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Pastoral livestock market integration amidst improvements in physical and communication infrastructure: Evidence from northern Kenya

Philemon Chelanga*
Department of Agricultural and Resource Economics, Jomo Kenyatta University of Agriculture and Technology, Kenya & African Agency for Inclusive Innovations. E-mail: pchelanga@aiid.co.ke

Nathaniel Jensen
Independent Researcher. E-mail: Nathaniel.d.jensen@gmail.com

Kavoi Mutuku Muendo
Department of Agricultural and Resource Economics, Jomo Kenyatta University of Agriculture and Technology, Kenya. E-mail: kavoi.muendo@gmail.com

* Corresponding author

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Abstract

This article analyses the level of integration in pastoral markets in Kenya using high-frequency data generated through a crowdsourcing endeavour. The vector error-correction model framework was used to estimate the causal relationships between the short- and long-run market price. The results indicate that a higher proportion of price variation in larger markets in the region was due to market price shocks, while variation in the smaller markets originated from the larger markets. Weekly adjustments and the convergence of prices on a long-run equilibrium after experiencing shocks were also observed. Price transmission was also evident between markets operating along different trading routes. However, markets located close to production catchments exhibited lower price trends, despite being connected. These results suggest a strong influence of the recent infrastructural investments on price transmission between markets in the region. The findings imply that more investments would enhance the competitive trading environment and reduce unidirectional price transmission.

Key words: high-frequency data, Kenya, livestock prices, pastoral markets

1. Introduction

Market integration is an important indicator of economic development, and studies on this topic have evolved over the last five decades in a bid to explain weaknesses in economic theory in relation to addressing apparent market failures (Bressler & King 1978; Fackler & Goodwin 2001; Von Cramon-Taubadel 2017). In Africa, studies focusing on the implications of large policy shifts, such as the structural adjustment programmes (SAPs) in the 1980s and the liberalisation policies on market integration in the 1990s are common (Alderman 1992; Rashid 2004). More recently, global trends like economic depression have shaped a new crop of studies focusing on both the global and regional contexts of market integration (e.g. the 2007/2008 economic crisis, discussed by Acharya *et al*. 2012 and Akhter 2017). Other studies delve into the different dimensions of market integration, such as the responsiveness of markets to changes in information access (Aker 2010), improvements in the physical infrastructure connecting markets (Jones & Salazar 2021), and environmental shocks like prolonged droughts (Salazar *et al*. 2018). Studies on this concept continue to be insightful as markets evolve (Von Cramon-Taubadel 2017).

Integrated markets allow the efficient transmission of price signals and macro-level policies to increase the incentives and reduce the constraints faced by traders and producers operating in the meso-markets (Barrett 2008; Gitau & Meyer 2019). As such, the actors become responsive to changes in demand and supply (Fackler & Goodwin 2001). Moreover, integrated markets increase the likelihood of producers adopting new technologies in production so that they can meet excess demand from distant markets (Barrett 2008). Adopting new communications technologies like mobile phones enhances distribution and marketing activities (Aker & Ksoll 2016). If traders fail to access distant markets, the efficiency gains from policy changes aimed at improving the trading environment are lost because incentives to trade are diminished (Barrett 2008). Despite several efforts by practitioners, market segments at the interface between rural and urban settings are those affected the most by these barriers to date (Aker 2010; Porteous 2019). These barriers are apparent in livestock markets in northern Kenya (Maina 2013).

This study provides insights into the state of livestock market integration in the pastoral livestock markets of Kenya. Its aim was to discover the effects of the recent public and private investments that resulted in improvements to roads, market infrastructure, telecommunication networks, access to mobile phones, and digital financial infrastructure (Roba *et al*. 2017; Parlasca 2021). The interaction between such technologies in an environment with improved physical infrastructure improves market integration (Barrett 2008; Bizimana *et al*. 2015). Therefore, it is not only logical to expect price information to flow effectively, but also that transfer costs between markets will be reduced and thereafter remain relatively stationary. This then implies the possible existence of integration between markets. If weak price transmission persists in the current market environment, then other market structure distortions to arbitrage exist besides transfer costs (Acosta *et al*. 2019). To further reiterate the need for this enquiry, a review by Von Cramon-Taubadel (2017) on price transmission and its implications in the African context suggests that the current improvement in physical and institutional trade infrastructure in developing nations justifies more studies on market integration.

This study used weekly market price data for goats collected through an innovative mobile phone-based crowdsourcing initiative conducted in northern Kenya for 43 weeks. The findings show that a higher proportion of price variation in the larger markets in the region is due to its shocks, while variation in smaller markets originates from the larger markets. Markets operating along the same trading route and having good connections of infrastructure exhibited both short- and long-run causal relationships. Similarly, the speed of convergence on long-run equilibrium through adjustments to the weekly price shocks was also evident in these markets. The remainder of the paper is organised as follows: Section 2 provides the context of the pastoral livestock markets. The methodology used, which entails the empirical strategy, data sources and variables, is detailed in Section 3. Section 4 provides both the descriptive and regression results. The conclusions and recommendations are detailed in Section 5.

2. Context of pastoral livestock markets

Most livestock in Kenya is produced in the drylands, which constitute 84% of the landmass and are home to 10 million pastoralists (Kenya National Bureau of Statistics [KNBS] 2019). The subsector also contributes 10% of the country's national gross domestic product (GDP) and 50% of agricultural GDP (KNBS 2019). A large proportion of pastoralists rely on livestock as their main source of livelihood. They access livestock markets to offload production surpluses, use the revenue to fill consumption deficits, and build up savings through restocking and/or cash (Little *et al*. 2014). Researchers and experts argue that the increasing demand for livestock products in local and global markets offers great potential for pastoralists to benefit (Bosire *et al*. 2017).

Pastoralists trade at informal markets (homesteads, grazing and water points) and formal markets (feeder,[1] intermediate[2] and terminal[3]) as they negotiate the need for herd mobility (Little *et al*. 2014). The formal markets are distributed in production catchments, often in the vicinity of major transport routes and towns (Roba *et al*. 2017). Local and government stakeholders have defined a systematic schedule of market days in different catchment areas and towns. Weekly market days are common and are organised to allow the flow of supply across market levels, i.e. from the feeder to intermediate to terminal markets (regional, national and international). Informal markets are organised by local traders and pastoralists at their convenience. In both channels, however, there are deleterious cyclical market price risks, commonly linked to information asymmetry, with huge welfare implications for pastoralists (Barrett & Luseno 2004).

Multisectoral efforts to bridge the information asymmetry gap and provide a conducive trading environment have been evolving in the drylands. In the recent past, public and private investments that include road expansion, physical market infrastructure, a policy environment to support markets, telecommunication networks and digital financial infrastructure have been put in place (Roba *et al*. 2017). Examples of such projects include a programme to the value of US$20 million sponsored by USAID (the United States Agency for International Development) to improve resilience and growth launched in 2013; the Isiolo-Moyale road, sponsored by African Development Bank (ADB) and China Exim Bank to the value of US$420 million and completed in 2017; a continuous effort by county governments to open up rural roads since 2013; telecommunication masts erected in many parts of the region since 2015; and other, similar efforts by various development agencies. Recent studies have shown an increasing trend in pastoral connectivity and the use of mobile phones (Parlasca 2021). Mobile phone access reduces transaction costs in trade by improving coordination and supervision (Aker 2010). Access to such technologies in an environment with improved physical infrastructure could improve market integration (Barrett 2008).

3. Methodology

3.1 Empirical strategy

The Enke-Samuelson-Takayama-Judge (ESTJ) model of Enke (1951), Samuelson (1952) and Takayama and Judge (1971) is commonly applied in studies on spatial market integration. The model is linked to the spatial equilibrium economic framework. The ESTJ model describes multiple

[1] Feeder markets are the smallest markets and are located near pastoralist settlements. They are commonly serviced by traders drawn from the local community and a few external traders. They are the main sources of supply to intermediate markets.

[2] Intermediate markets are relatively large markets located in major dryland towns, mediating supply between feeder markets and national and international terminal markets. In some cases these markets act as regional terminal markets.

[3] These are the largest markets and are commonly located in the cities and major towns in the country. They often receive supply from intermediate markets. The also act as supply markets for international markets.

equilibrium levels that may exist in two markets based on arbitrage conditions and tradability arrangements. Spatial market integration occurs when the ESTJ equilibrium conditions hold, irrespective of whether trade occurs or not (Takayama & Judge 1971). The size of transfer costs between the market pairs determines the different equilibrium conditions (Barrett 2008). Ideally, the variables needed for comprehensive analysis using the ESTJ framework are prices, transaction costs, trade volumes and trade volume quotas (Barrett 1996).

In this study, dynamic models were used for analysis because only price data was available. The approach of market integration using dynamic models is an advancement of the traditional bivariate correlation (Fackler & Goodwin 2001). Cointegration analysis, developed by Engle and Granger (1987), is the most common procedure used in dynamic models. The model assumes that price series are non-stationary and thus need a transformation of prices into levels that permit testing of the stationarity of the error term, and for the later estimation of the error correction model. It also considers delays in price shock transmission across markets due to transportation delays, delivery lags and traders' lack of perfect foresight of market conditions. These delays are practical and common in agricultural markets with surplus markets in rural settings. Fackler and Goodwin (2001) argue that the non-stationarity of price series in the agricultural commodity market is a reality that needs consideration, and thus any method that ignores it gives an erroneous measure of market integration.

Cointegration analysis is a stepwise procedure. Trend analysis using a graphical method is the preliminary test of stationarity in time-series data. The second step is a more precise and formal statistical test of stationarity known as the unit root. This is accomplished by using the standard augmented Dickey-Fuller (ADF) test. Other methods, like Phillips-Perron (PP) and Kwiatkowski-Philips-Schmidt-Shin (KPSS), are also used for validation due to the generally low statistical power of each of the methods to reject the null hypothesis of stationarity (Fackler & Goodwin 2001). The main strength of the ADF test is its ability to add lagged independent variables into the unit root regression test to take care of any possible serial correlation (Gujarati 2003). If the unit-root test equation consists of time-series data having characteristics of a random walk with drift and stochastic trend, the ADF test would consist of testing the following regression:

$$\Delta Y_t = \beta_1 + \beta_2 t + \delta Y_{t-1} + \sum_{t=1}^{m} \alpha_i \Delta Y_{t-i} + \varepsilon_t, \quad (1)$$

where ΔY_t is the first difference in the price series, ΔY_{t-i} is the change in lagged price series, β_i , δ and α_i are coefficients to be estimated, m is the number of lags to be included in the model, and ε_t is a pure white noise error term. The number of lagged differences to include is determined empirically; the idea is to include enough terms so that the error term in equation 1 is not serially correlated (Gujarati 2003). The key test is whether $\delta = 0$, i.e. if $\delta = 0$, then we have a unit root, meaning the price series under consideration is non-stationary. ADF provides a mechanism of statistically knowing whether $\delta = 0$ or not. Depending on the estimates of β_i , the ADF reduces to forms that correspond to price series that either exhibit random walk or random walk with drift, or random walk with drift and trend. PP and ADF are similar in procedure, but PP largely follows non-parametric statistical methods to control for autocorrelation. KPSS follows a Lagrange multiplier procedure.

The outcome of the unit root test shows whether two series are stationary or not. If found to be stationary, then the coefficients can be used for prediction and, if not, a transformation is required to make the time series stationary. This can be done through detrending or finding the first difference (Gujarati 2003). The whole idea is to ensure that a spurious regression is not run by using non-stationary time-series data. For instance, variables integrated of the first order, i.e. I (1), should be differenced before they are used in linear regression models, whether they are estimated by ordinary least square (OLS) or by instrumental variables (Wooldridge 2009). The third stage is estimating a cointegration equation with optimal lags obtained through common information criteria – mostly the Akaike information criterion (AIC).

To establish the statistically sound long-run relationship, depicted by the value of the cointegration parameter, two popular tests suggested by Engle and Granger (1987), called the Engle-Granger test, and Johansen (1988), called the Johansen test, were used. The Engle-Granger approach relies on residuals, while Johansen's (1988) approach relies on the relationship between the rank of the matrix and its characteristic roots (eigenvalues). Engle-Granger also requires the normalisation of all price series, but the Johansen approach does not.

The fourth step, involving the establishment of short-run equilibrium, the magnitude of price change, and the speed of price adjustment between market pairs was done using the vector error-correction (VEC) framework. The VEC framework corrects for the disequilibrium depicted by the error term in Equation (2). It also provides a mechanism to establish the direction of Granger causality in both the short and the long run (Granger 1988). If two markets are integrated, their relationship can validly be explained using the VEC framework, as follows:

$$\begin{pmatrix}\Delta p_{1t}\\ \Delta p_{2t}\end{pmatrix} = \begin{pmatrix}\mu_1\\ \mu_2\end{pmatrix} + \begin{pmatrix}\alpha_1\\ \alpha_2\end{pmatrix}(p_{1t-1} - \beta p_{2t-1}) + A_2\begin{pmatrix}\Delta p_{1t-1}\\ \Delta p_{2t-1}\end{pmatrix} + \ldots\ldots + A_k\begin{pmatrix}\Delta p_{1t-k}\\ \Delta p_{2t-k}\end{pmatrix} + \begin{pmatrix}v_{1t}\\ v_{2t}\end{pmatrix}, \quad (2)$$

where v_{1t} and v_{2t} are the *iid* disturbance term with zero mean and constant variance. The operator, Δ, denotes that the I (1) variable meets the stationarity condition. The parameters in matrices $A_2 \ldots A_k$ measure the short-run effects, while β is the cointegration parameter that characterises the long-run equilibrium relationship between price pairs. The price levels enter the model as a single entity $(p_{1t-1} - \beta p_{2t-1})$, and thus reflects any divergence from equilibrium. The vector, $\begin{pmatrix}\alpha_1\\ \alpha_2\end{pmatrix}$, is commonly called the error-correction coefficient. It measures the speed at which the markets return to equilibrium – a large value of the coefficient indicates a higher speed of adjustment of the model from the short run to the long run. Most importantly, the proximity of α_i to one is used to assess the extent to which interventions, transaction costs and other interventions delay full adjustment to the long-run equilibrium. The model can also take a multivariate form – and thus could be used to estimate the relationship between several market price series.

3.2 Data sources and variables

Pastoral livestock markets in northern Kenya were the focus of this study. The study was conducted in three purposively selected counties in northern Kenya: Marsabit, Samburu and Isiolo. Six markets, comprising four intermediate markets (Isiolo, Lekuru, Merille and Moyale) and two feeder markets (Korr and Archers Post) were selected in the three counties. These markets are geographically dispersed and hence represent a wide catchment area and two important trading routes (Alarcon *et al*. 2017). The Moyale-Isiolo trading route, which was the only tarmac road in the region, is represented by Merille, Archers Post, Isiolo, Korr and Moyale markets, while the Baragoi-Nyahururu trading route, which was partly tarmacked, is represented by Lekuru market. Most of the sampled markets operate on predetermined weekly cycles, with a few in major towns (Moyale and Isiolo) that are active daily, but with a single larger market day each week. The supply of livestock[4] during market days is usually in the hundreds, but can be much more or less in some cases. There is also variation in animal types supplied on a market day.

[4] Camels, cattle, sheep and goats are the main livestock traded in this region. The small ruminants (goats and sheep) are always present in larger volumes than the large ruminants (camels and cattle). However, goats are the most common and most frequently traded at all market levels.

The data on livestock prices was obtained from the crowdsourcing initiative undertaken between November 2019 to October 2020 (Chelanga *et al*. 2022). The crowdsourcing approach was adopted as an innovative alternative to previous data collection systems that have failed to provide reliable and consistent data from these markets over a long period (Tollens 2006). This approach provided reliable and representative high-frequency data that matched the weekly cycles of trade in the sampled markets. The livestock prices of the available animal types were captured following standardised livestock quality dimensions as indicated by the Kenya Bureau of Standards (KBS). To cover the heterogeneity in quality within livestock type traded, and to have representative data, protocols[5] to ensure multiple submissions per animal type were established (Chelanga *et al*. 2022).

The high-frequency data used provides a clearer picture of trade efficiency and market integration, unlike analyses based on aggregates over a longer span, e.g. biweekly, monthly, quarterly, etc. (Chelanga *et al*. 2022). If markets were integrated, price transmission between markets should be very quick because markets occur weekly and are visited by an overlapping network of traders – even up to the national terminal markets. From the crowdsourcing initiative, weekly prices of all animal types traded in the six sampled livestock markets were recorded for 43 weeks, although some were submitted for 41 and 42 weeks. This implies that, for regression analysis that requires complete price pairs, 41 weeks of market pairs were analysed. Although this reduced the length of the time-series data and associated additional insights from the weekly-linked speed of price adjustments and the precision of the VECM long-run causal estimates, it was the only feasible option. Furthermore, to ensure consistency and completeness, data from animal types present in all sampled market locations during all study weeks were used for analysis – in this case the prices for goats met this criterion. The price data submitted for goats was validated and then aggregated to weekly mean prices for each market. The price data was recorded in Kenya shillings (KES) and converted to United States dollar (US$) using the rate at the beginning of the survey, i.e. 101 KES = 1 US$. Price data used for regression was transformed into natural logarithms. This implies that the results are interpreted as elasticities –and thus as the percentage changes in both sides of the equation.

4. Results and discussion

4.1 Weekly market price trends

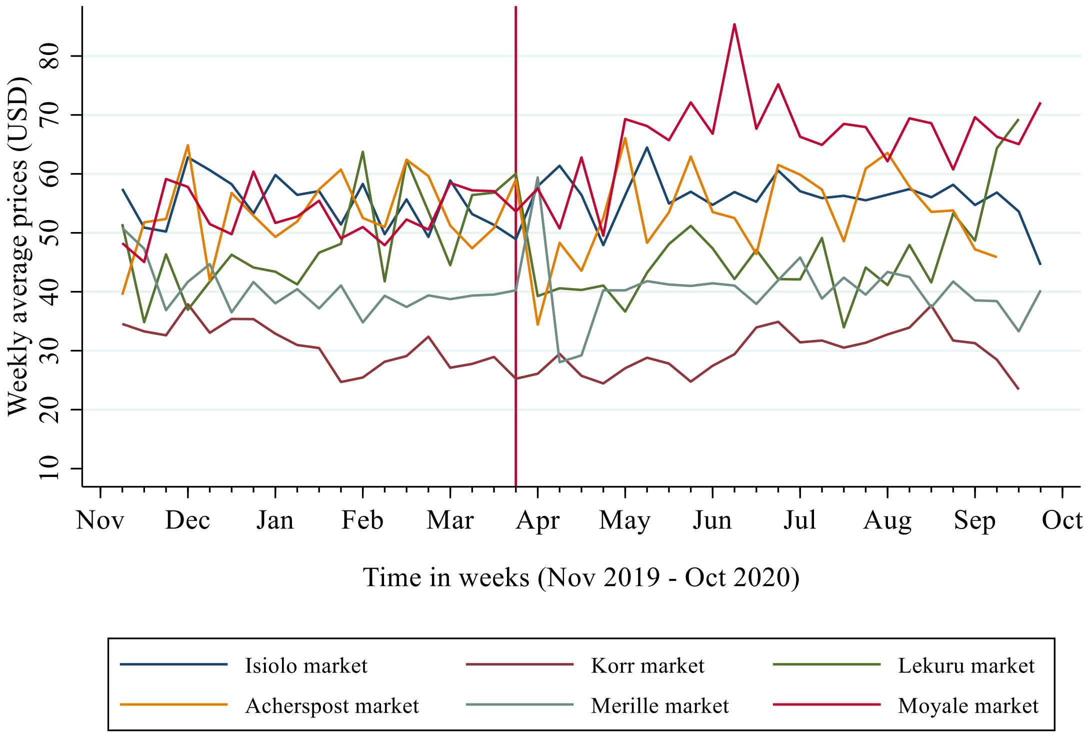
Figure 1 shows the weekly mean price for goats in each of the six sampled markets. The evolution of goat prices over the 43 weeks showed a predominant pattern of low variability among price series. There is no clear seasonality in price trends, but weekly price fluctuations can be observed. It is only in Moyale, which is a border market between Kenya and Ethiopia, that showed an increase in prices in the second half of the long rainy season (May to June). The price increase was likely occasioned by the cross-border price dynamics. In aggregate, the minimal variation and absence of glaring seasonality observed in the price trends could be attributed to the general normal forage conditions experienced in most pastoral rangelands in the region in 2019 and 2020.

Figure 1 also shows the response of market price trends to other exogenous non-market shocks during the period. As such, there are notable but short-period price shocks in a few markets (Merille, Lekuru and Archers Post) in the third week of April 2020 (the vertical line on the x-axis). This corresponds to the period in which the Kenyan government imposed COVID-19 movement restrictions. Prices

[5] There were guidelines for performing each task (for each animal type) whenever contributors were in the market such that payable submissions should be composed of varying animal body conditions that were proportional to the availability of each animal quality. Submissions were also made during the peak of market activity, which was typically controlled by time stamp to disallow submissions made too early or too late on the market day. This was complemented by having several contributors submitting tasks from the same market.

increased in Merille for two weeks consecutively after the restriction, dropped in the third week, and stabilised[6] thereafter. In the Lekuru and Archers Post markets, a decrease in prices was observed for two weeks after the restrictions, but they later stabilised. The restrictions affected formal market access and trade shifted temporarily to informal settings (Graham *et al*. 2021).

Prices in the Korr and Merille markets remained low over the entire period of the study. This could be attributed to their being located closer to the production catchments. Prices in other markets were at the same levels for most of the period. It was only in the Moyale market that trading began at the highest prices in the later weeks.



Source: KAZNET crowdsourcing data; 1 USD = 101 KES as at the start of the survey

Figure 1: Market price trends in the six sampled markets

Table 1 shows the pooled price summary statistics for the six sampled markets. The mean prices decrease as markets get closer to production catchments. This shows a clear trade flow of goats from low-price markets to higher-price markets. Consistent with the trends depicted in Figure 1, the average prices at Korr are the lowest (US$30.226). The Korr market is one of the important feeder markets in the region. The low prices reflect the infrastructural difficulties that raise transaction costs and limit access to regional markets (Roba *et al*. 2017). Prices are higher in Isiolo market than in the Archers Post, Merille and Korr markets. The latter three markets supply the Isiolo market. Moreover, the mean prices in Isiolo are also higher than those in Lekuru, and the flow of goats between the two markets is limited. Lekuru, however, has the highest coefficient of variation (CV), suggesting it has more price volatility than the rest. The mean price at Moyale market is the highest (US$60.5). Although it is located the furthest away, the high prices indicate the possibility of trade flow from the other sampled markets.

[6] Stabilisation in this context means that the price trends exhibited were like those before the COVID-19 movement restrictions.

Table 1: Summary of the price levels for goats traded in the sampled markets

Market	Observations	Mean	Standard deviation	Skewness	CV
Moyale	43	60.500	9.034	0.319	14.932
Isiolo	43	55.588	4.060	-0.446	7.304
Archers Post	41	53.307	7.068	-0.335	13.260
Merille	43	40.250	4.974	0.984	12.991
Lekuru	42	47.030	8.240	0.900	17.521
Korr	42	30.226	3.706	0.086	12.261

Notes: CV is the coefficient of variation. Data from some of the markets was only available for 41 or 42 weeks

4.2 Stationarity tests and estimation of optimal lags

Table 2 shows the stationarity tests using both the ADF and PP tests. As mentioned earlier, ADF could have a low statistical power to reject the null hypothesis of stationarity, and thus both tests were conducted for validation. Each of the tests confirmed the stationarity of price levels for most markets, except for the Korr market. However, the null hypothesis of the absence of stationarity was rejected after the first difference. The price series were therefore included in the cointegration equation in their first difference, i.e. all are I (1).

Table 2: Unit root tests using augmented Dicker Fuller and Phillips-Perron

Market	Augmented Dicker Fuller (ADF)		Phillips Perron (PP)	
	Levels	1st difference	Levels	1st difference
Isiolo	-5.677**	-11.993***	-5.544***	-12.282***
Archers Post	-6.352**	-13.517***	-6.367***	-13.742***
Merille	-7.131**	-7.007***	-7.503***	14.107***
Korr	-2.521	-10.115***	-2.537	-7.051***
Moyale	-3.119**	-10.111***	-2.985**	-15.069***
Lekuru	-4.009***	-9.308***	-4.247***	-12.515***

Note: *** and ** denote significance at the 5% and 10% levels respectively

Table 3 shows the results for the test for fit versus parsimony (simplicity) of the models to show the optimal lag length. The AIC test results show that including one lag in the cointegration equations would be optimal. These results are consistent with most of the tests – both Akaike's final prediction error (FPE) and the Hannan-Quinn information criterion (HQIC).

Table 3: Description of the optimal lags included in the cointegrations equation

Lag	LL	LR	df	p	FPE	AIC	HQIC	SBIC
0	-454.893	-	-	-	696 340	24.805	24.866	24.979*
1	-430.907	47.973	16	0	455 198*	24.373*	24.680*	25.244
2	-416.885	28.044	16	0.031	523 634	24.480	25.032	26.047
3	-405.749	22.272	16	0.135	741 731	24.743	25.541	27.007
4	-388.318	34.862*	16	0.004	815 589	24.665	25.800	27.626

Notes: * denotes significance at the 10% level. FPE = Akaike's final prediction error, AIC = Akaike information criterion, HQIC = Hannan-Quinn information criterion, SBIC = Schwarz's Bayesian information criterion.

4.3 Cointegration

Table 4 shows the results of the Johansen tests for cointegration. The results show that the maximum Eigen statistics are larger than the 5% critical values in four maximum ranks. This means there are a maximum of five cointegrated market price-series equations. In other words, the price series of the sampled markets exhibit both long-run and short-run relationships. In this case, the VEC model, which accounts for both the long-run and the short-run market price-series relationships, was deemed appropriate (Wooldridge 2009).

Table 4: Results of Johansen test for cointegration

Maximum rank	Eigenvalue	Maximum eigen statistic	5% critical value
0	-	50.601	39.370
1	0.718	48.799	33.460
2	0.705	27.931	27.070
3	0.503	17.117	20.970
4	0.348	13.150	14.070
5	0.280	7.346	3.760
6	0.168	-	-

Note: The null hypothesis is H_0; there is no cointegration in any of the price series. The decision criterion is the comparison between the magnitude of the maximum eigen statistic and the 5% critical value in each row, i.e. we reject the null hypothesis if the maximum eigen statistic is larger in magnitude than the 5% critical value. For instance, the rank '0' means that there is no cointegration equation in any pair of the series, i.e. if the maximum eigen statistic is lower than the 5% critical value.

4.4 Vector error-correction model

Table 5 shows the VECM short-run equilibrium estimates for three of the six sampled markets (Isiolo, Archers Post and Merille).[7] In the price equation for the Isiolo market, there is no significant market price variable. This means that shocks in other markets are small, but does not necessarily imply that the markets are not integrated (Von Cramon-Taubadel 2017). The absence of markets that significantly cause short-run price changes in the Isiolo market implies that the price dynamics in this market could be caused by shocks in other regional and terminal markets outside the region.

The coefficient of speed of the price adjustment in the Isiolo market is negative and significant. This indicates a significant (57.2%) correction of the weekly market shocks and convergence on long-run equilibrium. In the Archers Post market price equation, its prices are the only cause of significant variation in the short run. Based on the sign of the error-correction parameter, there are indications of long-run convergence, but no significant adjustments. This suggests the presence of high inefficiency within the market, despite being connected with good roads and telecommunication networks.

The Merille market price equation shows that prices in the Isiolo market have negative and significant short-run causal effects. However, Archers Post, which is closer to Merille than to Isiolo, experienced a positive and significant short-run effect. The error-correction parameter coefficient was positive, greater than 1, and significant at 1%. This indicates an over-correction of the previous week's market shocks, and thus the price series converges on long-run equilibrium in an oscillatory manner.

[7] The regression table was originally one long table, but it was separated into two to allow for simpler presentation and visualisation.

Table 5: VECM short-run estimates for Isiolo, Archers Post and Merille livestock market prices

Dependent variables	Independent variables	Coeff.	SE
Isiolo market prices	Speed of price adjustment (L._ce1)	-0.572***	0.169
	Isiolo market prices	-0.246	0.150
	Archers Post market prices	0.058	0.070
	Merille market prices	-0.059	0.102
	Korr market prices	0.235	0.145
	Moyale market prices	0.088	0.101
	Lekuru market prices	0.106	0.085
	Constant	-0.001	0.013
Archers Post market prices	Speed of price adjustment (L._ce1)	-0.412	0.360
	Isiolo market prices	-0.474	0.320
	Archers Post market prices	-0.51***	0.150
	Merille market prices	-0.156	0.218
	Korr market prices	0.251	0.309
	Moyale market prices	-0.06	0.215
	Lekuru market prices	0.151	0.181
	Constant	-0.003	0.027
Merille market prices	Speed of price adjustment (L._ce1)	1.067***	0.267
	Isiolo market prices	-0.563**	0.238
	Archers Post market prices	0.268**	0.112
	Merille market prices	0.153	0.162
	Korr market prices	-0.079	0.230
	Moyale market prices	0.131	0.159
	Lekuru market prices	-0.032	0.135
	Constant	-0.003	0.02
Number of observations	39		

Note: *** and ** denote significance at the 1% and 5% levels respectively. All prices were transformed into natural logs. SE stands for standard error, while Coeff. stands for coefficient. Isiolo market is the main regional terminal market, located in the largest town in the region. The Archers Post and Merille markets are located closer to the production catchments and are situated along the Isiolo-Moyale tarmac road.

Table 5 above is continued in Table 6, which shows the short-run market price relationships for the Korr, Moyale and Lekuru markets. The error-correction parameter is significant for the Korr and Moyale markets. In both cases, it indicates convergence on long-run equilibrium at a speed of 62.9% and 51.6% respectively.

In the Korr price equation, Isiolo and Lekuru market prices have positive and significant coefficients. This indicates the presence of short-run causal relationships between the prices in these markets. A 10% change in the Isiolo market prices causes a 3.09% change in the Korr market prices. Similarly, a 10% change in the Lekuru market prices causes a 3.1% change in the Korr market prices. Both Lekuru and Isiolo are large regional markets, and this relationship implies that the Korr market receives its price signal from these markets.

Table 6: VECM short-run estimates for Korr, Moyale and Lekuru livestock market prices

Dependent variables	Independent variables	Coeff.	SE
Korr market prices	Speed of price adjustment (L._ce1)	-0.629***	0.174
	Isiolo market prices	0.309**	0.155
	Archers Post market prices	-0.051	0.073
	Merille market prices	-0.068	0.106
	Korr market prices	-0.026	0.15
	Moyale market prices	0.127	0.104
	Lekuru market prices	0.31***	0.088
	Constant	-0.007	0.013
Moyale market prices	Speed of price adjustment (L._ce1)	-0.516***	0.195
	Isiolo market prices	-0.075	0.173
	Archers Post market prices	0.159*	0.081
	Merille market prices	-0.276**	0.118
	Korr market prices	0.088	0.167
	Moyale market prices	-0.571***	0.116
	Lekuru market prices	0.065	0.098
	Constant	0.011	0.014
Lekuru market prices	Speed of price adjustment (L._ce1)	0.228	0.357
	Isiolo market prices	-0.218	0.318
	Archers Post market prices	0.003	0.149
	Merille market prices	0.019	0.217
	Korr market prices	-0.288	0.307
	Moyale market prices	0.052	0.213
	Lekuru market prices	-0.696***	0.18
	Constant	0.014	0.027
Number of observations	39		

Notes: ***, ** and * indicate significance at the 1%, 5% and 10% levels respectively. All prices were transformed into natural logs. SE stands for standard error, while Coeff. stands for coefficient.

The Moyale market price equation shows a negative and significant short-run causal relationship with its own lagged prices as well as with the Merille market prices. However, the Archers Post market prices have a positive and significant effect. The Merille and Archers Post markets are closer to Moyale than the other sampled markets. Hence, the absence of significant causal relationships between the Moyale market and the other distant markets shows that distance between markets is still a deterrent to the strength of the price signal transmissions in the region. In the price equation for the Lekuru market, only its lagged price matters. As such, both the weak price effects of the other sampled markets and the long-run price equilibrium convergence suggest that trading routes influence the degree of market integration.

Table 7 shows the VECM long-run price equations,[8] from which the error-correction term was generated. Isiolo market was used as the outcome variable. The results show evidence of a long-run impact of Merille, Korr and Lekuru market prices on the Isiolo market prices. The Merille market prices had a positive impact on the Isiolo market. Prices in the Lekuru and Korr markets had a negative long-run impact on Isiolo market prices. In the long run, an increase in the Lekuru market price caused a decrease in Isiolo market prices, despite operating on different trading routes. The Archers Post market, which is closer to the Isiolo market, does not show any long-run price relationship. This suggests that, despite their proximity, both markets are independent, with inherent frictions. Also, the weak long-run relationship between Isiolo and Moyale could be attributed to the long distance between the markets. Furthermore, the Moyale market prices could be influencing other market prices across the Kenya-Ethiopia border.

[8] It is often called the Johansen normalisation restriction. The restriction is imposed on the Isiolo market price, which is the outcome variable in this long-run equation.

Table 7: VECM long-run estimates

Outcome	Markets prices (beta)	Coef.	SE
Error correction parameter (_cel)	Isiolo market prices	1	-
	Archers Post market prices	0.136	0.111
	Merille market prices	-0.703***	0.115
	Korr market prices	0.184**	0.088
	Moyale market prices	0.073	0.073
	Lekuru market prices	0.357***	0.088
	Constant	-4.256	-

Notes: *** and ** indicate significance at the 1% and 5% levels respectively. The direction of the effect of the coefficients in this regression is interpreted in an opposite manner, i.e. a negative coefficient is interpreted as a positive effect, and vice versa.

5. Conclusions and recommendations

The objective of this study was to establish the state of regional market integration in pastoral livestock markets in the light of recently improved infrastructure. Weekly market price data for goats collected through a mobile phone-based crowdsourcing initiative conducted for 43 weeks were analysed. The use of high-frequency data generated through an innovative crowdsourcing process represents a huge milestone in collecting market price data from rural agricultural settings. It demonstrates that the use of digital platforms is a viable option to counter the common challenges of missing data from markets in rural settings. Most markets exhibited correction of weekly price shocks and convergence into a long-run equilibrium implying low information asymmetry and market frictions. Both short-run and long-run relationships were established.

The short-run causal relationships between markets operating along the same trading route were dominant. Markets along the Moyale-Isiolo trading route showed indications of efficient price transmission. This was despite other markets, like Korr, being located far away (80 km) from the tarmac road. This implies that the improved infrastructural connectivity played a significant role in reducing market segmentation and consequently increased price transmission between the markets. It is notable that the prices at Isiolo market, which is the largest urban market in the region, had no significant short-run relationships with the other sampled markets, although they caused significant short-run effects on the prices of other markets (Merille and Korr), which are important surplus markets in the region (Roba *et al*. 2017). It was also evident that the Moyale border market had significant short-run relationships with closer inland markets (Merille and Archers Post). Smaller markets (e.g. Korr), which are located away from tarmac roads, hardly transmit significant price signals. They mostly receive shocks from other, larger markets in the region. Generally, the presence of short-run causal relationships between markets in the region provides evidence of increasing efficiency in information flow between markets located on the Moyale–Isiolo tarmac road.

There are long-run causal relationship between regional terminal markets and other intermediate and feeder markets in pastoral settings. This is evident for markets that experience a regular flow of trade (e.g. Merille and Korr), and for those that do not trade (e.g. Lekuru market). This further provides evidence of an efficient flow of price information such that traders can exploit possible arbitrage opportunities whenever they occur. It is also important to note that the pastoral border market prices have weak long-run causal relationships with inland regional markets. Furthermore, spatially close and well-connected inland markets (e.g. Isiolo and Archers Post) that exhibit weak long-run and short-run relationships warrant further investigation.

The research findings show that a high proportion of price variation in the intermediate markets in the region is due to its shocks, while variation in smaller markets originates from the larger markets. As such, intermediate markets are senders of price information, while the feeder markets are recipients of price information. This indicates unidirectional price transmission, i.e. from deficit markets to surplus markets. Although there is an indication of long-run relationships, the characteristics of the short-run relationships indicate deferred and slow rural agricultural market transformation.

Notwithstanding the current improvements in the efficiency of pastoral livestock markets, more investments, beyond in communication technologies, are needed to reduce market friction in feeder markets operating close to production catchment areas. For markets currently without good connectivity, further investments in physical infrastructure, like roads and modern markets, would be useful. However, in all the feeder markets, which are currently price takers, approaches that empower producers through cooperatives and increasing market information densities could strengthen their negotiating power and the resultant price transmission. Given the limitation of using only price data for our analysis, leveraging the applicability of crowdsourcing in such contexts, future studies should make use of study designs that capture transaction costs and actual livestock trade flows to provide more insights into the state of market integration in the region.

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