent variables can be specified as:

$$\Delta P_t^l = \alpha_\circ + \sum_{j=1}^{k} \alpha_j \Delta P_{t-j}^l + \sum_{j=1}^{m} \gamma_j \Delta P_{t-j}^r + \lambda_1^+ H_t \mu_{t-1} + \lambda_2^- (1 - H_t)\mu_{t-1} + \epsilon_{1t} \qquad (\mathbf{3.11})$$

$$\Delta P_t^r = \alpha_\circ + \sum_{j=1}^{k} \alpha_j \Delta P_{t-j}^r + \sum_{j=1}^{m} \gamma_j \Delta P_{t-j}^l + \lambda_1^+ H_t \mu_{t-1} + \lambda_2^- (1 - H_t)\mu_{t-1} + \epsilon_{1t} \qquad (\mathbf{3.12})$$

where $\alpha_\circ, \alpha_j, \gamma_j, \lambda_1^+$and λ_2^- are parameters to be estimated in the model, H_t is the corresponding Heaviside indicator from the threshold autoregressive model and ϵ_{1t} is the error term with zero mean and constant variance. Theoretically, the TAR/M-TAR models indicate only cointegration relationships but not causality. The vector error correction model is therefore useful in remedying this problem by determining the direction of causality between selected regional yam markets. For that matter, equations (3.11) and (3.12) will be estimated for all market pairs to ascertain the direction of causality between all regional markets. The VECM basically implies any change in local market prices is the sum of both long-run impact of the deviations from equilibrium value and the short-run effect of change in the central/reference market on the local market price. λ_1^+ and λ_2^- are the long-run adjustment coefficients while γ_j is the short-run adjustment coefficient. Using the Wald test, the Granger causality tests are performed by examining whether the joint significance of all γ_j are statistically different from zero i.e. $\gamma_0 = \gamma_1 = \cdots = 0$ (which implies short-term causality) or whether all γ_j are significant (which implies long term causality). The model will also reveal whether there is one-way causality or bi-directional causality from the different market pairs.

Finally, the length of time needed for complete transmission of price shock or complete adjustment will be analyzed from the VECM by impulse-responses calculations.

The general framework of the research methodology is summarized below.

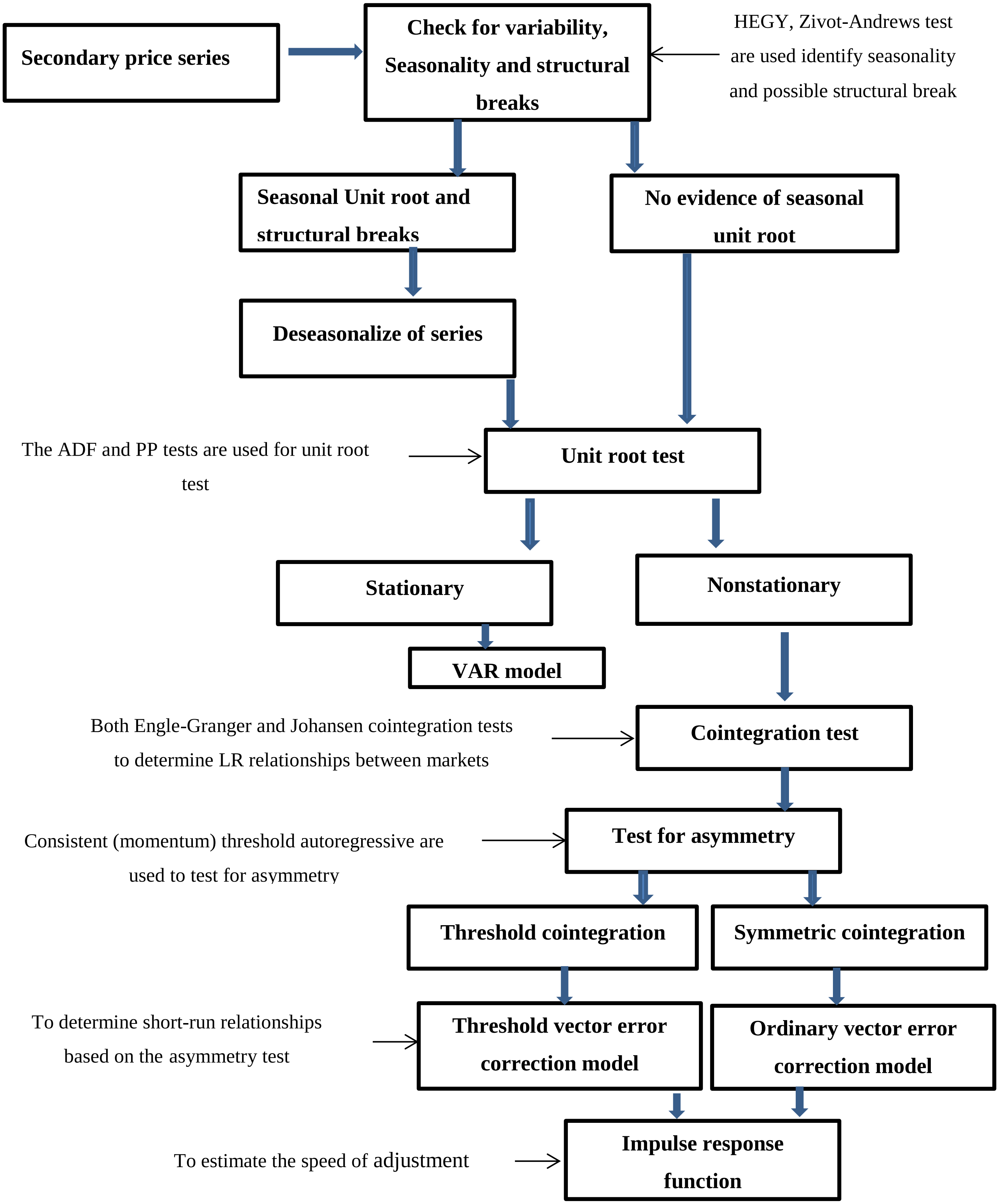

Figure 3.2 Summary of research methodology **Source**: Author

Chapter 4 - Results and discussion

4.1 Variations, seasonality and trend in market prices

Prices of agricultural commodities are known to exhibit seasonal patterns due to the seasonality involved in their cultivation. This is more so in Ghana where crop production is rain-fed and heavily dependent on the weather. Other factors which could influence agricultural prices are changes in infrastructure, government policies, behavior of market agents and shift in the consumption pattern among consumers. It is therefore imperative to have a graphical look at the series for this study in order to assess their behavior over time. Figure 4.1 shows the distribution of nominal prices of the five major markets under consideration. The line plots show cyclical movement of prices with peaks and troughs occurring almost at repeated intervals for all price series. Furthermore, the figure shows that prices peaked between June and August and are at lowest points between October and November. These periods coincide with growing and harvesting periods respectively. This is not surprising since there are no mechanisms for prolonged storage of yam in Ghana. It is observed that the Accra market, which is the main consumption market, recorded the highest prices during the peak periods due to high concentration of demand in the market. The highest jump in prices is recorded around July 2012. The cause of this huge jump is not known but could be attributed to the world food price hikes in 2012, although there were no such observations in 2007/2008. The general trend shows clearly that prices of the five markets are moving together with an increasing trend over the period.

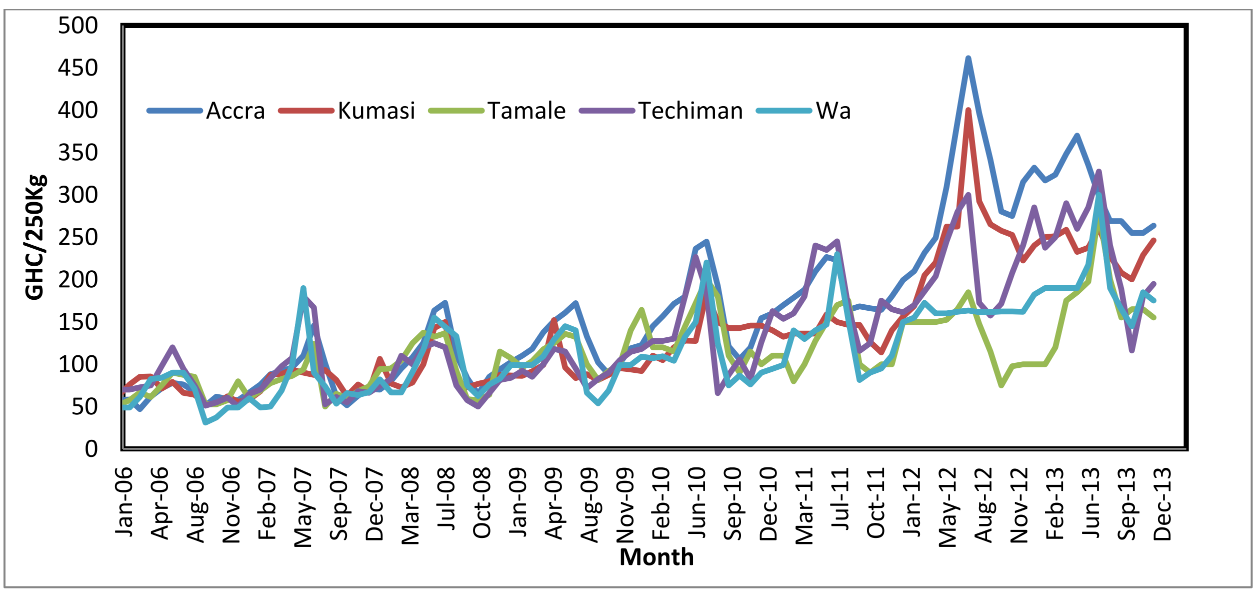

Figure 4.1 Nominal price levels of yam from 2006 to 2013 in five regional markets

Source: author

To augment the graphical behavior of the price series, a simple descriptive statistics of the regional market series are presented in table 4.1. The results show that the Accra market recording the highest unadjusted wholesale price (461.5/280Kg) and average price (GHC166.2/280Kg) whereas the Wa market records the minimum price (GHC31.0/280Kg) with the Tamale market recording the lowest average price (GHC 114.1/280Kg) amongst the five regional markets. The market with the least price variability is the Tamale market (37.3%) while the Accra market (57.9%) records the highest price variability over the period considered. The difference between the most and the least variable series is 20.6% indicating significant differences in the behavior of the various markets series. Finally, all the price series are positively skewed as shown on the descriptive statistics table with less difference between the magnitudes of the skewnesss. As noted by Otoo (2012), the positive skewness in all the series means that the series are mostly dominated by episodes of high prices which are not counterbalanced by episodes of low prices of same magnitudes.

Table 4.1 Descriptive statistics of wholesale nominal prices

Market	**Observ.**	**mean**	**Max**	**Min**	**Std. Dev**	**Coeff. Var.**	**Skewness**
AC	96	166.236	461.5	47.1	96.162	0.579	0.884
KU	96	136.365	400.0	52.5	70.861	0.520	1.099
TA	96	114.050	280.0	50.0	42.590	0.373	0.832
TE	96	137.681	327.5	50.0	70.064	0.509	0.791
WA	96	116.455	300.0	31.0	51.423	0.441	0.678

Source: Author's computation from price series

In order to review further the characteristics in the various price series, various tests are performed to ascertain the seasonality in each price. This is important because in the presence of seasonal unit roots in the series, the standard Augmented Dickey Fuller test will not have the same distribution as when there is no seasonal unit root. To examine the seasonality, each series is regressed on a monthly seasonal dummy and a constant using July as the reference month. The results which are not presented here show no evidence of seasonality in all the series. To confirm this, the HEGY auxiliary regression stated in equation (3.2) is estimated. The lag length needed to remove autocorrelation in the residuals is automatically selected using the AIC. The results from the test are presented in table 4.2.

Table 4.2 HEGY test for seasonality in price series

Frequencies	AC	KU	TA	TE	WA	Freq
π_1	1.650***	0.801***	1.311***	2.036***	1.281***	0
π_2	1.789***	0.246***	1.071***	1.873***	1.660***	Π
$\pi_3 = \pi_4$	3.101	8.145**	1.071	2.262	3.353	π/2
$\pi_5 = \pi_6$	9.298***	6.570**	7.462**	9.529***	3.351	2 π/3
$\pi_7 = \pi_8$	5.114	6.498*	2.171	5.264	3.104	π/3
$\pi_9 = \pi_{10}$	9.171***	11.294 ***	7.968**	16.580***	13.357***	5 π/6
$\pi_{11} = \pi_{12}$	5.694*	9.905 ***	2.536	8.0034**	4.137	π/6
T(lags)	64(19)	64(7)	64(6)	64(20)	64(6)	
*, ** and *** are rejected at 10%, 5% and 1% respectively						

Source: author's computation

The null hypothesis of unit seasonal root is rejected at zero and bi-monthly frequencies for all price series. The test however, produces mixed results for the joint frequencies showing the presence of seasonal unit root in all the price series apart from the KU series. The Kumasi series rejects the null hypothesis at all joint frequencies, although the rejection at the frequency of π/3 is at 10% significant level. The other markets series show seasonal units for at least two joint frequencies. Thus, at frequencies of π/2 and π/3 for AC; π/2, π/3 and π/6 for TA; π/2 and π/3 for TE and π/2, 2 π/3, π/3 and π/6 for the WA, the conventional F-statistics fails to reject the null hypothesis of seasonal unit root. Based on the rejection of the null hypothesis at most seasonal frequencies in the series coupled with insignificant seasonal dummy regressions, the study concludes that there are no seasonal patterns in the various series. In other words, seasonality is constant across all series.

4.2 Test for structural breaks and stationarity

The results from the Augmented Dickey Fuller (ADF) and Philips-peron (PP) unit root tests of all market prices are presented in table 4.3. The test is conducted at three levels: with only an intercept, with both intercept and trend and without intercept and trend for both ADF and PP using the optimal lags selected by AIC and BIC. The ADF accepts unit root hypothesis at 1% significance level for all series at level without a trend variable. A similar result is obtained for the PP test with the exception of TA and WA where the null hypothesis is rejected at 1% and 5% significant levels respectively without the trend variable. The null hypothesis is however rejected for all series in both tests when a trend term is included indicating trend stationary in all prices. Both ADF and PP tests reject existence of unit root at all significant levels for all prices series at first difference regardless of a trend variable.

Table 4.3 Test for unit root by ADF and PP

	ADF Test		PP Test	
Variable	(Lag)Level	(lag)1ST Difference	Level	1ST Difference
AC				
Intercept	(2) -1.419	(2)-6.971***	-5.890	-51.668***
Intercept +trend	(2)4.590***	(2)-6.928***	-31.071***	-51.673***
None	(2)0.743	(2)-6.921***	0.225	-51.430***
KU				
Intercept	(1)-1.122	(0)-10.897***	-4.370	-108.370***
Intercept +trend	(1) -4.063***	(0)-10.842***	-22.508**	-108.337***
None	(1) 0.698	(0)-10.886***	0.278	-108.370***
TA				
Intercept	(1)-3.569	(4)-6.337***	-20.927***	-79.372***
Intercept +trend	(1)-5.277***	(4)-6.300***	-38.307***	-79.383***
None	(1)0.179	(4)-6.328***	-1.355	-79.347***
TE				
Intercept	(4)-2.903	(0)-8.984***	-12.823*	-76.633***
Intercept +trend	(4)-5.454***	(0)-8.935***	-37.361 ***	-76.629***
None	(4)0.092	(0)-9.018***	0.095	-76.591***
WA				
Intercept	(4)-1.898	(4)-5.988***	-16.718 **	-72.416***
Intercept +trend	(4)-5.064***	(4)-5.957***	-40.807***	-72.459***
None	(4)0.429	(4)-5.987***	0.138	-72.310***

***, ** and * means rejection of null hypothesis at 1%, 5% and 10% respectively

Newey-west lag length in the PP test is 3 for all level and 1ST difference

Source: author

The stationarity test is followed by examining possible structural breaks in the data using the Zivot-Andrews unit root test. The test results, after allowing for a single break point in the intercept, the trend and/or both are presented in table 4.4.

Table 4.4 Zivot-Andrews test unit root test for structural breaks

	With Intercept	**Trend**	**Tend and Intercept**
Variable	t-min(Break Point)	t-min(Break Point)	t-min(Break Point)
AC	-6.465(2012m3)	-6.243(2012m10)	-7.216(2012m5)
KU	-4.941(2012m1)	-4.452(2009m8)	-5.417(2012m3)
TA	-6.064(2010m12)	-5.664(2010m1)	-6.087(2012m9)
TE	-6.063(2007m8)	-5.772(2008m11)	-6.000(2007m8)
WA	-6.556(2009m8)	-6.168(2011m10)	-6.525(2009m8

Critical values for intercept: 5% (-4.80) 1%(-5.34); trend: 5% (-4.42) 1%(-4.93) and both: 5% (-5.08) 1%(-5.57)

Source: author

Comparing the t-min values with the critical values at all levels of significance leads to the rejection of the null hypothesis of a possible structural break in all market series except the KU series. The null hypothesis is not rejected at all levels of specification for the KU series. It is rejected for all series at first difference at all levels of specification. In summary, the results from the HEGY, ADF, PP and Zivot-Andrews test have revealed several characteristics of the price series. The data series have little evidences of unit seasonal roots which could be rejected considering the fact that the null hypothesis is rejected at most frequencies. The tests also point to the fact that the series exhibit trend stationary process and the ADF and PP tests lead to the conclusion that series are integrated of order one i.e. I(1). The study therefore continues with the cointegration analysis. In situations where seasonality and trending could lead to spurious results, deseasonalized and detrended[2] data are used.

4.3 Determining long-run relationships between regional markets

The Engle-Granger test for cointegration is used to determine the long-run relationships between the reference market (AC) and other regional markets. The results of the first stage regression after correcting for autocorrelation in the residuals are presented in table 4.5. The slopes (β_1) which are the integration terms indicate to some extent strong integration based on the law of one price although much stronger relationships were expected. Thus, for very strong integration, the values are expected to be close to one. It is assumed that the somewhat weak relationships between the other regional market and the Accra market could be due to the long geographical distance between them. Consequently, another reference market (KU) which is also a net consumption market is used for the Engle-Granger test. Using the Kumasi as reference produces quite stronger evidence of integration between the other regional markets but not too different from using the Accra market. In both cases, long-run relationships between the KU-AC, the two net consumption markets remain the strongest. We therefore stick to the AC market as the central market since it the larger between the two and hence, remains our main focal market in this study.
However, a formal test of these parameters as a static representation of LOP will be invalid since prices used for the regressions are non-stationary. This is because the standard errors are inconsistent even though the parameters are consistent. The intercepts (β_0) represent the constant absolute margin between the local markets and the reference market. Their values are quite significant, although no formal test is performed on them. The Adjusted R^2 values show a good fit between the reference-local market pairs.

[2] Deseasonalized and detrended data are obtained by regressing the original data on seasonal dummies and trend variable respectively and adding the predicted residuals to the mean from the original data.

We proceed to the second stage regression of the test which is to examine the stationarity of the residuals from the first stage regression.

Table 4.5 Engle-Granger cointegration test results (first stage)

Local Markets	β_0	β_1	Adjusted R^2
Central market as AC			
KU	0.956(6.24)	0.776 (25.24)	0.870
TA	2.198(10.70)	0.499(12.10)	0.605
TE	0.981(4.87)	0.773(19.10)	0.793
WA	1.235(6.29)	0.692(17.56)	0.764
Central market as KU			
AC	-0.437(-2.04)	1.123(25.24)	0.870
TA	2.085(7.63)	0.539(9.51)	0.485
TE	0.588 (2.12)	0.8783(15.23)	0.709
WA	0.902(3.37)	0.783(14.09)	0.675

t-statistics in parentheses

Source: Author

The second stage of the Engle and Granger test of market integration is shown in table 4.6. We make use of the Dickey-Fuller type of equation (3.6) in chapter 3. It is found that the parameters (ρ) for all market pairs are significant at 1% when compared to Dickey-Fuller critical values except the TA-AC pair which is significant at the 5% significant level. The residuals from the first stage regression are therefore integrated of order zero I (0) and hence stationary. The null hypothesis of no cointegration between local regional markets and the reference market is rejected for all market pairs suggesting that other regional yam markets in Ghana are integrated with the Accra yam market in the long-run.

Table 4.6 Test for stationarity in the residuals

Markets	ρ(AC)	Q(12)		ρ(KU)	Q(12)
KU-AC	-0.478(-5.369)	7.242(0.841)	AC-KU	-0.462(-5.32)	9.280(0.679)
TA-AC	-0.393(-4.849)	8.451(0.749)	TA-KU	-0.362(-4.64)	17.178(0.143)
TE-AC	-0.503(-5.638)	10.721(0.553)	TE-KU	-0.456(-5.25)	14.606(0.264)
WA-AC	-0.562(-6.074)	12.400(0.414)	WA-KU	-0.487(-5.54)	19.364(0.080)

Dickey-fuller critical values are -4.014, -3.401 and -3.089 at 1%, 5% and 10% respectively and Q(4) are the probability values of Ljung-Box test statistics for autocorrelation

Source: author

The Engle-Granger results give evidence of long-run relationships between regional markets, but they are noted to have lower predictive power. It could also be noted that the results of the Engle-Granger test are sensitive to the choice the dependent variable. See AC-KU and KU-AC from table 4.6. Hence, the Johansen test of cointegration is performed for each market pair to confirm the results.

The appropriate lag lengths are selected by AIC and BIC and both the trace statistics and the Max-Eigen statistics are reported. Table 4.6 below shows the Johansen test of cointegration of the four market pairs from the Engle-Granger test. Both the Trace statistics and the Max-Eigen statistics reject the null hypothesis of no cointegration at the 1% significant conventional levels. The null hypothesis that there exists one or less cointegration vector is not rejected for the KU-AC market pair but is rejected for all other markets pairs. One advantage of the Johansen test is its ability to determine simultaneously the number of cointegrating vectors among all the markets simultaneously. The results from the simultaneous test of cointegration vectors between all the regional markets show four cointegrating equations among the five regional markets.

The Engle-Granger and Johansen tests therefore provide enough evidence that there is a long-run equilibrium relationship between regional yam markets. Thus, linear combinations of other regional markets and the reference market produce stationary results indicating that there are co-movements of market prices in the long-run.

Table 4.7 Results of Johansen cointegration test

Markets pairs	Trace H_0	Trace Statistics	Max H_0	Max-Eigen Statistic
KU-AC	r = 0	32.869***	r = 0	30.523***
	r ≤ 1	2.346***	r = 1	2.346
TA-AC	r = 0	26.534***	r = 0	22.506***
	r ≤ 1	4.028	r = 1	4.028
TE-AC	r = 0	30.872***	r = 0	26.247***
	r ≤ 1	4.625	r = 1	4.625
WA-AC	r = 0	45.214***	r = 0	40.263***
	r ≤ 1	4.951	r = 1	4.951

Trend specification: unrestricted constant in model. Dickey-fuller critical values are -4.014, -3.401 and -3.089 at 1%, 5% and 10% respectively.

Source: Author

4.4 Threshold cointegration and asymmetric adjustment

Having ascertained that different market pairs have long-run equilibrium relationships, the threshold autoregressive (TAR) and momentum threshold autoregressive (M-TAR) models are used to verify whether the cointegration exhibited is symmetric or asymmetric. The results of the threshold TAR and M-

TAR models are presented in table 4.8 and 4.9 respectively. The models are estimated at zero threshold levels and in each case, the Ljung-Box test (Q) test for autocorrelation is performed to ensure there is no serial correlation in the residuals. The test statistics are compared with Φ and Φ(M) -statistics generated by Enders and Siklos (2001) to make a decision on the null hypothesis of no cointegration *i.e* $\rho_1 = \rho_2 = 0$.

Table 4.8 Threshold autoregressive results (τ = 0)

Estimates	KU-AC	TA-AC	TE-AC	WA-AC
ρ_1	-0.579 (-4.03)	-0.432 (-3.49	-0.433(-3.11)	-0.701 (-5.46)
ρ_2	-0.469 (-3.26)	-0.363 (-3.36)	-0.554(-4.73)	-0.416 (-3.17)
$\rho_1 = \rho_2 = 0(\Phi)$	10.77***	11.74***	16.02***	19.92***
$\rho_1 = \rho_2$(F-Test)	0.39	0.17	0.44	2.40
Q(12)	8.0314 (0.7827)	8.0589(0.781)	11.914(0.453)	13.638(0.324)
AIC	-90.14694	-48.866	-34.567	-34.719
Lag(s)	0	0	0	0

t-statistics in parentheses and Q(12) is the probability value of Ljung-Box statistics. *, ** and *** are rejected at 10%, 5% and 1% significant levels respectively.

Source: author

Table 4.9 Momentum threshold autoregressive model (τ = 0)

Estimates	KU-AC	TA-AC	TE-AC	WA-AC
ρ_1	-0.559(-3.51)	-0.351 (-3.24)	-0.494 (-4.27)	-0.364 (-2.72)
ρ_2	-0.465(-2.91)	-0.447 (-3.63)	-0.517 (-3.64)	-0.733 (-5.90)
$\rho_1 = \rho_2 = 0$	8.02**	11.84***	15.73***	21.09***
$\rho_1 = \rho_2$	0.25	0.34	0.02	4.08**
Q(12)	6.7542(0.8734)	7.621 (0.8140)	10.528(0.570)	14.565(0.2661)
AIC	-86.274	-49.038	-34.129	-36.385
Lag(s)	-	-	-	-

t-statistics in parentheses and Q(12) is the probability value of Ljung-Box statistics. *, ** and *** are rejected at 10%, 5% and 1% significant levels respectively.

Source: Author

From the results above, the null hypothesis is rejected for all market pairs at all significance levels since the Φ-statistics is larger than the critical value i.e. 8.24 and 8.78 for no lagged change for the two variable case, for both TAR and M-TAR respectively (see table 1A in appendix for critical values).

This leads to the test of symmetric adjustment ($\rho_1 = \rho_2$) of prices between the market pairs. The test statistics fails to reject the null hypothesis for the TA-AC and TE-AC market pairs, but rejects the null hypothesis for all market pairs in the TAR model. For the M-TAR, the test statistics also fails to reject the null hypothesis for all market pairs except the WA-AC which is rejected at 5% significance level. We therefore compare results from TAR and M-TAR for the WA-AC market pair based on AIC values. It can be seen that the M-TAR specification for WA-AC performs better than TAR since the M-TAR has the lowest AIC value. The remaining market pairs: KU-AC, TA-AC and TE-AC therefore exhibit symmetric adjustments such that deviations from equilibrium price are not different regardless of a decrease or an increase in shocks. The WA-AC however, exhibits threshold adjustment with asymmetric adjustment in response to changes in Accra's market price. Thus the point estimates of ρ_1 = -0.701 and ρ_2 = -0.416 mean 70% of positive deviations and 42% of negative deviations are eliminated within a period of month. This result is contrary to other studies such as Ankamah (2012) where negative deviations are eliminated faster than positive deviations, although this study is a different commodity market. This could be due to differences in the choice of the reference market since his study uses a net production market as the reference market as opposed to the net consumption market in this study. It suggests consumers act more actively when there is a price fall in order to restore equilibrium than when there is a price increase. The reverse could be said for producers.

The TAR and M-TAR results here above are estimated at critical zero threshold ($\tau = 0$) without knowing the true value. A methodology proposed by Chan (1993) to estimate the consistent TAR and M-TAR deals with this. The method involves a grid search for the true critical threshold value. The consistent TAR and M-TAR results are presented in the table 4.10 and 4.11 respectively.

Again, the null hypothesis of no cointegration is rejected for both the consistent TAR and M-TAR when the test statistics are compared with the critical values provided by Enders and Siklos (2001). The test for symmetric adjustments ($\rho_1 = \rho_2$) shows symmetric adjustment between all market pairs under the consistent TAR except for WA-AC which is rejected at 10% significance levels. But the test reveals asymmetric adjustment for KU-AC, TA-AC and TE-AC markets under the consistent M-TAR at 10%, 5% and 5% significance levels respectively as noted in table 4.11.

Table 4.10 Consistent Threshold Autoregressive result

Estimates	**KU-AC**	**TA-AC**	**TE-AC**	**WA-AC**
τ	-0.00339	-0.2284845	0.0201902	0.00943
ρ_1	-0.497 (-3.49)	-.441(-3.88)	-0.501 (-3.49)	-0.864 (-6.20)
ρ_2	-0.458(-3.36)	-.342(-2.94)	-0.665 (-5.02)	-0.554 (-4.02)
$\rho_1 = \rho_2 = 0$	14.29***	11.86***	16.840**	23.90***
$\rho_1 = \rho_2$	0.050	0.370	0.800	2.98*
Q(12)	8.059(0.7805)	7.564(0.818)	7.632 (0.813)	12.084 (0.439)
AIC	-88.470	-49.065	-34.399	-38.438

t-statistics in parentheses and Q (12) is the probability value of Ljung-Box statistics. *, ** and *** are rejected at 10%, 5% and 1% significant levels respectively.

Source: Author

Table 4.11 Consistent Momentum Threshold Autoregressive results

Estimates	**KU-AC**	**TA-AC**	**TE-AC**	**WA-AC**
τ	0.1230	-0.11713	0.2384932	0.1074766
ρ_1	-0.692(-4.56)	-0.277(-2.93)	-0.785(-5.16)	-0.619 (-3.10)
ρ_2	-.369(-3.42)	-0.669(-4.59)	-0.365(-3.42)	-0.546 (-5.20)
$\rho_1 = \rho_2 = 0$	16.21***	14.81***	19.14***	18.32***
$\rho_1 = \rho_2$	2.99*	5.09**	5.11**	0.11
Q(12)	5.293(0.948)	8.128(0.775)	14.827(0.251)	11.967(0.4483)
AIC	-91.429	-53.755	-39.197	-32.40982

t-statistics in parentheses and Q(12) is the probability value of Ljung-Box statistics. *, ** and *** are rejected at 10%, 5% and 1% significant levels respectively.

Source: Author

Comparing the consistent TAR and consistent M-TAR based on the AIC for WA-AC shows the consistent TAR performs better. This means WA-AC market pair exhibits symmetric adjustment to some extent. For the three market pairs which exhibit asymmetric adjustment, the AIC values show that the consistent M-TAR specification performs better than the consistent TAR specifications. Thus in all cases the consistent M-TAR outperformed the consistent TAR for all market pairs since they have minimum AIC values apart from the WA-AC. The Ljung-Box test diagnostics performed for all the models show no serial correlation in the residuals, since the probability values for the test statistics are high enough to reject autocorrelation.

Generally, the performance of the consistent and non-consistent TAR and M-TAR are similar based on AIC values calculated. However, we opt for the consistent models since the zero threshold assumption for the non-consistent TAR and M-TAR could be too strong. Based on this reason and model performance revealed by AIC, the models selected for further analysis and inference are the consistent M-TAR for KU-AC, TA-AC, TE-AC and consistent TAR for WA-AC.

The result from the consistent TAR for WA-AC in table 4.10 shows point estimates of ρ_1 = -0.619 and ρ_2 = -0.546. These values imply that approximately 62% of positive and 55% of negative price deviations from equilibrium are eliminated within a period of one month. Thus, given that price series are at equilibrium at period *t* but are moved out of this equilibrium by invisible market forces to new equilibriums, then the results show that parts of the discrepancy from equilibrium will be eliminated in the process. The rate at which the discrepancy is eliminated depends on whether the direction of shock is positive or negative for asymmetry adjustment. For the WA-AC price pars, 62% of the discrepancy is eliminated if the shock is positive and 55% if otherwise. This further implies that 38% of positive discrepancy and 45% of negative discrepancy is carried over to the next month. Hence, the WA-AC market responds quickly to shocks which increase profit margins between the two markets than shocks which decrease the profit margin.

A similar trend is observed for the KU-AC and the TE-AC price pairs. In the KU-AC 69% of positive and 37% of negative deviations are eliminated within a period of one month meaning that 31% and 67% of positive and negative discrepancies respectively persist for the following month. Again, this implies that the market pair responds more quickly to shocks that stretch the profit margins than shocks that squeeze the profit margins. For the TE-AC markets, approximately 79% of positive deviations and 37% of negative discrepancies are eliminated after one month.

The TA-AC price pair however, responds differently to price shocks. From table 4.11, approximately 27% of positive deviations and 67% of negative deviations are eliminated within one month. This price pair therefore responds more quickly to shocks which squeeze the profit margin than those which stretch them. In other words, price falls are quickly adjusted compared to price increments between these two markets. For prices between the different market pairs to adjust in the long-run when there is a disequilibrium, it is expected that deviations exceed a certain threshold value due to the transaction costs borne by market agents in the adjustment process. Using the threshold values generated as proxy for transaction cost between market pairs as often hypothesized, we see that deviations must exceed certain values before adjustments are triggered for the true models selected. Thus, for KU-AC and TA-AC, absolute price deviations must exceed 12% before adjustment towards long-run equilibrium is triggered. For the TE-AC and WA-AC, absolute price deviations must not be less than 23% and 0.9% respectively in other to have an adjustment towards long-run equilibrium initiated.

4.5 Short-run relationships between regional markets

Having established that there are long-run relationships between other regional markets and the reference market, the study seeks to analyze the short-run dynamics between the price series using the Vector Error Correction Model (VECM). Table 4.12 below shows the asymmetric and symmetric VECM results from equation (3.11) and (3.12).

The estimation of the VECM is based on results from the consistent threshold models. This means for price pairs which exhibit consistent TAR cointegration, we estimate threshold VECM and vice versa. Thus, the momentum threshold VECM is estimated for KU-AC, TA-AC AND TE-AC price pairs while threshold VECM is estimated for WA-AC pair. For each model, we perform normality as well as the Ljung-Box Q test on the residuals to ensure that residuals are white noise processes and follow a normal distribution. The probability values at lag 12 of the Ljung-Box Q test are presented in tables of each model. Also since the influence of the reference market is expected to be distributed over time, the AIC is used to determine pre-estimation lag lengths for each model. The adjusted R^2 of each model is reported to show the extent to which variations in the dependent variables are explained by the right hand side variables.

Adjustment of local markets to restore equilibrium are measured by the $z_plus_{t-1}$and z_minus_{t-1} values for each model. These values therefore indicate how quickly deviations in the long-run are corrected. It can be seen from the first market pair, the KU-AC in table 4.12, that the adjustment coefficients are significant for both positive and negative deviations at 10% and 1% levels respectively. The point estimates show that the KU market adjust to eliminate 49% of a unit positive deviation within a month while it adjusts to eliminate 34% of a unit negative deviation created by the AC market within the same period. The AC market model also has both highly significant adjustments to positive and negative deviations from equilibrium, although the speed of elimination of positive deviations is lower compared to the KU model. For negative deviations, the AC models adjust quickly compared to the KU model. There is therefore, asymmetry in terms of speed of adjustment for positive and negative deviation between KU and AC. Thus, even though both markets respond to positive and negative price deviations from equilibrium, the speed of response differs depending on whether deviations are positive or negative.

Table 4.12 Vector error correction model results

Momentum Threshold VECM models						
	ΔKU	**ΔAC**	**ΔTA**	**ΔAC**	**ΔTE**	**ΔAC**
constant	0.006(0.42)	0.013(0.93)	-0.005(-0.26)	0.017(1.19)	-0.012(-0.56)	0.013(1.19)
ΔAC	0.493(4.79)***		0.587(4.28)***		0.473(4.93)***	
ΔAC_{t-1}	-0.012(-0.10)	0.424(4.22)***	0.232(1.50)	0.231(2.11)**	-0.064(-0.37)	0.102(1.10)
ΔAC_{t-2}	-.042(-0.36)	-0.190(-1.82)*	0.009(0.06)	-0.268(-2.7)***	0.139(0.95)	-0.22(2.95)***
$\Delta\ KU$		0.429(4.79)***				
ΔKU_{t-1}	-.083(-0.70)	0.012(0.11)				
ΔKU_{t-2}	-.091(-0.87)	0.104(1.07)				
ΔTA				0.302(4.28)***		
ΔTA_{t-1}			-.015(-0.13)	0.155(1.86)*		
ΔTA_{t-2}			-.017(-0.16)	0.045(0.58)		
ΔTE						0.343(7.67)***
ΔTE_{t-1}					-0.025((-0.19)	0.177(2.68)***
ΔTE_{t-2}					-0.227(-1.93)*	0.185(3.02)***
z_plus_{t-1}	-0.488(-3.92)***	0.336(2.80)***	-0.381(-3.2)***	0.043(0.48)	-0.636(-2.15)**	0.353(2.23)**
z_minus_{t-1}	-0.342(-1.96)*	0.450(2.83)***	-.444(-2.47)**	0.172(1.30)	-0.493(-3.8)***	0.149(2.01)**
Q(12)	12.33(0.410)	15.493 (0.216)	6.313(0.899)	17.805 (0.121)	3.631(0.989)	9.060(0.698)
F-statistics	7.28***	10.13***	7.91***	8.40***	12.42***	22.25***
Adj. R^2	0.323	0.410	0.345	0.360	0.465	0.618
SR_F-stat	10.54***	8.70***	9.38***	7.73***	20.39***	26.53***
ARCH(1) test	2.003	3.520	0.771	1.438	0.244	0.077
Threshold VECM Model						
	ΔWA	**ΔAC**				
Constant	0.066(2.10)**	0.008(0.34)				
ΔAC	0.554(3.85)***					
ΔAC_{t-1}	-0.099(-0.61)	0.276(2.51)**				
ΔAC_{t-2}	-0.025(-0.17)	-0.292(-3.00)***				
ΔWA		0.268(3.85)***				
ΔWA_{t-1}	0.327(2.84)***	0.132(1.60)				
ΔWA_{t-2}	0.055(0.51)	0.069(0.92)				
z_plus_{t-1}	-0.144(-2.07)***	0.115(0.74)				
z_minus_{t-1}	-0.365(-1.89)*	0.0533(0.39)				
Q(12)	2.866(0.379)	16.108 (0.186)				
F-statistics	12.91***	8.75***				
Adj. R^2	0.475	0.371				
SR_F-stat	5.80***	8.82***				
ARCH(1) test	0.116	2.024				

Source: author's computation

For TA-AC pairs, TA responds to both negative and positive deviations in the long-run price equilibrium when there is a change in AC market prices. The AC does not respond to the changes in TA market prices. The response of the TA prices to the AC is faster for negative deviation (44%) compared to a positive deviation (38%) indicating negative asymmetry. In the final momentum threshold VECM, the feedback mechanisms between prices of the TE-AC pair were symmetric in the sense that positive discrepancies from equilibrium adjust faster than negative discrepancies regardless of which of the two markets is used as the dependent variable.

The p-values of the SR_F-statistics for all the market in table 4.12 are significant at the 1% significant level. This suggests contemporaneous and lagged changes of the independent variables (central market) in each of the market pair significantly stimulate a response from the dependent variables (local markets) in the short-run. This means we reject the null hypothesis that there are no short-run linkages between all markets pairs. There is therefore two-way causality between all market pairs and hence an indication that regional yam markets in Ghana are not segmented. The significant contemporaneous effects for all market pairs mean that for instance, a 1% increase in AC market leads to 0.49%, 0.59% and 0.47% increases in the KU, TA and TE markets respectively. This implies a decline in the marketing margin by 0.51%, 0.41% and 0.53% respectively. In the reverse situation, a 1% increase in the KU, TA and TE market prices will increase prices in the AC market to 0.43%, 0.30% and 0.34% respectively.

From the threshold VECM, the results show that there is an asymmetry in terms of price feedbacks for the WA-AC market pair. Thus, the point estimates suggest that the WA adjust to eliminate 14% and 37% of positive and negative deviations caused by the AC market respectively, while the AC market neither adjust to positive nor negative price deviations caused by WA markets. However, the joint hypothesis of no short-run relationship is rejected at the 1% significance levels meaning there is a short-run linkage between the two markets. This means the linkage is bi-directional as expected. Again, the contemporaneous effect of a 1% increase in the price of the AC market leads to a 0.55% increase in the WA market while a similar percentage increase of the WA market leads to a 0.27% increase in the AC markets.

4.6 Impulse response estimation

From the various error correction models, we construct the impulse response functions. This gives information about the magnitude of response to a price change in one market and the time needed to restore equilibrium after a shock in the central market. For asymmetric adjustments, the response to a price shock is dependent on the history of the time series as well as the sign (positive or negative) and magnitude of the shock. Positive shocks are defined as shocks that lead to increment of the profit margin for actors in the local markets *i.e* when there is a decrease in the reference or central market price while negative shocks lead to a decrease in the profit margin of agents in the local markets (*i.e* increase in prices of the reference market). The estimation of the impulse response function therefore helps to know the time path required for a unit standard deviation shock in the central market to be eliminated from the VECM models above.

As noted in table 4.12, our market pairs in the VECM are KU-AC, TA-AC, TE-AC and WA-AC. It can be seen from the KU-AC pair that a 1 unit change in AC market price stimulates a 0.49 unit price change in the KU market. If this change in the AC price is a 1% decrease/increase (*i.e* a positive/negative shock to the profit margin of actors) then the KU market responds by increasing/decreasing by 0.49% (*i.e* fall/rise in profit margins of actors). The decrease and increase in the profit margin by 0.51% (1-0.49) is asymptotically corrected by a factor of 0.49 and 0.34 per period respectively in the following months as the AC prices continue to increase or decrease. In the reverse situation, 1% change in KU market price changes the AC market price by 0.43% leading to a 0.57%(1-0.43) shock to the profit margin. This is corrected by a factor of 0.34 and 0.45 per period of one month for a decrease or increase respectively. The results of the impulse response presented in figure A.1 and A.2 in appendix for KU-AC pair show that price transmission from AC markets to KU market and vice versa. From the figure, it takes approximately 14 months for KU market margins to return to equilibrium after experiencing a negative shock (thus, when there is an increase in AC market prices). However, it takes within 11months to return to equilibrium when there is a positive shock (*i.e* when there is a decrease in AC market prices). For the AC market response to changes in KU market prices, negative shocks are restored within 10 months while positive shocks take approximately 13 months.

Following similar reasoning from the discussion above, the TA-AC impulse response function shows that it takes approximately 16 months for the TA market price to adjust to negative shocks caused by AC markets whereas it takes 9 months to adjust to positive shocks. The AC on the other hand, takes within 18 months to adjust to negative shocks in the TA market whereas positive shocks persist for a long time. For the TE-AC market pair, the TE adjusts to restore equilibrium within 11 months for negative shocks caused by AC while it takes within 8 months to adjust for a positive shock. The AC takes approximately 24 and 15 months to adjust for negative and positive shocks caused by changes in the TE market prices respectively. Lastly, between the WA-AC market pair, the WA market adjusts within 11 months to establish equilibrium in response to negative shocks caused by the AC prices while it takes 26 months to adjust to positive shocks. In reverse, the AC takes 27 months to adjust to negative shocks caused by the WA market whereas positive shocks persist for a very long time.

The rationale behind market integration studies using price transmission as mentioned in the introductory chapter is to assess the efficiency of markets. This helps to avoid duplication of interventions (Goletti *et al.* 1995). Thus, taking our five regional markets, the evidence of short-run and long-run relationships we have established mean that a policy intervention in the reference market (AC) will eventually, be experienced by all four other regional markets. For instance, any policy that leads to shortage in the AC market is expected to lead to shortages in the KU, TA TE and WA markets. This is very important for a developing country like Ghana where many depend on agriculture for livelihoods. A government policy to raise price of yam producers could be initiated in the AC market. This also means that other commodities which are complements or substitutes to yam could also be influenced through the yam market. Nonetheless, the impact on of yam market integration on substitutes or complement commodities is another broad area of price transmission studies which deals with inter-commodity. For instance, cassava serves as substitute for some poor household in Ghana. This means, a study to assess the inter-commodity price relationships between yam and cassava could be interesting to look at.

Our results point to the fact that there should be regional balance of yam since the markets are linked. As stated in the chapter 1, yam production takes place in 7 out of the 10 regions in Ghana. Even though, we studied only 5 regional markets, we expect the remaining markets to behave in a similar way. If that happens to be the case, then a balance is expected between the yam-deficit and yam-surplus markets (Delgado, 1980). This means households who depend on the crop may rely on the market system for supply provided there is enough production from farmers.

However, the somewhat long periods of adjustment and the asymmetry of feedback between some regional market pairs are worth pointing out. This implies the feedback received by producers and consumers differ, when there is a shock to the market system equilibrium. The non-linear adjustment and slow speed mean that there remain some impediments to full efficiency of yam markets in Ghana. Von Cramon-Taubadel (1998) gave some reasons why we might observe such asymmetric relationships at different market levels. Some of these factors include: delays in transportation from one region to another; adjustment costs borne by market agents; market power, government interventions; price spreads between the central and local markets and the mode of price data collection. Other factors include the inventory/stock management behavior of market actors (Langyintuo, 2010), lack of bi-directional information flow between markets (Abdulai 2000).

As noted by Ankamah (2012), for maize markets in Ghana, specific causes of asymmetries cannot be pointed out directly. This is more so for this study, since we did not model explicitly, structural and behavioral factors as found in Goletti *et al*. (1995). Nonetheless, a closer look at the yam marketing dynamics in Ghana gives some indications of a few possible causes. Firstly, although the commodity is not stored for long periods due to lack of storage facilities, transportation from one region takes a lot time due to their bulky nature and the poor road connecting some of the local markets with the reference market. The water transportation routes also take several days due to lack of Ferries and slow canoe transportation. This could lead to delay in delivery and hence prevent swift adjustment of prices between regional markets. We could also point out that the capacity of traders to determine the time of release of products into markets to be a likely cause (Langyintuo, 2010). However, the perishable nature of yam, which inhibits prolonged stocking, leaves this assertion open to verification. The issue of market power and government intervention mentioned in some literature could be potential causes in the yam market. Since we did not attempt to model market power in the process, we neither reject nor accept this as a possible cause of asymmetry. On government interventions, although there have been several government intervention in the root crop sector, such as the RTIMP, we do not have any evidence of market distortion from such policies. However, information flow between markets can be ruled out since high penetration of Information Communication Technology tools, such as mobile phones, have aided easy information flow among regional markets. In any case, they could be the main reason why we find linkages between regional markets both in the short-run and in long-run. Finally, on the mode of price recording, this could be a very important factor considering the sensitivity of price transmission models to data frequency (Amikuzuno, 2010). The data used for this study is a monthly data, which are recorded by averaging weekly market prices. This may lead to loss of important information contained in the price series. Since high frequency data are noted to capture the dynamics of price transmission better (Amikuzuno (2010), we may also attribute the asymmetry to in the data recording process. A higher frequency data, such as weekly, is needed to verify this claim.

Chapter 5 – Summary and conclusion

Intermittent fluctuations in world food prices raise food security concerns in many developing countries including Ghana. Over the past decades, governments in Ghana and other donor partners have invested in the root and tuber crop sector with the sole objective of boosting production in such crops where the country is self-sufficient in terms of food balance sheets. However, the issue of distribution remains a major problem without efficient marketing system. A well-integrated marketing system is needed to distribute food from surplus regions to deficit regions. This will help improve welfare of both consumers and producers of agricultural commodities and more so, considering the fact that the agricultural sector is the second largest employer in Ghana. A good knowledge of price mechanisms also helps policy makers to avoid duplication of interventions in markets that are linked. The author is also of the view that market integration studies have focused mainly on the grain/cereal sector and much less on the root crop sector.
The objective of this study is therefore to determine the dynamics and price mechanism between the regional yam markets in Ghana. By so doing, we adopted the cointegration approach to determine the long-run relation and the vectors error correction model to determine the short-run relationships between the central market (Accra) and local markets (Kumasi, Tamale, Techiman and Wa). We sought to also determine whether there are linear or non-linear adjustments between the central market and other regional markets as well as time period required for adjustments with the help of the consistent threshold models and impulse response functions.

The study used secondary monthly wholesale price data from 2006 to 2013 to achieve its objectives. Preliminary investigations of the price series show all the prices series are positively skewed meaning there are possibly episodes of high price increases which are not counterbalanced by the same magnitude of price falls. The coefficient of variations also showed quite significant differences between the various price series. Stationarity assessment of the data revealed that they are all integrated of order one processes. Thus, price series are non-stationary at levels without trend, but become stationary at first difference. There was also no evidence of structural breaks in the data. The results for the main objectives presented and discussed in chapter 4 show both short-run and long-run linkages between the central market and other regional yam markets in Ghana. This shows that regional yam markets are integrated and not isolated. These findings contradict Acquah *et al.* (2012) about cassava markets. We attribute this to the fact that yam is more traded compared to cassava in Ghana. Yam is also exported and this could drive linkages between the different regional markets.

However, we find adjustments between market pairs after a price shock to exhibit asymmetric feedbacks with many markets responding faster to positive than negative shocks caused by the Accra market. Thus, the Kumasi, Tamale and Techiman markets adjust faster to positive shocks (*i.e* deviations that increase profit margin) whiles only the Wa markets adjust faster to negative shock (*i.e* deviation that decrease the profit margin) caused by the Accra market. The adjustments of the Accra market in response to shocks caused by other regional markets were mixed and in some cases the shocks persisted, indicating unidirectional feedbacks.

We attribute the linkage between regional yam markets to improvement in communication tools, such as mobile phones over the past decade. We point out a few possible causes of asymmetry. Improvement in other infrastructures such as roads and efficient trucks for transporting the commodity could see much of the asymmetries eliminated between regional yam markets in Ghana.

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Appendix A

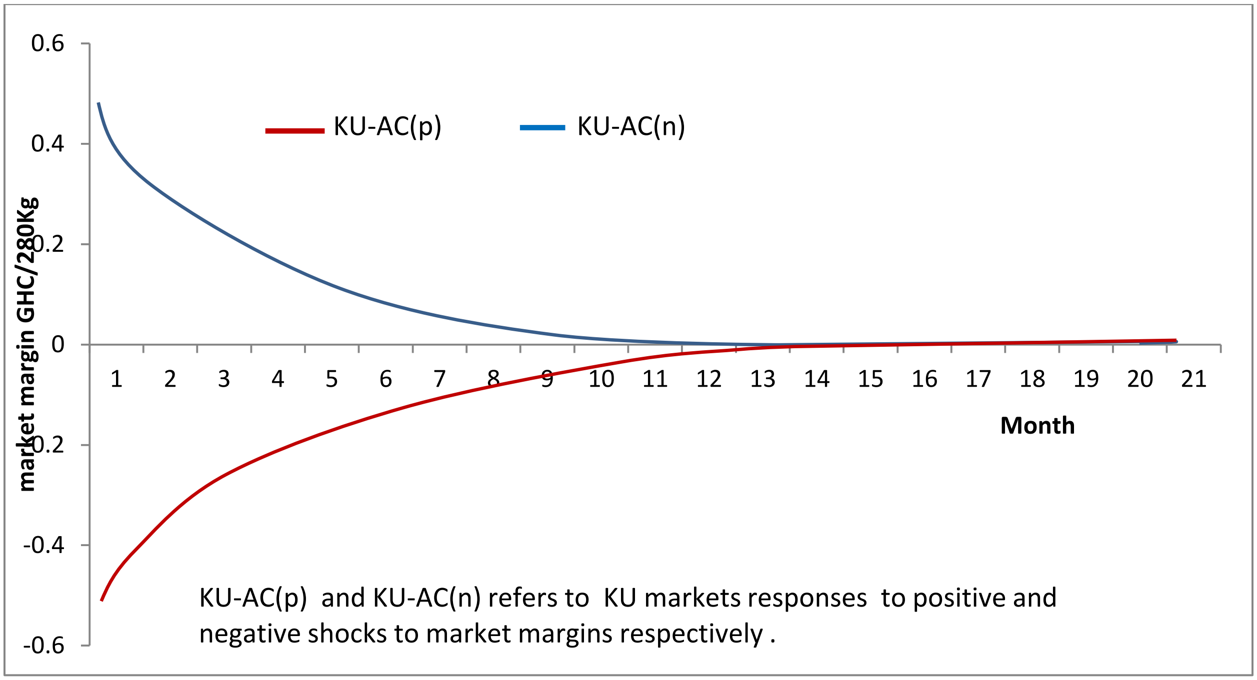

Figure A.1 Response of KU market to shock in AC market price **Source:** Author

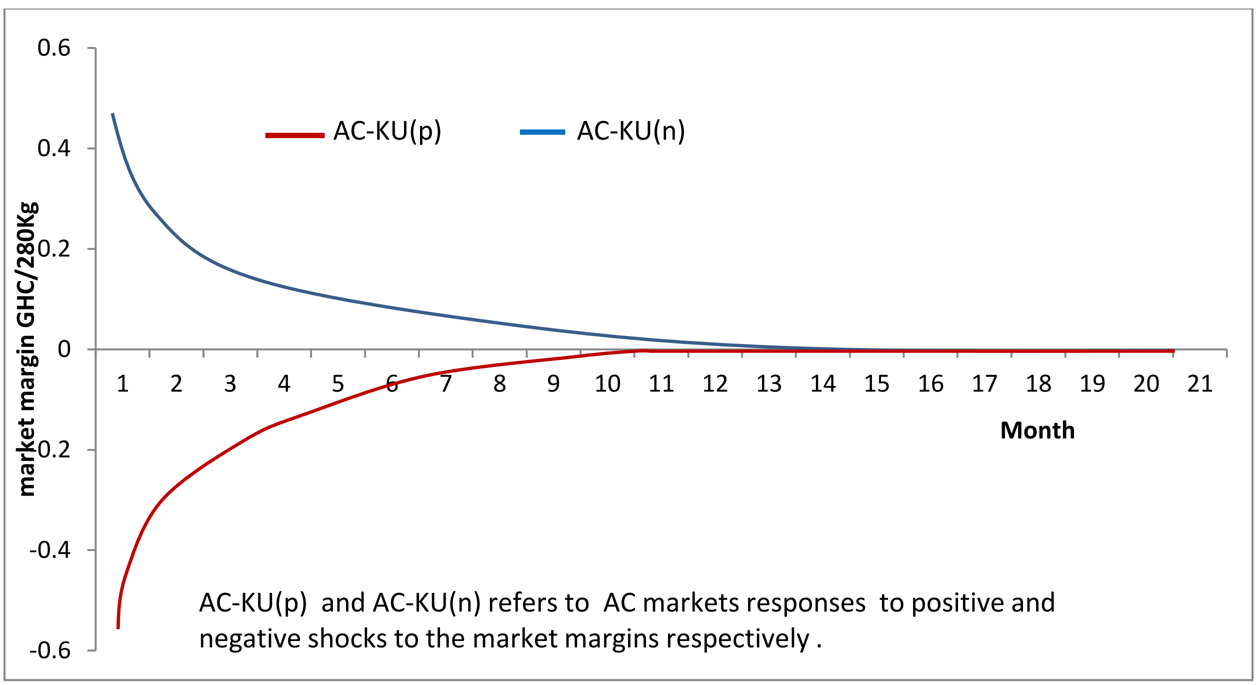

Figure A. 2 Response of AC market to shock in KU market price **Source:** Author

Table A.1 Critical values for TAR and MTAR test (τ=0)

	No lagged changes			*One lagged change*			*Four lagged changes*		
Obs.	*90%*	*95%*	*99%*	*90%*	*95%*	*99%*	*90%*	*95%*	*99%*
				Panel A TAR adjustment					
50	5 09	6 20	8 78	5 08	6 18	8 67	5 22	6.33	9 05
100	5 01	5 98	8 24	4 99	6 01	8 30	5 20	6.28	8 82
250	4 94	5 91	8 08	4 92	5 87	8 04	5 23	6 35	8 94
500	4 91	5 85	7 89	4 88	5 79	7 81	5 21	6 33	9 09
				Panel B M-TAR adjustment					
50	5 59	6 73	9 50	5 56	6 67	9 32	5 32	6.39	8 89
100	5 45	6 51	8 78	5 47	6 51	8 85	5 20	6 20	8 46
250	5 38	6 42	8 61	5 36	6 38	8 62	5 13	6 12	8 26
500	5 36	6 35	8 43	5 32	6 28	8 40	5 06	6 05	8 31

Source: Enders and Siklos (2001)

Table A.2 Critical values for TAR and MTAR test (τ is unknown)

	No lagged changes			*One lagged change*			*Four lagged changes*		
Obs	*90%*	*95%*	*99%*	*90%*	*95%*	*99%*	*90%*	*95%*	*99%*
				Panel A TAR adjustment					
50	6 05	7 24	9 90	6 20	7 31	10 00	6 79	8 05	11 05
100	5 95	6 95	9 27	6 02	7 08	9 51	6 35	7 41	9 88
250	5 93	6 93	9 15	5 92	6 93	9 18	6 44	7 56	10 18
				Panel B. M-TAR adjustment					
50	5 97	7 12	9 96	5.99	7 14	9 93	5.99	7 11	9 79
100	5.73	6 78	9 14	5 76	6 86	9 29	5 52	6 56	8 91
250	5.58	6 62	8 82	5 57	6 63	8 84	5 32	6.32	8 47

Source: Enders and Siklos (2001)