ESSAYS ON DYNAMICS OF CATTLE PRICES IN THREE DEVELOPING COUNTRIES OF MALI, KENYA, AND TANZANIA

A Dissertation

By

JEAN-CLAUDE BIZIMANA

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

May 2012

Major Subject: Agricultural Economics

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ABSTRACT

Essays on Dynamics of Cattle Prices in Three Developing Countries of Mali, Kenya, and Tanzania. (May 2012)

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One of the growing agricultural subsectors in developing countries is livestock. Livestock and livestock products account for a third of the agricultural gross output. However, the lack of viable livestock market information systems to increase efficiency of markets and support the decision making of traders, pastoralists, and policy makers are still an obstacle for a full development of this subsector. It is along these lines that the USAID, through the Global Livestock-Collaborative Research Support Program, supported the introduction of livestock market information systems in Kenya and Tanzania in 2003, and later in Mali in 2007.

The overall objective of the dissertation is to test for cattle markets integration in three African developing countries of Mali, Kenya, and Tanzania. One way of assessing the efficiency of market and the impacts of liberalization policies is to test for market integration and price transmission. We also analyzed price leadership among the markets in each of the three case studies.

Autoregressive models (vector autoregressive models and error correction model) were used to determine the level of cattle market integration.

The results show a low level of cattle markets integration in Mali. The cattle markets in Mali are more-or-less independent with regard to price transmission among markets. Kenya cattle markets showed a good level of integration among the markets. Chepareria market in the Rift Valley region (west) seemed to lead other markets in price signal transmission. Tanzanian cattle markets exhibited a higher level of integration with Pugu market, in Dar es Salaam, leading other cattle markets in price signal transmission.

In conclusion, the cattle markets in Tanzania and Kenya appeared to have a relatively higher level of market integration compared to the cattle markets in Mali. There is a reasonable belief that the time the livestock market information system has been in place, in each country, played a role in the market integration process. More time and better communications seem to have allowed the market actors to learn arbitrage skills and strengthen their trade relationships that ultimately led to the market integration.

DEDICATION

"Be strong and take heart, all you who hope in the LORD"

(Ps 31:24 NIV)

To:

My wife Ignacie

My children Jayden and Keagan

In loving memory of my sister Claudine

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NOMENCLATURE

ADB	African Development Bank Group
ADF	African Development Fund
ASAL	Arid to Semi-Arid Lands
CATS	Co-integration Analysis for Time Series
CPI	Consumer Price Index
CV	Coefficient of Variation
DAG	Directed Acyclic Graph
DNPIA	Direction Nationale des Productions et des Industries Animales
ECM	Error Correction Model
ERS	Elliot, Rothemberg and Stock test
FAO	Food and Agriculture Organization
FEVD	Forecast Error Variance Decomposition
GDP	Gross Domestic Product
GL-CRSP	Global Livestock- Collaborative Research Support Program
HQ	Hannan Quinn
IGAD	Intergovernmental Authority for Development
IMF	International Mometary Fund
IRF	Impulse Response Function
ILRI	International Livestock Research Institute
KNBS	Kenya National Bureau of Statistics

LEWS	Livestock Early Warning System
LINKS	Livestock Information Network and Knowledge System
LMIS	Livestock Market Information System
LOP	Law of One Price
MLPI	Mali Livestock and Pastoralist Initiative
OLS	Ordinary Least Square
OMA	Observatoire du Marche Agricole
RATS	Regression Analysis for Time Series
RMSE	Root Mean Square Error
SAP	Structural Adjustment Program
SL	Schwartz Loss
SMS	Short Message Service
USAID	United State Agency for International Development
VAR	Vector Autoregression
VMA	Vector Moving Average
WB	World Bank

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CHAPTER I

INTRODUCTION

1.1 Livestock and markets in developing countries

1.1.1 Livestock commodities

The majority of the 1.5 billion people in the world who make their living from farming are located in the tropical regions of developing countries and use small plots of land with rudimentary tools (Robbins 2003). Agriculture employs more than half of the total labor force in developing countries and almost three quarters in lower-income developing countries (FAO 2002).

One of the growing agricultural sub-sectors in developing countries is livestock. Estimates indicate that livestock and livestock products contribute about a third of the agricultural gross output in the developing countries (Bruinsma 2003; Nin, Ehui, and Benin 2007). This percentage is rapidly growing in developing countries because of increasing consumer demand for livestock products related to rising population, increases in income, and urbanization. The demand for animal products in developing countries is estimated to double in the next twenty years (ILRI 2011). According to Carlos Seré, Director General of ILRI, the livelihoods of a billion people in the world, particularly in Africa and Asia, depend on livestock where if removed, many of these people would have few choices to make their livings (ILRI 2009).

This dissertation follows the style of the *American Journal of Agricultural Economics.*

This rapid worldwide growth in demand for products from animal origin has been termed the "Livestock Revolution" by Delgado et al. (1999) in comparison to the Green Revolution that occurred in the 1960-70's.

FAO (2010) states that interventions for strengthening the livestock sector in the developing world are relevant to reducing poverty and hunger as hundreds of millions of rural households rely on livestock rearing to sustain their livelihoods. However, there are still constraints that may hamper this "revolution" if corrective measures are not taken. Some of these issues are related to the lack of viable livestock market information systems to support the decision making of traders, pastoralists, and policy makers (LINKS 2005). One way of strengthening the livestock sector in developing countries is to build a market economy where government participation in marketing and pricing of commodities is reduced significantly and market competition prevails (Verbeke et al. 2009).

1.1.2 Agricultural markets in developing countries

Generally, it is believed that in more open and liberalized economies, such as Western economies, market efficiency and integration are predominant (Yang et al. 2000; Samuelson 1952; Takayama and Judge 1964). On the contrary, economies of the developing countries (for example in Africa), which are less liberalized and sometimes controlled by the government, show a low level of market integration (Akiyama et al. 2003; FAO 2004). This concern was at the heart of the structural reforms (Structural Adjustment Programs) advocated by the World Bank and International Monetary Fund in the 1980's to several African countries (Jayne et al. 1997). The main critique of the government-controlled economies was the underperformance of the economy.

Many advocates of the market reforms posited that the relaxation of controls on private trade and investment would increase productivity and decrease cost (Jayne et al. 1997). They report that since 1980 more than thirty African countries started agricultural policy reforms as part of the Structural Adjustment Programs (SAP). Some of these reforms were at the center of the creation of market news services which sought to encourage the competitive growth of the private sector by improving market transparency.

A study by FAO (2004) indicates that testing for price transmission was one way of checking the degree of efficiency of markets in terms of their closeness to the competitive model or as a test of market integration. The results from the study show that five African countries (Senegal, Ghana, Ethiopia, Egypt, and Uganda) tended to have a lower degree of price transmission compared to Asian countries, in which transmission appeared to be complete.

Several other studies have been conducted in sub-Saharan African. Rashid et al. (2010) report empirical results on food market integration from studies done in West, East and Southern Africa. In West Africa, research on grain market integration, specifically relationship between maize, sorghum and millet prices was carried out in Ghana in three markets using the Ravallion model and the co-integration approach (Alderman 1992).

In 1998, Badiane and Shively examined the degree of integration and the speed of adjustment of maize price from 1980 to 1993 in three Ghanaian maize markets. The study was conducted using autoregressive model in price levels as well model in price variability. Lutz, Van Tilburg, and van der Kamp (1994) studied the impact of agricultural market liberalization on maize price in seven markets in Benin. A co-integration approach (Johansen test) was used to find the number of common trends among the seven markets. The speed of adjustment to the long-run equilibrium was analyzed as well.

In East Africa, several market integration studies on prices were conducted in Ethiopia (see Negassa 1998; Dercon 1995; Negassa and Meyers 2007; Jaleta and Gebremedhin 2009). The commodities that were examined in those various studies covered maize, teff, and wheat. The methodological approaches ranged from granger causality, parity bound method, and co-integration. In Uganda, Rashid (2004) examined the effect of market liberalization on maize price co-movement using co-integration approach. The study compared the maize price behavior before and after the liberalization policy was put in place in the 19990's. Van Campenhout (2007) examined the price transmission between maize prices in seven markets in Tanzania from 1989 to 2000 using the threshold autoregressive model.

In Southern Africa, Goletti and Babu (1994) and Meyers (2008) studied spatial market integration in Malawi. Goletti and Babu examined maize prices on eight markets from 1984 to 1991 covering the period before and after the market liberalization using co-integration methods. Meyers analyzed maize prices on ten markets from 2001 to 2008.

Moser, Barrett, and Minten (2009) examined rice markets integration in Madagascar, for almost 1400 communes. Finally one study examined cross-border market integration in four southern African countries of Botswana, South Africa, Malawi, and Mozambique (Mutambatsere, Mabaya, and Christy 2007). Parity bound method and co-integration approaches were used to carry out these studies.

In general, results from the above studies showed relatively well functioning markets in terms of integration in the long run with shortfalls in the short-run. Distance was suggested as the main reason of lack of market integration in several markets (Badiane and Shively 1998; Jaleta and Gebremedhin 2009; Moser, Barrett, and Minten 2009).

As Baulch (1997a p. 512-513) observed:

> …in the absence of market integration producers and consumers of agricultural products will not realize the gains from liberalization. For in these circumstances, the correct price signals will not be transmitted down the marketing chain, and farmers will fail to specialize according to comparative advantage. In short, if 'getting prices right'… is seen as the crucial policy prescription for agricultural development, the presence of market integration is a vital precondition for it to be effective.

1.2 Objective and research questions

The focus of this dissertation work is to determine the level of market integration or test for price transmission between markets in a developing world setting (specific case of Africa). Livestock markets are targeted here for three reasons. First, several rural households in developing countries, especially in grazing and arid lands of Africa rely on livestock for their living. Second, literature shows that several research works related to market integration and price transmission, conducted in Africa (see above cases), concerned mainly the grain markets (Akiyama et al. 2003). Third, the availability of reliable livestock data collected under MLPI and LINKS projects[1] motivated us to choose cattle as the commodity for this study.

The main objective in this dissertation is to test for cattle markets integration in three African countries: Mali, Kenya, and Tanzania. As mentioned earlier, one way of assessing the efficiency of market and the effects of liberalization policies is to test for market integration and price transmission. Generally market reforms (such as market liberalization and privatization) are intended to improve economy's efficiency which subsequently increases productivity and profits. Rashid et al. (2010) argue that the main goal of analyzing market integration is to have a better understanding of the implementation of short and long term policy interventions. For market integration purposes, those policies include but not limited to improving infrastructure (roads, markets), providing access to information, and promoting competition. However, due to the lack of enough data, our study will be limited to testing market integration and price

[1]MLPI: Mali Livestock and Pastoralist Initiative; LINKS: Livestock Information Network and Knoweldge Systems (see more details later)

transmission among markets in each country in order to have an idea of the level of competitiveness in the cattle markets. The inter-country price information transmission will not be coverd here but could be studied with better data.

Price leadership among the markets in each of the three case studies will be analyzed as well. The study of prices dynamics and transmission between and among markets in each case study will serve as a determinant factor of market integration. We identified the following research questions:

1. Are the individual cattle markets, in Mali, Kenya and Tanzania, integrated into a single market in each country?
2. Where is the price of cattle discovered among the cattle markets of each country?

By answering the above questions, we will get a glimpse on the level of cattle market integration in Mali, Kenya and Tanzania and which market in each country is leading others in sending the price signals. From our findings we will discuss as well possible policy implications regarding the implementation of market information systems in each of the three countries that were launched in 2003 and 2007.

1.3 Theoretical background

1.3.1 Competitive market and equilibrium

The availability of valuable commodities to trade creates an incentive to develop a social arrangement that allows buyers and sellers to discover information and carry out a voluntary exchange more efficiently, that is develop a market. Generally, a market is defined as any place where the sellers of a particular good or service can meet with the buyers of that good and service and where there is a potential for a transaction to take place. The buyers must have something they can offer in exchange, to have potential transaction. According to Ghoshray (2010, p.1), Marshall (1947) and Stigler (1969) define a market as an area within which the prices of the same good tend to be equal, when transportation costs are accounted for. Within the boundaries of a country, the extent of a commodity market may include domestic regions linked by arbitrageurs. The same definition of a market can go beyond national boundaries to embrace several countries when there is trade between each other.

There are several types of markets which can vary from free to regulated markets, complete to incomplete and perfectly competitive to monopolistic markets to name a few. We will limit our discussion to the main characteristics of a "perfectly competitive market" which must satisfy the conditions of equilibrium and Pareto efficiency.

In neoclassical economics, the general equilibrium theory introduced by Arrow and Debreu in 1954 is a theory that establishes the general market equilibrium for many goods, consumers and producers (Duffie and Sonnenschein 1989; Jain 2004). Jain

(2004) points out that Leon Walras (1878) did the first attempt to model prices for an entire economy where every good in the economy would have a price at equilibrium (or general equilibrium market) but without success. An answer was provided later by the Nobel laureates Kenneth Arrow and Gerald Debreu in 1954 where they showed that under concave utilities and some mild conditions, a general equilibrium market always exists (Arrow and Debreu 1954). The General Equilibrium model presented by Arrow and Debreu is concerned with the allocation of commodities through exchange at one moment in time, to make the economic agents better off, hence the notion of Pareto optimality (Geanakoplos 2004).

The General Equilibrium model has generated three fundamental theorems (Geanakoplos 2004). First, the existence theorem showing an equilibrium point to exist under some abstract conditions. Second, the first welfare theorem which states that, every market's equilibrium is Pareto optimal under certain conditions. Third, the second welfare theorem stating that, every Pareto optimal is a competitive equilibrium. The first welfare theorem expresses the efficiency of the ideal market system but without mentioning the initial distribution of resources. The second welfare theorem implies that any income redistribution is best done through lump sum rather than manipulating the market. Duffie and Sonnenschein (1989) argue that one of the greatest achievements in economic theory, by K. Arrow and G. Debreu, is the determination of value in competitive markets and the extent to which competitive markets lead to an efficient allocation of resources.

One of the fundamental assumptions of a competitive market is to have complete information available to both buyers and sellers, of for instance, prices, product characteristics, and production techniques. This assumption highlights the importance of information, especially in commodity market, to create the ideal "perfect competitive market" which ultimately leads to an efficient production and an increase in welfare for both consumers and producers.

1.3.2 Role of information in economics

As mentioned earlier, equal availability of information (of price for example) for both buyers and sellers is key to a perfectly competitive market. The knowledge of political and economical situations around the world, weather forecasts, and other type of information generated daily, are the basis for the markets to function efficiently (Roberts 2010). Informational considerations are crucial to the analysis of a wide range of phenomena and constitute a central part of the foundations of economic analysis (Stiglitz 1985). Stiglitz suggests that some scholars in the field of economics (citing Samuelson) have not given deserved importance to information in economic analysis. In the traditional paradigm, prominent scholars (such as Marshall and Samuelson) argued that economic analysis was based on three maxims: continuity, convexity, and the law of supply and demand. For instance, Samuelson's idea that the analysis of the maximization behavior was the foundations of the economic analysis was just a partial truth, providing only one of the central building blocks.

In the same way, Stiglitz (1985) cautions on the main concepts of the modern general equilibrium model, that stress on the interaction of markets and the role of price in conveying information. Although partially valid, these concepts do not represent the whole truth.on the importance of information in economics. In standard competitive model, all is built around information problem where the economy is unable to confront the problem of repeatedly processing the information. Stiglitz points out that the way information is conveyed in the economy is based on how information is continuously collected and processed and decisions are being made based on it. One of his conclusions was that prices were only one of the mechanisms by which information is conveyed in the economy.

Stiglitz (1985), states that many models have been constructed to examine the economic behavior in the presence of imperfect information. In adverse selection models, there is imperfect information concerning the characteristics of what is being bought or sold in the market. While in moral hazard models, there is imperfect information with regard to the action which the individual undertakes.

Frieden and Hawkins (2009) posit that information flow is central to economic activity and a key player in the capital market. They argue that the interaction between information and economic agents in the price discovery process show that information flows play a primary role in determining the dynamic laws of an economic system. The early models on competitive general equilibrium developed by Debreu and Arrow considered information as given and perfectly known. However, information economics pioneers such as Stigler challenged this view, showing that information is imperfect and costly to obtain. Stigler (1982) gave an example about the theory of oligopoly in which Cournot made the assumption that each of the rivals in a market does not behave based on the behavioral pattern of the other. It was proven not to be a correct assumption by later theories of oligopoly which all rest upon different assumptions regarding the patterns of behavior that each player attributes to his rivals in the market place.

Stigler (1961) in studying the role of information in market prices observed that price dispersion is a sign of market ignorance. Markets and advertising can, however, be instrumental in reducing the price gap. The work by Stigler was later followed by other scholars such as Akerlof, Spencer, and Rothschild and Stiglitz who are considered to be the founding fathers of the information economics field. Rothschild and Stiglitz observed that "some of the most important conclusions of the economic theory are not robust to considerations of imperfect information". (Frieden and Hawkins 2009)

1.3.3 Spatial equilibrium and the law of one price

Several studies have been carried out to study the equilibrium and linkages of prices of commodities between markets at local and international level or spatial equilibrium (Baulch 1997; Barrett and Li 2002; Dawson and Dey 2002; Bukenya and Labys 2005). Assumptions of a full price transmission and market integration are similar to those of standard equilibrium model where in a competitive and undistorted world, the law of one price (LOP) regulates spatial price relations (FAO 2004).

According to Samuelson (1952), the first explicit statement that competitive market price is determined by the intersection of supply and demand functions seemed to have been given by Cournot (1838) with regard to a problem of price relations between two spatially separated markets. The early models of spatial equilibrium were developed by Enke (1951), Samuelson (1952) and Fox (1953).

Enke (1951) used an electrical circuit model to illustrate an equilibrium of prices and commodity movements when a number of buyers and sellers trade a homogenous good. Using different case scenarios of trade between regions to determine the equilibrium price, Enke (1951) gives an example of three trading regions where he uses a mathematical procedure to find the equilibrium point. However, in a case of a large trading system of a single commodity, it is difficult to find a solution by mathematical procedures. Since the export supply schedules can be viewed as linear, it is possible to use a physical analogue in electricity to find a solution to the equilibrium problem.

Samuelson (1952) in his work studied the spatial price equilibrium model and linear programming. He points out some of the failures of the “marginalism” theory to solve equilibrium by introducing a new field of linear programming to resolve this issue. His work was an extension of Enke’s findings by using a different and new methodology based on linear programming to solve for spatial price equilibrium. In fact, the Enke procedure solves for a maximum of the social net pay-off (SNP) but does not take into account the transport costs. Samuelson uses the Koopmans-Hitchcock linear programming method to solve for a maximum SNP, but at the same time he minimizes the transport costs from one region to another to attain the spatial price equilibrium. In brief Samuelson introduced what the mathematical theories call “dual problem” in linear programming where, a maximization problem can be turned into a related minimization problem.

Fox (1953) applied the theoretical findings by his peers (Enke and Samuelson) to solve for a spatial equilibrium price problem of livestock feeds in the US. He formulated the problem based on Enke procedure and solved it following Samuelson linear programming steps to find a unique equilibrium trade pattern between surplus and deficit regions in corn.

Takayama and Judge (1964) are as well recognized as two economist scholars to have contributed a great deal in the field of spatial equilibrium. They extended the Enke-Samuelson spatial equilibrium models by introducing quadratic programming to solve for the equilibrium. In other words, they convert Samuelson formulation into a quadratic program where a computational algorithm is used to obtain directly and efficiently the competitive optimal solution for regional prices and quantities and interregional flows.

Theories on spatial competition suggest that in the short run, prices of similar products in varied markets might differ (Enders 2010). However, arbitrageurs will prevent the various prices from moving too far apart even if the prices are non-stationary. In an integrated and competitive market for instance, prices observed in different locations at one point in time will differ by the amount up to the transaction costs from one location to another as suggested by the law of one price (LOP) (Dawson and Dey 2002; Park, Mjelde and Bessler 2007).

The LOP simply put is a situation where commodity arbitrage ensures that each good has a single price (defined in a common currency unit) throughout the world when all transaction costs have been taken into account (Ardeni, 1989). Yang, Bessler, and Leatham (2000) defines the LOP as a state in which for a given commodity a representative price adjusted for exchange rate and allowance for transportation costs will prevail across all countries.

The LOP also measures the extent of market and market integration for spatially separated markets. One way of finding empirical evidence of market integration and price convergence has been achieved in the context of the law of one price (Bukenya and Labys 2005). According to Baffes and Ajwad (2001), the issue of price linkages in product markets both at local and international levels has been studied in the literature extensively either under the notion of the law of one price (e.g. Ardeni 1989; Dawson and Dey 2002; Bukenya and Labys 2005) or under the notion of market integration (e.g. Ravallion 1986; Sexton et al. 1991; Baulch 1997). Yang, Bessler, and Leatham (2000) point out that if a single price is recorded over several spatially separate markets, this means that those markets are integrated as a single market.

The LOP is, however, one property of the competitive spatial market equilibrium. Barrett and Li (2002) argue that market integration and spatial market equilibrium are two different concepts. Market integration is more related to products tradability between spatially distinct markets regardless of the existence of spatial market equilibrium. As for competitive market equilibrium it reflects exhaustion of profits by competitive pressures whether or not there is actual physical flow of goods between markets.

Roehner (1995a) presented two slightly different concepts of market integration. In the first one, he defines a regional or market integration as a situation where "enough" arbitragers are present in the market and act efficiently to meet one of the conditions of efficiency such as the perfect information. The second concept largely defines the degree or level of market integration which is determined by the level of inter-market price differentials. If these differentials are large (in relative terms), then the market is poorly integrated; if they are small, the market is integrated.

1.4 Methodological approach

1.4.1 Background on methods

Several approaches to measure market integration have been presented in the literature. None of the models studied seemed to be unanimously accepted. Different researchers showed shortfalls and flaws for every approach presented in the literature (Baffes and Ajwad 2001; Negassa, Myers, and Gabre-Madhin 2003)

The empirical methods to investigate spatial market integration evolved over time from simple price correlation between market location in 1970's to early 1980's, to autoregression approaches in the late 1980's and 1990's to co-integration methods in 1990's (Rashid et al. 2010). The relatively recent approaches that take into account transfer cost are the parity bound model (PBM) and the threshold autoregressive model (TAR) (Baulch 1997b; Barrett and Li 2002).

Negassa, Myers, and Gabre-Madhin (2003) produced a summary of different approaches used in spatial market integration tests and their weaknesses. The following is based on their comments.

Price correlation method to measure market integration is too simplistic: assumes instantaneous price adjustment and does not capture dynamic relationships of a marketing system. Other approaches to remedy the weaknesses of the price correlations method were developed. Those include the Ravallion method (1986), Engle and Granger approach (1987) and the Johansen method (1988).

The Ravallion method assumes radial spatial market structure between local markets and a central market where price formation in the local market depend on its trade with the central market. The main problem with the method is the assumption of constant inter-market transfer costs. Becuase the Ravallion method uses OLS regression to test for spatial market integration, the presence of stochastic trends (unit roots) in the price series would violate the classical assumptions of OLS regression.

The Engle-Granger method is mainly based on cointegration analysis, unit root test and the application of the error correction model to determine the short and long run relationships between variables (for example price series). The same as for the Ravallion method, the Engle Granger approach assumes stationary spatial marketing margins for markets to be integrated. However, if the transaction costs are non-stationary, the lack of cointegration does not necessary imply the absence of market integration (Barrett, 1996).

The fact that the Engle-Granger cointegration approach did not explore co-integration possibilities in a multivariate setting led to the development of another cointegration approach by Johansen (1988). The latter method explores co-integration in a multivariate system using maximum likelihood approach. A multivariate test for market integration under non-stationary prices has also been developed and applied according to Negassa, Myers, and Gabre-Madhin (2003).

In another research, Baulch (1997a) studied statistical performance of four econometric approaches used to test spatial market integration: law of one price, the Ravallion model, Granger-causality, and co-integration. A spatial price equilibrium (SPE) model was used to generate food price time series data of length similar to short sample size found in developing countries. Monte Carlo simulations were carried out on the generated food prices and showed statistical flaws in all four tests for market integration.

Although there were improvements of methods used to test for market integration, over the years, none of the methods was shown to be perfect; they all had weaknesses. In this dissertation, we will follow the approach that uses autoregressive models, co-integration and error correction model (ECM) to determine the level of market integration in three countries s of Mali, Kenya and Tanzania (Dawson and Dey 2002; Bukenya and Labys 2005; Stockton, Bessler, and Wilson 2010; Vitale and Bessler 2006; Bessler and Kergna 2003; Yang, Bessler, and Leatham 2000).

1.4.2 The error correction model

In time series study, the first important characteristic to check is the stationarity of the series given its relevance to subsequent econometric analysis. While several studies in the economic literature (Dhasmana 2011; Yang, Bessler, and Leatham 2000; Ardeni 1989) agree that commodity prices are non-stationary in nature and follow a random walk model, they disagree on the type of non-stationarity. The form of non-stationarity could have a deterministic trend, a stochastic trend or structural breaks.

Agricultural products, for example wheat, which can be carried over through time and space, are subject to arbitrage and hard to predict due to certain factors such as production fluctuation (Samuelson 1971). Their prices are stochastic speculative prices that follow a Brownian motion model and therefore are non-stationary. This applies as well to the cattle market prices. However, as pointed out by Granger (1981), even though the prices are individually non-stationary and are made stationary by differencing, we may have linear combinations with other variables that are stationary without differencing; those variables are said to be co-integrated.

Co-integration analysis was introduced by Engle and Granger (1987). It explores the co-movements and interactions of different variables (for example prices). Co-integration occurs when two or more series have the same stochastic trend in common. In this case, regression analysis can reveal long-run relationship among time series variables. Given some limitations of the Engle-Granger co-integration method (see previous discussion), other co-integration approach such as Johansen's co-integration test, is used here to derive maximum likelihood estimators of the co-integration vectors for an autoregressive process with independent Gaussian errors (Johansen 1988). The approach has the ability to conduct multivariate co-integration test and both short-run and long-run structures are included in the co-integrated vector autoregression (VAR) where the co-integrating relations determine the rank of the long-run matrix.

If we assume the existence of co-integration, the data generating process of P_t (price at time t for example) can be appropriately modeled in an error correction model (ECM) with k-1 lags which is derived from a levels vector autoregression (VAR) with k lags. Suppose that in our price market study we have n variables (n markets) where the ECM is presented as follows:

$$\Delta P_t = \Pi P_{t-1} + \sum_{i=1}^{k-1} \Gamma_i \Delta P_{t-i} + \mu + e_t \quad \text{where } t = 1,\ldots,T\ ;\ e_t \sim \text{Niid}\,(0, \Sigma) \qquad (1)$$

In the above equation, Δ is the difference operator ($\Delta P_t = P_t - P_{t-1}$), P_t is (n x 1) vector of prices at time t from each of the n markets; Γ_i is a (n x n) matrix of coefficients associating price changes lagged i period to current changes in prices; $\Pi = \alpha\beta'$ is (n x n) matrix coefficients associating lagged levels of prices to current changes in prices (or n x n + 1 if a constant is in the co-integration space); μ is a constant and e_t is a (n x 1) vector of white noise innovations.

The co-movement of prices, as mentioned above, can exhibit long-run and short-run relationships. The long-run structure can be analyzed through testing hypotheses on the β; the short-run structure can be studied through testing hypotheses on α and Γ_i (Johansen and Juselius 1994). The contemporaneous structure can be examined through structural analysis of e_t or more conveniently through the directed graph analysis of the covariance matrix (Σ) (Vitale and Bessler 2006).

The number of co-integrating relations, r, can inform us on the long-run structure of market interdependence. The rank of Π (i.e. row rank of β) determines the number of co-integrating vectors r.

There are three cases of interest (Vitale and Bessler 2006): (a) if Π is of full rank, then P_t is stationary in levels and a VAR in levels is an appropriate model; (b) if Π has zero rank, then it contains no long-run information and the appropriate model is a VAR in first differences; and (c) if the rank of Π is a positive number, r, which is less than n (the number of series), there exist matrices α and β, with dimension n x r such that $\Pi = \alpha\beta'$. To determine this number, trace tests (Enders 2010) on the eigenvalues of Π are used in our n markets study.

It is widely accepted that like the standard VAR models, individual coefficients of the ECM are difficult to interpret because the coefficients estimated are those of the reduced form equation and not the original structural equation model. Under such cases, innovation accounting may be the best description of the dynamic structure (Enders 2010; Swanson and Granger 1997). The innovation accounting techniques discussed in this dissertation are limited to forecast error variance decomposition and impulse response functions. We first describe below the original model to analyze the dynamic relationships in a vector of variables (in this case a vector of prices) also called vector autoregression (VAR) and their dynamic properties. A VAR is a set of n time series regressions, in which the regressors are lagged values of all n series. A VAR extends the univariate autoregression to a list, or “vector,” of time series variables (Enders 1995).

1.4.3 Vector autoregression and innovation accounting

A levels vector autoregression (VAR) equation can be expressed into two forms: a structural VAR and a standard VAR (reduced form). The structural VAR introduces feedback given that all the variables are allowed to affect each other in the contemporaneous time (Enders 2010). Consider a system with three variables y, z and w where the structural VAR has 1 lag:

$$y_t = b_{10} - b_{12}z_t - b_{13}w_t + \alpha_{11}y_{t-1} + \alpha_{12}z_{t-1} + \alpha_{13}w_{t-1} + \varepsilon_{yt}$$

$$z_t = b_{20} - b_{21}y_t - b_{23}w_t + \alpha_{21}y_{t-1} + \alpha_{22}z_{t-1} + \alpha_{23}w_{t-1} + \varepsilon_{zt}$$

$$w_t = b_{30} - b_{31}y_t - b_{32}z_t + \alpha_{31}y_{t-1} + \alpha_{32}z_{t-1} + \alpha_{33}w_{t-1} + \varepsilon_{wt}$$

The compact form is: $Bx_t = \Gamma_0 + \Gamma_1 x_{t-1} + \varepsilon_t$ (2)

where $x_t = \begin{bmatrix} y_t \\ z_t \\ w_t \end{bmatrix}$; $B = \begin{bmatrix} 1 & b_{12} & b_{13} \\ b_{21} & 1 & b_{23} \\ b_{31} & b_{32} & 1 \end{bmatrix}$; $\Gamma_0 = \begin{bmatrix} b_{10} \\ b_{20} \\ b_{30} \end{bmatrix}$; $\Gamma_1 = \begin{bmatrix} \alpha_{11} & \alpha_{12} & \alpha_{13} \\ \alpha_{21} & \alpha_{22} & \alpha_{23} \\ \alpha_{31} & \alpha_{32} & \alpha_{33} \end{bmatrix}$; $\varepsilon_t = \begin{bmatrix} \varepsilon_{yt} \\ \varepsilon_{zt} \\ \varepsilon_{wt} \end{bmatrix}$

However, this is not a recommendable form of VAR for estimation due to possible endogeneity problems. Using matrix algebra we can transform the structural form into a standard VAR form or reduced form (that is more usable for estimation purposes) by premultiplying both sides of equation 2 by B^{-1}, leading to the ollowing system:

$$y_t = a_{10} + a_{11}y_{t-1} + a_{12}z_{t-1} + a_{13}w_{t-1} + e_{yt}$$

$$z_t = a_{20} + a_{21}y_{t-1} + a_{22}z_{t-1} + a_{23}w_{t-1} + e_{zt}$$

$$w_t = a_{30} + a_{31}y_{t-1} + a_{32}z_{t-1} + a_{33}w_{t-1} + e_{wt}$$

The compact form is: $x_t = A_0 + A_1 x_{t-1} + e_t$ (3)

where, $x_t = \begin{bmatrix} y_t \\ z_t \\ w_t \end{bmatrix}$; $A_0 = \begin{bmatrix} a_{10} \\ a_{20} \\ a_{30} \end{bmatrix}$; $A_1 = \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix}$; $e_t = \begin{bmatrix} e_{yt} \\ e_{zt} \\ e_{wt} \end{bmatrix}$

As an example of the above transformation of equation 2, we have:

$$A_0 = \Gamma_0 * B^{-1} = \begin{bmatrix} b_{10} \\ b_{20} \\ b_{30} \end{bmatrix} * \begin{bmatrix} 1 & b_{12} & b_{13} \\ b_{21} & 1 & b_{23} \\ b_{31} & b_{32} & 1 \end{bmatrix}^{-1}.$$

Sims advocated the unconstrained VAR model to provide a theory-free method to estimate economic relationships (Hsiao 1979; Sims 1980). Hsiao (1979 p.553) reports that: "Sims (1977) suggested an alternative strategy for empirical model building, where all variables are treated as joint dependent, to avoid infecting the model by spurious a priori constraints". However, Hsiao (1979) warns about the risks of exhausting the degree of freedom if, every variable is allowed to influence every other variable with the same length, without restrictions. Another problem related to using Sims's model is to producing coefficient estimates with insignificant t-statistics. To overcome the problems associated with Sims's model, Hsiao suggested a procedure to reduce the number of parameters to be estimated. This procedure allows a variable to depend on a subset of variables under consideration and enter the equation with different lags. In this study, in order to identify the interdependence among variables, the Hsiao search procedure (Hsiao 1979) was used to obtain a restricted VAR (subset VAR). The Schwarz-loss metric was used to determine the lag order (see details on the results of the search in appendix).

To capture more on the dynamic properties of a VAR model, innovation accounting techniques are used. They comprise: impulse response function, forecast error variance decomposition and historical decomposition. In this dissertation, we will use the forecast error variance decomposition and the impulse response functions tools to check for these properties. We convert the VAR in its vector moving average representation (VMA) to summarize the dynamic price relationships in our markets study (Swanson, and Granger 1997; Enders 2010).

The vector P_t is written as a function of the infinite sum of past innovations:

$$P_t = \sum_{i=0}^{\infty} C_i e_{t-i} \tag{4}$$

where C_i is n x n matrix of parameters which associate historical innovations at lag i to current X_t. The parameter estimates of C_i come from the estimation of ECM and the algebraic manipulation of these coefficient estimates back into a levels VAR model (Bessler and Davis 2004; Vitale and Bessler 2006). However, the matrix C_0 is not generally an identity matrix, since some elements of the vector are not orthogonal. Hence, the analysis of equation (4) without making some adjustment may not reflect the true dynamic behavior characterizing the data. For this reason a transformed moving average representation on orthogonalised innovations, $u_t=Me_t$, is used where M is such that E $(u_t u_t^1)$ = D. Here D is a diagonal matrix. Traditionally, the Choleski factorization of the innovation matrix was used to provide the causal relationship between series innovations in contemporaneous time. Vitale and Bessler (2006) pointed out that the Choleski decomposition is a recursive method and does not necessarily reflect the true causal relationships between contemporaneous innovations. Instead they used Bernanke ordering to solve this problem, where the innovation vector e_t from the estimated VAR model is written as $e_t=M^{-1}u_t$. We write the vector P_t in terms of orthogonalized innovations (see equation 5 below).

$$P_t = \sum_{i=0}^{\infty} \Theta_i u_{t-i} \tag{5}$$

Here the vector P is written as an infinite series of orthogonalized innovations, u_{t-i}.

Directed acyclic graphs (DAG) are used to place zeros on the M matrix. Details on DAG are presented below.

1.4.4 Inductive causation and directed acyclic graph

Co-integration methods are important in determining the co-movements of variables; but they do not necessarily inform us on the causality between variables. In an attempt to solve this problem, we use directed acyclic graphs methods of inductive causation to explain causal relationship between variables. A directed graph is a diagram that represents a causal flow among a set of variables (Vitale and Bessler 2006). Capital letters such as X_1, X_2, . . . ,X_n are used to represent variables and lines (edges) with arrowheads at one end represent causal flows (e.g. $X_1 \rightarrow X_2$ indicates X_1 causes X_2) (Haigh and Bessler 2004). The graphs with directed edges ($X_1 \rightarrow X_2$ is called a directed edge) are of importance since they show the direction of the causal flow. Graphs with no cycles are said to be acyclic.

The important characteristic of inductive causation methods is the conditional independence property on variables to determine different causal flows between variables (Pearl, 1995; Haigh and Bessler 2004). The basic idea used to determine the direction of causal flows for a set of observational variables is that of "screening off" that was formalized in terms of d-separation by Pearl (2000) (Hoover 2003; Vitale and Bessler 2006).

For instance, for three variables X_1, X_2, and X_3, if on one hand we have X_2 as a common cause of X_1 and X_3 ($X_1 \leftarrow X_2 \rightarrow X_3$), then the unconditional association between X_1 and X_3 will be non-zero given the fact that both X_1 and X_3 have a common cause in

X_2 (diagram called causal fork). By measuring linear association between X_1 and X_3, we find that X_1 and X_3 have non-zero correlation. However, if we condition on X_2, the partial correlation between X_1 and X_3 will be zero. Common causes "screen off" association between their common effects. On the other hand, if we have the variables in the relation, $X_4 \rightarrow X_5 \leftarrow X_6$, where X_4 and X_6 have a common effect, X_4 and X_6 will have no association or zero correlation if we apply linear association. This diagram is called a causal inverted fork by Pearl (2000). However, if we condition on X_5, the association between X_4 and X_6 is non-zero or the partial correlation between X_4 and X_6 given X_5 is non-zero. Common effects do not "screen-off" the association with common causes. Finally, if we have the representation of variables X_7, X_8, and X_9 as a causal chain $X_7 \rightarrow X_8 \rightarrow X_9$ the unconditional association (correlation) between X_7 and X_9 variables will be non-zero. But if we condition on X8, the association (partial correlation) between X_7 and X_9, will be zero since X_8 "screens off" association between X_7 and X_9 in a causal chain. Pearl (2000) formalized the screening-off notions into the idea of d-separation that connects formally causal flows and probability representation. Pearl (1995; 2000) under the assumption that the variables follow a Markov process, DAGs can be used to represent conditional independence and determine joint distribution as follows:

$$\Pr(x_1, x_2, \ldots, x_n) = \prod_{i=1}^{n} \Pr(x_i \mid pa_i) \qquad (6)$$

where Pr is the probability of variables $x_1, x_2, \ldots, x_n$ and pa_i (also called Markovian parents) the realization of some subset of the variables that precede (come before in a causal sense) x_i in order $(x_1, x_2, \ldots, x_n)$.

Spirtes, Glymour, and Scheines (1993) incorporated the d-separation into an algorithm (PC algorithm) for determining causal flows among a set of more than three variables and building directed graphs. Basically, the PC algorithm is a sequential set of commands that starts with an unrestricted graph where every variable is connected to every other variable and proceeds step-wise to remove edges between variables that are not correlated and direct causal flows for those which are associated[2]. The estimation of the ECM (including the co-integration analysis), VAR, and innovation accounting were carried out using RATS (version 6.2) and CATS 2 software. The DAG analysis to determine the causal relationship between variables was conducted using TETRAD 4.3.9-14.

1.5 Organization of the dissertation

The dissertation is organized in four separate chapters. The first chapter (this current chapter) presents the introduction and an overview of the various concepts and facts about livestock commodities, agricultural market in developing countries, and the role of information in the market integration process. This chapter also presents the methodological approach that was followed in three case studies to answer the research questions set forth in the dissertation.

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[2] GES (Greedy search algorithm) is an alternative machine learning algorithm written by research workers at Carnegie Mellon University. It differs from PC algorithm in that it uses a statistical loss metric rather than a p-value to select model. For further reading see Chickering (2002) and Tetrad homepage: http://www.phil.cmu.edu/projects/tetrad/

The second chapter presents a brief description of three case studies (Mali, Kenya, and Tanzania) analyzed in the dissertation. Country profiles for the respective countries and the importance of livestock in their economy are discussed. Finally, the role of market information systems (MIS) projects in the three countries is described.

The third chapter presents and discusses the results in the respective three case studies. A conclusion and comparison of the MIS on market integration in the respective countries close the section.

The last chapter (four) summarizes the general conclusions and policy recommendations based on the results from the three case studies.

CHAPTER II

CASE STUDIES: BACKGROUND INFORMATION

This second chapter describes briefly the case studies of Mali, Kenya, and Tanzania on aspects such as economic importance of livestock, market liberalization, and the development of livestock market information systems (LMIS). The livestock market information systems were achieved in the three countries under the Global Livestock Collaborative Research Support Programs (GL-CRSP) funded by the USAID and implemented by universities from the US (Texas A&M Universvity, and Syracuse University). Finally, we present the study area for each case and the data used in the empirical analysis.

2.1 Case study 1: Mali

2.1.1 Economic importance of livestock in Mali

The Republic of Mali is a landlocked country located in the Western part of Africa. Mali is a low-income, agro-pastoral economy where agriculture accounts for 40% of the GDP, 75% of employment, and 30% of export earnings (Ministry of Agriculture 2009). The livestock sector alone contributes around 44% of the agricultural GDP (15% of overall GDP) and 30% of the employment (SWAC 2008). The livestock sub-sector has always been a key player in Malian economy accounting on average for 11% of the GDP during the period 1991-2002 and contributing to export earnings for about 62.4 billions of FCFA in 2001, ranking third after the cotton and gold (Ministry of Livestock and Fisheries 2004).

Livestock are the highest valued agricultural commodity in intra-regional trade in West Africa (Williams, Spycher, and Okike 2006). Livestock trade links Sahelian countries such as Mali, Burkina Faso, and Niger in the arid and semi-arid regions as exporters to the humid coastal countries of Nigeria, Cote d'Ivoire and Ghana. This trade grew over the years where traded cattle went from 13 million US dollars in 1970 to 150 million dollars in 2000 in real value terms. As pointed out by Fafchachamps and Gavian (1996), who studied livestock sector in Niger (Niger has many similarities with Mali), the livestock production is a major industry in semi-arid Africa, in general, and specifically in the Sahel region. In fact Sahelian farmers and pastoralists rely on the accumulation of livestock for both income generation and a form of precautionary savings.

Livestock and especially cattle play a great role in income generating activities of the Malian population (Abdulai and CroleRees 2001). Livestock and cotton are the important differentiating factors of income generation among households in Mali. Generally in rural household in Sub-Saharan Africa, holding cattle is considered as a sign of wealth for two main reasons. First, households can use livestock as collateral for loans. Second, households can also generate revenues from animals and by-products sold. This research work on cattle market integration in Mali is an addition to previous contributions by Dembele and Staatz (2004), Staatz, Diarra, and Traore (2002), Bessler and Kergna (2003) and Vitale and Bessler (2006) who studied the link between market information system, market liberalization policies and market price integration in the cereal and grain markets in Mali.

2.1.2 Livestock marketing and market liberalization in Mali

FAO (2005) reports that since 1981 the government of Mali adopted the economic reforms comprising price and trade liberalization, reform regarding business regulations and the privatization of state-owned enterprises. Some of the economic reforms were at the heart of the creation of market news services that sought to encourage the competitive growth of the private sector by improving market transparency.

The Market Information System (MIS) was created in Mali in 1989 as a part of the Cereal Reform Program and in response to the Structural Adjustment reforms (Dembele and Staatz 2004; Staatz, Diarra, and Traore 2002). Before the cereal reforms of the 1980's, the goal of the Malian government was to supply cereal at a cheap price to urban consumers. This led the government to set up prices regardless of the market equilibrium price established by supply and demand (Dembele, Staatz, and Weber 2003). However, in the 1970's, due to drought, producers' prices were depressed in Mali compared to neighboring countries. With low prices incentives and slow growth in productivity in the cereal sector, Mali moved from a cereal exporter to a net food importer. This situation led the government to initiate the cereal market reform program known by its French acronym, PRMC (Programme de Restructuration du Marche Cerealier) in 1981. Vitale and Bessler (2006) noted that Mali has been an exception in the West Africa to take on market reforms back in the 1980s. They show the success of the grain market liberalization in integrating markets.

On the contrary, policy in livestock development has, since colonial times, lacked a clear orientation in terms of livestock marketing and market information gathering and dissemination (Ministry of Livestock and Fisheries, 2004). As opposed to the cereal and grain marketing boards that evolved from government control in 1989 to a private-led agency "Observatoire du Marche Agricole" (OMA) or agricultural market watch in 1998, the livestock marketing agency changed only names, but remained under government control (Dembele and Staatz 2004). Kaitho and Kariuki (2006) point out that the lack of transparent and timely price information on livestock is a significant obstacle to any attempt to develop a vibrant and profitable livestock industry.

A partnership in 2007 between Texas A&M University and Global Livestock CRSP initiated the Mali Livestock and Pastoralist Initiative (MLPI) to develop a livestock market information system (LMIS) for Mali (Angerer, Keita, and Dial 2010). The project introduced the use of cell phones to disseminate livestock price information to cattle producers and traders in an attempt to improve market transparency. The goal of the MLPI project is to develop reliable and timely livestock market information in the country and provide a basis for livestock producers and traders to make informed marketing decisions and reduce risk. In a country where traditionally information is passed on by the word of mouth, the introduction and the growth of cell phone use in recent years has transformed the country in many aspects including the commodity trading. Angerer, Keita and Dial (2010, p.4) stated: "The implementation of the LMIS in Mali represents for the first time that near real-time market information on livestock has been available to the public…."

Thirty years after the introduction of Structural Adjustment Program by the WB and IMF in several African countries, these reforms have produced mixed results (Coulter and Onumah 2002). Although stimulating the creation of market news services, the reforms did not succeed in establishing a private-led and competitive market economy. It is the reason why market integration is still an attractive field that researchers continue to explore to assess how commodity markets, such as livestock markets, are competitive. This research will assess the level of cattle market integration in the Republic of Mali and determine where the price is discovered among the cattle markets under study.

2.1.3 Livestock market information system

Pastoralists in Mali are facing challenges due mainly to climate change, reduction in grazeable land due to crop development, land degradation and market access. To partially remedy to this situation, there is a need to provide information to help pastoralists in their decision-making process and reduce risks. Breakthroughs in communication technologies are making information for decision making more accessible and affordable and offers opportunities to streamline the information. It is along these lines that the USAID Mission to Mali identified an overall goal to improve productivity and income for livestock producers in the northern region of Mali through capacity building and the use and access of new technologies (Angerer, Keita, and Dial 2010).

To assist in meeting this overall goal, Texas A&M University, under the GL-CRSP, partnered with “Observatoire du Marche Agricole” (OMA) and the “Direction

Nationale des Productions et des Industries Animales" (DNPIA) to establish a state-of-the-art livestock market information system (LMIS) for Mali, also known as the Mali Livestock and Pastoralist Initiative (MLPI) project. The project introduced the use of cell phones to collect information at markets on a near real-time basis and allow that information to be disseminated via cell phones and internet to livestock producers and traders in an attempt to improve market transparency, competition and efficiency. The LMIS for Mali is patterned after the system developed in East Africa (Ethiopia, Kenya, and Tanzania) as part of the USAID/GL-CRSP's Livestock Information Network and Knowledge System (LINKS) project. The goal of the LMIS project is to develop reliable and timely livestock market information in the country and provide a basis for livestock producers and traders to make informed marketing decisions and reduce risk.

2.1.4 Study area

Six markets were selected for this study as shown in figure 1 and described below.

*Kida*l is located in the desert region of Kidal, cercle of Kidal. The average number of cattle present at the market is between 64 and 228 per month. It is supplied mainly by local village markets and neighboring district of Tassik and Amassine.

Gossi is located in the Tombouctou region, in the cercle of Gourma Rharous. The market receives on average between 265 and 541 cattle each month. Gossi is supplied mainly by animals from Wabaria market, small local markets and individual cattle producers.

Konna is located in the Mopti region, in the cercle of Mopti. The market counts on average between 350 and 680 heads of cattle each month. Some of the cattle come from Gossi and Douentza located north of Konna and others come from local village markets.

Wabaria is located in the Gao region, in the cercle of Gao. Wabaria market counts on average 942 and 1050 heads of cattle each month. Wabaria is supplied by livestock markets of Meneka, Lelehoye and Ansongo, all located in the Gao region.

Kati is located in Koulikolo region, cercle of Kati. On average the number of cattle traded in Kati ranges between 4300 and 8463 per month making Kati the third largest livestock market in Mali. Animals come from the districts of Kati, Kambila and Nara.

Niamana is located in the Koulikolo region, cercle of Kati (20 km east of Bamako); it is the largest cattle market in Mali. The average number of cattle traded in Niamana varies between 21300 and 26610 heads each month. Niamana is supplied by all regions of Mali except Kidal and cattle transactions occur daily (daily market).

The other markets above are mostly supplied by local village markets. Except the market of Kati, located about seven miles north of Niamana market, all the remaining five markets are located on the main road Bamako-Gao-Kidal.

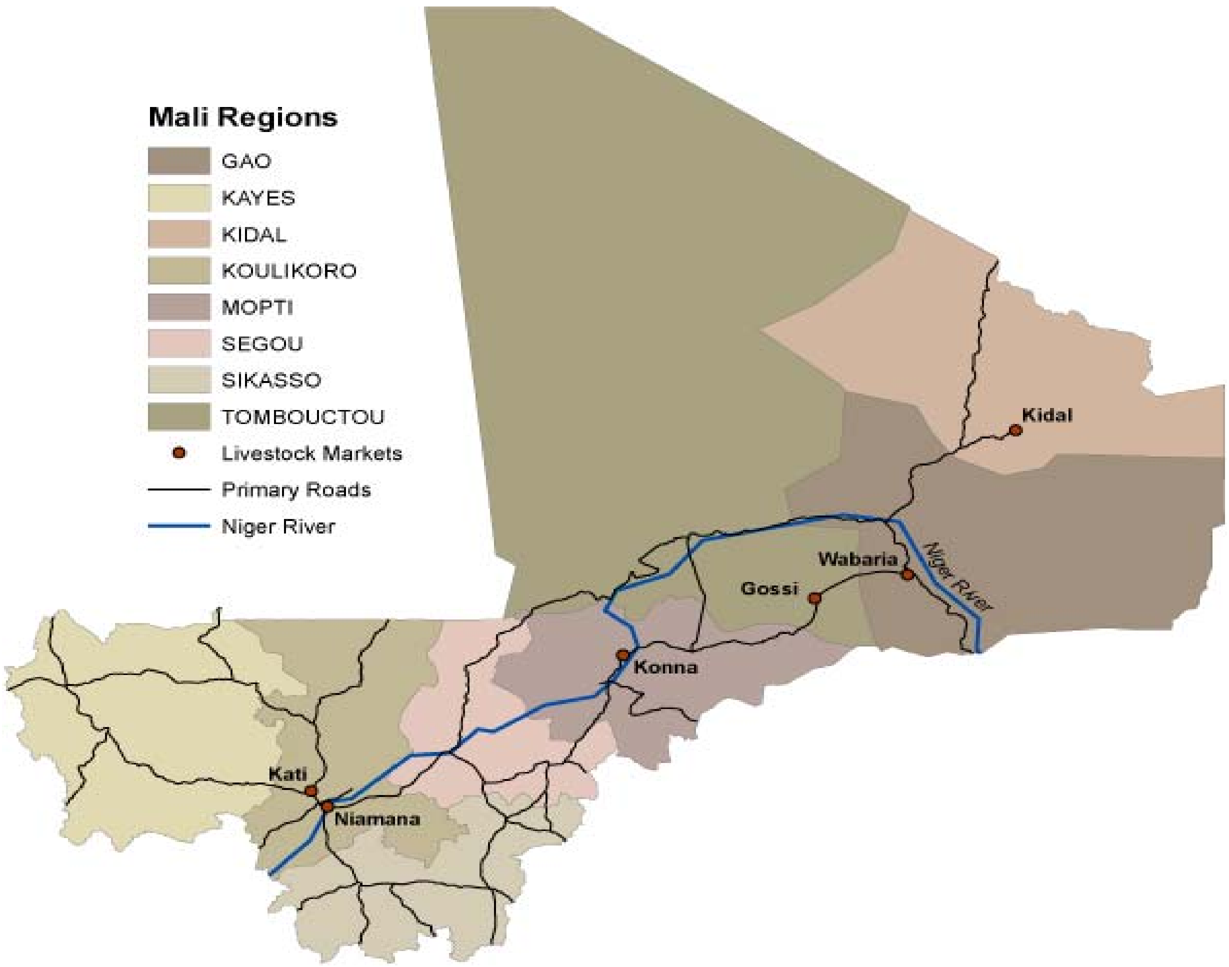

Figure 1. Map of eight administrative regions of Mali and the livestock markets

2.1.5 Data

In this study, we analyze weekly data on price of cattle collected from November 2008 to September 2010 in the six markets described above: Gossi, Kidal, Konna, Niamana, Wabaria and Kati. The markets were selected because they were the first to implement the LMIS technology and thus had more data than any other livestock markets under the Mali Livestock and Pastoralist Initiative (MLPI) project.

The category of cattle targeted in the study is that of adult male Zebu cattle with a fat body condition (or medium where fat is not available)[3]. In some instances where information on adult bulls was lacking, we used data on adult castrated fat. Due to permanent dry conditions in Kidal (desert region) where fat animals are not common, we used instead animals of medium category.

The data were collected under the MLPI project which introduced the cell phones to collect market prices in 2008. The data started being collected after the markets monitors in each of the selected markets under MLPI were trained on how to collect price and volume information on livestock and send them to a central server using SMS messages. Our data collection verification visit to several livestock markets in August 2009 showed that the way market monitors collected price and volume information was satisfactory and consistent across markets. Each market monitor collects data on five different animals of the same kind, breed, age, gender and conformation (fatness). A mean price from the five animals is computed and sent to the database via SMS. The procedure is the same as that used in Kenya and Tanzania.

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[3] This category (adult male from Zebu breed) was selected throughout this dissertation given its high proportion in numbers compared to other categories

2.2 Case study 2: Kenya

2.2.1 Importance of livestock in Kenya

The Republic of Kenya is located in the eastern part of Africa, bordering Somalia, Ethiopia, Sudan, Uganda, Tanzania and the Indian Ocean. Agriculture is an important player in the Kenyan economy, contributing to about 26% of total GDP (Library of Congress 2007). Recent data from the Kenya National Bureau of Statistics (Republic of Kenya, 2010) indicate that agriculture and forestry contributed about 22% to the real GDP in the third quarter of 2010. Kabubo-Marriara (2008) reported that livestock alone accounts for over 12% to the GDP and forms 47% of the agricultural GDP.

Livestock plays an important role in the livelihood of a large portion of the population in rural areas of Africa, especially in semi-arid regions, where milk, meat and blood are important dietary components (Kabuko-Marriara 2008). Livestock is equally important in the generation of prestige, and remains an important component of bride price payments in some communities. Livestock is also used as a store of wealth or as a means of dealing with risk as an insurance against droughts.

Livestock plays a central role in Kenya as well, whose economy partly relies on the livestock sector. The proportion of land under pasture compared to total agricultural land is 80.5% in Kenya (FAO 2005). More than 80% of land in Kenya is arid to semi-arid lands (ASALs) characterized by low, unreliable and poorly distributed rainfall; the ASALs are mainly used for extensive livestock production (Barrett and Luseno 2004; Kabubo-Marriara 2008). It is estimated that the ASALs support about 25% of the

Kenya's human population and slightly over 50% of its livestock. In ASALs, the livestock sector accounts for 90% of employment and more than 95% of family incomes. However, the highest level of poverty (about 65%) and a very low access to basic social services such as infrastructure and education facilities are found in the ASALs region (FAO 2005). FAO reports that stagnation in production and productivity of livestock was observed in the last two decades, worsening the fragile living conditions of the population in ASAL regions and reducing the supply of livestock products in Kenya. Among other constraints that led to this situation is the existence of incomplete market and lack of reliable marketing systems in addition to recurrent droughts and diseases outbreaks.

2.2.2 Market liberalization in Kenya

Market reforms were introduced in many of African countries in the 1980's by the World Bank and the International Monetary Funds (Jayne et al. 1997) under the SAP. The food and financial crises of the 1980s in Sub-Saharan Africa led to a policy focus on food security and macroeconomic adjustments (Hoshmand 1996). The aim of these structural adjustment policies was to allow international and domestic markets to play a greater role in coordinating national economic activities. Even though the process of market liberalization has been slow in many African countries, Stambuli (2005) argues that African states are moving towards market liberalization to eliminate price distortions and unrealistic low interest rates.

In the case for Kenya as well, market-oriented reforms were also introduced in the latter half of the 1980s but took a relatively long period to be implemented (Barrel et al. 2006). The first phase of the agricultural reforms in Kenya was implemented from 1986 to 1988 (Hoshmand 1996). The main policy goal was to increase agricultural production by increasing the supply of fertilizer, improving procedures for setting producer prices, relaxing market regulations, and improving extension services. For instance, discussing the fertilizer market in Kenya, Freeman and Kawugongo (2003) argued that the economic cost associated with poorly performing domestic markets was an important reason to liberalize agricultural inputs markets under structural adjustment programs, a view shared by Barrel et al. (2006). Freeman and Kawugongo reports that prior to the mid 1980s, the government was extensively involved in the import, pricing, and marketing of fertilizer using policy instruments such as price subsidies, price control, licensing of importers and distributors, and import quotas. It took about ten years, from 1983 to1993, to have the fertilizer market completely liberalized. In the livestock sector, the milk marketing was liberalized in 1992 (Alila and Atieno 2006). After the liberalization of the domestic marketing of agricultural products that saw the role of marketing boards in Kenya reduced, private traders took over the marketing of livestock and livestock products (Alila and Atieno 2006). However, the private traders failed to produce positive results due to a lack of experience in management.

In livestock markets, some of the major strategic needs and policy issues identified in Kenya were related to the lack of information flow and equal access to critical livestock market information (LINKS 2005). In a household survey carried out in Kenya and Ethiopia, Barrett, Bellemare, and Osterloh (2004) report that most respondents cited the traders and friends as their primary sources of livestock price information. Also, the frequency with which respondents check primary price information was quite satisfactory since on average half of the surveyed household responded that they gathered price information on a weekly basis. Even though Barrett, Bellemare, and Osterloh (2004) downplayed any scarcity of livestock price information in their conclusions, the reliability of this information leaves much to be desired (LINKS 2005). This concern was the main reason for the introduction in Kenya, Ethiopia and Tanzania of the livestock market information system project known as “LINKS” (Livestock Information Network Knowledge).

2.2.3 Livestock market information system and LINKS project

Among many agricultural policies issue in Kenya is the poor marketing facilities and institutions, where specifically for livestock marketing there is limited access to livestock markets (Alila and Atieno 2006). Another issue is the poor timing of livestock sales, with majority of pastoralists selling their stock under very desperate circumstances that in some way is linked to the lack of sufficient infrastructure such as livestock markets and roads. While the ASALs area is endowed with livestock production potential, lack of markets for livestock has increased the vulnerability of pastoralists who depend on livestock products for their living (Alila and Atieno 2006).

According to IGAD (2007) incomplete market and poor marketing systems for meat and live animals, coupled with a lack of service provision and infrastructure in pastoralist areas are some of the policy issues in the Kenya livestock sector. A review on livestock market development activities in eastern Africa (Kenya included) has revealed a lack of viable livestock market information systems that would support decision making of traders, pastoralists and policy makers and improve the livelihoods of the pastoralist communities (LINKS 2005). The pastoralists living in Kenya ASAL regions where livestock generates 95% of family income are among the poorest people in Sub-Sahara Africa (Barrett and Luseno 2004).

However, the lack of a well functioning market system poses an obstacle to the development of ASAL region given the information gap (of price for example), the high transaction costs and poor infrastructure that lead to a low and variable producer price and a subsequent low marketed off-take rate of livestock (Barrett, Bellemare, and Osterloh 2004; Barrett and Luseno 2004). Even though Barrett, Bellemare, and Osterloh (2004) seem to conclude that marketing cost and information gap are not limiting factors of livestock marketing in Kenya, their survey results show, in particular on information gaps, that 45% of respondents cited their friend as the source of price information. However, in another research, Komen, Kariuki, and Kaitho (2009) stated that the establishment of reliable and timely national and regional market information, in Kenya, was vital in enabling producers, traders and policy makers make informed market decisions. Good communication and livestock information systems are also expected to reinforce commitments to productivity and to enhance the international competitiveness of the livestock industry in the region in general and in Kenya in particular (LINKS 2005). Given the high dependency of pastoral family livelihood on cash income from the sale of livestock and livestock products, institutional focus has been directed toward improving livestock market information, infrastructure and efficiency.

A reliable market information system creates transparency and a basis for the pastoralists to make marketing decisions. This idea led to the development of the LINKS project (Livestock Information Network and Knowledge System) (Komen, Kariuki, and Kaitho 2009). LINKS was a sub-project within the Global Livestock Collaborative Research Support Program (GL-CRSP) implemented by Texas A&M University and funded by USAID. The LINKS project was developed from the GL-CRSP Livestock Early Warning System (LEWS) project established in 1997 (LINKS website). The LINKS project used LEWS technology inside a broader livestock information and analysis system that aimed to improve livestock markets and trade, to enhance the well-being of pastoralists in eastern Africa. LINKS provided regular livestock prices and volume information on most of the major livestock markets in Ethiopia, Kenya and Tanzania along with information on forage conditions, disease outbreak, conflict and water supply to support decision making at multiple scales. This system provides near real time market information which is available on request via SMS text message system, email, WorldSpace radio systems and on the internet.

The different reforms (such as the SAP market reforms of the 1980s), government policies and market information systems introduced over the years (see examples above) in Kenya had a goal of creating a competitive market. However, due to the lack of enough data, this research will not evaluate the effects of those different policies but rather will limit its investigation on the level of cattle markets integration in Kenya. Also the study will seek to find out in which market the price of livestock is discovered and how it influences other livestock market prices.

2.2.4 Study area

A summary description and a map of the selected cattle markets are provided below in table 1 and figure 2 respectively.

Table 1. Kenya cattle market description

Market	Location	Latitude	Longitude	Type	Market Size*
Dagoretti	Nairobi	-1.286	36.819	Terminal	Large
Njiru	Nairobi	-1.119	36.924	Terminal	Large
Isiolo	Eastern-Central	0.345	37.585	Supply	Large
Garsen	Coastal-South	-2.274	40.115	Supply	Large
Chepareria	Rift Valley-West	1.315	35.202	Supply	Medium
Garissa	North Eastern	-0.449	39.65	Supply	Large

Source: Mr. Kariuki Gatarwa (personal communication, 2010)[4]
* Size is based on volume of cattle (number of heads)

According to Kariuki Gatarwa, Nairobi markets (Njiru and Dagoretti) are among the largest terminal markets in Kenya along with Mombasa.

Nairobi-Njiru receives animals mainly of Boran breed from markets in Northern Kenya (Isiolo, Marsabit, Moyale) and Northeastern (Bangale, Garissa, Wajir, Mandera) but sometimes receives some Zebu breed from Emali in southern Kenya.

[4] Mr. Kariuki Gatarwa was the main contact and LINKS project officer based in Nairobi (see for example Kariuki et al. 2009. From LINKS to NLMIS: issues, challenges and lessons learned. GL-CRSP Research Brief 09-01-LINKS. University of California, Davis)

Nairobi-Dagoretti receives animals mainly of Zebu and mixed breeds from markets in southern Kenya and western Kenya.

Garissa is the largest cattle supply market and supplies major markets in Kenya such as Machakos, Nairobi and Mombasa including other smaller terminal markets in between. Garissa is supplied in majority (75%) by cattle coming from Somalia (FEWS-NET 2008). The rest of the livestock come from Wajir, Mandera, and Ijara districts of Kenya, as well as from border areas of Ethiopia.

Garsen supplies mainly Mombasa market and both are located in the coastal belt of the Indian ocean..

Chepareria is located in the Rift Valley region, which has the high density of cattle in Kenya and supplies animals to markets located mainly in western Kenya.

Isiolo is mainly supplied in livestock by markets in the northern part of Kenya, from Moyale (Ethiopian border) through Marsabit and end up most of the time at the Nairobi terminal market.

Isiolo, Garissa, and Nairobi were the initial markets to implement the LINKS system with Marsabit, Moyale and Wajir coming on board later.

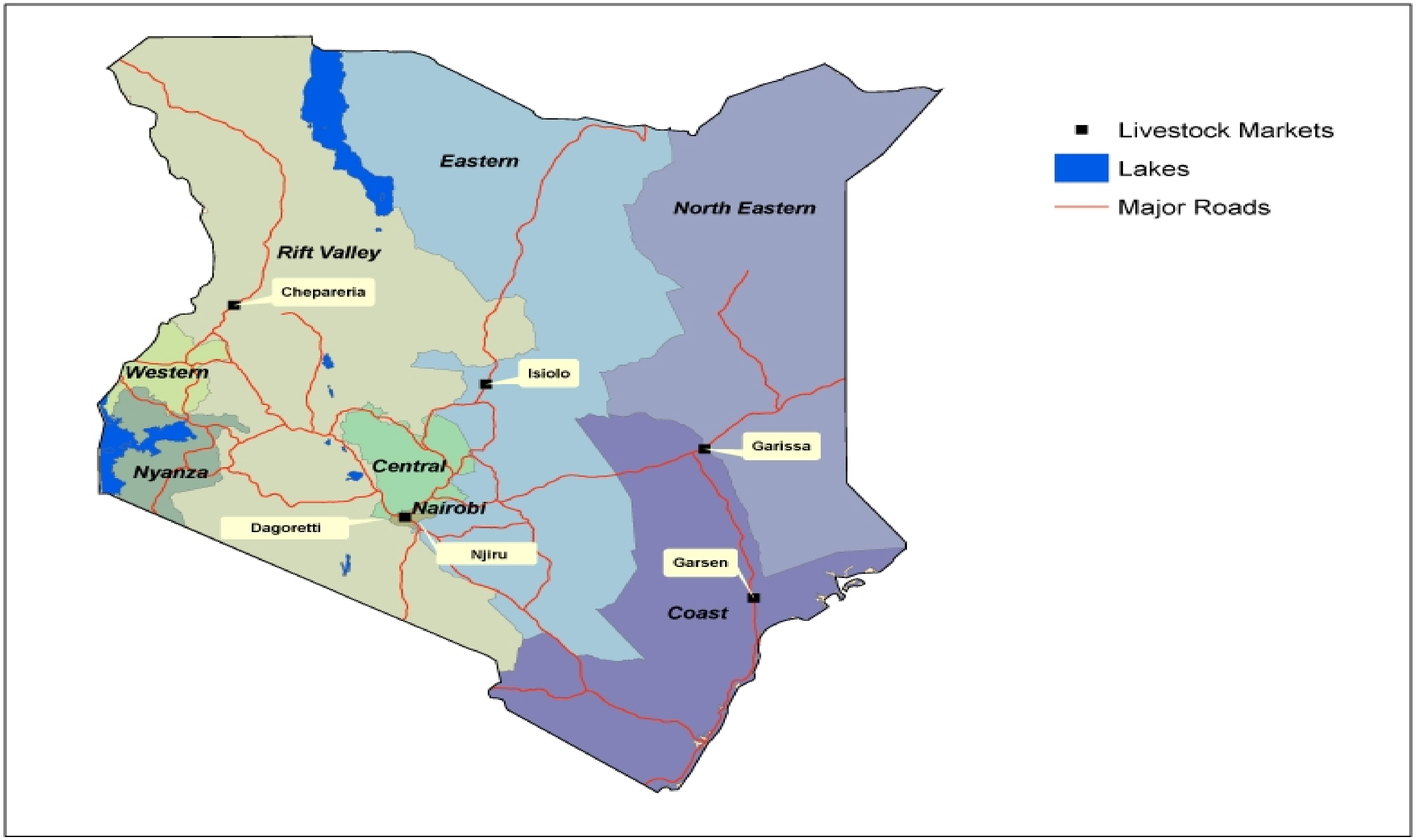

Figure 2. Map of administrative regions of Kenya and the livestock markets

2.2.5 Data

Weekly cattle prices collected from June 2006 to December 2009 on six markets of Nairobi-Njiru, Nairobi-Dagoretti, Isiolo, Garsen, Chepareria and Garissa are analyzed to study the market price dynamics. The regions represented by these markets are located in South such as the capital city Nairobi, East, Central and West of Kenya. The choice of the markets was based on the availability of the price information collected. The category of cattle targeted in this study is that, of adult male (except for Njiru market which has female) with essentially a moderate fat body condition (category G2) from the breed of boran[5]. In some instances where information on adult and moderate fat male were lacking we used data on adult castrate of medium fat body (G3). Garissa market had the largest missing data gap, mainly due to drought conditions (EWS Bulletins, 2009). We used forecasting procedure to fill in the data, where a univariate autoregression, fit to earlier date, t-k, k>0 is used to forecast date for missing observation at period t.

The data are collected at the livestock markets by market monitors supervised by the in-country LINKS project partners. Market monitors are trained on how to construct and type in SMS (Short Messaging System) messages in their cell phones to send out price and volume information. A complete SMS message needs to have the codes in a definite sequence for the SMS server to parse the SMS message and automatically put the data in the database. The monitors are trained on various aspects of data collection and reporting including sampling at the market, grading, data recording and coding,

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[5] Boran is an East African shorthorned zebu type whose name originates from the cattle of Borana people of the Southern Ethiopia.

sending and querying data through short message service and the internet. A datasheet has been developed to help the market monitors with recording data in the field and ensure that data collected are reflective of the type of animal, classes that are being sold on the market. Each market monitor tries to collect data on five different animals of the same kind, breed, age, gender and conformation (fatness). A mean price from the average on the five animals is computed and sent to the database via SMS.

2.3 Case study 3: Tanzania

2.3.1 Importance of livestock in Tanzania

The United Republic of Tanzania is located in Eastern Africa, bordering the Indian Ocean, Kenya, Mozambique, Burundi, Democratic Republic of Congo, Uganda, Malawi, Zambia, and Rwanda. A short time after their independence in early 1960s, the mainland Tanganyika and the island Zanzibar came together to form the nation of Tanzania in 1964. Tanzania's economy, like many other developing countries, is heavily dependent on agriculture. The agriculture accounts for 45% of the total GDP more than 70% of total exports and employs about 90% of women and 78% of men in the rural areas (ADB 2004).

Livestock is an integral part of the agricultural sector in Tanzania accounting for nearly 30% of the agricultural GDP and 12% of the national GDP (FAO 2005). As with many developing countries, livestock remains an important asset in Tanzania specifically for the poor in rural areas, where not only is livestock sold for cash to procure other goods, but also is a rich source of proteins and has a wealth and cultural value in wedding ceremonies.

About 99% of livestock rearing in Tanzania is carried out by traditional smallholder farmers, among whom 62.3% are categorized as poor according to FAO (2005). Verbeke et al. (2009) reports that the living conditions of livestock keepers in several pastoral African countries including Tanzania, are deplorable, where many live below the poverty line of US$ 1 per day. Pastoralism is concentrated in the northern plains grazing areas where dry climatic conditions do not allow sustained crop production, but instead favor livestock rearing. The dryland areas (arid and semi-arid) cover approximately 65% of the country and supports roughly 30% of human population and 60% of livestock in Tanzania (Hella et al. 2001). However, the great variability of rainfall patterns poses a threat to the pastoral communities specifically in the arid and semi-arid regions where the coefficient of variation in rainfall can reach 60% (Hella et al. 2001). Predictions from the ASARECA-Animal Agriculture Research Network or A-AARNET (2007) state that this situation is expected to worsen in the coming years due to the global climate change phenomena. Thus, high variability of rainfall in semi-arid Tanzania makes the livestock enterprise very uncertain and the marketing strategies stochastic (Hella et al. 2001). One of the strategies to help livestock to continue as a viable business and a tool of poverty reduction in Tanzania is to improve market participation.

2.3.2 Market liberalization in Tanzania

The waves of economic reforms that swept across Africa in the 1980s under the World Bank (WB) and International Monetary Funds (IMF) leadership (called “Structural Adjustment Programs” or SAP) also reached Tanzania, which had a socialist type of government since independence in 1964. The reforms introduced in early 1980s aimed at creating more efficient economies that would increase productivity and competitiveness (Grosen and Coskun 2010). Gorsen and Coskun point out that until the economic crisis of 1980s Tanzania had adopted a socialist development approach called "Ujamaa" in Swahili language, which promoted the government intervention in economic and social activities of the country.

In 1986, the government of Tanzania shifted from a centrally planned to a market economy where several sectors of the economy were liberalized and state-owned companies privatized (FAO 2005; Grosen and Coskun 2010). It is the economic crisis of 1980's that triggered the move to economic reforms. In fact the "Ujamaa" political orientation failed to bring prosperity and development in the country and saw the GDP decline and the economy collapse in 1980 (Grosen and Coskun 2010). Other related factors that contributed to the economic crisis were the deterioration of the terms of trade, protectionism by industrialized countries and a decline in demand for Tanzanian agricultural products on international markets. The agricultural sector was one of the priorities in the IMF stabilization program according to Grosen and Coskun (2010). However, more attention was given to the mining sector to attract foreign investment where government granted licenses to private companies for mining activities. The mining sector, especially the gold mines, plays an important role in the economy of Tanzania, ranking as the third largest producer of gold in Africa after South Africa and Ghana.

Structural adjustment in Tanzania went through three phases (Grosen and Coskun 2010). The first phase focused on trade liberalization whereas the second focusd on foreign investment deregulations. The third phase was concerned with the reform in public service by reducing the number of civil servants. Ponte (1998) points out that from 1963-1976 most food crops (grains, oilseeds, pulses) were traded monopolistically through cooperative unions and primary cooperative societies. After 1976, crop marketing boards replaced these organizations until 1982. Note that until 1987 the government prohibited all commercial sales.

The first sign of change from a centrally planned to a free economy came with the signing of credit agreements between the WB and IMF and Tanzania government under the Economic Recovery Program in 1986. In 1987, all restrictions on the transports and movements were lifted and private traders were allowed to buy grains from the cooperative unions. Another milestone was reached in 1989 when private traders were allowed to buy directly from producers (see also Eskola 2005). It took several years for the private structures to take root and help implement the principles and rules of an open and free market. Ponte (1998) who did a study in the Tanzanian Districts of Morogoro and Songea, reported that in Morogoro, the marketing of all crops, except for cotton, was controlled by private traders, accounting for 65.3 percent of total crop sales. The cooperative units held a share of 11.4 percent of the total purchase. As for Songea by 1994/95, private traders completely controlled all non-export crops, where they purchased 43.5 percent of all crop sales. Grosen and Coskun (2010) state that, despite 17 years of IMF policy and political independence, Tanzanian is still underdeveloped and dependent on outside economic forces, since it continues to export raw material on the international market. Several of the African countries that implemented the SAP saw mixed results over years due to institutional barriers, international trade regulations and subsidies on crops by developed countries (Jayne 1997).

2.3.3 Institutional development and livestock market information system

The official market liberalization by the Tanzanian government in the 1980s did not remove the informal barriers to an open economy such as insufficient market information (Eskola 2005). Specifically in livestock sector, Verbeke et al. (2009) reports that in Tanzania, Kenya and Uganda the cash market is the common channel through which livestock are marketed. It is an open and competitive platform for buying and selling livestock for all agents, but suffers from a high level of information asymmetries concerning market conditions, participants and goods, which results in high transaction costs.

In addition to the problem of insufficient market information, there is a lack of institutional arrangements to help in the process of market development and integration. Poulton, Kydd, and Dorward (2006) argue that the fundamental constraints to market development in Africa are more institutional than financial. In fact, given the absence of legal framework to carry out transactions (lack of contracts and ability to enforce informal agreements) most of the trading goes through middleman and brokers which increase the transaction costs (Eskola 2005). Most deals are done between relatives and close personal friends where, for example, producers would likely trust traders from the same ethnic background to carry out a transaction. Trade is build around social capital and personal contacts that serve as a guarantee for the transaction to take place (Verbeke et al. 2009). Sales of cattle are much of the time less related to prices prevailing on the market but rather, dependent on social relations. In a survey conducted by Eskola (2005), traders and buyers indicated that their neighbors and other traders were their main source of market information to show the importance of these social networks to trade. Dorward et al. (2005) posit that institutional development and improved communication are among the requirements for market access in developing countries.

Given the high dependency of pastoral family livelihood on cash income from the sale of livestock and livestock products, institutional focus has been directed toward improving livestock market information, infrastructure and efficiency (LINKS 2005). A reliable market information system creates transparency and a basis for the pastoralists to make marketing decisions. This led to the development of the LINKS project (see LINKS introduction in the Kenya case study).

LINKS provided regular livestock prices and volume information on most of the major livestock markets in Ethiopia, Kenya and Tanzania along with information on forage conditions, disease outbreak, conflict and water supply to support decision making at multiple scales. This system provides near real time market information which is available on request via SMS text message system, email, WorldSpace radio systems and on the internet.

In summary, the high fluctuation of rainfall in semi-arid regions of Tanzania makes the livestock rearing a difficult business in terms of risks and increases the vulnerability of the populations living in those regions. This situation continues to deteriorate with the desert and dry conditions gaining more land despite the fact that the livestock sector has been chosen as one of the main axis of poverty reduction in Africa and developing countries. The development of a market information system for livestock will not only enhance a market-based economy but also help pastoralists make better marketing decisions, reduce their risks and increase their income (Angerer, Keita, and Dial 2010). To evaluate some of the aspects of a competitive market in Tanzania this research will analyze the level of integration among four Tanzanian cattle markets for the period from 2006 to 2010. Also this study seeks to find out where the price of livestock is discovered and how it influences other livestock market prices. Due to the lack of enough data our research will neither evaluate the effects of the structural adjustment programs of the 1980s nor the impact of the introduction of a livestock market information system by the LINKS project in Tanzania on livestock markets.

2.3.4 Study area

Four markets were selected to be part of this study as shown in figure 3. Their description is as follows (Julian K. Gutta[6], 2011 personal communication):

Pugu is located at 22 kms west of Dar es Salaam along the central railway (latitude: -6.823; Longitude: 39.270). This is a secondary market dominated mostly by traders; very few producers bring in animals to the market. It is a daily market. The herd is about 1600 animals per day on average but only around 900 -

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[6] Julian K. Gutta was the main in-country contact and coordinator of LINKS project. Currently he is the Market Specialist in Tanzanian Ministry of Industry, Trade and Marketing (See LINKS 2007 Annual Report)

1000 of these are sold per day. Pugu is the largest cattle market in Africa. Pugu receives supply mainly from Dodoma, Singida, Tabora, Shinyanga, Morogoro , Pwani, Mwanza, and to a less extent from Iringa, Mbeya and Sumbawanga. The market operates seven days a week and 365 days a year. The market also supplies Zanzibar, Mtwara, Lindi and Comoro.

Igunga is located in Tabora region (latitude: -4.284; Longitude: 33.874). It is a producer market drawing animals from Igunga, Nzega and Iramba districts. Igunga is the largest market in the district with about 700-900 heads per market day and operates four days per month (once a week). The market is also accessible throughout the year. The market supplies animals to Pugu, Meserani-Monduli, Igunga and Tabora

Kishapu (Muhunze) is a producer market located in Shinyaga region. Kishapu district (latitude: -3.665; longitude: 33.421). It is the largest market in the region and operates four days per month (once a week) with a herd of about 800 – 1000 animals per market day. The market supplies animals to Shinyanga, Meserani, Monduli, Weruweru- Moshi and Pugu markets.

Monduli (Meserani) is located in Monduli District (latitude: -3.366; longitude: 33.674) at about 30 kms North West of Arusha municipal. Monduli is the largest market in Arusha region. It is a secondary market operating four days per month (once a week) with an average herd of 500 – 800 per market day. It supplies animals to Arusha and Kenya.

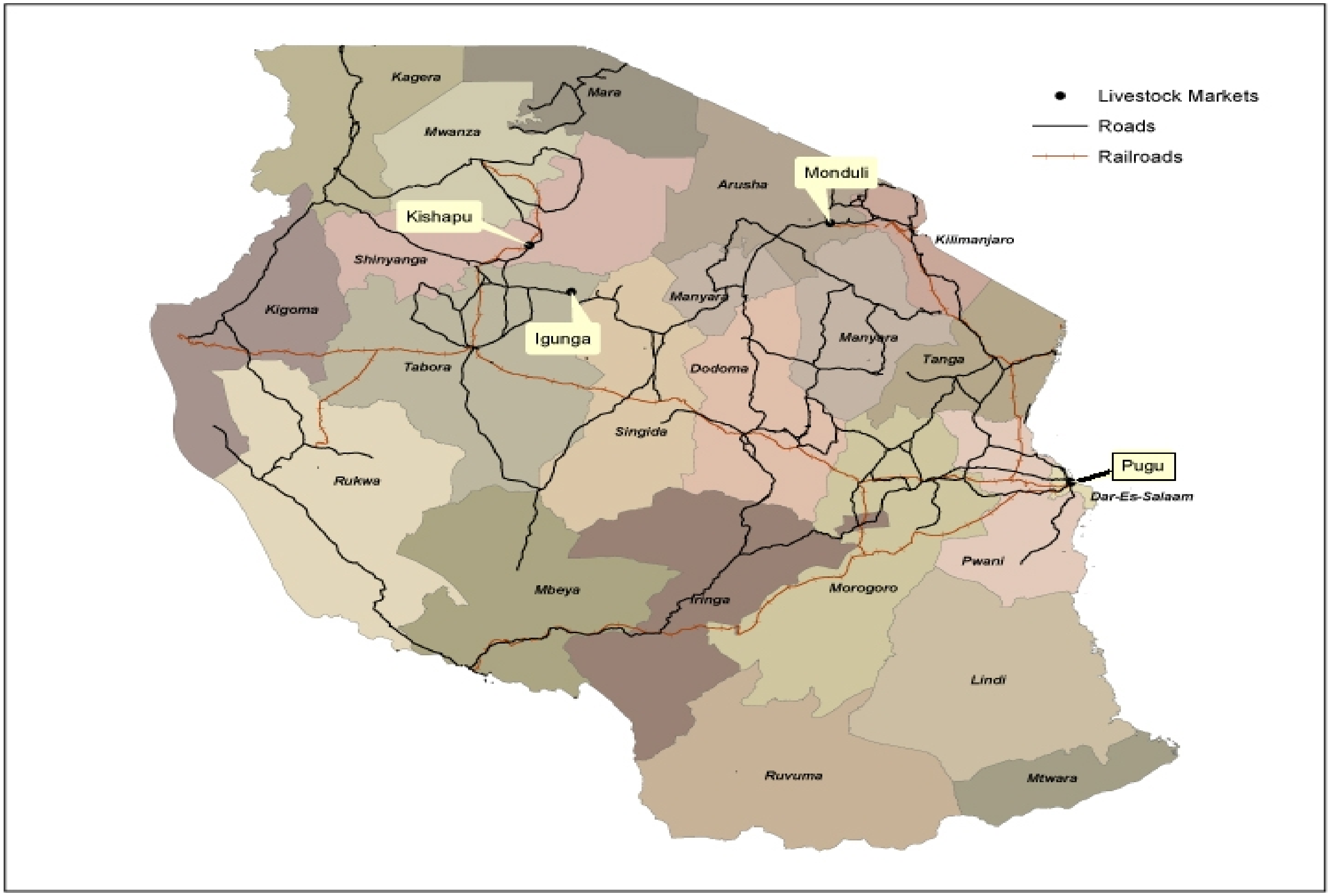

Figure 3. Map of administrative regions of Tanzania and the livestock markets

2.3.5 Data

Weekly cattle prices are analyzed to study the market integration process in Tanzania following the introduction in 2003 by the LINKS project of a livestock market information system to collect and disseminate livestock market price information. We analyze weekly data on price of cattle collected from February 2006 to January 2010 (209 observations) in four cattle markets of Pugu (Dar-Es-Salaam), Igunga (Tabora), Kishapu (Shinyanga) and Moduli (Arusha), which were among the first to implement the LINKS livestock market information system. The category of cattle targeted in this study is made up of adult male with mainly a fat body condition of grade two (or grade three in case fat animals are not available due to drought conditions) from Zebu breed. In some instances where information on adult male were lacking we used data on adult castrate fat.

The data are collected at the livestock markets by market monitors supervised by the LINKS project in-country partners. These monitors are trained on how to construct and type in SMS messages in their cell phones. Given that the data collection methodology was similar for Kenya and Tanzania, see details on data collection in Kenya case study.

CHAPTER III

RESULTS AND DISCUSSION

The third chapter discusses the results of the three case studies, namely the case study of Mali, Kenya, and Tanzania. The results of each case study are first presented and then discussions based on those results, the economic theory, and previous results from the literature, follow before the conclusions.

3.1 Case study 1: Mali

3.1.1 Results presentation and discussion

The evolution of cattle prices over nearly two years on six markets scattered around the country is shown in figure 4. There appears to be two types of pattern of variation in the six price series. Some prices seem to follow a more or less random walk while others show a tendency to return to their long-run mean (mean reversion). We notice more particularly erratic variations of prices in Kidal market during the entire period of study possibly due to the predominant presence on the market of thin to medium fat immature male cattle. Given the persistent dry conditions of the Kidal region located in the desert zone, it is rare to find fat animals; only small ruminats and chamels which can survive to these conditons, are predominant in the region. We also observed for the markets of Gossi, Konna, Wabaria, and to some extent Wabaria an increase upward and downward trend of prices from November 2008 to May-June 2009 that culminated in a drop in price around June and July 2009. The peak in prices might be explained by the high demand in meat during the festivals (Ramadan and Tabaski) while the low prices are observed towards the end of the dry season around June when animals are in bad conditions due to the scarcity of water and forage (Dr. Aly Dial, personal communication, 2010). This situation was aggravated by a severe drought that hit the regions of Mopti, Gao and Kidal around the period of June 2009. Note that the cattle prices are in “Franc CFA (FCFA)”, a currency used in eight West African countries of Mali, Benin, Burkina Faso, Senegal, Côte d’Ivoire, Guinea Bissau, Togo, and Niger.

The mean, standard deviation, coefficient of variation and their respective rank in order from the highest (1) to the lowest (6), are presented in table 2 for six cattle markets in Mali from November 2008 to September 2010. Kati has the highest average price followed by Niamana and Wabaria. Those three markets are the largest in this group of markets in terms of number of heads present at the market place and body quality (fatness). Niamana ranks number one and Kati number three at the national level. The last two markets, Gossi and Kidal have fewer animals with a body condition of medium to thin. This is possibly due (mainly for Kidal) to the dry conditions of the region (desert). We also notice considerable of variability in price in Kidal and Gossi for probably the reasons presented above.

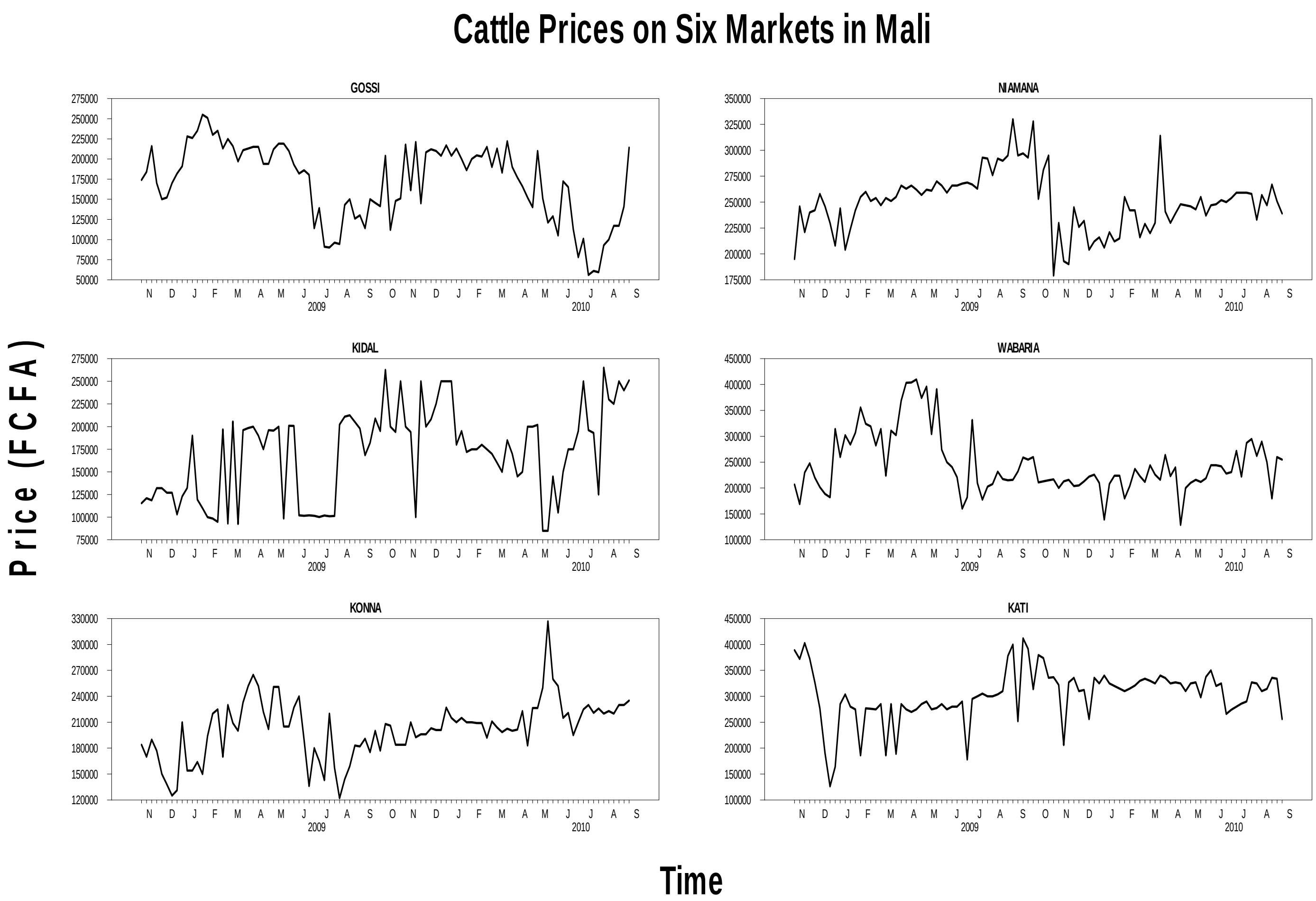

Figure 4. Price series in levels for six cattle markets in Mali, 2008-2010

Table 2. Summary statistics on prices of cattle from six markets in Mali, 2008-2010

Market	Mean	Rank	SD	Rank	CV	Rank
Gossi	171550	6	47609.2	4	27.75	2
Kidal	171211	5	49739.7	3	29.05	1
Konna	202100	4	33828.3	5	16.73	5
Niamana	250134	2	28254.7	6	11.29	6
Wabaria	243567	3	61814.4	1	25.37	3
Kati	302808	1	50966.2	2	16.83	4

The data are average weekly price recorded in each market, measured in Franc CFA (CFA) per head. The column labeled “Mean” refers to the simple mean price for the market listed in the far left-hand column of each row. The columns labeled by “SD” indicate the standard deviation of observed prices from the corresponding market. The column labeled “CV” refers to the coefficient of variation for each market. Ranks columns are in order from the highest (1) to the lowest (6). The number of observation in each market is 97.

The Augmented Dickey-Fuller (ADF) tests results on levels and first difference of cattle prices in six markets of Mali from 2008-2010 are presented in table 3. The null hypothesis on each levels test is that the price in each market is non-stationary. The tests for the levels show that three series among the six (in bold) are non-stationary, while three others are stationary. We notice that for the ADF in first difference, all the series are stationary after differencing the data in levels. The p-value on Ljung-Box Q statistic applied to the residuals from each ADF test show that the residuals are not auto-correlated. We fail to reject the null hypothesis of non auto-correlated residuals at 5% significant level.

Given that the ADF tests in general are known to have low power, the Elliot, Rothemberg and Stock or ERS test (unit root test) was performed to verify and confirm the stationarity of the price series. The ERS test (GLS version), which is a modification of ADF test is believed to have a maximum power and to be efficient (Pfaff 2008;

Armstrong 2001). The null hypothesis is that of unit root. The results show that we fail to reject at 5% critical value the null hypothesis of unit root in all six markets in the case where we consider no deterministic trend (constant and time trend) at all in the equation[7]. This is the case of a pure random walk that is most of the time assumed for agricultural commodity prices (Samuelson 1971). However, in this research, we will consider the ADF results in further discussion.

Table 3. Unit root test on prices of cattle from six markets in Mali, 2008-2010

Augmented Dickey-Fuller (levels)				Augmented Dickey-Fuller (1st diff)		
Market	t-test	k	Q (p-value)	t-test	k	Q (p-value)
Gossi	-2.68317	1	35.65 (0.06)	-5.9414	2	32.55 (0.11)
Kidal	-3.71786	1	20.36 (0.67)	-7.5102	2	24.61 (0.42)
Konna	-3.08419	1	13.75 (0.95)	-6.7914	2	16.34 (0.87)
Niamana	-2.25513	1	34.33 (0.07)	-6.2957	2	28.83 (0.22)
Wabaria	-2.55701	1	21.09 (0.63)	-7.0253	2	22.37 (0.55)
Kati	-3.44429	1	35.43 (0.06)	-4.8786	2	31.70 (0.13)

The critical value (t-stat) to reject the null hypothesis (at 5% significance level) of non-stationarity is -2.89. The column labeled "k" indicates the number of lags of the dependent variable used to produce "white noise" residuals. The value of k results from the minimization of the Schwarz loss metric on values of k ranging from 1 to 3. The column labeled "Q (p-value)" refers to the Ljung-Box statistic (Portmanteau test) test of white noise residuals from ADF regression. The number of observation in each market is 97.

A lag length test was performed (table 4) to determine the maximum number of lags for the model. There are several approaches to determine the optimal lag length of a VAR. Schwartz loss and Hannan Quinn tests were carried out for this task. Both metrics found local minima at one lag for the VAR model.

[7] In other cases where we consider a linear time trend and/or a constant, we reject the null of unit root in all six markets (for details on ERS results contact the author). In brief if we consider that the cattle price series follow a pure random walk (no stochastic or deterministic trend), which is normally assumed for prices, the ERS results show that the price series in all markets are non-stationary.

Table 4. Loss metrics (SL and HQ) on lag length from VARs on cattle prices from six markets, in Mali, 2008-2010

Lag length (k)	SL	HQ
1	102.52*	101.90*
2	103.84	102.68
3	105.04	103.34
4	106.53	104.28

Metrics considered are Schwarz-loss (SL) and Hannan and Quinn's (HQ) measure on lag length (k) of a levels VAR: $SL = \log(|\Sigma|) + (6k)(\log T)/T$; $HQ = \log(|\Sigma|) + (2.00)(6k)\log(\log T))/T$
Σ is the error covariance matrix and T is the total number of observations on each series. The symbol "| |" denotes the determinant operator and log is the natural logarithm. The single asterisk "*" indicates minimum of the Schwarz Loss metric and HQ measure

Next, we test if there exist for the individual non-stationary series, certain linear combinations of prices in levels from different markets that may be stationary, or co-integrated. The trace tests results for co-integration obtained using the CATS procedures are presented in table 5. The trace test determines the appropriate number r of co-integrating vectors (rank test) by a sequential testing procedure as described in Johansen (1992) and Juselius (2006). First, we begin by testing if all six roots are unit roots (r=0) with (marked with asterisk) and without a constant in the co-integrating space. If rejected we proceed with the testing whether the five roots are unit roots and continue until we fail to reject the null hypothesis. This occurs at r=5 (marked with a # sign) suggesting that we have five co-integrating vectors with a constant in the co-integrating space.

Table 5. **Trace test on cattle prices from six markets in Mali, 2008-2010**

Ho: r	T*	P-value*	D*	T	P-value	D
=0	169.10	0.000	R	174.84	0.000	R
≤1	105.62	0.000	R	108.50	0.000	R
≤2	68.50	0.001	R	69.93	0.001	R
≤3	37.16	0.029	R	37.70	0.025	R
≤4	22.50	0.022	R	22.70	0.021	R
≤5	8.41	0.070	F#	8.43	0.069	F#

The test statistic (T) is the trace test corresponding to the number of co-integrating vectors (r) presented in the far left-hand column and a p-value. Entries associated with an asterisk (*) have constant within the co-integrating vectors. Entries without an asterisk have no constant in the co-integrating vector but instead have the constant outside the co-integrating vector. The column labeled "D" indicates the decision to reject (R) or fail to reject (F) at a 5% percent level of significance the null hypothesis Ho that the number of co-integrating vectors r=0, r≤1, …, r≤5.

Despite the possibility of co-integration between series, earlier results from the unit root tests prompted us to search for an appropriate model to estimate the cattle price series. Those results show that only three out of six series are non-stationary..Yang et al. (2000) cite non-stationarity of the series as a precondition to carry out co-integration analysis.

To choose the appropriate model for our study, we did a forecast performance comparison for three possible models: the univariate model, the vector autoregression model (VAR) and the error correction model (ECM). The results show that the univariate and the VAR models (unrestricted VAR) perform better (have lowest RMSE) than the ECM, in five markets out of six (see figures 5-10 below). A possible reason for the ECM underperformance could be the over-differencing the already stationary series.

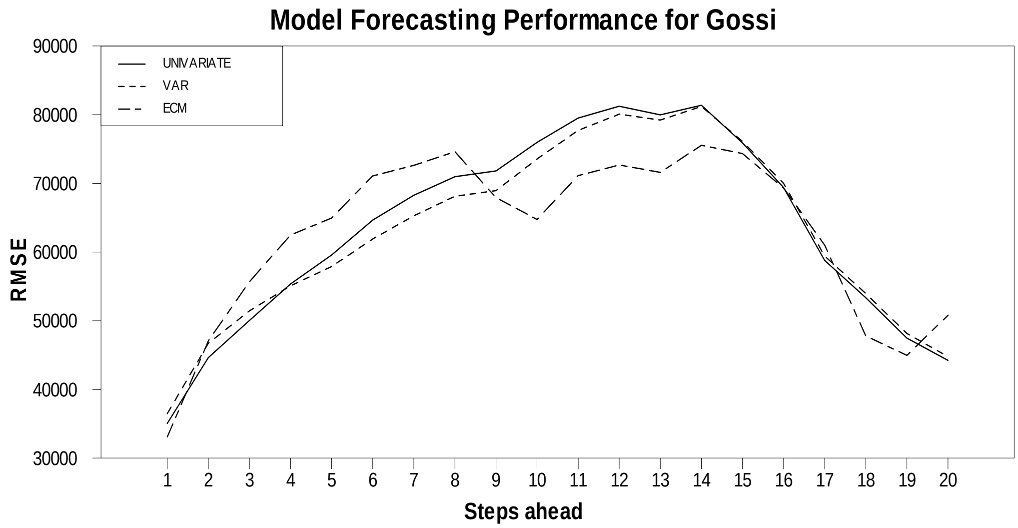

Figure 5. Comparison of forecast performance among ECM, VAR, and univariate models for Gossi market

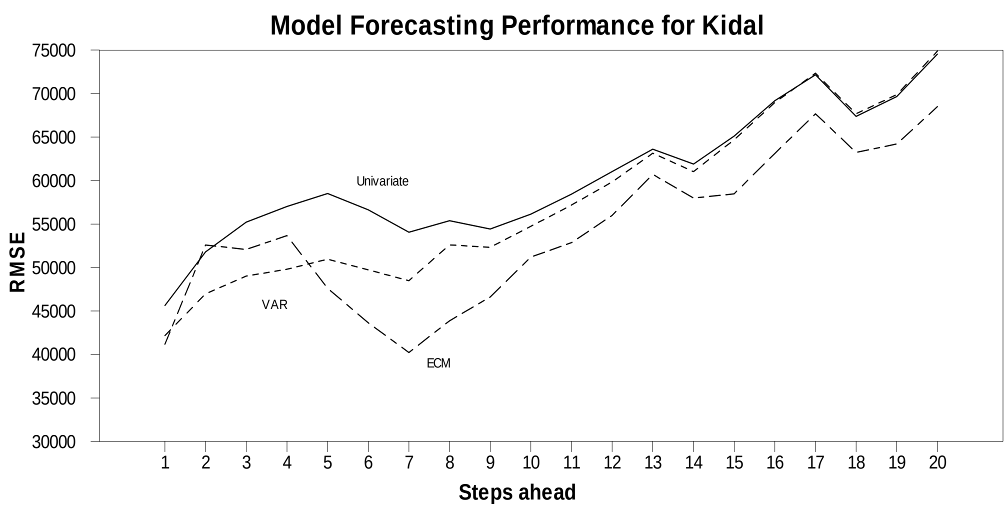

Figure 6. Comparison of forecast performance among ECM, VAR, and univariate models for Kidal market

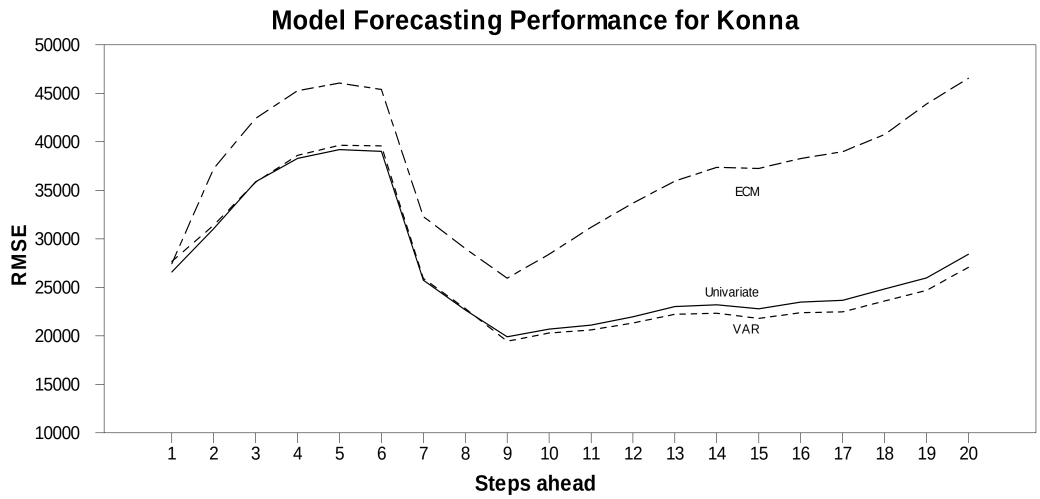

Figure 7. Comparison of forecast performance among ECM, VAR, and univariate models for Konna market

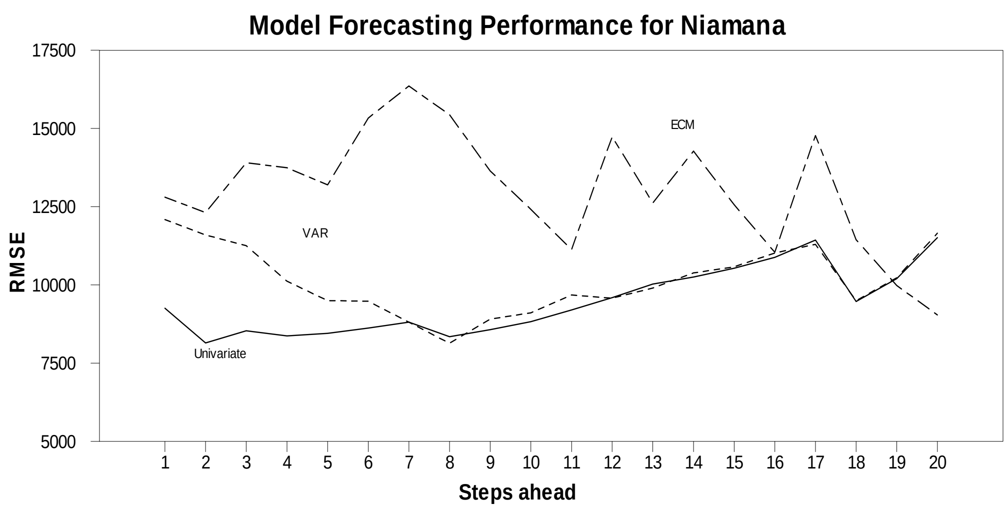

Figure 8. Comparison of forecast performance among ECM, VAR, and univariate models for Niamana market

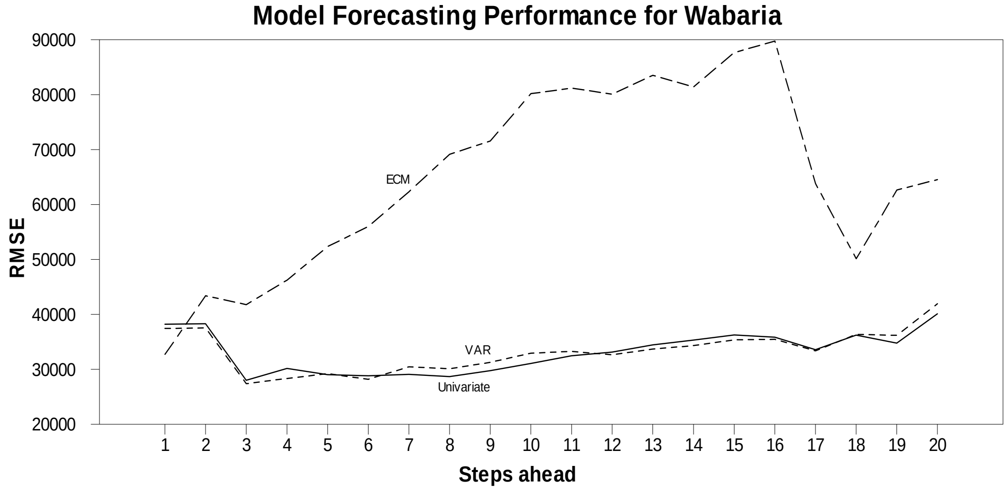

Figure 9. Comparison of forecast performance among ECM, VAR, and univariate models for Wabaria market

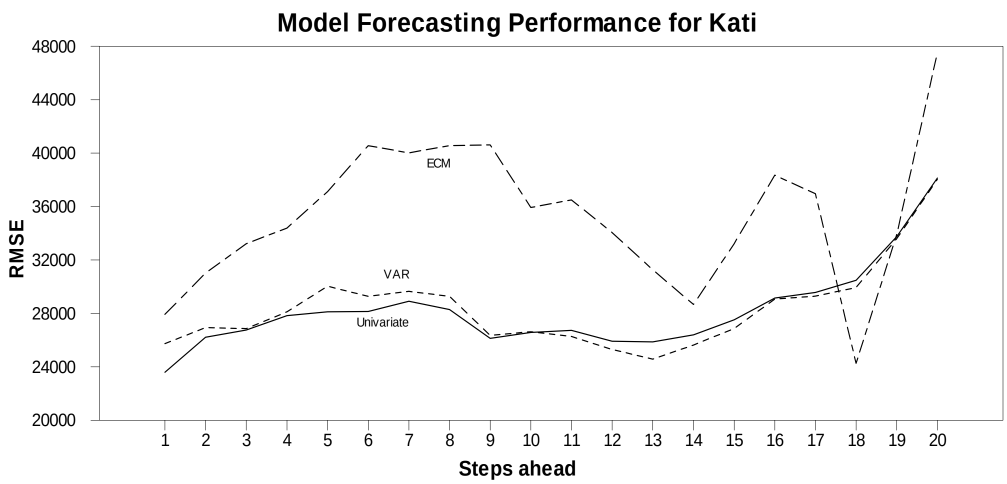

Figure 10. Comparison of forecast performance among ECM, VAR, and univariate models for Kati market

Further analysis was carried out to identify a parsimonious VAR model (or subset VAR) that appropriately study the price dynamics among markets following Hsiao search procedure (Hsiao 1979). The results show that all the markets are exogenous except Wabaria market. The price dependent variable in each market is explained by one to two lags of its self except for Wabaria, which is explained by its lagged price and Kati price at one lag (see equation 7). The results on the Hsiao search are presented in details in appendix A.1. The identified subset VAR is the following:

$$\begin{cases} \mathrm{PGO_t} = \mathrm{a}_1 + \alpha_{11}\mathrm{PGO_{t\text{-}1}} + \alpha_{12}\mathrm{PGO_{t\text{-}2}} + \varepsilon_{t1} \\ \mathrm{PKI_t} = \mathrm{a}_2 + \alpha_{21}\mathrm{PKI_{t\text{-}1}} + \alpha_{22}\mathrm{PKI_{t\text{-}2}} + \varepsilon_{t2} \\ \mathrm{PKO_t} = \mathrm{a}_3 + \alpha_{31}\mathrm{PKO_{t\text{-}1}} + \varepsilon_{t3} \\ \mathrm{PNI_t} = \mathrm{a}_4 + \alpha_{41}\mathrm{PNI_{t\text{-}1}} + \alpha_{42}\mathrm{PNI_{t\text{-}2}} + \varepsilon_{t4} \\ \mathrm{PWA_t} = \mathrm{a}_5 + \alpha_{51}\mathrm{PWA_{t\text{-}1}} + \alpha_{52}\mathrm{PWA_{t\text{-}2}} + \beta_{56}\mathrm{PKA_{t\text{-}1}} + \varepsilon_{t5} \\ \mathrm{PKA_t} = \mathrm{a}_6 + \alpha_{61}\mathrm{PKA_{t\text{-}1}} + \varepsilon_{t6} \end{cases} \quad (7)$$

where PGO_t, PKI_t, PKO_t, PNI_t, PWA_t, and PKA_t are respectively cattle prices for Gossi, Kidal, Konna, Niamana, Wabaria, and Kati markets in current time. The prices with a subscript t-1, on the right-hand side of the equation, are the prices for the same markets but lagged one period (ex. PGO_{t-1}); ε_{tn} is the error term.

In brief, the markets tend to rely on their recent past price to determine their current price; reliance on other market price information is almost non existent. Forecast performance tests were as well conducted to choose the best model among the Univariate, unrestricted VAR and a subset VAR. All the three models showed no significant difference in terms of RMSE comparison. However to be able to carry out innovation accounting and contemporaneous correlation analyses, we considered the unrestricted VAR model only.

Contemporaneous correlations between price innovations in each market were analyzed using graphical structure (DAG) to check whether the cattle markets influenced each other in current time. Overall observation indicates that there is an interaction between markets in current time as shown by the equation below and the DAG figure.

The contemporaneous correlations between price innovations in each market are presented in equation (8). Each market name is abbreviated by writing the first three letters of the market in the order: Gossi, Kidal, Konna, Niamana, Wabaria and Kati

$$
\begin{array}{c} \\ \text{Corr}(e_t)= \end{array}
\begin{array}{c} \quad\text{GOS} \quad \text{KID} \quad\quad \text{KON} \quad\quad \text{NIA} \quad\quad \text{WAB} \quad \text{KAT} \\
\begin{bmatrix}
1.000 & & & & & \\
0.101 & 1.000 & & & & \\
-0.114 & -0.006 & 1.000 & & & \\
-0.115 & -0.196 & -0.030 & 1.000 & & \\
0.108 & -0.191 & 0.217 & 0.022 & 1.000 & \\
0.111 & 0.012 & -0.113 & 0.112 & -0.013 & 1.000
\end{bmatrix}\end{array} \qquad (8)
$$

From the matrix above we notice that contemporaneous correlation between markets is weak with a value of less than 0.2 in 93% of cases; the highest correlation being 0.217 between Konna and Wabaria markets. The lowest correlation is between Kidal and Konna (0.006). The interpretation of the results above means that new information (innovations) from the cattle markets is slowly transmitted between markets. The distance between regions may explain these results. In a study carried out by Bessler and Kergna (2003), they found that price innovations in the millet markets in Bamako translated to each neighboring market at high rate (0.74-0.98). However, in another study on millet markets prices across regions in Mali, Vitale and Bessler (2006) found lower correlation coefficients between different regional markets (0.01-0.78). The difference in these results is probably due to the distance separating the markets. The price signals are transmitted quickly in markets located in Bamako compared to slow transmission among markets located in different regions. Also the difference between rates for price transmission in cattle and grain market might be due to the type of commodity; it might be easier to move around the grain than the cattle commodity.

To obtain more insight on the contemporaneous correlation, the graph structure (figure 11) was analyzed based on the correlation matrix results obtained in equation 7 from the unrestricted VAR model estimation.

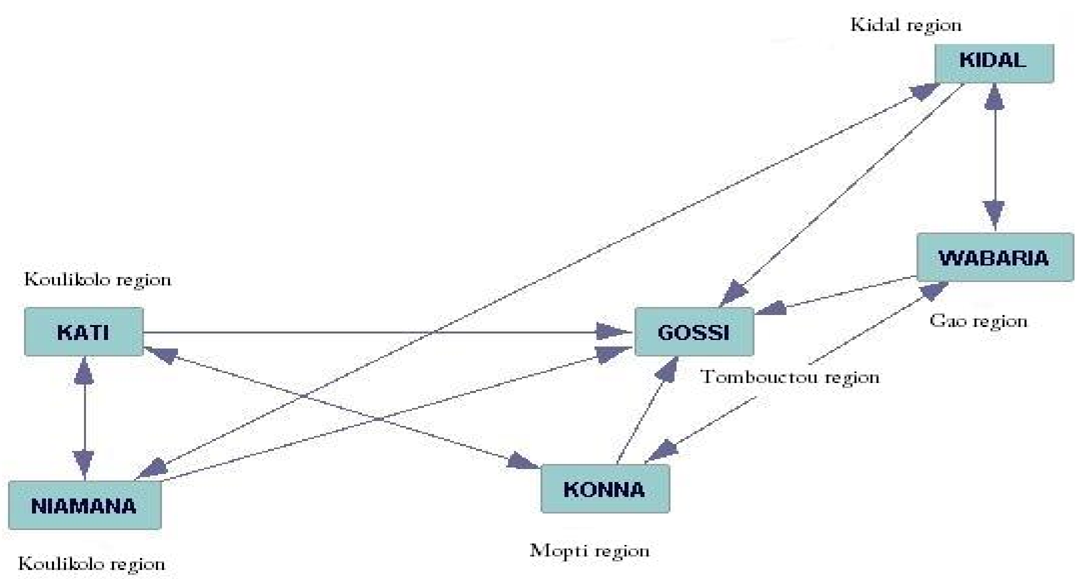

Figure 11. Causal flow on innovations from an unrestricted VAR on cattle price from six markets in Mali, 2008-2010

The causal relationships were obtained using a PC algorithm at 20% significance level as suggested in Spirtes, Glymour, and Scheines (2000) for sample size less than 100. Notice that Gossi market is a price information "sink" in current time, as edges from the remaining five markets are directed into Gossi and no edge is directed out of Gossi. We can interpret this result as an indication that Gossi is a receiver of information in contemporaneous time but does not provide information. Summary statistics results in table 2 agree with this conclusion to some extent given that Gossi has the second highest CV. The CV is an indication of dispersion of a probability distribution.

We notice several bi-directed edges between variables indicating the possible existence of omitted variables. It would be very hard to make relevant discussion in such a situation where there is no clear orientation of edges between certain variables. The possible explanation would be the existence of several intermediate cattle markets in between the markets currently under study. Due to the distance separating the six markets under study, we can interpret the bi-directed arrow between some markets as an indication of the existence of a common cause market that unconditionally move both markets[8]. That type of causal flow would fall under the category of causal fork (Pearl, 2000).

Spirtes, Glymour, and Scheines (2000) warn about the possibility of two types of mistakes that can be committed using the PC algorithm: edge inclusion or exclusion and edge direction. The edge direction error is more predominant than the edge inclusion or exclusion error. However, based on prior information and other results (especially GES algorithm results on three different models which are not presented here), we tentatively placed the edge direction (as in figure 12). The results suggest Kati market as an independent market in current time. We see arrows from Kati pointing to other markets with no arrows going into Kati. This conclusion is to be taken with caution for two reasons.

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[8] We base our interpretation on the assumption of common cause principle as stipulated in Reichenbach's (1956) (see course notes, Dr David A. Bessler)

First, the issues of edge inclusion, omission or direction described above concerning the PC algorithm. Second, Kati has virtually no trading relationship with any market studied in this essay specifically Niamana, despite their close location (Dial, personal communication, 2010). Kati cattle market is the main supply of cattle to the cattle market of Bamako Abottoir that in returns supplies the slaughterhouse of Bamako. Kati market receives cattle mainly from Nara (Koulikoro region) and Nioro (Kayes region). Other markets (Kidal, Wabaria, Konna and Niamana) are receiving and sending information as indicated by directions of arrows in and out of those markets (see figure 12).

Surprisingly, Niamana market, which is the largest cattle market in Mali, did not take the lead in moving and dominating other markets prices in contemporenous time. Located at seven miles from the capital city Bamako, a high demand area for cattle, Niamana enjoys the largest number of cattle heads brought on market for trade and receives animals from all over the country. Nevertheless, this observation does not rule out Niamana as a possible source of cattle price information. An in-depth analysis is recommended to identify the exact causal dynamics around Kati and Niamana market.

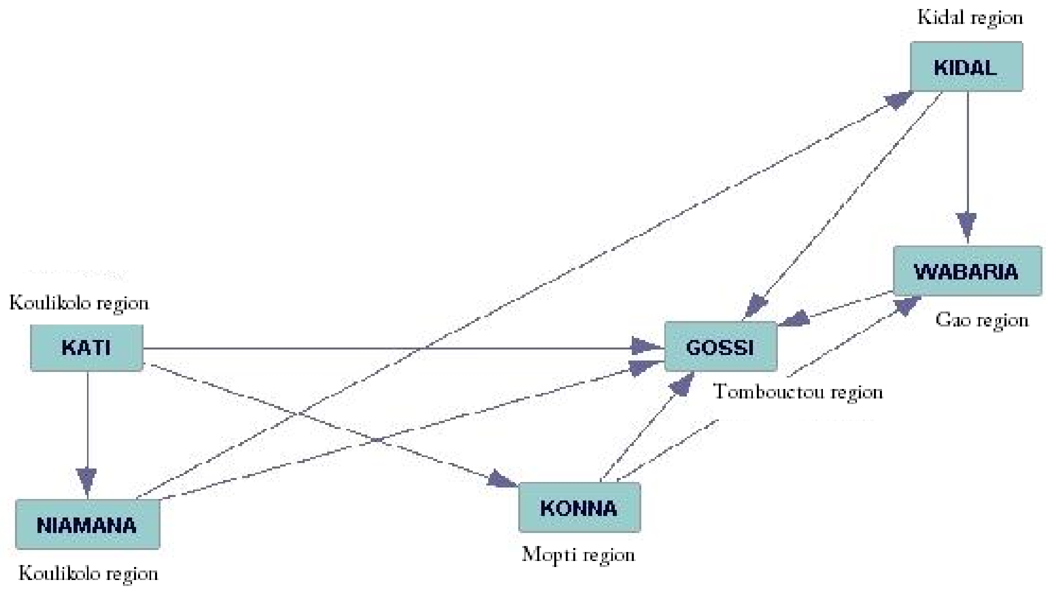

Figure 12. Causal flow without bi-directed edge on innovations from an unrestricted VAR on cattle prices

The forecast error variance decompositions were analyzed to see how much change in the future (uncertainty or error variance) of one market price is caused by uncertainty in other markets. The results of the forecast error variance decomposition on cattle prices in each of the six markets, at horizon of zero, one, four and eight weeks ahead are presented in table 6. It is the percentage of forecast error uncertainty in one market accounted for by earlier innovations in other markets. For example, the innovations associated with current prices in Kati market are solely (100%) explained by own-price shocks. Niamana and Konna show similar behavior with 98.7% of price variation explained by own-price shocks. The innovations in the remaining markets of Wabaria, Kidal, and Gossi are explained by own-price shock at 91, 96, and 93% respectively. For instance, in Kidal market, 3.8% change in price, are explained by

Niamana while in Gossi, 5.1% change are explained by Niamana, Wabaria and Kati combined. Kidal and Konna accounted for 8% in price variation that occurred in Wabaria in current time. In general, we notice that in contemporaneous time, there is a limited interaction and transmission of shocks between markets. This observation is in line with our previous results (equation 8) on correlation matrix, which suggests a very weak correlation between markets in contemporaneous time.

At one horizon (one week ahead) we do not see significant change in all markets in terms of shock transmission except for Wabaria market. The percentage change in price explained by own-price shocks, for Wabaria market, dropped from 91 to 81% where Kati market alone explains 8% of price variation. Kati continued to exhibit exogeneity characteristics where 95% of price change at one horizon is explained by own-price shocks.

At longer horizons (four and eight weeks ahead) all the markets under study, except Wabaria, show relatively limited interaction among them. The highest percentage of price variation in each market explained by innovations from another market ranges from 6.06 to 8.47 % in all markets except Wabaria, that records 15.05 %. Moreover, at horizon eight, the percentage of price variation explained by own-price shock in the six markets ranges from 71 to 87%.

Table 6. Forecast error variance decomposition on cattle prices in Mali, 2008-2010

Horizon	Gossi	Kidal	Konna	Niamana	Wabaria	Kati
			(Gossi)			
0	93.081	0.573	1.1	1.658	2.455	1.133
1	87.902	1.715	1.297	4.383	3.657	1.046
4	79.519	2.988	1.916	6.818	5.797	2.962
8	76.897	2.986	2.451	6.829	6.85	3.988
			(Kidal)			
0	0	96.134	0	3.817	0	0.049
1	1.046	91.909	0.133	3.539	1.164	2.209
4	4.468	84.858	1.865	3.432	2.154	3.223
8	6.069	81.915	2.736	3.906	2.18	3.194
			(Konna)			
0	0	0	98.721	0	0	1.279
1	0.128	2.7	95	0.168	0.042	1.961
4	0.281	7.612	88.668	0.421	0.937	2.081
8	0.281	8.477	87.017	0.422	1.678	2.124
			(Niamana)			
0	0	0	0	98.745	0	1.255
1	2.057	1.263	0.015	91.803	1.611	3.251
4	6.508	2.415	0.138	85.323	2.481	3.136
8	7.873	2.632	0.233	83.787	2.429	3.046
			(Wabaria)			
0	0	3.467	4.625	0.138	91.729	0.041
1	0.702	2.525	5.537	1.863	81.08	8.292
4	2.104	2.052	4.493	3.761	73.418	14.172
8	2.766	1.921	4.312	4.09	71.855	15.055
			(Kati)			
0	0	0	0	0	0	100
1	0.512	1.451	1.818	0.081	0.656	95.483
4	2.708	3.577	5.888	0.178	1.428	86.221
8	3.998	3.852	7.156	0.19	1.534	83.27

Wabaria records the lowest percentage (71%) while Konna has the highest percentage (87%) meaning relatively less exogeneity for Wabaria than for Konna. Wabaria appears to be less exogenous compared to other cattle markets studied in this research. Kati alone accounts for 14.17% and 15.05% of price variation in Wabaria at four and eight horizons. These findings corroborates previous results on identification of the subset VAR (see equation 6) showing that all the markets are explained by themselves at lag one or two except Wabaria market that is explained by itself and Kati lagged at one period. In general the six cattle markets exhibit exogeneity characteristics at horizon eight where price variation explained by own price shocks ranges from 71% to 87.01%. We can interpret this result from the error variance decomposition at longer horizon (eight) as another evident sign of independence between the cattle markets under study.

The impulse response function (figure 13) shows how different markets (listed at the beginning of each row) respond over a certain period of time (16 weeks) to a one-time-only shock or innovation from other markets (listed at the heading of each column). In other words, it evaluates the dynamic responses to adjustment of each price to shocks in series. If the figure is read vertically, it shows how the innovation or shock (new information) from each market (listed at the heading of each column) affects prices in every market listed at the beginning of each row. The overall results show in general a low level of interaction among all the markets..This result is another proof of low level of market integration in Mali.

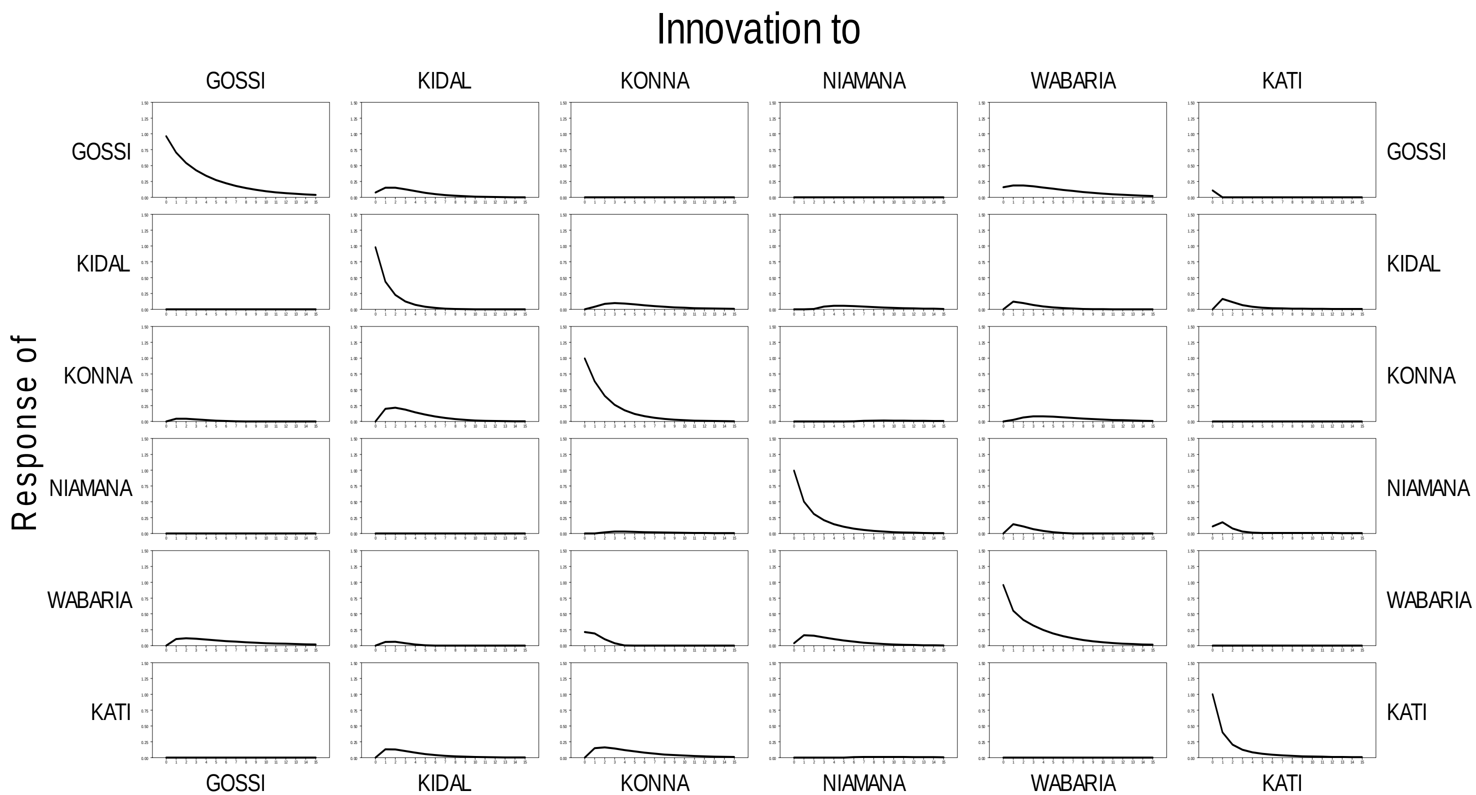

Figure 13. Response of each market to a one-time-only shock in each series, Mali 2008-2010

In conclusion, all the markets under study exhibit signs of independence across time by reacting very moderately to innovations from other markets. This confirms previous findings on subset VAR identification and correlation matrix that indicated less interaction between markets (see equations 7 and 8). Whether it is contemporaneously or in lagged period, the six markets show limited market price interdependence and transmission and consequently less integration. Barrett (2006) and Rashid et al. (2010) cite four reasons of limited or lack of market integration that includes poor communication and transport infrastructure, limited rule of law, and restricted access to commercial finance. The following reasons may explain the lack of price transmission between cattle markets in Mali. First, the markets considered in this study are spread out from South-west to North-east along the axis road Bamako-Gao-Kidal which measures around 720 miles. In a survey conducted in 2011 by MLPI partners in Mali (results are not published) on 346 livestock producers, 70.2% of the respondents mentioned the distance to the market as the main reason for them to sell their livestock on a particular market (Dr. Jay Angerer, personal communication 2011)[9]. Second, long distance and high transportation cost may inhibit any attempt to trade cattle across markets looking for the best offer through competitive mechanism of arbitrage. Instead traders in each of the six markets rely on price in past period to determine the current cattle prices (see subset VAR identification model). Generally, in developing countries, empirical studies on market integration suggest that the high variability of prices is mainly due to

[9] The results of the survey were accessed on October 12, 2011 at https://www.surveymonkey.com/sr_pass.aspx?sm=Kbbo1RbTuHFviS5XUfeb78fgiep8%2fMCRRKldkUQdLxc%3d. The access to the survey results require a password provided by Dr. Jay Angerer.

significant forgone arbitrage opportunities (Barrett 2006). Alila and Atieno (2006) point out, in the case of Kenya, that most pastoralists are forced to sell their livestock in desperate circumstances due to the lack of infrastructures such as livestock markets and good roads.

The rapid dissemination of price information using modern technologies such as cell phone and internet, under the MLPI project, was expected to close the distance gap by having the cattle traders react to new price information coming in. However, this is not the case in a developing country like Mali where the use of modern communication technologies is still limited (Fall 2007). In the survey conducted by the MLPI in 2011 in Mali, only 50.2% of respondents said to use SMS to acquire price information while 100% do not consider internet and newspaper as their best means of acquiring price and volume market information. Also, despite the introduction of cell phone on livestock markets to collect and disseminate price information, it takes some time to learn properly how to use efficiently these tools in a way that reduces uncertainty in the cattle markets (learn arbitrage skills) as pointed out by Rashid et al. (2010). In fact the results of the MLPI survey show that even though 82.8% of respondents said to have cell phones, only 50.2% use them to acquire price information.

Other major finding and consequence of limited market integration is the absence of a market leader capable of influencing the price of other markets without being affected by their shocks. No market among the six has emerged as price leader. All the markets show a high level of independence with regard to others.

3.1.2 Conclusions

Weekly data on male adult cattle prices in Mali are studied from November 2008 to September 2010 in six livestock markets of Gossi, Kidal, Konna, Niamana, Wabaria and Kati. The goal is to analyze cattle price interdependence in the six markets to determine the level of market integration and where the price is discovered. Despite the existence of long-run relationships between markets from the error correction model (EMC) results, further analysis using forecast performance comparison shows a low performance of the ECM model. The unrestricted VAR and a subset VAR emerge as plausible models to study market interdependence. The identification of the subset VAR model revealed that each dependent variable was estimated by one or two lags of itself except for Wabaria market.

Contemporaneous correlation analysis between price innovations in each market, using DAG and correlation matrix, revealed a weak relationship between markets. Further analysis using the innovation accounting techniques showed similar results. In fact, the forecast error variance decomposition and the impulse response function showed limited interaction between price markets in current and lagged time. The percentage of price variation explained by shocks from other markets was relatively low; the large portion being accounted for by own-price shocks. This was noticed in all the markets studied, namely Kidal, Konna, Niamana, Wabaria, Gossi and Kati which exhibited clear characteristics of exogeneity and independence. None of the markets emerged as a price leader possibly due to the lack of strong trade relationships between markets; the long distance separating markets is cited as a potential factor preventing markets from being linked. The six markets under study seem to have a low level of market integration, as suggested by these results.

Note that the distance separating markets is not necessarilly the main obstacle in linking market provided an effective dissemination of price information. However, there are strong beliefs that the use of modern communication tools such as cell phones to disseminate price information in Mali may not have played a significant role to close the gap of geographically separated cattle markets. An explanation of this phenomenon might be a need for more time for the economic actors to learn arbitrage skills and the livestock market information system to consolidate before we can see strong signs of market integration.

Further research that would include supply markets and other important livestock markets such as Fatoma, Sofara, Douentza, Lere and Nara is recommended to uncover any possibility of interdependence and linkages among markets prices. A thorough investigation on cattle markets supplying Kati is also recommended to shed some light on the Kati behavior in this study. A study of the period prior to the introduction of cell phones in 2008 is as well recommended to evaluate the impact that the introduction of modern communication tools to disseminate price information might have had on the market integration process. Other research (survey or regression) to guide any future policy recommendation would be to analyze how the distance to markets (imply roads and market facilities) and means of transportation (trekking or truck) impact the level of trade and market integration.

3.2 Case Study 2: Kenya

3.2.1 Results presentation and discussion

Cattle prices were studied over a period of three years and half on six markets scattered around Kenya. The evolution of prices from June 2006 to December 2009 is shown in the figure 14. At first glance, some markets such as Isiolo, Garissa (and to some extent Garsen) follow a more or less similar pattern of variation in price series close to a random walk while others (Njiru and Dagoretti) exhibit a mean reversion tendency. Chepareria cattle market prices also behave slightly as a random walk with first a decreasing and then an increasing trend. One observation that stands out for two (Garissa and Isiolo) of the six markets is a steady drop in price from April to September 2009, which may have been caused by drought conditions (EWS Bulletin 2009), and an increase thereafter. Garissa and Isiolo markets are, in fact, located in the arid districts of Garissa and Isiolo. This trend is also noticed to some extent for the Dagoretti and Garsen markets which are located in arid and semi-arid regions (see figure 14). The cattle prices are expressed in Kenyan Shillings (KES).

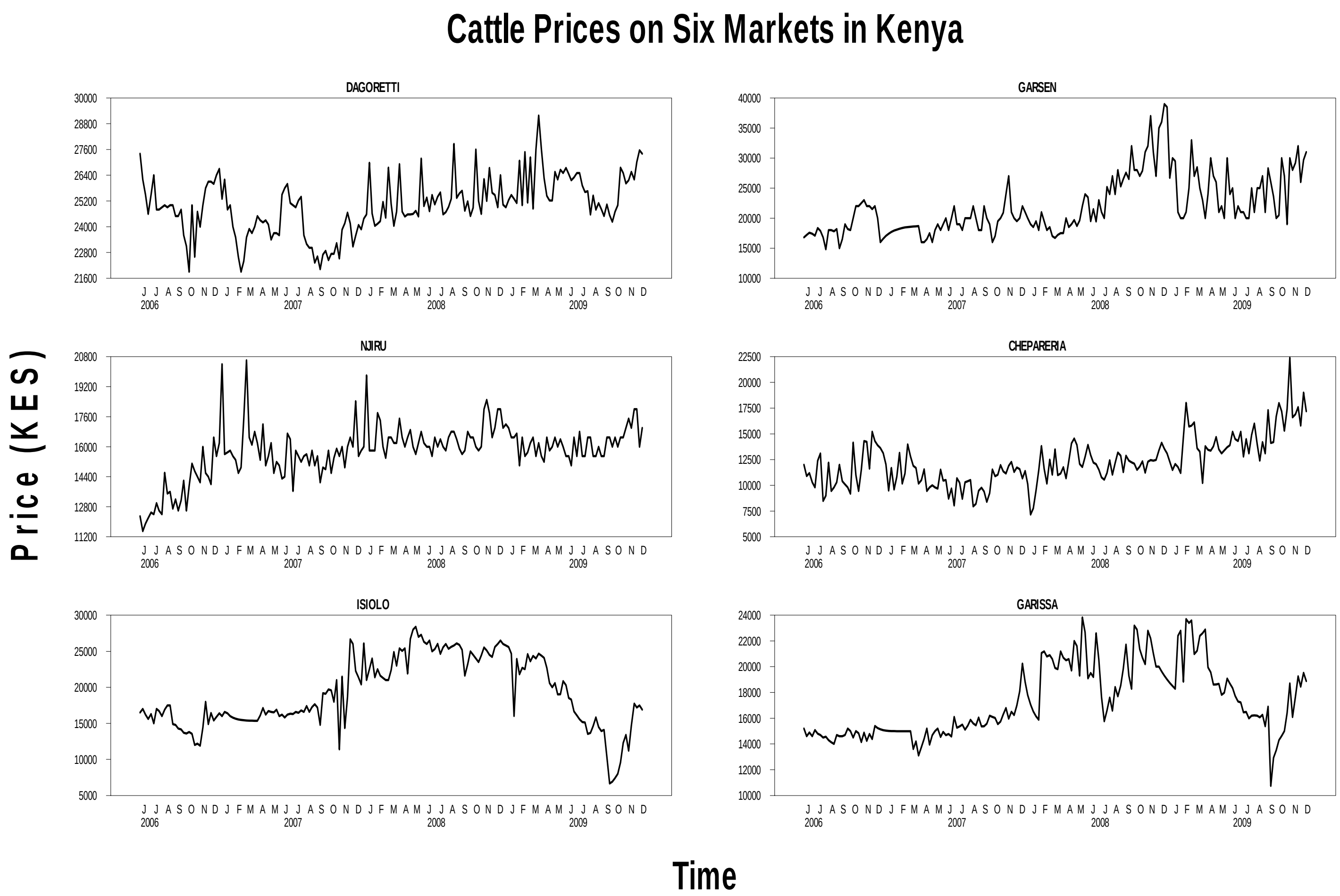

Figure 14. Price series in levels for six cattle markets in Kenya, 2006-2009

The mean, standard deviation, coefficient of variation and their respective rank in order from the highest (1) to the lowest (6) are presented in table 7 for the six cattle markets in Kenya from June 2006 to December 2009. The Dagoretti market has the highest average cattle price followed by Garsen and Isiolo in the second and third place respectively..Dagoretti along with Njiru have the lowest price variability with their CV ranking six and five. A possible explanation could be that these are large and terminal markets in the capital city that receive animals from various regions across the country, which prevent them from abrupt disruptions (shocks) in supplies. Isiolo market has the highest price variability (high CV) followed by Garsen market.

Table 7. Summary statistics on prices of cattle from six markets, Kenya 2006-2009

Market	Mean	Rank	SD	Rank	CV	Rank
Dagoreti	25010	1	1310.33	6	5.23	6
Njiru	15767	5	1415.5	5	8.97	5
Isiolo	19145	3	4874.76	2	25.46	1
Garsen	22028	2	4899.4	1	22.24	2
Chepareria	12288	6	2369	4	19.27	3
Garissa	17325	4	2794.14	3	16.13	4

The data are average weekly price recorded in each market, measured in Kenyan Shilling (KES) per head. The column labeled “Mean” refers to the simple mean price for the market listed in the far left-hand column of each row. The columns labeled by “SD” indicate the standard deviation of observed prices from the corresponding market. The column labeled “CV” refers to the coefficient of variation for each market. Ranks columns are in order from the highest (1) to the lowest (6). The number of observations is 185.

The Augmented Dickey-Fuller (ADF) tests results on levels and first difference of cattle prices in six markets of Kenya from 2006-2009 are presented in table 8. The null hypothesis on each levels test is that the price in each market is non-stationary. The tests for the levels show that two price series (Dagoretti and Njiru in bold) are stationary while the remaining four are non-stationary. For the ADF in first difference, all the series are stationary. The p-value on Ljung-Box Q statistic applied to the residuals from each ADF test show that the residuals are not autocorrelated at 5% significance level. We fail to reject the null hypothesis of non autocorrelated residuals.

Table 8. Unit root test on prices of cattle from six markets in Kenya, 2006-2009

Augmented Dickey-Fuller (levels)				Augmented Dickey-Fuller (1st diff)		
Market	t-test	k	Q (p-value)	t-test	k	Q (p-value)
Dagoreti	-3.8748	1	23.78 (0.64)	-9.6702	2	26.05 (0.51)
Njiru	-4.0878	3	36.97 (0.09)	-9.2679	2	39.53 (0.05)
Isiolo	-2.1004	1	22.24 (0.72)	-6.6354	2	22.54 (0.70)
Garsen	-2.3113	1	22.95 (0.68)	-8.7481	2	24.26 (0.61)
Chepareria	-1.9854	2	33.30 (0.18)	-10.324	2	35.61 (0.12)
Garissa	-2.1901	2	35.74 (0.12)	-9.9488	2	36.07 (0.11)

The critical value (t-stat) to reject the null hypothesis (at 5% significance level) of non-stationarity is -2.89. The column named "k" indicates the number of lags of the dependent variable used to produce "white noise" residuals. The value of k results from the minimization of the Schwarz loss metric on values of k ranging from 1 to 3. The column labeled "Q (p-value)" refers to the Ljung-Box statistic (Portmanteau test) test of white noise residuals from ADF regression.

Given that the ADF tests in general are known to have low power, the Elliot, Rothemberg and Stock or ERS test (unit root test) was performed to verify and confirm the stationarity of the price series. The ERS test (GLS version), which is a modification of ADF test, is believed to have a maximum power and to be efficient (Pfaff 2008; Armstrong 2001). The null hypothesis is that of unit root. The results show that we fail to reject at 5% critical value the null hypothesis of unit root in all six markets in the case we do not consider a constant and time trend at all in the equation[10]. This is the case of a pure random walk that is most of the time assumed for agricultural commodity prices

[10] In other cases where we consider a constant and / or a linear time trend, we reject the null of unit root in all six markets (for details on ERS results contact the primary author). In brief if we consider that the cattle price series follow a pure random walk (no stochastic or deterministic trend), which is normally assumed for prices, the ERS results show that the price series in all markets are non-stationary.

(Samuelson 1971). However, in this research, we will consider the ADF results in further discussion.

A lag length test was performed (table 9) to determine the maximum number of lags for the model. There are several approaches to determine the optimal lag length of a VAR. Schwartz loss (SL) and Hannan Quinn (HQ) tests were carried out to determine the lag length. The Schwartz loss metric found the local minimum at one lag while the Hannan and Quinn metric was minimized at two lags for the VAR model. To resolve this problem, we followed a procedure that determines simultaneously the lag length (p) and co-integration rank (r) (table 10) as indicated in Wang and Bessler (2008) and Athanasopoulos et al. (2011) using HQ and SL. The results show that HQ is minimized at p=1 and r=4 while SC is minimized at p=1 and r=4 (in bold and asterisk). We conclude that the maximum lag length p is equal to one and the co-integration rank r is equal to four. The rank test results (r=4) by the information criterion (see table 10) agree with the findings from the trace test (see table 11).

Table 9. Loss metrics (SL and HQ) on lag length from VARs on cattle prices from six markets in Kenya, 2006-2009

Lag length (k)	SL	HQ
1	88.59*	88.23
2	88.89	88.21*
3	89.5	88.51
4	90.01	88.71

Metrics considered are Schwarz-loss (SL) and Hannan and Quinn's (HQ) measure on lag length (k) of a levels VAR: SL = log(|Σ|) + (6k) (log T)/T ; HQ = log(|Σ|) + (2.00) (6k) log(log T))/T
Σ is the error covariance matrix and T is the total number of observations on each series. The symbol "| |" denotes the determinant operator and log is the natural logarithm. The single asterisk "*" indicates minimum of the Schwarz Loss metric and HQ measure

Table 10. Simultaneous determination of lag order and co-integration rank for six markets in Kenya, 2006-2009

r	6	5	4	3	2	1
Lag = 1						
SL	88.79	88.77	**88.73***	88.77	88.82	88.88
HQ	88.36	88.36	**88.35***	88.46	88.59	88.76
Lag = 2						
SL	89.26	89.22	89.14	89.09	89.03	**88.96**
HQ	88.44	88.43	**88.38**	88.4	88.43	88.46
Lag =3						
SL	90.04	90	89.91	89.84	89.72	**89.6**
HQ	88.85	88.83	88.78	88.77	88.74	**88.73**

The trace test (table 11) determines the appropriate number r of co-integrating vectors (rank test) by a sequential testing procedure as described in Johansen (1992) and Juselius (2006). First we begin by testing if all six roots are unit roots (r=0) with (marked with asterisk) and without a constant in the co-integrating space. If rejected we proceed with the testing whether the five roots are unit roots and continue until we fail to reject the null hypothesis. This occurs at r=4 (marked with a # sign) suggesting that we have four co-integrating vectors with a constant in the co-integrating space and two common trend.

Table 11. Trace test (lag = 1) on cattle prices from six markets in Kenya, 2006-2009

Ho: r	T*	P-value*	D*	T	P-value	D
=0	270.52	0.000	R	275.08	0.000	R
≤1	171.05	0.000	R	173.39	0.000	R
≤2	108.04	0.000	R	109.18	0.000	R
≤3	57.82	0.000	R	58.26	0.000	R
≤4	**18.86**	**0.076**	**F#**	**18.94**	**0.074**	**F#**
≤5	6.76	0.144	F	6.77	0.143	F

The test statistic (T) is the trace test corresponding to the number of co-integrating vectors (r) presented in the far left-hand column and a p-value. Entries associated with an asterisk have constant within the co-integrating vectors. Entries without an asterisk have no constant in the co-integrating vector but instead have the constant outside the co-integrating vector. The column labeled "D" indicates the decision to reject (R) or fail to reject (F) at a 5% percent level of significance the null hypothesis Ho that the number of co-integrating vectors r=0, r≤1, …, r≤5.

Despite the possibility of co-integration between series, the existence of stationary series (see ADF unit test results in table 8) prompted us to search for an appropriate model to estimate the cattle price series. Yang, Bessler, and Leatham (2000) cite non-stationarity of the series as a precondition to carry out co-integration analysis.

To choose the appropriate model for our study, we did a forecast performance comparison for three possible models: the univariate model, the vector autoregression model (VAR) and the error correction model (ECM). The results show that the univariate and the VAR models (unrestricted VAR) perform better (have lowest RMSE) than the ECM, in five markets out of six (see figures 15-20). The ECM underperformed possibly due to over-differencing already stationary series.

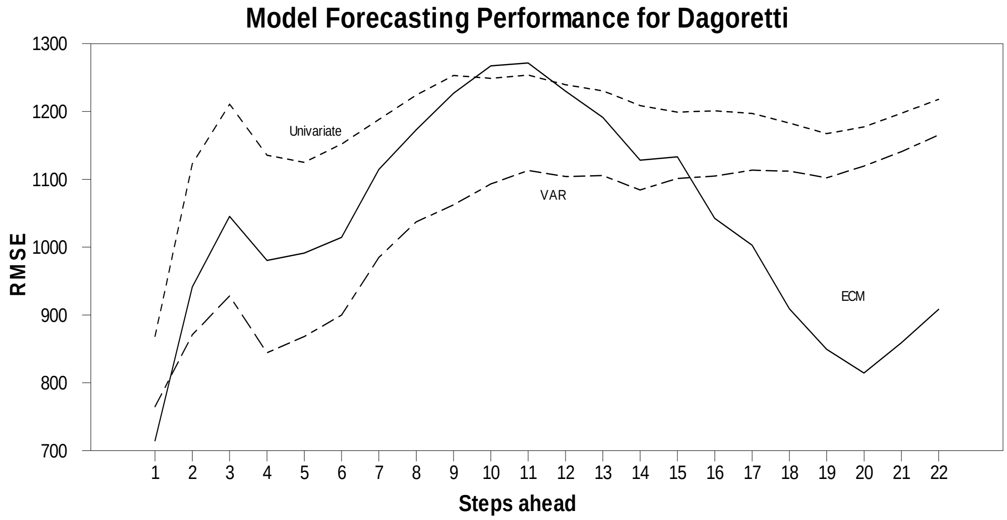

Figure 15. Comparison of forecast performance among ECM, VAR, and univariate models for Dagoretti market

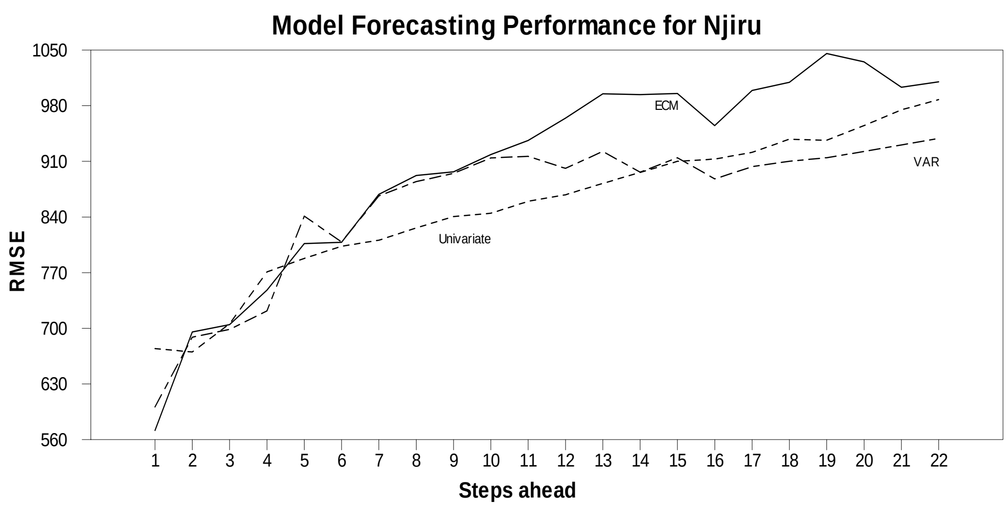

Figure 16. Comparison of forecast performance among ECM, VAR, and univariate models for Njiru market

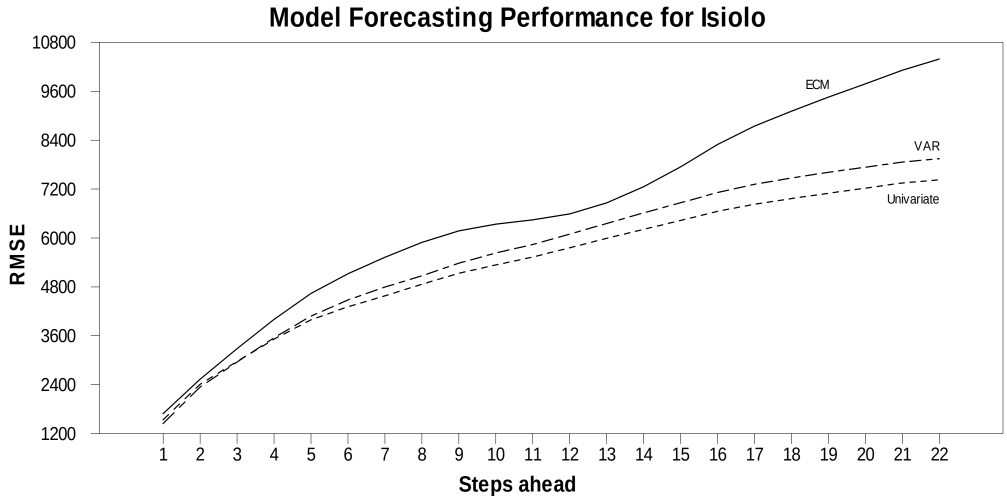

Figure 17. Comparison of forecast performance among ECM, VAR, and univariate models for Isiolo market

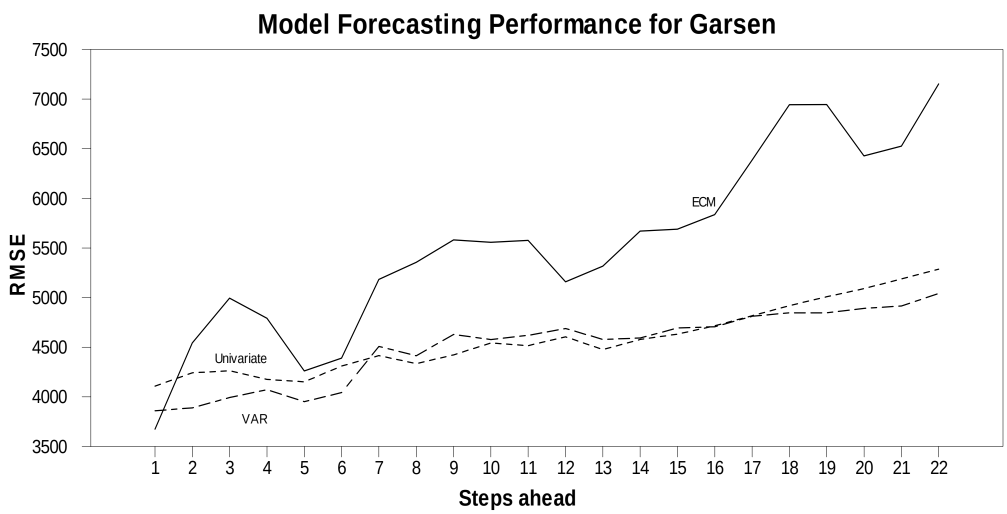

Figure 18. Comparison of forecast performance among ECM, VAR, and univariate models for Garsen market

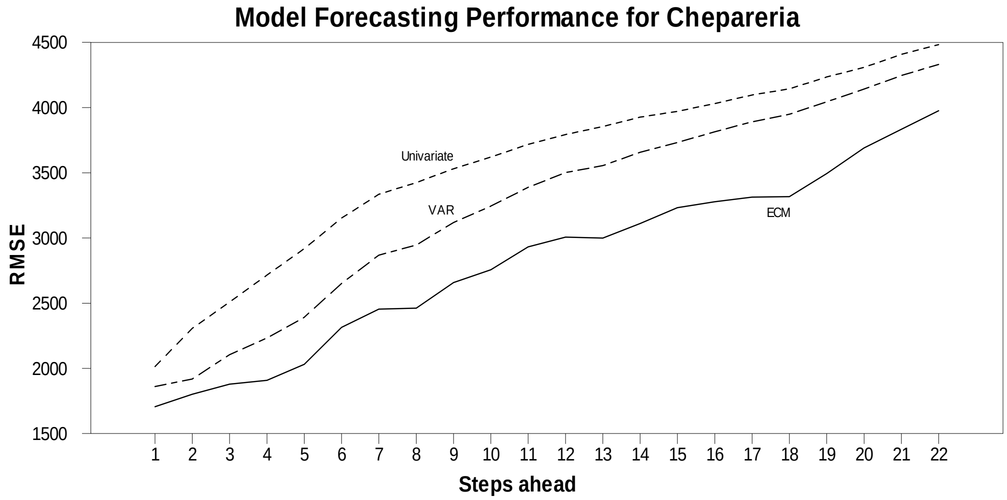

Figure 19. Comparison of forecast performance among ECM, VAR, and univariate models for Chepareria market

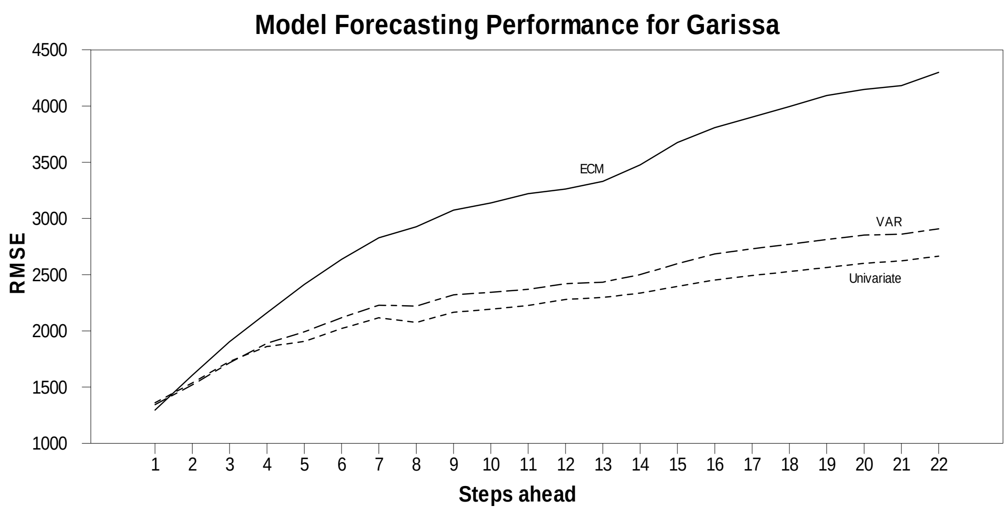

Figure 20. Comparison of forecast performance among ECM, VAR, and univariate models for Garissa market

Further search was carried out to identify a parsimonious VAR model (or subset VAR), that appropriately study the dynamics relationships among our markets prices following Hsiao search procedure (Hsiao 1979). The results show that only the markets of Chepareria and Garissa are exogenous; they are solely explained by three lags of themselves on the right-hand side. The remaining markets (Dagoretti, Njiru, Garsen and Isiolo) are explained each by both its lagged price and a lagged price from another market from this study (see equation 9). The results on the Hsiao search are presented in appendix A.2. The identified subset VAR is as follows:

$$\begin{cases} \mathrm{PDAG_t} = \mathrm{a_1} + \alpha_{11}\mathrm{PDAG_{t\text{-}1}} + \alpha_{12}\mathrm{PDAG_{t\text{-}2}} + \beta_{12}\mathrm{PNJI_{t\text{-}1}} + \varepsilon_{t1} \\ \mathrm{PNJI_t} = \mathrm{a_2} + \alpha_{21}\mathrm{PNJI_{t\text{-}1}} + \alpha_{22}\mathrm{PNJI_{t\text{-}2}} + \alpha_{23}\mathrm{PNJI_{t\text{-}3}} + \beta_{25}\mathrm{PCHEP_{t\text{-}1}} + \varepsilon_{t2} \\ \mathrm{PISI_t} = \mathrm{a_3} + \alpha_{31}\mathrm{PISI_{t\text{-}1}} + \alpha_{32}\mathrm{PISI_{t\text{-}2}} + \beta_{36}\mathrm{PGSA_{t\text{-}1}} + \varepsilon_{t3} \\ \mathrm{PGSE_t} = \mathrm{a_4} + \alpha_{41}\mathrm{PGES_{t\text{-}1}} + \alpha_{42}\mathrm{PGES_{t\text{-}2}} + \beta_{45}\mathrm{PCHEP_{t\text{-}1}} + \varepsilon_{t4} \\ \mathrm{PCHEP_t} = \mathrm{a_5} + \alpha_{51}\mathrm{PCHEP_{t\text{-}1}} + \alpha_{52}\mathrm{PCHEP_{t\text{-}2}} + \alpha_{53}\mathrm{PCHEP_{t\text{-}3}} + \varepsilon_{t5} \\ \mathrm{PGSA_t} = \mathrm{a_6} + \alpha_{61}\mathrm{PGSA_{t\text{-}1}} + \alpha_{62}\mathrm{PGSA_{t\text{-}2}} + \alpha_{63}\mathrm{PGSA_{t\text{-}3}} + \varepsilon_{t6} \end{cases} \tag{9}$$

where $PDAG_t$, $PNJI_t$, $PISI_t$, $PGSE_t$, $PCHEP_t$, and $PGSA_t$ are respectively cattle prices for Dagoretti, Njiru, Isiolo, Garsen, Chepareria, and Garissa markets in current time. The prices with a subscript t-1, on the right-hand side of the equation, are the prices for the same markets but lagged one period (ex. $PDAG_{t-1}$); ε_{tn} is the error term.

Following the identification of the restricted (subset) VAR, we notice that the cattle markets in Kenya rely both on their recent past prices and other markets past prices information to determine their current price. The markets are not independent in lag time. Forecast performance tests were conducted to choose the best model among the Univariate, unrestricted VAR and the subset VAR. The subset VAR and the unrestricted VAR showed better forecasting abilities than the univariate model in most of the markets when we compare the RMSE. However, to be able to carry out innovation accounting and the contemporaneous correlation analyses, we considered the unrestricted VAR model only.

Contemporaneous correlations between price innovations in each market were analyzed using a direct acyclic graph (DAG) to check whether the cattle markets influenced each other in current time. Results on interaction among markets in contemporaneous time are presented in equation 10 and figure 21. The contemporaneous correlations between price innovations in each market are presented in equation 9. Each market name is abbreviated by writing the first three letters (except for Garsen to distinguish it with Garissa) of the market in the order: Dagoretti, Njiru, Isiolo, Garsen, Chepareria, and Garissa

$$\begin{array}{c} \\ \text{Corr}(e_t) = \end{array} \begin{array}{c} \begin{array}{cccccc} \text{DAG} & \text{NJI} & \text{ISI} & \text{GSE} & \text{CHE} & \text{GAR} \end{array} \\ \begin{bmatrix} 1.000 & & & & & \\ -0.066 & 1.000 & & & & \\ 0.019 & 0.100 & 1.000 & & & \\ -0.082 & 0.075 & 0.084 & 1.000 & & \\ -0.039 & 0.108 & -0.048 & 0.199 & 1.000 & \\ -0.033 & 0.115 & 0.220 & 0.088 & 0.244 & 1.000 \end{bmatrix} \end{array} \qquad (10)$$

From the matrix above we notice that contemporaneous correlation between price markets innovations is weak with a value of less than 0.24 in 93% of the cases; the highest correlation being 0.244 between Chepareria and Garissa markets. The lowest correlation is between Dagoretti and Isiolo (0.019).

To obtain more insight on the contemporaneous correlation, the graphical structure (figure 3) was analyzed based on the correlation matrix results obtained in equation 2 from the unrestricted VAR model estimation.

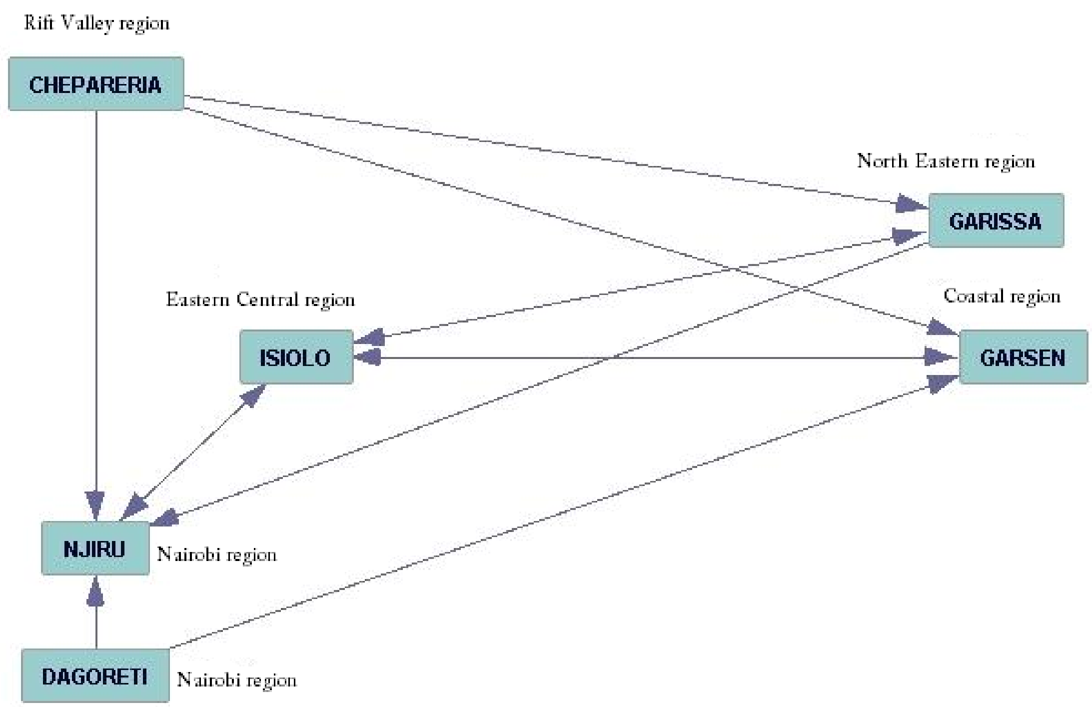

Figure 21. Causal flow of innovations from an unrestricted VAR on cattle price from six markets in Kenya, 2006-2009

The graphical structure was obtained using a PC algorithm at 10% significance level as suggested in Spirtes, Glymour, and Scheines (2000) for sample size between 100 and 200. The figure shows that Dagoretti and Chepareria markets are exogenous in contemporaneous time. Causal flows emanate from these markets and no arrows are directed into them. The price signals, coming from Chepareria market located in a high cattle production zone of Rift Valley (see map in figure 2), cause innovations in Njiru, Garissa, and Garsen. According to a census carried out in 2009, the cattle population in Rift Valley region counted for 41.9% of the total cattle population in Kenya (Ministry of Planning, National Development, and Vision 2030 2010). Here the flow of information goes from a cattle supply region, the Rift Valley, to secondary cattle markets such as Garissa and Njiru. The same behavior is observed for Dagoretti market in Nairobi. The DAG figure shows a flow of price information from Dagoretti to Njiru and Garsen. Moreover, the summary statistics results from table 7 show that Dagoretti has the lowest CV (rank six) among the six markets indicating less variability in its price. These two results together (DAG and CV) suggest Dagoretti market to have a potential to influence and lead prices in other markets. We can hypothesize that the market of Chepareria and Dagoretti are a source of information (innovation) in contemporaneous time. As for Njiru and Garsen, they behave as price "sink", receiving information from other markets in contemporaneous time for reasons which are not clear at this point.

There are few bi-directed edges between markets, specifically in relation with Isiolo market, signaling the existence of omitted variables. Isiolo appears to interact with Njiru, Garsen, and Garissa markets through intermediaries markets. Spirtes, Glymour, and Scheines (2000) warn about the possibility of two types of mistakes that can be committed using the PC algorithm: edge inclusion or exclusion and edge direction. Separate results from the GES algorithm and prior information on cattle trade between Isiolo and Njiru, point to the possibility of causal flows from Isiolo to Garissa, Garsen and Njiru. Isiolo would be, in this case, a source of information in current time. These results are, however,to be taken with caution.

The results of the forecast error variance decomposition on cattle prices in each of the six markets in Kenya, are presented.in table 12 at horizon of zero, one, four and eight weeks ahead. These decompositions are studied to see how much change in the future (uncertainty or error variance) of one market price is caused by new information from other markets. It is the percentage of forecast error uncertainty in one market accounted for by earlier innovations in other markets. For instance, the innovations associated with current prices in Dagoretti, Isiolo, and Chepareria markets are solely (100%) explained by own-price shocks. The remaining markets of Njiru, Garsen and Garissa have, 96.8%, 94.4%, and 88.1% of price variation explained by own-price shock. Note that, Chepareria accounts for 4.04 and 6.48% of price variation in contemporaneous time in the markets of Garsen and Garissa. In general, we notice limited interaction and transmission of shocks among markets in contemporaneous time.

At one horizon (one week ahead) the markets do not show significant variation in price due to innovations from other markets. The highest price variations are found in Njiru, Garsen, and Garissa, and range from 6.5% to 9.7%. These price variations are mostly due to innovations from Chepareria market. Chepareria seems to take a lead in influencing other market price variations at horizon one. For instance,in Njiru market, Chepareria accounts for 6.5% in price variation compared to Isiolo that is responsible for 2.59% price variation. In Garsen market, 8.6% of price variation is explained by Chepareria while only 1.3% of price variation is explained by Isiolo. Isiolo and Chepareria account for 9.7 and 7.8% in price variation in Garissa market. We notice that price innovations from Chepareria market consistently influence prices in all other markets at one horizon, except for Isiolo which is mainly influenced by Garissa.

Table 12. Forecast error variance decomposition on cattle prices, Kenya 2006-2009

Horizon	Dagoretti	Njiru	Isiolo	Garsen	Chepareria	Garissa
			(Dagoreti)			
0	100	0	0	0	0	0
1	95.267	0.067	0.083	0.248	2.264	2.071
4	78.589	0.303	0.118	1.515	11.808	7.668
8	69.234	0.442	0.137	2.53	17.527	10.129
			(Njiru)			
0	0.381	96.806	1.149	0	1.227	0.437
1	1.922	88.354	2.598	0.282	6.502	0.342
4	2.388	76.835	4.393	1.317	14.393	0.674
8	2.322	72.335	4.83	1.88	16.754	1.878
			(Isiolo)			
0	0	0	100	0	0	0
1	0	0.19	96.394	0.022	0.162	3.232
4	0.052	0.843	86.012	0.109	0.15	12.835
8	0.077	1.255	79.93	0.135	0.23	18.373
			(Garsen)			
0	0.579	0	0.919	94.457	4.046	0
1	0.458	0.031	1.376	89.354	8.635	0.146
4	0.497	0.205	1.946	76.933	18.489	1.93
8	0.997	0.381	2.165	68.166	23.639	4.651
			(Chepareria)			
0	0	0	0	0	100	0
1	1.769	0.011	0.896	0.312	96.375	0.636
4	5.026	0.056	3.393	1.931	87.202	2.392
8	5.845	0.079	4.448	3.276	83.349	3.002
			(Garissa)			
0	0	0	5.403	0	6.489	88.108
1	0.095	0.178	9.79	0.003	7.804	82.13
4	0.343	0.839	18.653	0.072	9.589	70.504
8	0.431	1.276	23.552	0.19	10.342	64.21

At longer horizon (four and eight weeks ahead) more interaction and price shocks transmission are noticed among markets. For instance, innovations from Chepareria market explain 17.52, 16.75, 23.6 and 10.3% of price variation in Dagoretti, Njiru, Garsen and Garissa at horizon eight. Isiolo accounted for 23% of price variation in Garissa at horizon eight with, vice-versa, Garissa explaining almost 20% of price variation in Isiolo.

Chepareria shows consistently across time (in lag and current time) exogeneity characteristics by influencing other markets' prices variation without being much affected by price variation from other markets. As Barrett and Li (2002) point out that price transmission can occur without trade, Chepareria is able to influence price variation in markets like Garissa and Garsen located very far away. Chepareria emerges as the sole potential price leader in this cattle market integration study.

Garissa market, which is the largest cattle supply market in Kenya, appeared to be the least exogenous market if we consider the error variance decomposition results. Earlier results on the restricted VAR showed us however that Garissa market was highly exogenous in lag time where its current price was explained by itself up to three lags. A possible explanation for the discrepancy would be the introduction of noise in Garissa dataset after filling in missing data by forecasting method[11].

[11] The results and conclusion on Garissa market are tentative given a number of missing data that was found in the original dataset due some times to the market closure (outbreak of the Rift Valley Fever) and other times to prolonged absence of the market monitor for various reasons.

Dagoretti, Njiru, and Garsen showed less ability to influence others' market price variation. According to the LINKS main contact in Kenya (Mr. Gatarwa Kariuki, see footnote 4), the Dagoretti cattle market is mostly supplied by cattle markets from the South and West (sometimes cattle cross Tanzania border to supply Dagoretti) meaning that its influence as a high demand area might extend to those southern and western cattle markets rather than the markets considered in this study. Njiru market behavior, as a price receiver (see DAG figure 21 and table 12), might be linked to the cattle gender (sex) considered in Njiru: female; all others being male. As for Garsen, it has built more trade relationship with Mombassa cattle market (both being located to the coastal belt) than other markets featured in this study.

The impulse response function (figure 22) shows how different markets (listed at the beginning of each row) respond over a certain period of time (16 weeks) to a one-time-only shock or innovation from other markets (listed at the heading of each column). The impulse response function evaluates the dynamic responses to adjustment of each price to shocks in series. If the figure is read vertically, it shows how the innovation or shock (new information) from each market (listed at the heading of each column) affects prices in every market listed at the beginning of each row. The result that stands out in this figure is the response by all the markets, except Isiolo, to a one-time shock from Chepareria market. The finding confirms the predominance and leadership of Chepareria market in influencing other markets price variations. Other results that catche our attention are strong responses from Isiolo and Dagoretti, and to some extent Garsen and Chepareria, to a one-time shock from Garissa. These findings agree with the error variance decomposition results in which Garissa explains about 10.12 and 18.37% of price variations in Dagoretti and Isiolo (and just 4.6 and 3.0% for Garsen and Chepareria). The main observation from the impulse response function and the forecast error variance decomposition results is a higher level of interaction and integration among the cattle markets prices in Kenya than the one found among the cattle markets in Mali.

In conclusion, among the six markets under study, Chepareria market exhibits strong signs of independence across time and leadership over the other markets. Chepareria low response to innovations from other markets and its important role in their prices variations suggest Chepareria as leader of this group of cattle markets under study. The remaining five markets have interaction between them to a certain level and with Chepareria as shown by the restricted VAR equation 1. There are clear signs of market integration and price transmission across the six markets. Three of the six markets, however, Dagoretti, Njiru, and Garsen, are interacting less with other markets if we consider the error variance decomposition. It is not completely clear whether their location and sources of cattle supply might be the reason for this behavior. Dagoretti and Njiru are both terminal markets located in the capital city Nairobi and are supplied by several primary and secondary markets located mainly in South and West of Kenya. Garsen market located in the Coastal region is the main supply of cattle to Mombassa terminal market and has no direct trade relationship with the rest of markets. The Njiru market is the only market among the six for which we considered female cattle.

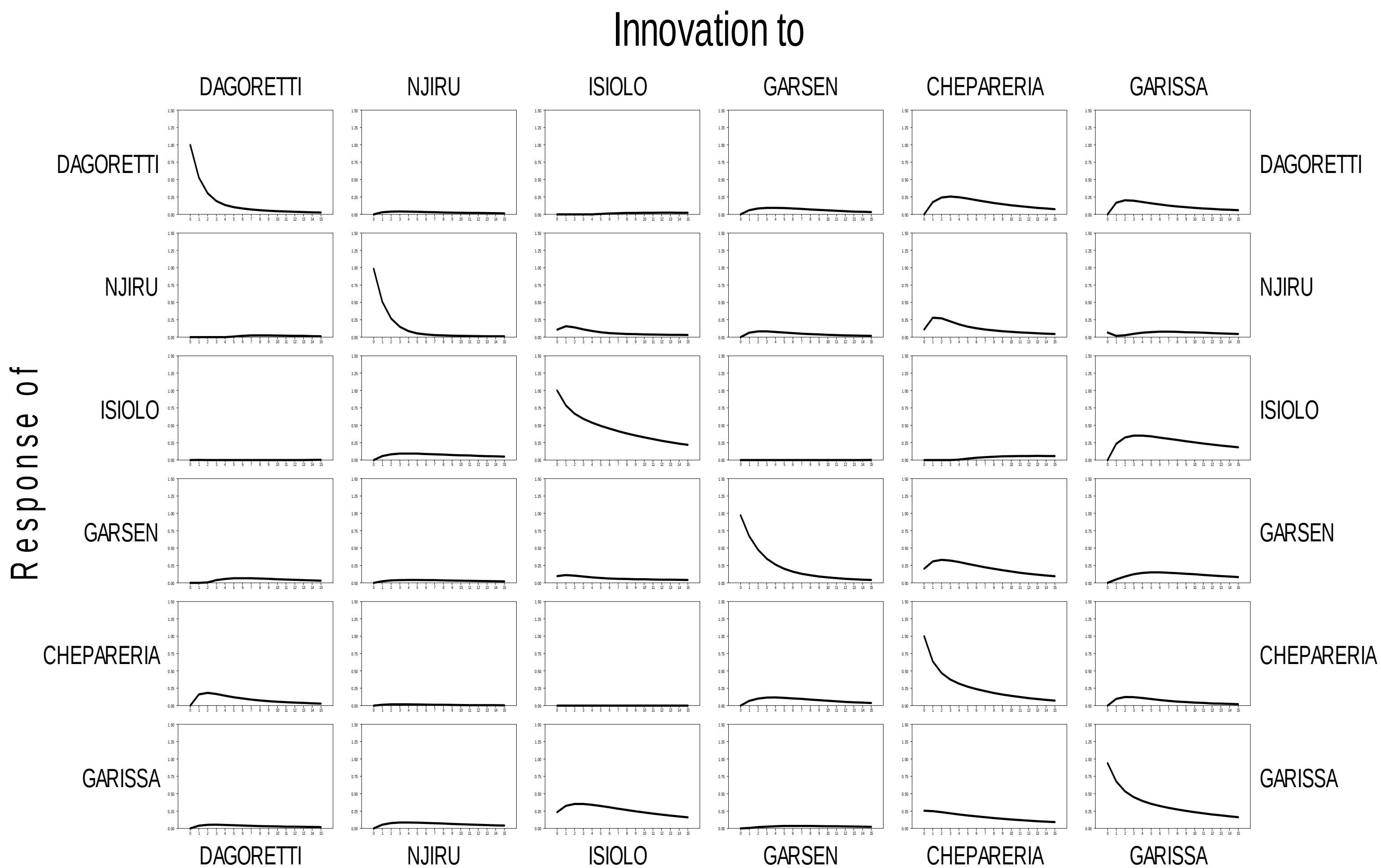

Figure 22. Response of each market to a one-time-only shock in each series, Kenya 2006-2009

The relatively high level of cattle market integration observed in Kenya can be attributed to a better level of information communication (especially of market prices). As Barrett (2006) pointed out, the reasons of limited market integration include but not limited to poor communication and transport infrastructure. In this particular case of Kenya, we can cite poor infrastructure (market and roads) as an obstacle to facilitate products marketing and sale (Alila and Atieno 2006; Kabubo-Mariara 2008). High transportation costs and lack of enough markets can hinder commodity exchange and trade. However, the introduction and use of modern communication technologies (cell phones, internet), by the LINKS project to disseminate livestock price information in Kenya, might have helped to overcome the communication issue in market integration. Started in 2003, the project trained and equipped market monitors to collect livestock price information on a number of livestock markets that included Isiolo, Garissa and Nairobi. The price information is stored on a server and easy to access by the public using cell phone and internet. The availability of livestock price information coupled with an increase in number of cell phone and internet users in Kenya (Farrell 2007) might have contributed to the process of cattle markets integration in Kenya.

3.2.2 Conclusions

In the current study, we analyzed weekly data on adult male cattle (except for Njiru where we used female) prices in Kenya from May 2006 to December 2009 in six livestock markets of Dagoretti, Njiru, Isiolo, Garsen, Chepareria, and Garissa. The goal was to study cattle price interdependence in the six markets to determine the level of market integration and where the price is discovered. Despite the evidence of long run relationships among markets from the error correction model (EMC) results, further analysis using forecast performance comparison showed a low performance of the ECM model relative to VAR models. The unrestricted VAR and a subset VAR emerged as appropriate models to study market interdependence. The identification of the subset VAR shows that most of the market cattle prices in the VAR system are explained by their lagged prices and lagged prices of other markets except for Chepareria and Garissa which are explained only by their own lagged values.

Contemporaneous correlation analysis between price innovations in each market, using directed acyclic graph and correlation matrix, revealed some relationship among markets. Price shocks from the six cattle markets are transmitted among markets in contemporaneous time with the predominance of Chepareria as leader in the group. Price signals are flowing from the Chepareria market, located in high cattle population area in Rift Valley, to cattle markets in Northeast (Garissa), Coastal area (Garsen), and capital city (Nairobi). In other words, the information is sent from supply regions to metropolitan areas such as Nairobi where there is high demand or to large supply or secondary markets such as Garissa.

The forecast error variance decomposition and the impulse response function showed more interaction between markets at longer horizon for all the markets. Chepareria markets dominated again all the markets, consistently explaining their price variation. Garsen, Dagoretti, and Njiru did not show great ability to influence other markets' prices. The innovation accounting and the directed acyclic graphs results indicated Chepareria market as a price leader among the six markets; no other market among the remaining five showed the same ability to influence price markets in this group. The relatively good level of interaction between cattle markets in Kenya could be partly attributed to an effective dissemination of cattle price information using modern technologies (cell phone and internet) introduced by the LINKS project.

However, this latter statement needs to be investigated more to determine the exact role played by the use of modern communication tools to integrate the livestock markets in Kenya. Specifically, data on cattle prices for the period prior to and after the introduction of cell phones should be explored. Also more livestock markets need to be added to the list of markets to study to discover other possible dynamics and interaction between markets. We need as well to study in depth the markets surrounding Isiolo given the existence, in our resuts of several possible omitted variables between Isiolo and the markets of Garissa, Garsen and Njiru. To guide future policy recommendation, research (survey, regression analysis) on how the distance to markets (imply roads and market facilties) and transportation means (trekking or truck) impact trade and market integration is recommended

3.3 Case study 3: Tanzania

3.3.1 Results presentation and discussion

Prices of cattle on four markets of Pugu, Igunga, Kishapu and Monduli in Tanzania are examined over a period of four years. The evolution of prices from February 2006 to January 2010, are presented in figure 23. The striking observation in the figure is a regular upward trend of cattle prices for all four markets during the period under study. This could be either linked to a possible increase in inflation rates during the period of study or just a regular random walk price with drift and/or trend.

We can also identify similar behavior of prices in some series over a given section of the time period. For example, during the priod around January to June 2007, cattle prices in Pugu, Igunga, and Monduli dropped rapidly before picking up again for reasons we cannot clarify yet. In general all the price series in figure 23 seem to follow a pattern similar to a random walk, with upward drift, wandering up and down with no apparent mean reversion, which is a characteristic of agricultural commodity price behavior (Samuelson, 1971).

Note that the currency in which the cattle prices are expressed is the Tanzania Shilling (TZS).

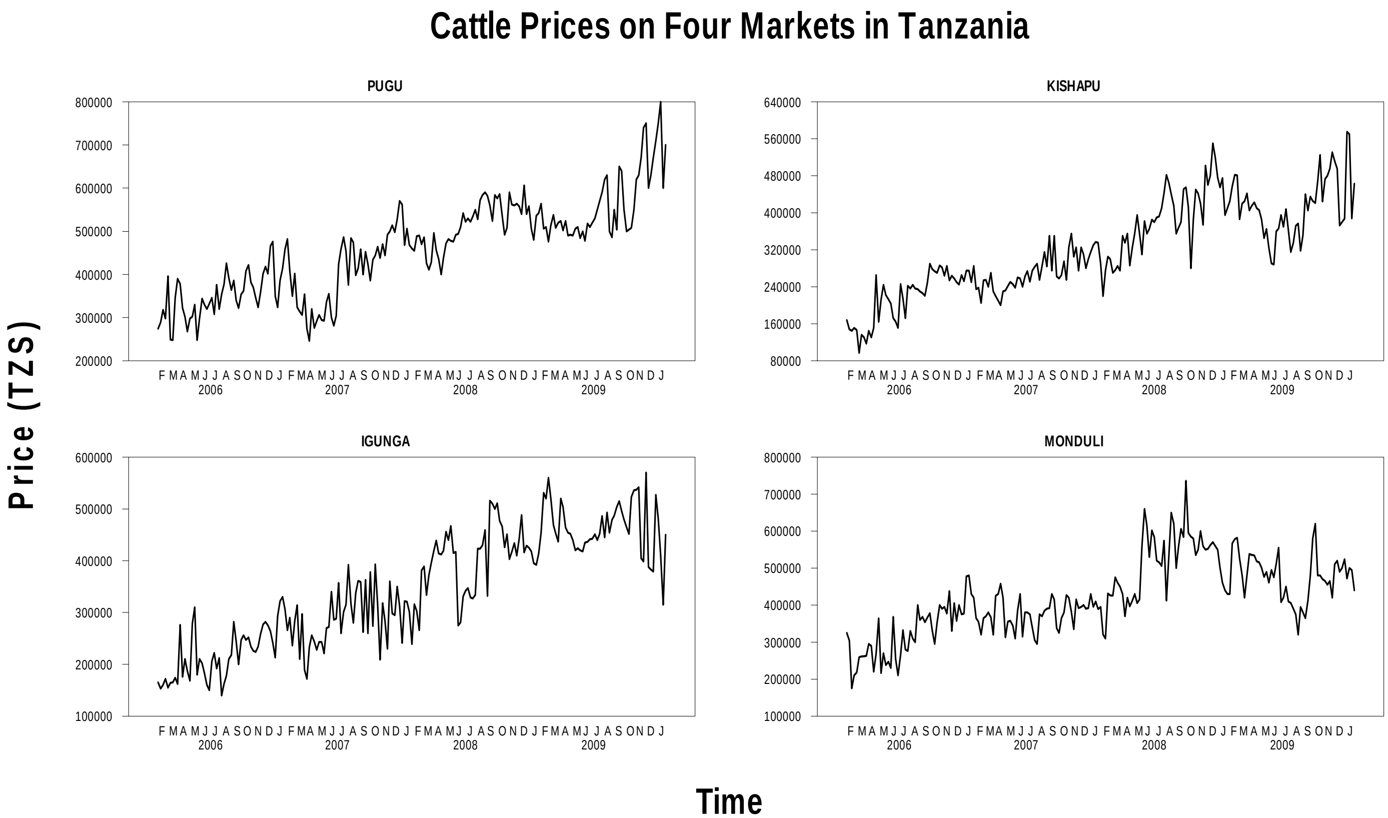

Figure 23. Weekly price series in levels for four cattle markets in Tanzania, 2006-2010

The mean, standard deviation, coefficient of variation, and their respective rank in order from the highest (1) to the lowest (6) are presented in table 13 for four cattle markets in Tanzania from February 2006 to January 2010. The Pugu market has the highest average cattle price followed by Monduli market. This is expected for Pugu since it is located in the largest city of Tanzania, Dar es Salaam, and receives cattle from all over the country. Kishapu has the lowest average cattle price. Pugu has the lowest CV while Igunga ranks first in terms of CV meaning that cattle prices in Pugu have a low variability while prices in Igunga have high variability. Since Pugu is supplied by several cattle markets around the country, this prevents Pugu from drastic changes in supply which perhaps plays a buffer role in price variation.

Table 13. **Summary statistics on prices of cattle from four markets in Tanzania, 2006-2010**

Market	Mean	Rank	SD	Rank	CV	Rank
Pugu	459885	1	110466	1	24.02	4
Igunga	343437	3	110374	2	32.13	1
Kishapu	322567	4	100228	4	31.07	2
Monduli	421417	2	101992	3	24.2	3

The data are average weekly price recorded in each market, measured in Tanzanian Shilling (TZS) per head. The column labeled “Mean” refers to the simple mean price for the market listed in the far left-hand column of each row. The columns labeled by “SD” indicate the standard deviation of observed prices from the corresponding market. The column labeled “CV” refers to the coefficient of variation for each market. Ranks columns are in order from the highest (1) to the lowest (6). The number of observations is 209.

The Augmented Dickey-Fuller (ADF) tests results on levels and first difference of cattle prices in four markets of Tanzania from 2006-2010, are presented in table 14. The null hypothesis on each levels test is that the price in each market is non-stationary. The tests on the levels show that all the price series are non-stationary. The t statistics are in fact greater than -2.89 (5% critical level) in all the four price series. We notice that for the ADF in first difference, all the series are stationary. The p-value on Ljung-Box Q statistic applied to the residuals from each ADF test show that the residuals are not autocorrelated at 5% significant level.

Table 14. Unit root test on prices of cattle from four markets in Tanzania, 2006-2010

Augmented Dickey-Fuller (levels)				Augmented Dickey-Fuller (1st diff)		
Market	t-test	k	Q (p-value)	t-test	k	Q (p-value)
Pugu	-0.4389	5	40.16 (0.06)	-7.5493	4	30.00 (0.36)
Igunga	-2.4458	2	26.94 (0.52)	-10.639	2	28.80 (0.42)
Kishapu	-1.4447	3	29.71 (0.37)	-8.3884	3	31.25 (0.30)
Monduli	-2.8773	2	14.40 (0.98)	-9.7459	2	11.85 (0.99)

The critical value (t-stat) to reject the null hypothesis (at 5% significance level) of non-stationarity is -2.89. The column named "k" indicates the number of lags of the dependent variable used to produce "white noise" residuals. The value of k results from the minimization of the Schwarz loss metric on values of k ranging from 1 to 3. The column labeled "Q (p-value)" refers to the Ljung-Box statistic (Portmanteau test) test of white noise residuals from ADF regression.

Given that the ADF tests in general are known to have low power, the Elliot, Rothemberg and Stock or ERS test (unit root test) was performed to verify the ADF results on integration of the price series. The ERS test (GLS version) which is a modification of ADF test is believed to have a maximum power and to be efficient (Pfaff 2008; Armstrong 2001). The null hypothesis is that of unit root. The results show that we fail to reject at 5% critical value the null hypothesis of unit root in all four markets in case we do not consider a constant and time trend at all in the equation[12].

This is the case of a pure random walk that is most of the time assumed for agricultural commodity prices (Samuelson 1971). However, in this research we will consider the ADF results in further discussion.

A lag length test was performed to determine the maximum number of lags for the model. There are several approaches to determine the optimal lag length of a VAR. Schwartz loss (SL) and Hannan Quinn (HQ) tests were carried out to determine the lag length. Both Schwartz loss and Hannan and Quinn metrics were minimized at one lag for the VAR model (see results in table 15). The same results were found using a co-integration procedure that determines simultaneously lag length and number of co-integrating vectors (Wang and Bessler 2009; Athanasopoulos et al. 2011). The results indicate that both SC and HQ are minimized at lag length one with a co-integration rank of three. The rank test results (r=3) by the information criterion agree with the findings from the trace test (see table 16 below).

[12] In other cases where we consider a constant and / or a linear time trend, we reject the null of unit root in all four markets (for details on ERS results contact the primary author). In brief if we consider that the cattle price series follow a pure random walk (no stochastic or deterministic trend), which is normally assumed for prices, the ERS results show that the price series in all markets are non-stationary.

Table 15. Loss metrics (SL and HQ) on lag length from VARs on cattle prices from four markets in Tanzania, 2006-2010

Lag length (k)	SL	HQ
1	86.29*	86.06*
2	86.7	86.27
3	87.08	86.45
4	87.55	86.73

Metrics considered are Schwarz-loss (SL) and Hannan and Quinn's (HQ) measure on lag length (k) of a levels VAR: $SL = \log(|\Sigma|) + (4k)(\log T)/T$; $HQ = \log(|\Sigma|) + (2.00)(4k)\log(\log T))/T$
Σ is the error covariance matrix and T is the total number of observations on each series. The symbol "| |" denotes the determinant operator and log is the natural logarithm. The single asterisk "*" indicates minimum of the Schwarz Loss metric and HQ measure

The trace test (table 16) determines the appropriate number r of co-integrating vectors (rank test) by a sequential testing procedure as described in Johansen (1992) and Juselius (2006). First, we begin by testing if all six roots are unit roots (r=0) with (marked with asterisk) and without a constant in the co-integrating space. If rejected we proceed with the testing whether the five roots are unit roots and continue until we fail to reject the null hypothesis. This occurs at r=3 (marked with a # sign) suggesting that we have three co-integrating vectors with a constant in the co-integrating space and one common trend. In this situation, the ECM and co-integration methods would be the best tools to determine the data generating process (DGP).

Table 16. **Trace test (lag = 1) on cattle prices from six markets in Tanzania, 2006-2010**

Ho: r	T*	P-value*	D*	T	P-value	D
=0	162.05	0.000	R	163.56	0.000	R
≤1	93.34	0.000	R	93.95	0.000	R
≤2	40.15	0.000	R	40.31	0.000	R
≤3	5.47	**0.244**	**F#**	5.48	**0.243**	**F#**

The test statistic (T) is the trace test corresponding to the number of co-integrating vectors (r) presented in the far left-hand column and a p-value. Entries associated with an asterisk have constant within the co-integrating vectors. Entries without an asterisk have no constant in the co-integrating vector but instead have the constant outside the co-integrating vector. The column labeled "D" indicates the decision to reject (R) or fail to reject (F) at a 5% percent level of significance the null hypothesis Ho that the number of co-integrating vectors r=0, r≤1, r≤2, r≤3.

Despite the existence of strong price linkages (given that r=3 is the maximum number of co-integrating vectors), we did a forecast performance comparison between several models (including the ECM) to choose the model that best describe the DGP. Three models were evaluated: the univariate model, the vector autoregression model (VAR) and the error correction model (ECM). The results show that the ECM and the VAR models (unrestricted VAR) perform better (have lowest RMSE) relative to the univariate model, in three markets out of four (see figures 24-27).

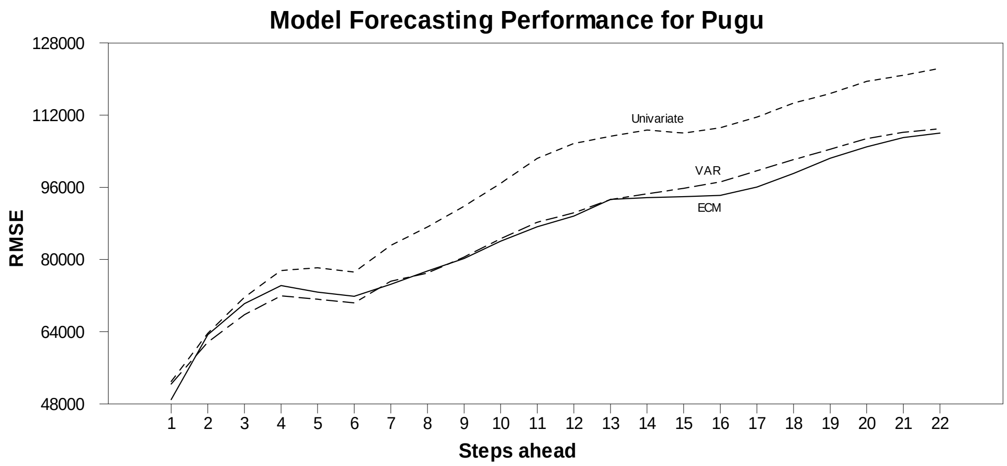

Figure 24. Comparison of forecast performance among ECM, VAR, and univariate models for Pugu market

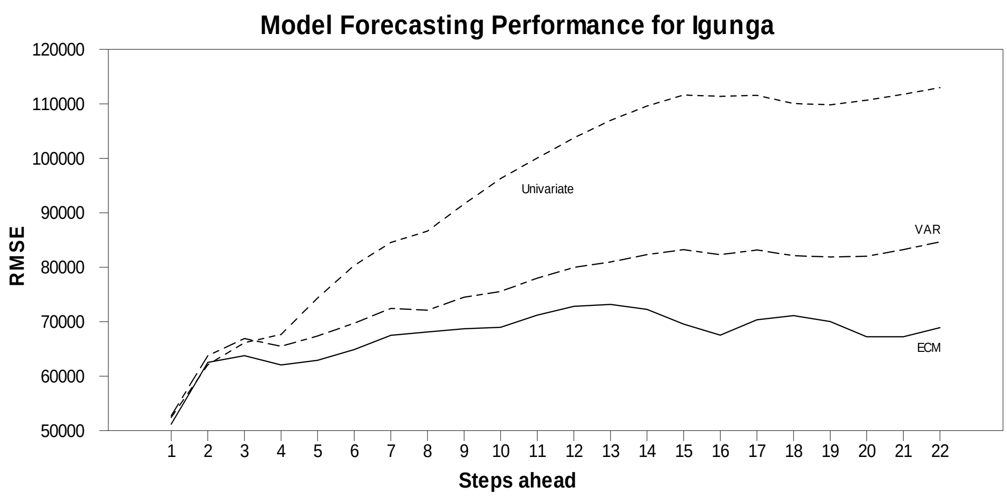

Figure 25. Comparison of forecast performance among ECM, VAR, and univariate models for Igunga market

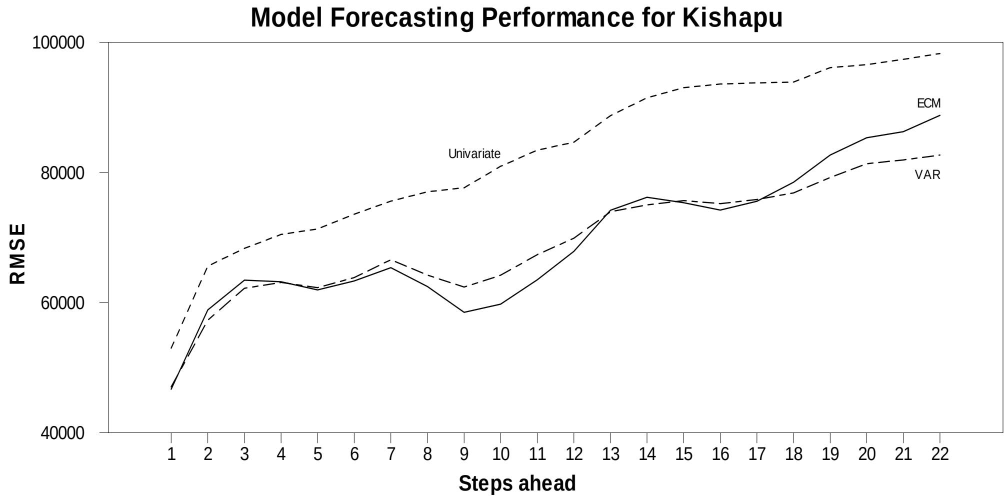

Figure 26. Comparison of forecast performance among ECM, VAR, and univariate models for Kishapu market

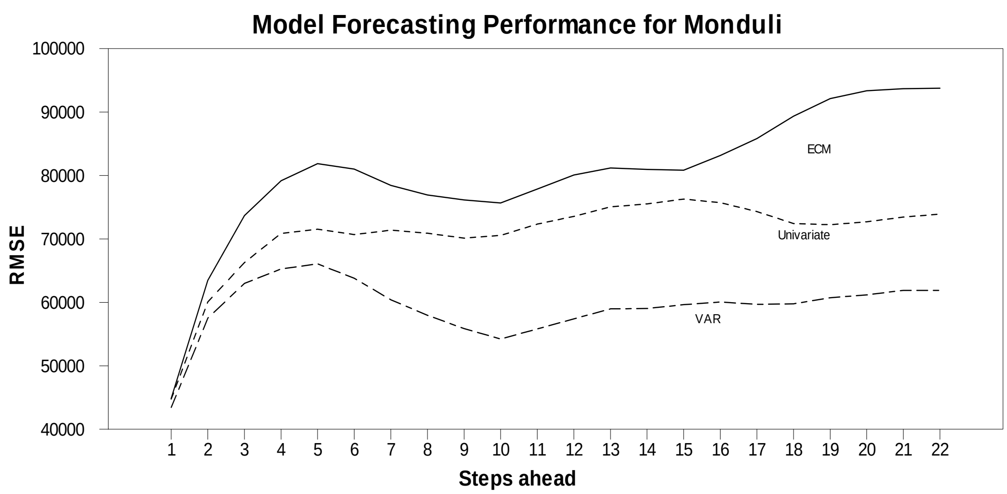

Figure 27. Comparison of forecast performance among ECM, VAR, and univariate models for Monduli market

To compare this case study on Tanzania with those of Mali and Kenya we chose to use the VAR model. Further search was carried out to identify a parsimonious VAR model, called also subset VAR to appropriately estimate our model following Hsiao search procedure (Hsiao 1979). The results of Hsiao search (see appendix A.3) show that only the market of Igunga is exogenous; the dependent variable is explained by three lags of itself on the right-hand side[13]. The remaining markets (Pugu, Kishapu and Moduli) are explained on the right-hand side of their equations by both their lagged values and lagged variables from other markets in the study (see equation 11 below). The identified subset VAR is the following:

$$\begin{cases} \mathrm{PPUG_t} = \mathrm{a_1} + \alpha_{11}\mathrm{PPUG}_{t-1} + \beta_{12}\mathrm{PIGU}_{t-1} + \varepsilon_{t1} \\ \mathrm{PIGU_t} = \mathrm{a_2} + \alpha_{21}\mathrm{PIGU}_{t-1} + \alpha_{22}\mathrm{PIGU}_{t-2} + \alpha_{23}\mathrm{PIGU}_{t-3} + \varepsilon_{t2} \\ \mathrm{PKIS_t} = \mathrm{a_3} + \alpha_{31}\mathrm{PKIS}_{t-1} + \beta_{33}\mathrm{PIGU}_{t-1} + \varepsilon_{t3} \\ \mathrm{PMON_t} = \mathrm{a_4} + \alpha_{41}\mathrm{PMON_{t-1}} + \beta_{43}\mathrm{PKIS_{t-1}} + \mathrm{e_{t4}} \end{cases} \tag{11}$$

where $PPUG_t$, $PIGU_t$, $PKIS_t$, and $PMON_t$ are respectively cattle prices for Pugu, Igunga, Kishapu, and Monduli markets in current time. The prices with a subscript t-1, on the right-hand side of the equations, are the prices for the same markets but lagged one period (ex. $PPUG_{t-1}$); ε_{tn} is the error term.

Following the identification of the restricted (subset) VAR, we notice that the cattle markets in Tanzania rely both on their recent past price and other markets prices information to determine their current price; the markets are not independent in lag time.

[13] The result on model specification with Hsiao search method on Igunga seems to be contrary to the forecasting results presented in figure 25, where the multivariate VAR outperforms the univariate model of Igunga prices. This suggests, perhaps, that other market prices affect Igunga at long lags.

Contemporaneous correlations between price innovations in each market were analyzed using DAG to study the influence among cattle markets in current time. The equation (12) and the DAG figure (28) indicate that there is an interaction between markets in current time. The contemporaneous correlation among price innovations in each market is presented in equation 12. Each market name is abbreviated by writing the first three letters of the market in the order: Pugu, Igunga, Kishapu, and Monduli.

$$\begin{array}{ccccc} & PUG & IGU & KIS & MON \end{array}$$

$$Corr\,(e_t) = \begin{bmatrix} 1.000 & & & \\ 0.172 & 1.000 & & \\ 0.257 & 0.262 & 1.000 & \\ -0.013 & 0.098 & 0.088 & 1.000 \end{bmatrix} \qquad (12)$$

From the matrix above we observe that contemporaneous correlation between price markets innovations is relatively weak with a value of less than 0.25 in 66% of the cases. The highest correlation is 0.262 between Igunga and Kishapu markets. The lowest correlation is -0.013 between Pugu and Monduli.

To obtain more insight on the contemporaneous correlation, graphical structure (figure 28) was analyzed based on the correlation matrix results obtained in equation 2 from the unrestricted VAR model estimation.

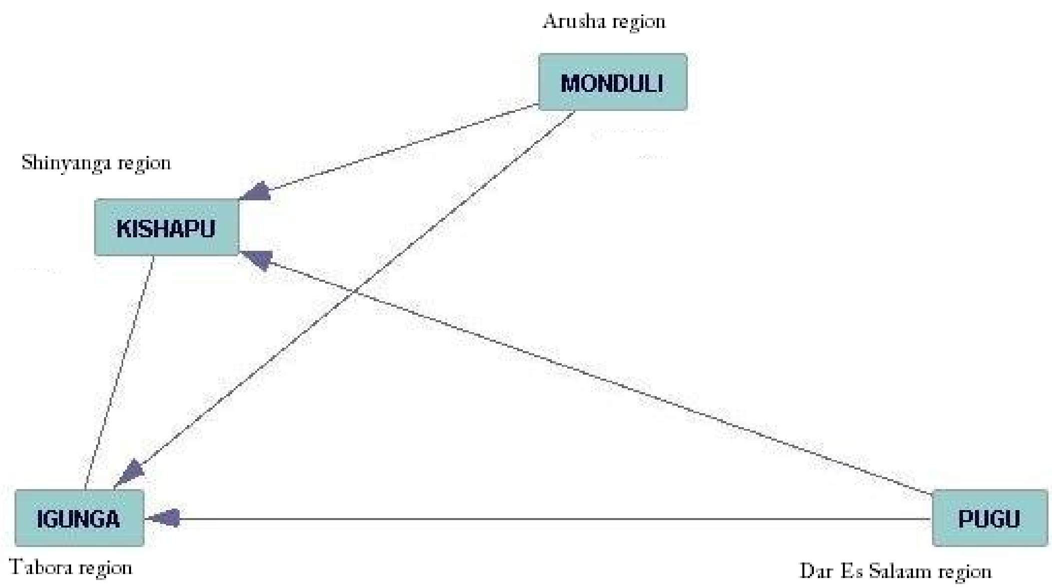

Figure 28. Causal flow of innovations from an unrestricted VAR on cattle price from six markets in Tanzania, 2006-2010

The graphical structure was obtained using a PC algorithm at 10% significance level as suggested in Spirtes, Glymour, and Scheines (2000) for sample size between 100 and 200. The arrows and edges from figure 28 characterize the information flow, or causal structure of the contemporaneous innovations (surprises). The results on figure 28 show that Pugu and Monduli markets are exogenous in contemporaneous time. Causal flows are emanating from Pugu and Monduli markets, but no arrows are directed into them. We can hypothesize that these markets are source of information (innovation) in current time.

Pugu, located in the Dar es Salaam region, is the largest livestock market in Tanzania. It receives animals from all over the country (except from Monduli in Arusha) including the markets of Kishapu (Shinyanga) and Igunga (Tabora). The Pugu market has largely cattle traders and brokers and few cattle producers to show the level of cattle trading happening in the market. The supply chain starts from the producing regions in the Northwest part of Tanzania (FAO 2005) and end at the East coast in Dar es Salaam where there is a large pool of cattle consumers. Dar es Salaam is the second largest region in terms of population (behind Mwanza) in Tanzania and the biggest in terms of urban population (Tanzania 2006); being for that reason a high demand end point. Prices innovations from Pugu cattle markets in Dar es Salaam, a high demand region, cause innovations in supply markets of Kishapu and Igunga which sell 63 and 90% of their cattle respectively to Pugu market.

Monduli (Arusha) cattle market is exogenous in contemporaneous time. Innovations from Monduli cause price innovations in the markets of Kishapu (Shinyanga) and Igunga (Tabora), but Monduli seems not to be influenced by any cattle market under study. Besides Kishapu that sells 15% of its cattle to Monduli, there are no known cattle trading relationships between Igunga and Monduli. However, as we will see later that price innovations in Igunga influence prices in Kishapu, it is possible that Kishapu, as a collider between Monduli and Igunga, opens up the information flow between Monduli and Igunga. In other terms, common effects (Kishapu) do not “screen off” association of their common cause (Monduli and Igunga) (Pearl 2000).

It is worthy noting that there is no arrow or edge directed between Pugu and Monduli (Arusha). A possible explanation is the absence of a known trading relationship between Monduli (Arusha) and Pugu; cattle produced in Monduli are sold at 90% to

Themi by trekking (J. Gutta, personal communication 2010). The summary statistics results from table 1 are interesting when compared to these graphical results. Pugu and Monduli which have the lowest CVs (Pugu rank four while Monduli ranks three), indicating less variability in their price.

Kishapu on the other hand appears to be a price information "sink" receiving information from other markets. This is even more compelling when we explore its relationship with Igunga in contemporaneous time using GES algorithm since the PC algorithm produced an undirected edge between Igunga and Kishapu. The DAG results based on GES algorithm (not presented here) show that Igunga influences Kishapu price innovations. Kishapu being an information receiver is interpreted as a result of its location in the high cattle production zone in the Northern plains. Kishapu is in fact, located at one end of the supply chain (producers), and receives information from consumers on the other end of the supply chain in Dar es Salaam. Kishapu prices are influenced by price innovations coming from cattle high demand regions like Dar es Salaam (Pugu) and other surrounding cattle markets such as Igunga in Tabora and Monduli in Arusha. Based on the graphical structure presented in figure 28, with the edge directed from Igunga to Kishapu, we analyzed the innovation accounting results, namely the forecast error variance decomposition (FEVD) and the impulse response function (IRF). Their results and discussions are presented below.

The results of the forecast error variance decomposition on cattle prices in each of the four markets in Tanzania, at horizon of zero, one, four and eight weeks ahead are presented in table 17. These decompositions are studied to see how much change in the future (uncertainty or error variance) of one market price is caused by new information arising in other markets. It is the percentage of forecast error uncertainty in one market accounted for by earlier innovations in other markets. For instance, the innovations associated with current prices in Pugu and Monduli markets are solely (100%) explained by own-price shocks. For Igunga market, 95.96% of price variations in current time are explained by own-price shock; Pugu explains about 3% of price variation in Igunga in current time. Kishapu market seems to account for more shocks from other markets. In fact, about 88% of price variation in Kishapu, are explained by own-price shocks while Pugu and Igunga together account for about 11% of price variation in Kishapu. In general, Pugu and Monduli (and Igunga to some extent) exhibit exogeneity characteristics in contemporaneous time.

At one horizon (one week ahead), Pugu and Monduli continue to show strong exogeneity properties where 98.15% and 97.5% of price variation are explained by own-price shocks. For Igunga and Kishapu, 92.3% and 76.6% of price variation are explained by own-price shocks respectively. Pugu and Igunga continue to influence price change in Kishapu where, combined, they explain about 20% of price variation.

At longer horizons, four and eight weeks ahead, we notice stronger interaction and price shocks transmission between markets. For instance in Pugu market, at horizon eight, 12.1 % and 5.12% of price variation are explained by Igunga and Kishapu respectively (compared to 7 and 3% at horizon four). In Igunga market, almost 20% of price variations are explained by Pugu market at horizon eight (compared to 12% at horizon four). Kishapu which seems to be the least exogenous among all markets, has at horizon eight almost 50% of price variations explained by Pugu (28.48%) and Igunga (21.1%) combined. Kishapu appears to be a price information “sink” both contemporaneously and in lag time. As for Monduli market, Pugu and Igunga combined account for almost 22% of price variation in Monduli at horizon eight (and 10% at horizon four).

Table 17. Forecast error variance decomposition on cattle prices in Tanzania, 2006- 2010

Horizon	Pugu	Igunga	Kishapu	Monduli
		(Pugu)		
0	100.00	0.00	0.00	0.00
1	98.15	1.14	0.70	0.01
4	89.38	6.84	3.21	0.57
8	80.78	12.17	5.12	1.92
		(Igunga)		
0	3.03	95.96	0.00	1.02
1	5.22	92.31	0.53	1.94
4	12.06	80.75	2.86	4.33
8	18.27	71.09	4.79	5.85
		(Kishapu)		
0	6.69	4.52	87.95	0.85
1	11.71	8.59	76.65	3.06
4	22.21	16.79	53.87	7.12
8	28.48	21.10	41.93	8.49
		(Monduli)		
0	0.00	0.00	0.00	100.00
1	0.41	0.86	1.21	97.52
4	4.55	6.10	4.98	84.37
8	10.95	11.35	6.98	70.72

In brief, Pugu market prices have demonstrated across time less variability and potential to influence other markets’ prices, emerging thus as a potential market leader.

This is a situation of a “demand pull” driving price information changes from high demand region of Dar es Salaam to low demand and producing zone in Northern part of Tanzania (Shinyanga and Tabora) in current and lag time. Igunga market is influenced by other market price innovations, especially Pugu, but also Igunga showed more ability to influence all the remaining three markets prices (especially Kishapu) in current and lag time (see table 17). Igunga can be ranked second in terms of market leadership after Pugu. Kishapu market was subject to other markets price shocks, behaving thus as price information “sink” across time due probably to its status of high cattle production zone. It is most likely that price innovations will be discovered in deficit or high demand regions (for consumption or export) and be passed to surplus or producing regions that become information “sink” (Vitale and Bessler 2006; Yu, Bessler and Fuller 2007; Haigh and Bessler 2004). Note that it was not the case for Kenya case study.

Results from the impulse response function are displayed in figure 29. The impulse response function illustrates how each market (listed at the beginning of each row) responds over a certain period of time (16 weeks) to a one-time-only shock or innovation from other markets (listed at the heading of each column). The impulse response function evaluates the dynamic responses to adjustment of each price to shocks in series. If the figure is read vertically, it shows how the innovation or shock (new information) from each market (listed at the heading of each column) affects prices in every market listed at the beginning of each row.

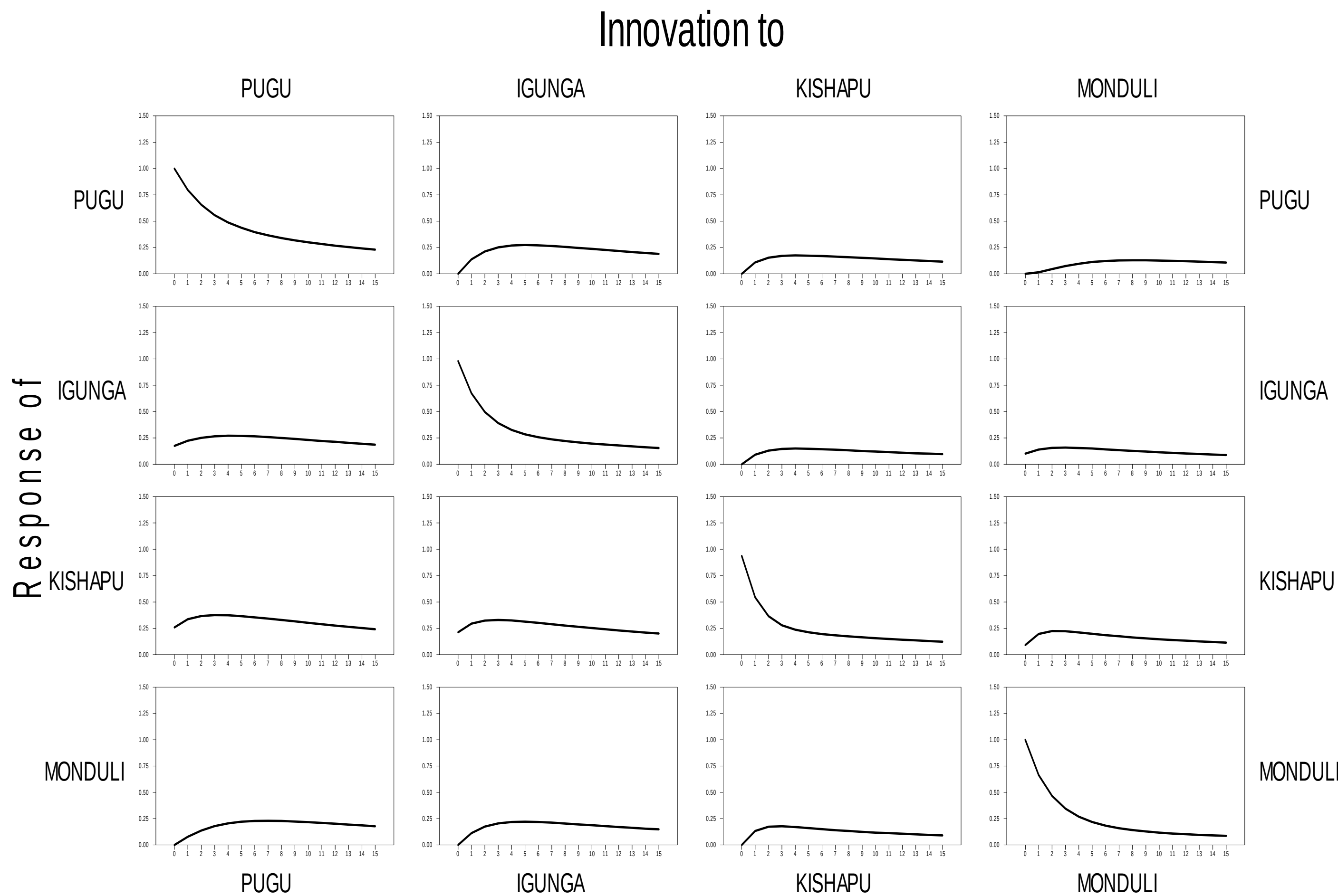

Figure 29. Response of each market to a one-time-only shock in each series, Tanzania 2006-2010

In figure 29, we notice that innovations from Pugu are felt by all other markets in the study namely: Igunga, Kishapu and Monduli. Similar results are observed for Igunga market. The reactions from other markets due to innovations from Igunga indicate that Igunga has a potential to influence other markets cattle prices. These results agree with previous findings from the forecast error variance decomposition that showed Pugu and Igunga markets as leaders in this study. Markets however react less vigorously to a one-time shock from Kishapu and Monduli. The main observation in this figure is the higher level interaction among markets in Tanzania compared to Mali and Kenya.

In conclusion, the market of Pugu consistently showed strong exogeneity characteristics by influencing other markets' price changes without being much influenced by them. Pugu has emerged as price leader in this group. Igunga market behaved in a similar way as Pugu at a lesser extent but showed stronger independence and exogeneity characteristics than Monduli and Kishapu markets. Kishapu market behaved as a price information "sink" among the four markets. Overall results show clear signs of market integration among the four cattle markets under study in Tanzania.

Possible factors that led to a good level of cattle market integration are related to an increase in price market information dissemination among cattle traders, producers, and consumers (Barrett 2005). In addition to a livestock market information system introduced in 2003 by the LINKS project that promotes the collection and dissemination of livestock market price information using modern communication tools (cell phone), there is as well an increase in the use of cell phone to exchange information by the general public (CET 2007; Sife, Kiondo and Lyimo-Macha 2010).

3.3.2 Conclusions

Weekly cattle price data were analyzed on four livestock markets of Pugu (Dar es Salaam), Igunga (Tabora), Kishapu (Shinyanga), and Monduli (Arusha) in Tanzania from February 2006 to January 2010. The goal of this research was to study cattle price interdependence in the four markets to determine the level of market integration and where the price is discovered. Several models were compared using forecast performance to choose one that best describes the level of market integration. The error correction model (ECM) and the vector autoregression (VAR) model performed better than the univariate model. We, however, chose to use the VAR (both unrestricted and restricted) for two reasons: 1) to explain the price dynamics in the four markets; 2) to do a comparison with earlier study findings on cattle market integration in Mali and Kenya.

The identification of the subset VAR shows that most of the markets (three cases out of four) in the VAR system are explained by their lagged prices and lagged prices of other markets except for Igunga market. Igunga is explained by its own lagged variable up to three periods. These results indicate that the four markets under study are interdependent.

Contemporaneous correlation analysis between price innovations in each market, using the DAG and correlation matrix, revealed a flow of information among the four markets in contemporaneous time. Two of the four markets (Monduli and Pugu) appeared to be exogenous in contemporaneous time. The price signals move generally from the cattle high demand zone in Dar es salaam (Pugu market) to the cattle producing zone in north west and central parts of Tanzania in Tabora and Shinyanga regions (for

Kishapu and Igunga markets). Dar es Salaam being the main trading center of Tanzania, cattle traders bring in cattle from all over the country for sale given the high demand. Price signals are as well sent from Monduli to Kishapu (which normally trades cattle with Monduli) and Igunga markets. Kishapu behaved as a price information “sink” due probably to its location around the cattle producing zones in North-west regions of Shinyanga and Mwanza.

The forecast error variance decomposition and the impulse response function showed considerable interaction between markets at all horizons for the four markets. The results suggest Pugu as the price market leader in the group, displaying exogeneity and independence properties in lag and current time more than any other market in the group. Kishapu appeared to be a price information “sink” subject to price innovations from other markets. We can partly attribute the relatively good level of market integration to the improved system of disseminating livestock market price information. In addition to the use of modern information and communication tools (cell phone, internet) initiated in 2003 by the LINKS project, the price and volume information are published in several local newspapers, and broadcast on TV and radio programs by the government agencies.

However, further investigation is recommended to determine the exact role played by the use of modern communication tools in the livestock markets integration process in Tanzania. Specifically, data on cattle prices for the period prior and after the introduction of cell phones as a tool to disseminate livestock market price information should be explored. Other livestock markets located around and between Pugu, Igunga, Kishapu, and Moduli need to be included in further studies to discover other possible dynamics and interaction among markets. For the purpose of future policy recommendations, an in-depth study on how the distance to markets (which implies roads and markets facilities) and means of transportation (trekking or truck) might impact the trade and market integration processes.

CHAPTER IV

CONCLUSIONS

The goal of this section is to summarize the results on cattle market integration processes in three developing countries of Mali, Kenya, and Tanzania and make comparison of the three case studies. The main reason we compare the three case studies is to study whether the time of introduction of the livestock market information system (LMIS) in each of the three countries may have played a role in the market integration process. We are examining whether the empirical analysis of cattle market integration in Mali, Kenya, and Tanzania show different behavior that might be linked to the length of time the system has been in place.

In a study on spatial price analysis in Africa, Rashid et al. (2010) pointed out that the materialization of competitive systems in market exchanges take time as traders learn arbitrage skills and build market relationships. As a reminder, the LMIS was introduced in Mali in 2007 under the Mali Livestock and Pastoralist Initiative project or MLPI while the LMIS was introduced in 2003 in the East Africa countries of Kenya, Ethiopia and Tanzania under the Livestock Information Networks and Knowledge Systems project or LINKS. It is worth noting that due to the lack of cattle market price data prior to introduction of the livestock market information systems (LMIS) in the respective countries, we were unable to evaluate the actual impact of the use of cell phone and internet, introduced under LMIS, on market integration processes. However, previous studies showed a positive impact of the market information system on grain market integration in Africa (see Vitale and Bessler 2006; Dembele, Staatz, and Weber 2003; Rashid et al. 2010). For this reason, we attributed part of the success of the cattle market integration process in Mali, Kenya, and Tanzania to the introduction and implementation of LMIS, although we have no direct measure of such contribution.

Despite the lack of a formal treatment and control in a randomized design we offer the following reasons to carry out the results comparison of the three case studies. First, the livestock market information system in Mali (MLPI) was patterned and designed after the system developed in East Africa under the LINKS project. Both systems have similar procedures of collecting and reporting the livestock price and volume data using SMS. Second, the MLPI and LINKS were introduced at different times (four year difference) in these case studies. The LINKS started collecting data around 2004 in Kenya and Tanzania while the MLPI started data collection in Mali in 2008. Third, the category of the data considered in the three case studies is the same. We targeted mature males cattle of medium body fat (grade 2 or M) mostly from zebu breed. Lastly, the methodological approach used to evaluate the level of cattle market integration was similar for the three case studies. The methods were all based on vector autoregression. They comprised the univariate model, the restricted and unrestricted vector autoregression and the error correction models (ECM). The innovation accounting methods (forecast error variance decomposition and Impulse response function) were used to analyze the dynamics of prices in the three countries.

Because of the presence of stationary series in two of the case studies (Mali and Kenya), we decided not to rely completely on the error correction model to analyze the price interdependence. We conducted a forecast performance test between three plausible models to analyze our data in each of the case studies. We found that the ECM for the cases of Mali and Kenya underperformed compared to the univariate and the unrestricted VAR models. Further analysis revealed that the restricted and unrestricted VAR were the best models for forecast and estimation purposes. We attributed the possibility of underperformance of the ECM to over-differencing of stationary series for Kenya and Mali price series. This issue was not noticed for the Tanzania case (had all series non-stationary) where the ECM and VAR emerged as the best performing models after the forecast performance test. ECM and VAR also produced similar results for the innovation accounting analysis. Below, we present the results from the identification of the restricted VAR obtained using the Hsiao search (Hsiao 1979). The summary conclusions in each of the three case studies are as follows.

The Mali case study in which six cattle market prices were considered (VAR of six variables), the identification of the restricted VAR model revealed that each dependent variable was estimated by one or two lags of itself except for Wabaria market ($PWAB_t$). Wabaria market has on the right-hand side of its equation, price of Kati lagged one period in addition to two lags of itself as shown by the system of equations below (equation 7). Despite the existence of contemporaneous correlations between markets (see edge counts on DAG results), it is obvious that the correlations are weak when you consider the coefficients in the correlation matrix.

The innovation accounting analysis corroborates these results and shows limited interaction between price markets in current and lagged time. The percentage of price variation explained by shocks from other markets was relatively low; the large portion being accounted for by own-price shocks. None of the markets emerged as a price leader, which was expected since each market relies on its past price values to make the best prediction of its future values. The cattle markets in Mali under study appear to be poorly integrated.

$$\begin{cases} \mathrm{PGO_t} = \mathrm{a}_1 + \alpha_{11} PGO_{t-1} + \alpha_{12}\ PGO_{t-2} + \varepsilon_{t1} \\ \mathrm{PKI_t} = \mathrm{a}_2 + \alpha_{21} PKI_{t-1} + \alpha_{22} PKI_{t-2} + \varepsilon_{t2} \\ \mathrm{PKO_t} = \mathrm{a}_3 + \alpha_{31} PKO_{t-1} + \varepsilon_{t3} \\ \mathrm{PNI_t} = \mathrm{a}_4 + \alpha_{41}\ PNI_{t-1} + \alpha_{42}\ PNI_{t-2} + \varepsilon_{t4} \\ \mathrm{PWA_t} = \mathrm{a}_5 + \alpha_{51}\ PWA_{t-1} + \alpha_{52}\ \mathrm{PWA_{t\text{-}2}} + \beta_{56} \mathrm{PKA_{t-1}} + \varepsilon_{t5} \\ \mathrm{PKA_t} = \mathrm{a}_6 + \alpha_{61}\ PKA_{t-1} + \varepsilon_{t6} \end{cases} \tag{7}$$

where PGO_t, PKI_t, PKO_t, PNI_t, PWA_t, and PKA_t are respectively cattle prices in current time, for Gossi, Kidal, Konna, Niamana, Wabaria, and Kati markets. The prices with a subscript t-1, on the right-hand side of the equation, are the prices for the same markets but lagged one period (ex. PGO_{t-1}); ε_{tn} is the error term.

The Kenya case study in which six cattle market prices were analyzed (VAR of six variables), the identification of the restricted VAR shows that prices in most of the markets (four out of six) are explained by their lagged prices and lagged prices of other markets (see equation 9 below). Chepareria and Garissa markets ($PCHEP_t$ and $PGSA_t$) make the exception and are explained by their own lagged prices up to three periods.

Contemporaneous correlation analysis between price innovations in each market, using the directed acyclic graphs and the correlation matrix, revealed a relatively weak relationship between markets. The contemporaneous interdependence between the six market prices is evident if you count the number of edges between markets but the correlation matrix coefficients show a relatively low level of correlation between markets. This means that price shocks from cattle markets are weakly transmitted among markets in contemporaneous time. Interestingly the innovation accounting results supports these findings. The forecast error variance decomposition and the impulse response function showed more interaction between markets but at longer horizons (four and eight weeks ahead). The prices tended to exhibit independence at shorter horizons (zero horizon or contemporaneous and one horizon) where price variations are explained by own price shocks. Chepareria market emerged as a dominant market over other markets. It consistently explained price variation in other markets without being much influenced by them as shown by the innovation accounting and DAG results. We concluded that the cattle markets in Kenya have a relatively good level of integration.

$$\begin{cases} \mathrm{PDAG_t} = \mathrm{a}_1 + \alpha_{11} PDAG_{t-1} + \alpha_{12}\ PDAG_{t-2} + \beta_{12} PNJI_{t-1} + \varepsilon_{t1} \\ \mathrm{PNJI_t} = \mathrm{a}_2 + \alpha_{21} PNJI_{t-1} + \alpha_{22} PNJI_{t-2} + \alpha_{23} PNJI_{t-3} + \beta_{25} PCHEP_{t-1} + \varepsilon_{t2} \\ \mathrm{PISI_t} = \mathrm{a}_3 + \alpha_{31} PISI_{t-1} + \alpha_{32} PISI_{t-2} + \beta_{36} PGSA_{t-1} + \varepsilon_{t3} \\ \mathrm{PGSE_t} = \mathrm{a}_4 + \alpha_{41}\ PGSE_{t-1} + \alpha_{42} PGSE_{t-2} + \beta_{45} PCHEP_{t-1} + \varepsilon_{t4} \\ \mathrm{PCHEP_t} = \mathrm{a}_5 + \alpha_{51}\ PCHEP_{t-1} + \alpha_{52} \mathrm{PCHEP_{t\text{-}2}} + \alpha_{56} \mathrm{PCHEP_{t-3}} + \varepsilon_{t5} \\ \mathrm{PGSA_t} = \mathrm{a}_6 + \alpha_{61}\ PGSA_{t-1} + \alpha_{62}\ PGSA_{t-2} + \alpha_{63}\ PGSA_{t-3} + \varepsilon_{t6} \end{cases} \tag{9}$$

where $PDAG_t$, $PNJI_t$, $PISI_t$, $PGSE_t$, $PCHEP_t$, and $PGSA_t$ are respectively cattle prices for Dagoretti, Njiru, Isiolo, Garsen, Chepareria, and Garissa markets in current time. The prices with a subscript t-1, on the right-hand side of the equation, are the prices for the same markets but lagged one period (ex. $PDAG_{t-1}$); ε_{tn} is the error term.

The Tanzania case study involved four cattle market prices analysis (VAR of four variables). The identification of the restricted VAR shows that most of the market prices in the VAR system (three out of four) are explained by their lagged prices and lagged prices of other markets except for the market of Igunga ($PIGU_t$) (equation 11 below).

Contemporaneous correlation among price innovations in each market was analyzed using the directed graphs and the correlation matrix. The results revealed a relatively weak relationship among the markets. The actual correlations between market prices in contemporaneous time are evident if you count the number of edges between markets but the correlation matrix coefficients show a relatively less strong linkage between markets. This result can be interpreted as signal that price innovations (shocks) are weakly transmitted among markets in current time. However, we noticed a high level of interaction between markets at longer horizons (four and eight) as shown by the innovation accounting results.

The innovation accounting results corroborate mostly these findings except for Kishapu market that showed early on (horizon 0 and 1) a relatively high level of interaction with other markets (or low level of exogeneity). In fact, the forecast error variance decomposition and the impulse response function showed a high level of interaction between the four markets specifically at longer horizons (four and eight). As a result, the four cattle markets in exhibited a higher degree of cattle market integration compared to Kenya and far better than the level of integration in Mali.

Pugu emerged as a price market leader in the group followed by Igunga while Kishapu behaved as price information "sink".

$$\begin{cases} \text{PPUG}_t = a_1 + \alpha_{11}\text{PPUG}_{t-1} + \beta_{12}\text{PIGU}_{t-1} + \varepsilon_{t1} \\ \text{PIGU}_t = a_2 + \alpha_{21}\text{PIGU}_{t-1} + \alpha_{22}\text{PIGU}_{t-2} + \alpha_{23}\text{PIGU}_{t-3} + \varepsilon_{t2} \\ \text{PKIS}_t = a_3 + \alpha_{31}\text{PKIS}_{t-1} + \beta_{33}\text{PIGU}_{t-1} + \varepsilon_{t3} \\ \text{PMON}_t = a_4 + \alpha_{41}\text{PMON}_{t-1} + \beta_{43}\text{PKIS}_{t-1} + e_{t4} \end{cases} \tag{11}$$

where $PPUG_t$, $PIGU_t$, $PKIS_t$, and $PMON_t$ are respectively cattle prices for Pugu, Igunga, Kishapu, and Monduli markets in current time. The prices with a subscript t-1, on the right-hand side of the equations, are the prices for the same markets but lagged one period (ex. $PPUG_{t-1}$); ε_{tn} is the error term.

To verify and cross-check the above conclusions, we compared the exogeneity level among the three countries and evaluated, through regression analysis, the correlation between demand and supply of cattle, and the level of exogeneity. The exogeneity test considered two categories: most and least exogenous cattle markets in each of the three countries. We chose in each country the most exogenous market on average from the error variance decomposition results. To characterize the exogeneity, we considered the percentage of variation by own-price shock over 16 period horizons for each most exogenous market in each country. The same procedure was applied to the least exogenous cattle markets in each country.

The results (figure 30) show that there is a difference among the most exogenous markets in Mali, Kenya, and Tanzania. Pugu market in Tanzania shows lower level of exogeneity in comparison with Kenya and Mali, which agree with our previous conclusions stipulating that the level of integration in Tanzania markets was much better than Kenya and Mali. As for the “least exogenous” market case (figure 31), we observed a noticeable difference between the three countries. Kishapu market from Tanzania shows a consistent decline in exogeneity over the 16 period horizons compared to Kenya and Mali. The results from the two graphs show that cattle markets in Tanzania interact more between them or in other terms are more integrated than their counterpart in Kenya and Mali. Cattle markets in Mali show consistently more exogeneity (consequently less integration) in both cases (see figures 30 and 31). This finding is in line with previous results on the level of cattle markets interaction in each of the three countries where Mali cattle markets showed low level of integration compared to the markets in Kenya and Tanzania.

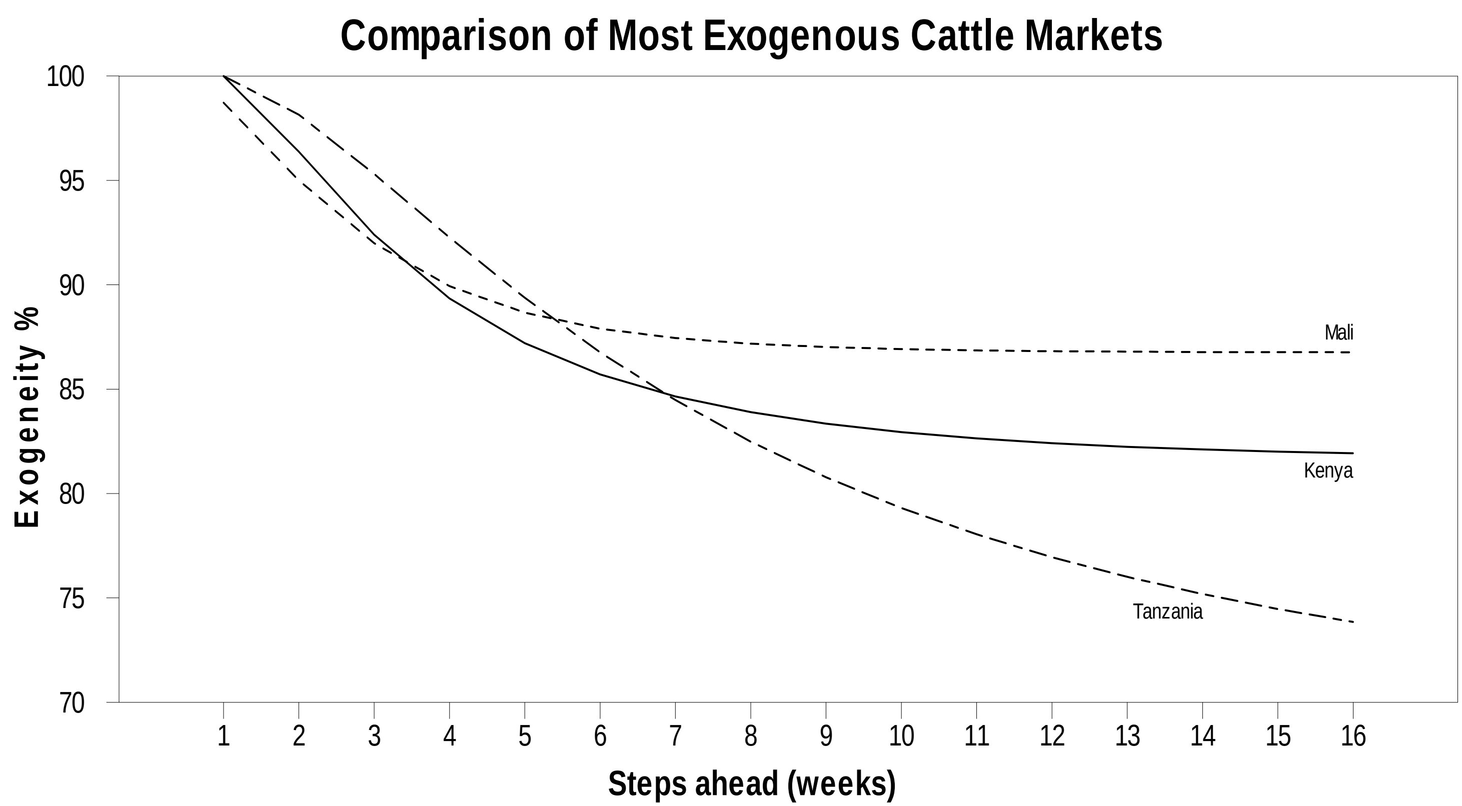

Figure 30. Country comparison of the most exogenous cattle market

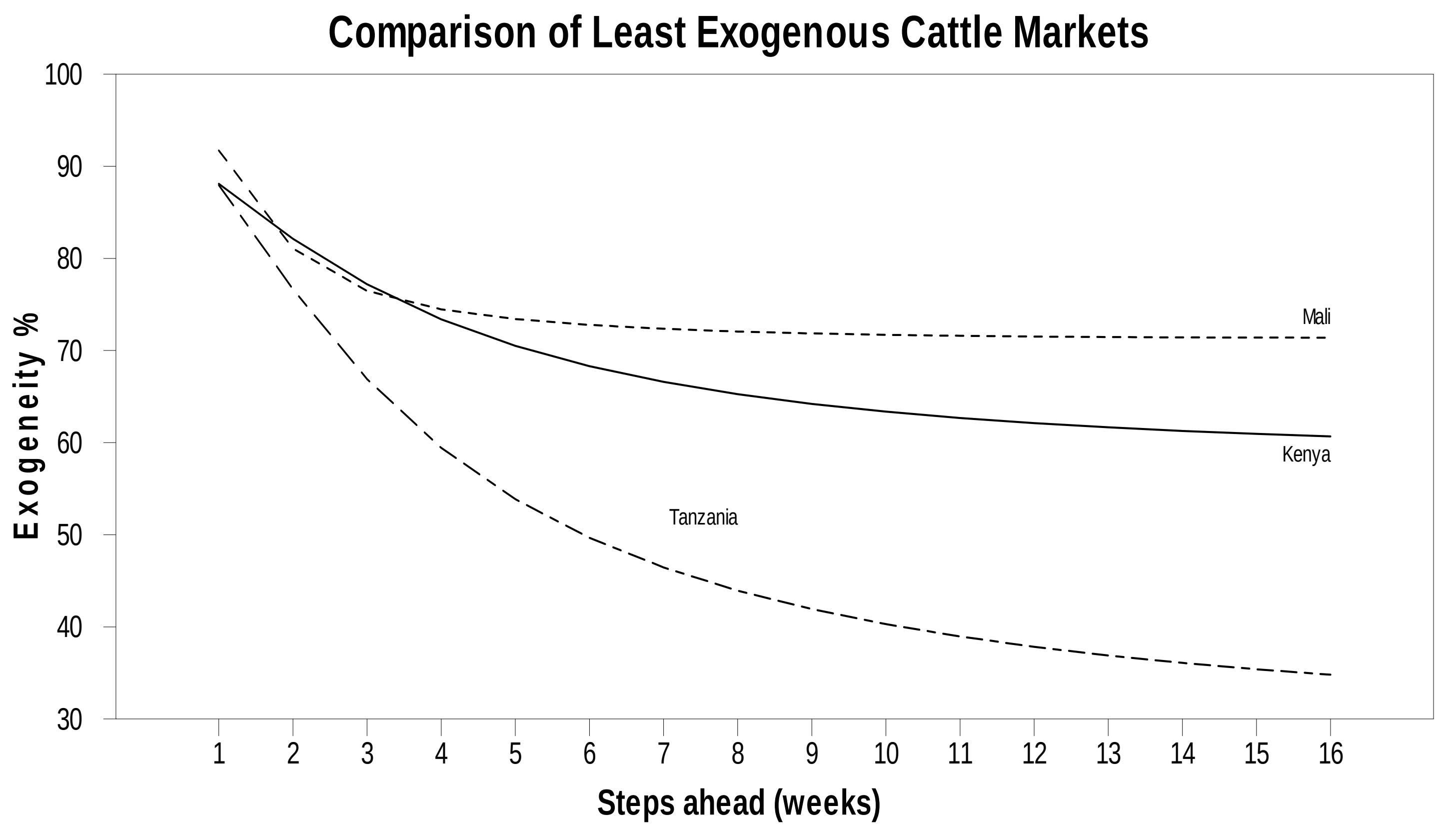

Figure 31. Country comparison of the least exogenous cattle market

We did as well a regression analysis to study any correlation between the degree of exogeneity of cattle markets in the three countries with regard to the population residing in the nearest city to these markets (a proxy for demand) and the average number of cattle brought for sale at the markets per month (table 18). We examined the degree of exogeneity of the markets in the short (0 period horizon) and long run (12 period horizons). The results indicate that in the short run period, there is a positive correlation between the number of population and the level of exogeneity of the cattle markets. A possible explanation is that the cattle markets located in high demand areas, such as large cities are more exogenous (independent) and interact less with other markets in terms of sending price signals in the short term. As the demand for cattle becomes higher in those areas, the cattle prices remain stable for some time before starting to interact with other cattle markets prices such as the supply markets.

The regression coefficient on the supply side is negative in the short term meaning a negative correlation between the cattle supply (number of cattle brought on the market) and the level of exogeneity of the cattle market. For instance, a shock in the supply chain would cause the level of exogeneity of the cattle market to drop; meaning that it would prompts the markets agents to interact more with other suppliers and consumers of cattle as new information on supply comes in. Note, however that the regression coefficients from the estimation are not significantly different from zero at 10% due probably to the small sample size (16 observations) and aggregation of the data for the three countries.

In the long run perspective (12 period horizons), there is a negative correlation between the number of population and the level of exogeneity (independence) of the cattle market (table 18). The level of exogeneity (or independence) of the cattle markets located in high demand areas will decline with time as the population living around those cattle markets keep increasing, driving up thus the demand. Note that this result is significantly different from zero at 10% level.

The supply of cattle reacts differently to the level of exogeneity in the long run. There is a positive correlation between the number of cattle supplied at 12 period horizon and the level of exogeneity. A consistent supply over some period of time builds the confidence of the cattle supplier which creates stability of the prices and solid trade relationships with the consumers. The lag effect might also contribute to maintaining the level of response and interaction between markets lower.

Table 18. Regression coefficient estimates

Horizon	Variables	Coefficients	Std Error	t Stat	P-value
Short run (0 period ahead)	Intercept	96.784132	1.926295	50.243656	2.816E-16
	Population	4.258E-07	1.233E-06	0.345288	0.735400
	Cattle Supply	-0.000331	0.000390	-0.849144	0.411165
Long run (12 periods ahead)	Intercept	78.150022	4.948046	15.794114	7.293E-10
	Population	-6.33E-06	3.167E-06	-2.000411	0.066791*
	Cattle Supply	0.000369	0.001002	0.368016	0.718783

Asterisk (*) indicates significance level at 10%

After analyzing the results on restricted VAR and exogeneity for Mali, Kenya, and Tanzania, we concluded that the cattle market integration processes occurred differently in the three case studies. More broadly, we can say that the level of market integration in East African countries of Kenya and Tanzania, where the LMIS started in 2003, showed a better performance than the LMIS introduced in West Africa country of Mali in 2007. There is a reasonable belief that the time factor or maturity of the LMIS has played a role in allowing the market integration process to take place at different pace. The data collected and analyzed for Kenya and Tanzania spanned over a period of four years (from 2006 to 2010) during which the market integration process took place and consolidated. On the contrary, the data used in the case of Mali covered less than two years (November 2008 to September 2010) after the LMIS was introduced. The novelty of the system might have played a negative role in slowing down the market integration process in Mali.

Rashid et al. (2010) pointed out earlier that these systems should be allowed more time for the market actors to learn arbitrage skills and strengthen their trade relationships based on the principle of competition. Unpublished results from a survey in Mali, carried out in 2011 on 346 livestock producers, showed that 66.1% of the respondents did not know the MLPI/LMIS project and 78.6% rely on word of mouth to learn about prevailing cattle prices on the markets (Jay Angerer, personal communication, 2011, see footnote 9). Also, despite the fact that 82.8% of respondents have a cell phone, only 55.2% use the cell phone to acquire livestock market price information.

From the results in figures 30 and 31, we also notice that Tanzania cattle markets stand out if we look at the level of market integration (exogeneity) in comparison with Kenya and Mali. Tanzanian cattle markets consistently showed less degree of exogeneity and more interaction among its markets compared to Kenya and Mali, which means a higher level of market integration. A possible explanation is considered here. The implementation and the ownership of the LINKS/LMIS system by the Tanzania government (Ministry of Trade and Industry or MIT) seemed to have been more aggressive than in Kenya and Mali (Jay Angerer, personal communication, 2011). The Tanzania government invested considerable resources to expand the channels of the livestock price information dissemination. Besides the price and quantity data made available through the LINKS website (same as in Kenya and Mali), there were also weekly reports that were disseminated in English and "Swahili" through several newspapers such as the Guardian, the Citizen, Mwananchi, and the Majira (Pica-Ciamara et al., 2011). Price data were as well disseminated through TV and radio programs and market boards in the Community Information Centers.

As for Kenya, Kariuki et al. (2009) acknowledged that the district teams in charge of implementing the LMIS mentioned a limitation for information dissemination due to large areas covered by the pastoral districts, the poor road network, low mobile phone coverage, and lack of knowledge of the best media to use for various communities. In Mali, attemps to multiply the livestock price information channels (radio and billbords) have not yet materialize due to the lack of funding. Tanzania seemed alone to have built a solid network of livestock price information dissemination compared to Kenya and Mali.

We acknowledge, however, that other factors not captured in this study might have contributed to the level of cattle market integration processes in Mali, Kenya, and Tanzania. The introduction and the implementation of the livestock market information system (LMIS) have certainly contributed to a more transparent and competitive cattle market in the three countries given the overall interaction level between cattle markets in each of them. For this reason we partially credit the level of success of market integration in each country to an improvement in price information disseminate due to the use of modern communication technologies (cell phones and internet).

We identified following limitations in this study. Given the lack of enough livestock data to cover the period before and after the introduction by the LMIS of modern communication tools (cell phones, internet) to disseminate prices, we were unable to evaluate the impact of those communication tools on market integration process. Also the research conclusions in the three cases studies (Mali, Kenya, and Tanzania) will be limited to the cattle markets actually studied. Further research is recommended for both the evaluation of the impact of the use of modern communication technologies on the cattle markets integration and the inclusion of more markets. Also with better data, we recommend to study the inter-country cattle markets integration between Kenya and Tanzanania which share a border. Finally for future policy recommendations, a study to explore other factors of market integration such as the distance to markets, using surveys and regression analysis, is recommended.

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APPENDIX A.1

HSIAO SEARCH: CASE STUDY OF MALI

Table A.1. 1. Search on Gossi cattle price with lags of Gossi cattle prices, Kidal cattle prices, Konna cattle prices, Niamana cattle prices, Wabaria cattle prices and Kati cattle prices, 2008-2010 data.

SL	Lags PGO			Lags PKI			Lags PKO			Lags PNI			Lags PWA			Lags PKA		
	-1	-2	-3	-1	-2	-3	-1	-2	-3	-1	-2	-3	-1	-2	-3	-1	-2	-3
20.67	x																	
20.62**	x	x																
20.67	x	x	x															
20.65*	x	x		x														
20.71	x	x		x	x													
20.76	x	x		x	x	x												
20.72	x			x														
20.65*	x	x		x														
20.70	x	x	x	x														
20.68*	x	x					x											
20.72	x	x					x	x										
20.75	x	x					x	x	x									
20.67	x	x								x								
20.73	x	x								x	x							
20.78	x	x								x	x	x						
20.67	x	x											x					
20.71	x	x											x	x				
20.75	x	x											x	x	x			
20.66	x	x														x		
20.70	x	x														x	x	
20.75	x	x														x	x	x

Final autoregressive model for Gossi market:

$$\mathrm{PGO_t} = \mathrm{a}_1 + \alpha_{11} PGO_{t-1} + \alpha_{12}\, PGO_{t-2} + \varepsilon_{t1}$$

Table A.1.2. Search on Kidal cattle price with lags of Kidal cattle prices, Gossi cattle prices, Konna cattle prices, Niamana cattle prices, Wabaria cattle prices and Kati cattle prices, 2008-2010 data.

SL	Lags PKI			Lags PGO			Lags PKO			Lags PNI			Lags PWA			Lags PKA		
	-1	-2	-3	-1	-2	-3	-1	-2	-3	-1	-2	-3	-1	-2	-3	-1	-2	-3
21.42	x																	
21.37**	x	x																
21.44	x	x	x															
21.40*	x	x		x														
21.41	x	x		x	x													
21.47	x	x		x	x	x												
21.45	x			x														
21.40*	x	x		x														
21.47	x	x	x	x														
21.43*	x	x					x											
21.48	x	x					x	x										
21.53	x	x					x	x	x									
21.42	x	x								x								
21.47	x	x								x	x							
21.54	x	x								x	x	x						
21.42	x	x											x					
20.47	x	x											x	x				
20.54	x	x											x	x	x			
21.41	x	x														x		
21.44	x	x														x	x	
21.51	x	x														x	x	x

Final autoregressive model for Kidal market:

$$\mathrm{PKI}_t = \mathrm{a}_2 + \alpha_{21} PKI_{t-1} + \alpha_{22} PKI_{t-2} + \varepsilon_{t2}$$

Table A.1.3. Search on Konna cattle price with lags of Konna cattle prices, Gossi cattle prices, Kidal cattle prices, Niamana cattle prices, Wabaria cattle prices and Kati cattle prices, 2008-2010 data.

SL	Lags PKO			Lags PGO			Lags PKI			Lags PWA			Lags PNI			Lags PKA		
	-1	-2	-3	-1	-2	-3	-1	-2	-3	-1	-2	-3	-1	-2	-3	-1	-2	-3
20.39**	x																	
20.43	x	x																
20.47	x	x	x															
20.44*	x			x														
20.50	x			x	x													
20.56	x			x	x	x												
20.44	x			x														
20.48	x	x		x														
20.52	x	x	x	x														
20.40*	x						x											
20.46	x						x	x										
20.52	x						x	x	x									
20.44	x									x								
20.46	x									x	x							
20.53	x									x	x	x						
20.44	x												x					
20.50	x												x	x				
20.57	x												x	x	x			
20.44	x															x		
20.50	x															x	x	
20.57	x															x	x	x

Final autoregressive model for Konna market:

$$\mathrm{PKO_t} = \mathrm{a}_3 + \alpha_{31} PKO_{t-1} + \varepsilon_{t3}$$

Table A.1.4. Search on Niamana cattle price with lags of Niamana cattle prices, Kati cattle prices, Gossi cattle prices, Konna cattle prices, Wabaria cattle prices and Kidal cattle prices, 2008-2010 data.

SL	Lags PNI			Lags PKA			Lags PGO			Lags PKO			Lags PWA			Lags PKI		
	-1	-2	-3	-1	-2	-3	-1	-2	-3	-1	-2	-3	-1	-2	-3	-1	-2	-3
20.14	x																	
20.06**	x	x																
20.08	x	x	x															
20.11*	x	x		x														
20.15	x	x		x	x													
20.19	x	x		x	x	x												
20.11*	x	x					x											
20.14	x	x					x	x										
20.21	x	x					x	x	x									
20.12*	x	x								x								
20.16	x	x								x	x							
20.23	x	x								x	x	x						
20.11	x	x											x					
20.16	x	x											x	x				
20.23	x	x											x	x	x			
20.11	x	x														x		
20.17	x	x														x	x	
20.22	x	x														x	x	x
20.19	x	x														x		
20.11*	x	x														x		
20.13	x	x	x													x		

Final autoregressive model for Niamana market:

$$\mathrm{PNI}_t = a_4 + \alpha_{41}\, PNI_{t-1} + \alpha_{42}\, PNI_{t-2} + \varepsilon_{t4}$$

Table A.1.5. Search on Wabaria cattle price with lags of Wabaria cattle prices, Gossi cattle prices, Konna cattle prices, Kidal cattle prices, Niamana cattle prices and Kati cattle prices, 2008-2010 data.

SL	Lags PWA			Lags PGO			Lags PKO			Lags PKI			Lags PNI			Lags PKA		
	-1	-2	-3	-1	-2	-3	-1	-2	-3	-1	-2	-3	-1	-2	-3	-1	-2	-3
21.40	x																	
21.36*	x	x																
21.42	x	x	x															
21.42*	x	x		x														
21.47	x	x		x	x													
21.54	x	x		x	x	x												
21.42*	x	x					x											
21.48	x	x					x	x										
21.54	x	x					x	x	x									
21.42*	x	x								x								
21.46	x	x								x	x							
21.52	x	x								x	x	x						
21.42*	x	x											x					
21.47	x	x											x	x				
21.54	x	x											x	x	x			
21.32**	x	x														x		
21.38	x	x														x	x	
21.43	x	x														x	x	x
21.34	x															x		
21.32*	x	x														x		
21.37	x	x	x													x		

Final autoregressive model for Wabaria market:

$$\text{PWA}_t = \text{a}_5 + \alpha_{51}\, PWA_{t-1} + \alpha_{52}\, \text{PWA}_{t\text{-}2} + \beta_{56}\text{PKA}_{t-1} + \varepsilon_{t5}$$

Table A.1.6. Search on Kati cattle price with lags of Kati cattle prices, Niamana cattle prices, Konna cattle prices, Gossi cattle prices, Wabaria cattle prices and Kidal cattle prices, 2008-2010 data.

SL	Lags PKA			Lags PNI			Lags PKO			Lags PGO			Lags PWA			Lags PKI		
	-1	-2	-3	-1	-2	-3	-1	-2	-3	-1	-2	-3	-1	-2	-3	-1	-2	-3
21.45**	x																	
21.49	x	x																
21.53	x	x	x															
21.51*	x			x														
21.55	x			x	x													
21.58	x			x	x	x												
21.47*	x						x											
21.53	x						x	x										
21.52	x						x	x	x									
21.48*	x									x								
21.55	x									x	x							
21.59	x									x	x	x						
21.50*	x												x					
21.57	x												x	x				
21.57	x												x	x	x			
21.47*	x															x		
21.53	x															x	x	
21.52	x															x	x	x

Final autoregressive model for Kati market:

$$\mathrm{PKA}_t = a_6 + \alpha_{61}\, PKA_{t-1} + \varepsilon_{t6}$$

APPENDIX A.2

HSIAO SEARCH: CASE STUDY OF KENYA

Table A.2.1. Search on Dagoretti cattle price with lags of Dagoretti cattle prices, Njiru cattle prices, Isiolo cattle prices, Garsen cattle prices, Chepareria cattle prices and Garissa cattle prices, 2006-2009 data

SL	Lags PDAG			Lags PNJI			Lags PISI			Lags PGSE			Lags PCHEP			Lags PGAR		
	-1	-2	-3	-1	-2	-3	-1	-2	-3	-1	-2	-3	-1	-2	-3	-1	-2	-3
13.80	x																	
13.72	x	x																
13.75	x	x	x															
13.71**	x	x		x														
13.73	x	x		x	x													
13.77	x	x		x	x	x												
13.74	x	x		x			x											
13.78	x	x		x			x	x										
13.82	x	x		x			x	x	x									
13.72	x	x		x						x								
13.76	x	x		x						x	x							
13.79	x	x		x						x	x	x						
13.7147	x	x		x									x					
13.7221	x	x		x									x	x				
13.723	x	x		x									x	x	x			
13.718	x	x		x												x		
13.72	x	x		x												x	x	
13.76	x	x		x												x	x	x
13.8	x			x														
13.71	x	x		x														
13.75	x	x	x	x														

Final autoregressive model for Dagoretti market:

$$\mathrm{PDAG}_t = a_1 + \alpha_{11} PDAG_{t-1} + \alpha_{12}\, PDAG_{t-2} + \beta_{12} PNJI_{t-1} + \varepsilon_{t1}$$

Table A.2. 2. Search on Njiru cattle price with lags of Njiru cattle prices, Dagoretti cattle prices, Isiolo cattle prices, Garsen cattle prices, Chepareria cattle prices and Garissa cattle prices, 2006-2009 data

SL	Lags PNJI			Lags PDAG			Lags PISI			Lags PGSE			Lags PCHEP			Lags PGAR		
	-1	-2	-3	-1	-2	-3	-1	-2	-3	-1	-2	-3	-1	-2	-3	-1	-2	-3
13.98	x																	
13.93	x	x																
13.88	x	x	x															
13.92	x	x	x	x														
13.95	x	x	x	x	x													
13.98	x	x	x	x	x	x												
13.91	x	x	x				x											
13.95	x	x	x				x	x										
13.97	x	x	x				x	x	x									
13.89	x	x	x							x								
13.93	x	x	x							x	x							
13.96	x	x	x							x	x	x						
13.87**	x	x	x										x					
13.90	x	x	x										x	x				
13.93	x	x	x										x	x	x			
13.90	x	x	x										x			x		
13.94	x	x	x										x			x	x	
13.96	x	x	x										x			x	x	x
13.96	x												x					
13.91	x	x											x					
13.87	x	x	x										x					

Final autoregressive model for Njiru market is:

$$\mathrm{PNJI_t} = \mathrm{a}_2 + \alpha_{21} PNJI_{t-1} + \alpha_{22} PNJI_{t-2} + \alpha_{23} PNJI_{t-3} + \beta_{25} PCHEP_{t-1} + \varepsilon_{t2}$$

Table A.2.3. Search on Isiolo cattle prices with lags of Isiolo cattle prices, Njiru cattle prices, Garissa cattle prices, Dagoretti cattle prices, Garsen cattle prices and Chepareria cattle prices, 2006-2009 data

SL	Lags PISI			Lags PNJI			Lags PGSA			Lags PDAG			Lags PGSE			Lags PCHEP		
	-1	-2	-3	-1	-2	-3	-1	-2	-3	-1	-2	-3	-1	-2	-3	-1	-2	-3
15.35	x																	
15.23	x	x																
15.27	x	x	x															
15.26	x	x		x														
15.29	x	x		x	x													
15.33	x	x		x	x	x												
15.22**	x	x					x											
15.25	x	x					x	x										
15.29	x	x					x	x	x									
15.25	x	x					x			x								
15.29	x	x					x			x	x							
15.31	x	x					**x**			x	x	x						
15.25	x	x					x						x					
15.27	x	x					x						x	x				
15.31	x	x					**x**						x	x	x			
15.25	x	x					x									x		
15.28	x	x					x									x	x	
15.32	x	x					**x**									x	x	x
15.32	x						x											
15.22	x	x					x											
15.26	x	x	x				x											

Final autoregressive model for Isiolo market:

$$\mathrm{PISI}_t = \mathrm{a}_3 + \alpha_{31} PISI_{t-1} + \alpha_{32} PISI_{t-2} + \beta_{36} PGSA_{t-1} + \varepsilon_{t3}$$

Table A.2.4. Search on Garsen cattle prices with lags of Garsen cattle prices, Dagoretti cattle prices, Njiru cattle prices, Garissa cattle prices, Isiolo cattle prices and Chepareria cattle prices, 2006-2009 data

SL	Lags PGSE			Lags PDAG			Lags PNJI			Lags PGSA			Lags PISI			Lags PCHEP		
	-1	-2	-3	-1	-2	-3	-1	-2	-3	-1	-2	-3	-1	-2	-3	-1	-2	-3
16.03	x																	
16.02	x	x																
16.04	x	x	x															
16.04	x	x		x														
16.08	x	x		x	x													
16.08	x	x		x	x	x												
16.05	x	x					x											
16.08	x	x					x	x										
16.12	x	x					x	x	x									
16.03	x	x								x								
16.06	x	x								x	x							
16.10	x	x								x	x	x						
16.04	x	x											x					
16.08	x	x											x	x				
16.11	x	x											x	x	x			
16.01**	x	x														x		
16.04	x	x														x	x	
16.07	x	x														x	x	x
16.02	x															x		
16.01	x	x														x		
16.04	x	x	x													x		

Final autoregressive model for Garsen market:

$$\mathrm{PGSE}_t = a_4 + \alpha_{41} PGSE_{t-1} + \alpha_{42} PGSE_{t-2} + \beta_{45} PCHEP_{t-1} + \varepsilon_{t4}$$

Table A.2. 5. Search on Chepareria cattle prices with lags of Chepareria cattle prices, Dagoretti cattle prices, Isiolo cattle prices, Njiru cattle prices, Garsen cattle prices and Garissa cattle prices, 2006-2009 data

SL	Lags PCHEP			Lags PDAG			Lags PISI			Lags PNJI			Lags PGSE			Lags PGSA		
	-1	-2	-3	-1	-2	-3	-1	-2	-3	-1	-2	-3	-1	-2	-3	-1	-2	-3
14.79	x																	
14.79	x	x																
14.74**	x	x	x															
14.76	x	x	x	x														
14.79	x	x	x	x	x													
14.82	x	x	x	x	x	x												
14.76	x	x	x				x											
14.80	x	x	x				x	x										
14.83	x	x	x				x	x	x									
14.76	x	x	x							x								
14.77	x	x	x							x	x							
14.81	x	x	x							x	x	x						
14.77	x	x	x										x					
14.79	x	x	x										x	x				
14.82	x	x	x										x	x	x			
14.77	x	x	x													x		
14.80	x	x	x													x	x	
14.83	x	x	x													x	x	x

Final autoregressive model for Chepareria market:

$$\mathrm{PCHEP_t} = \mathrm{a}_5 + \alpha_{51}\ PCHEP_{t-1} + \alpha_{52}\mathrm{PCHEP_{t\text{-}2}} + \alpha_{56}\mathrm{PCHEP_{t-3}} + \varepsilon_{t5}$$

Table A.2. 6. Search on Garissa cattle prices with lags of Garissa cattle prices, Isiolo cattle prices, Njiru cattle prices, Garsen cattle prices, Chepareria cattle prices and Dagoretti cattle prices, 2006-2009 data

SL	Lags PGSA			Lags PISI			Lags PNJI			Lags PGSE			Lags PCHEP			Lags PDAG		
	-1	-2	-3	-1	-2	-3	-1	-2	-3	-1	-2	-3	-1	-2	-3	-1	-2	-3
14.43	x																	
14.43	x	x																
14.24**	x	x	x															
14.44	x	x	x	x														
14.45	x	x	x	x	x													
14.48	x	x	x	x	x	x												
14.45	x	x	x				x											
14.48	x	x	x				x	x										
14.51	x	x	x				x	x	x									
14.45	x	x	x							x								
14.47	x	x	x							x	x							
14.51	x	x	x							x	x	x						
14.45	x	x	x										x					
14.48	x	x	x										x	x				
14.51	x	x	x										x	x	x			
14.45	x	x	x													x		
14.48	x	x	x													x	x	
14.51	x	x	x													x	x	x

Final autoregressive model for Garissa market:

$$\mathrm{PGSA}_t = a_6 + \alpha_{61}\, PGSA_{t-1} + \alpha_{62}\, PGSA_{t-2} + \alpha_{63}\, PGSA_{t-3} + \varepsilon_{t6}$$

APPENDIX A.3

HSIAO SEARCH: CASE STUDY OF TANZANIA

Table A.3. 1. Search on Pugu cattle price with lags of Pugu cattle prices, Igunga cattle prices, Kishapu cattle prices, and Monduli cattle prices, 2006-2010 data

SL	Lags PPUG			Lags PIGU			Lags PKIS			Lags PMON		
	-1	-2	-3	-1	-2	-3	-1	-2	-3	-1	-2	-3
21.52	x											
21.53	x	x										
21.52	x	x	x									
21.49**	x			x								
21.52	x			x	x							
21.55	x			x	x	x						
21.50	x			x			x					
21.53	x			x			x	x				
21.54	x			x			x	x	x			
21.52	x			x						x		
21.54	x			x						x	x	
21.57	x			x						x	x	x
21.49	x			x								
21.51	x	x		x								
21.52	x	x	x	x								

Final autoregressive model for Pugu market:

$$\mathrm{PPUG_t} = \mathrm{a_1} + \alpha_{11}\mathrm{PPUG}_{t-1} + \beta_{12}\mathrm{PIGU}_{t-1} + \varepsilon_{t1}$$

Table A.3.2. Search on Igunga cattle price with lags of Igunga cattle prices, Kishapu cattle prices, Monduli cattle prices, and Pugu cattle prices, 2006-2010 data

SL	Lags PIGU			Lags PKIS			Lags PMON			Lags PPUG		
	-1	-2	-3	-1	-2	-3	-1	-2	-3	-1	-2	-3
21.81	x											
21.71	x	x										
21.68**	x	x	x									
21.71	x	x	x	x								
21.73	x	x	x	x	x							
21.76	x	x	x	x	x	x						
21.71	x	x	x				x					
21.74	x	x	x				x	x				
21.77	x	x	x				x	x	x			
21.71	x	x	x							x		
21.74	x	x	x							x	x	
21.76	x	x	x							x	x	x

Final autoregressive model for Igunga market:

$$\text{PIGU}_t = a_2 + \alpha_{21}\text{PIGU}_{t-1} + \alpha_{22}\text{PIGU}_{t-2} + \alpha_{23}\text{PIGU}_{t-3} + \varepsilon_{t2}$$

Table A.3.3. Search on Kishapu cattle price with lags of Kishapu cattle prices, Monduli cattle prices, Igunga cattle prices, and Pugu cattle prices, 2006-2010 data

SL	Lags PKIS			Lags PMON			Lags PIGU			Lags PPUG		
	-1	-2	-3	-1	-2	-3	-1	-2	-3	-1	-2	-3
21.37	x											
21.36	x	x										
21.34	x	x	x									
21.35	x	x	x	x								
21.38	x	x	x	x	x							
21.40	x	x	x	x	x	x						
21.32**	**x**	x	x				x					
21.35	x	x	x				x	x				
21.38	x	x	x				x	x	x			
21.71	x	x	x				x			x		
21.74	x	x	x				x			x	x	
21.76	x	x	x				x			x	x	x
21.3233	x						x					
21.3246	x	x					x					
21.3247	x	x	x				x					

Final autoregressive model for Kishapu market:

$$\mathrm{PKIS_t} = \mathrm{a}_3 + \alpha_{31}\mathrm{PKIS}_{t-1} + \beta_{33}\mathrm{PIGU}_{t-1} + \varepsilon_{t3}$$

Table A.3.4. Search on Monduli cattle price with lags of Monduli cattle prices, Kishapu cattle prices, Igunga cattle prices, and Pugu cattle prices, 2006-2010 data

SL	Lags PMON			Lags PKIS			Lags PIGU			Lags PPUG		
	-1	-2	-3	-1	-2	-3	-1	-2	-3	-1	-2	-3
21.79	x											
21.80	x	x										
21.75	x	x	x									
21.72	x	x	x	x								
21.75	x	x	x	x	x							
21.77	x	x	x	x	x	x						
21.74	x	x	x	x			x					
21.77	x	x	x	x			x	x				
21.80	x	x	x	x			x	x	x			
21.71	x	x	x	x						x		
21.74	x	x	x	x						x	x	
21.76	x	x	x	x						x	x	x
21.71**	x			x								
21.74	x	x		x								
21.72	x	x	x	x								

Final autoregressive model for Monduli market:

$$\text{PMON}_t = a_4 + \alpha_{41}\text{PMON}_{t\text{-}1} + \beta_{43}\text{PKIS}_{t\text{-}1} + e_{t4}$$

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