SUDAN

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Evaluating Cereal Market (Dis)Integration in Sudan

Kibrom A. Abay[1], Lina Abdelfattah, Clemens Breisinger, and Khalid Siddig

[1] Corresponding author: K.Abay@cgiar.org

CONTENTS

TABLES

FIGURES

ABSTRACT

This paper evaluates spatial market and price transmission in cereal markets in Sudan, focusing on wheat and sorghum, two major cereal crops. We use comprehensive and long-ranging monthly cereal price data and a multivariate vector of error-correction cointegration models (VECM) to characterize both short-term and long-term price transmissions across local cereal markets. We find that among the 15 local wheat markets and 18 sorghum markets we can only detect significant spatial market integration among 7 wheat and 10 sorghum markets. Despite some strong spatial market integration among a few neighboring markets, there is no market integration between several regions. For example, cereal markets in Darfur are not integrated with cereal markets in the rest of the country. Among integrated markets, we observe significant variations in the strength of price transmission elasticities as well as speed of adjustment to long-term equilibrium, which implies that shocks (and price policies) in some markets can affect only some other markets. Most of the strong price transmission and spatial market dependence follow existing trade flows and road networks, insinuating that infrastructural barriers may be obstructing spatial market integration. We also find that markets in production surplus states are less responsive to price changes in neighboring markets than those located in cereal deficit states. Finally, we also observe relatively stronger spatial integration and short-term adjustment in sorghum markets than wheat markets. Shocks to sorghum prices in sorghum producing markets have permanent impact while shocks to wheat prices in wheat producing markets endure transitory effects. These findings have important policy implications for improving the efficiency of cereal markets in Sudan and other similar settings.

Keywords: spatial market integration, cereal markets, price transmission, market efficiency.

1. INTRODUCTION

The functioning of markets plays a key role for affordable food prices and food security. However, in Sudan, agricultural markets are often adversely impacted by fragile political and economic circumstances, a weak business environment, and a lack of market infrastructure, institutions, and information (FEWS NET, 2015; IFAD, 2017; Dorosh, 2021; Resnick, 2021). [2] Large distances between markets and a lack of road networks are commonly cited as major sources of price dispersion and market disintegration in developing countries (e.g., Aker and Mbiti, 2010; Aker, 2010; Aker and Fafchamps, 2014; Minten and Kyle, 1999; Dillon and Barrett, 2015). Given the importance of food prices for stability and food security in general, and bread and wheat flour prices in Sudan specifically (Maystadt, Trinh Tan and Breisinger, 2014; Resnick, 2021), this paper evaluates spatial market (dis)integration and price transmission in cereal markets in Sudan. Sudan's economy and markets provide an interesting case for evaluating market integration and price transmission in less developed and fragile economies. Until 2019, the Sudanese economy was marred by sanctions and conflicts resulting in slow growth and persistently high food insecurity (FEWS NET, 2020). In December 2020, the sanctions on Sudan were lifted and a power-sharing deal was struck between a civilian government and the military. Several reform steps were taken, including reduction of fuel subsidies, the move towards a market-oriented exchange rate, and the introduction of a cash transfer program (IBRD, 2020). However, after the recent change in government, the political context remains fragile and the economic situation is characterized by a weak currency, high inflation, and growing food insecurity (IBRD, 2020; FAO, 2020).

There are several other longstanding challenges that may affect prices and local market integration in Sudan. Underinvestment in agriculture and basic infrastructure over the last few decades means roads and related facilities that are important for efficient cereal trade remain underdeveloped in many parts of Sudan. The significant spatial variation in production (and production potential) and the seasonality of farming systems results in states that are surplus producers of specific crops while deficient in others. Sudan is also highly import dependent for wheat further highlighting the importance of functioning markets and value chains for food security in Sudan.

To capture these spatial variations in production and consumption across crops, we focus on wheat and sorghum, two of the main cereal staple crops in Sudan. Sudan is one of the largest sorghum producing countries in the world with an average annual production of 4.8 million tones and a cultivated area of 10.25 million hectares between 2012/2013 and 2019/2020 (CBS, 2021). During this same period, wheat production averaged about 0.5 million tones and a cultivated area of 0.21 million hectares (CBS, 2021). About 80 percent of domestic wheat demand is satisfied through import. Trade, both international and domestic, has an important role in balancing the demand and supply of wheat and sorghum in Sudan. Thus, external shocks and global changes in demand and supply of wheat and sorghum will likely trigger significant impact on cereal markets in Sudan, albeit with varying impacts across crops and domestic markets depending on price transmission rates. Better functioning and integrated markets are therefore

[2] Agricultural markets in Sudan are also characterized by limited marketing opportunities, high transaction costs, and inequities in profit margins across value chain actors, which collectively limit smallholders' bargaining power (IFAD, 2017).

crucial not only for domestically traded goods and services but also for globally traded commodities.

Using long-ranging monthly cereal price data we conduct comprehensive market integration and price transmission analyses, focusing on local wheat and sorghum markets. We consider a comprehensive list of cereal markets that represent different locations and market characteristics throughout the country. Some of these markets are located in surplus producing states while others are located in self-sufficient and deficit markets. Some of these markets are located in conflict affected and remote areas while the remaining markets are located in areas with improved infrastructure and trade linkages. We employ Johansen's (1988) multivariate cointegration framework to estimate short-run and long-run price transmission elasticities. We particularly estimate multivariate vector of error-correction cointegration models (VECM) to characterize price transmission across local markets. This builds on previous research that assess market integration within and across countries (e.g., Badiane and Shively, 1998; Abdulai, 2000; González-Rivera and Helfand, 2001; Cudjoe, Breisinger and Diao, 2010; Goodwin, Holt and Prestemon, 2011; Dillon and Barrett, 2015; Svanidze and Götz, 2019a; Svanidze and Götz, 2019b; Heigermoser, Götz and Svanidze, 2021). We identify how and whether prices respond to changes and shocks in major consumption/production hotspot areas. We also characterize price transmission processes across nearby (within state) and distant markets (across states). We finally identify some leading and follower markets by testing weak exogeneity of price series.

Our analyses show several important findings and stylized patterns in wheat and sorghum markets in Sudan. First, among the 15 local wheat and 18 sorghum markets we can only detect significant spatial market integration among the 7 wheat and 10 sorghum markets. For example, wheat and sorghum markets in Darfur are not integrated with several markets in the rest of the country. Secondly, among integrated markets, we observe significant variations in the strength of price transmission elasticities as well as speed of adjustment to long-term equilibrium. Third, markets in production surplus states are less responsive to price changes in neighboring markets than those located in production deficient states. Finally, we also find some interesting crop-specific patterns and differences in market integration and price transmissions.

These findings have important policy implications for improving the efficiency of cereal markets in Sudan. The lack of market integration between different regions and markets suggests significant market inefficiency which may be improved through investments in market infrastructure and policies. The significant variation in the strength of price transmission elasticities as well as speed of adjustment to long-term equilibrium across markets justify targeted and region-specific market interventions and investments to improve the functioning of specific markets. Finally, the strong spatial integration among some markets, even in contexts where road and related infrastructure are not well-developed, necessitates understanding and supporting local institutions or mechanisms facilitating integration of markets (De Matteis, Turkmen Ceylan and Kebede, 2021; Hastings, Phillips, Ubilava and Vasnev, 2021).

This research contributes to the scant literature on the spatial integration of cereal markets in less developed and conflict-affected regions of the world. We are not aware of rigorous analyses on price transmission and market integration in conflict affected economies such as Sudan. An exception to this is a recent study by Hastings, Phillips, Ubilava and Vasnev (2021) who show that conflict intensity remains an important factor that inhibits spatial market integration across Somalia's markets.

The remaining sections of the paper are organized as follows: The next section provides contextual background on agricultural production and grain markets in Sudan. Section 3 describes the data and descriptive statistics while Section 4 presents our econometric approach. In Section 5 we present and discuss the empirical results and Section 6 offers concluding remarks.

2. AGRICULTURAL PRODUCTION AND GRAIN MARKETS IN SUDAN

Agriculture remains the backbone of the Sudanese economy employing 38-45 percent of the labor force and accounting for 22-34 percent of GDP between 2011 and 2019 (World Bank, 2021). Sudan produces a diverse range of crops, including cereals, which are practiced under three types of farming systems: (1) irrigated agriculture; (2) semi-mechanized rainfed agriculture; and (3) traditional rainfed agriculture. According to the Food and Agriculture Organization (FAO, 2020), 1.6 million hectares of Sudan's land is under irrigated agriculture. Large-scale mechanized federal schemes, including the Gezira Scheme, account for about 75 percent of this irrigated land area. Semi-mechanized rainfed agriculture, where mechanization is limited to land preparation and seeding, is practiced on a broad belt of 6.7 million hectares that receives around 500 mm of rainfall and runs through Kassala, Gedarif, Blue Nile, White Nile, Sennar, and South Kordofan States (FAO, 2020).[3] Traditional rainfed agriculture takes place on around 9 million hectares predominately located in the west of the country (Darfur and much of Kordofan States) where sorghum is one of the main cereal crops produced. Most operations are carried out manually and employ the largest share of farmers (FAO, 2020).

Wheat, sorghum, and millet are the three main staple foods in Sudan. Differences in rainfall patterns result in variable overall staple food availability and prices, driving the country to a structural deficit during an average year. The food availability and net trade flows also vary considerably by commodity and location. According to FEWS NET (2015), in aggregate terms, the country produces surplus sorghum (mainly concentrated in the eastern Gedarif and Sennar States), is self-sufficient in millet, and is structurally deficit in wheat, which is considered a nationally strategic commodity. To cover the deficit in wheat, Sudan imports around 75-80 percent of its supply, exposing it to external shocks related to currency and international fuel prices as well as other prices of agricultural inputs.[4]

Khartoum, the capital, is the country's largest consumption center with limited production potential, where around a quarter of the population lives. Persistent civil unrest in areas such as Darfur, South Kordofan, and Blue Nile States, as well as years of droughts, drove the rapid rate of urbanization, which in turn is associated with a shift in consumption preferences.

[3] Sorghum accounts for 80 percent of the cultivated land, producing around 45percent of Sudan's requirements on average.

[4] Besides imports, Sudan satisfies its wheat demand through in-kind aid. For example, the country had borrowed 540,000 tons of wheat from Saudi Arabia and the United Arab Emirates in April 2019 (FAO, 2020).

Table 1 provides state-level information on the distribution of cereal production and demand as well as corresponding surplus/deficit, averaged over five years (2008/9 - 2012/13).[5] Khartoum is the state with the highest deficit while Gedarif is the state with highest surplus. Other states and markets with cereal deficit include the North and South Darfur States. Darfur, originally a state that was self-sufficient in staple food production, is now heavily reliant on imports and relief commodities after prolonged periods of civil unrest that have severely disrupted production patterns. It also sources staple food from central and western Sudan. The Obeid market in North Kordofan State is the country's main cereal market, a vital supplier to central Sudan, and acts as a transit point connecting eastern and western Sudan. In the following sub-sections, we discuss the direction and intensity of trade flows within Sudan, with a focus on wheat and sorghum. This will subsequently inform the cointegration analysis in section 4.

Table 1: Average Cereal Production and Deficit in Sudan (000s MT), by state (2008/9-2012/13)

State	Total cereal production (000s MT)	Total cereal requirement[a]	Net surplus/deficit (000s MT)
Gedarif	667	253.90	413.106
Sennar	374	230.68	143.32
South Kordofan	360	264.55	95.45
Gezira	696	625.61	70.39
White Nile	349	304.70	44.30
Blue Nile	152	141.04	10.96
Northern	129	118.84	10.16
West Kordofan	N/A	N/A	N/A
West Darfur	152	223.38	-71.38
River Nile	101	191.11	-90.11
Kassala	132	311.56	-179.56
Red Sea	8	199.58	-191.58
North Kordofan	221	448.80	-227.80
North Darfur	97	325.73	-228.73
South Darfur	442	686.35	-244.35
Khartoum	20	954.11	-934.11
National	**4,153**	**5,278.00**	**-1,126.94**

Source: Adapted from FEWS NET (2015) using data from the Food Security Technical Secretariat of the Ministry of Agriculture and Natural Resources (FAO, 2015).
Notes: [a] Estimates assume an annual grain requirement of 0.146 MT/per capita (FSTS, 2014), roughly equivalent to 1,400 kcal from grains per day. Cereals include sorghum, wheat, and millet.

[5] This time period is relevant to our sample and analysis because our timeseries data starts from 2012.

2.1 Wheat Markets and Trade in Sudan

Wheat is the second most important food commodity in Sudan, mainly used as a staple food. Demand for wheat, which has grown rapidly in the last 15-20 years, is met through local production (about 20 percent) and through commercial imports (about 80 percent, which are dominated by the country's few large wheat milling industries).[6] The rapid growth in wheat consumption is driven by changing consumer preferences for bread. Even rural households have started to shift their eating habits towards wheat-based food and now frequently sell their stock of sorghum and millet to buy wheat.

Khartoum is the largest wheat (local and imported) consumption center, absorbing supply mainly from Madani and Dongola (the two major sources of domestic wheat for Khartoum, see Figure 1). Port Sudan is the country's main entry point for imported wheat and is where most milling companies have storage facilities. Wheat is then transported to Khartoum where 80 percent of it is used by large processing firms, while the remaining 20 percent is transported to the other milling firms elsewhere in the country. Typically, locally produced wheat is traded amongst adjacent markets, unlike imported wheat or sorghum. Key markets trading locally produced wheat are Dongola, Damer, Madani, and Kosti. Some areas in Darfur also produce small quantities of wheat for local consumption. The production and trade flow map developed by the Famine Early Warning Systems Network (Figure 1) shows Madani in Gezira State as the top wheat-producing market, followed by Dongola market in the Northern State, and Damer in River Nile State. Because of the existence of primary roads, collection and wholesale trade between these markets are strongly reinforced. On the other hand, markets in Darfur have separate wheat trade channels, producing a negligible quantity of rainfed wheat which is used for local consumption.[7]

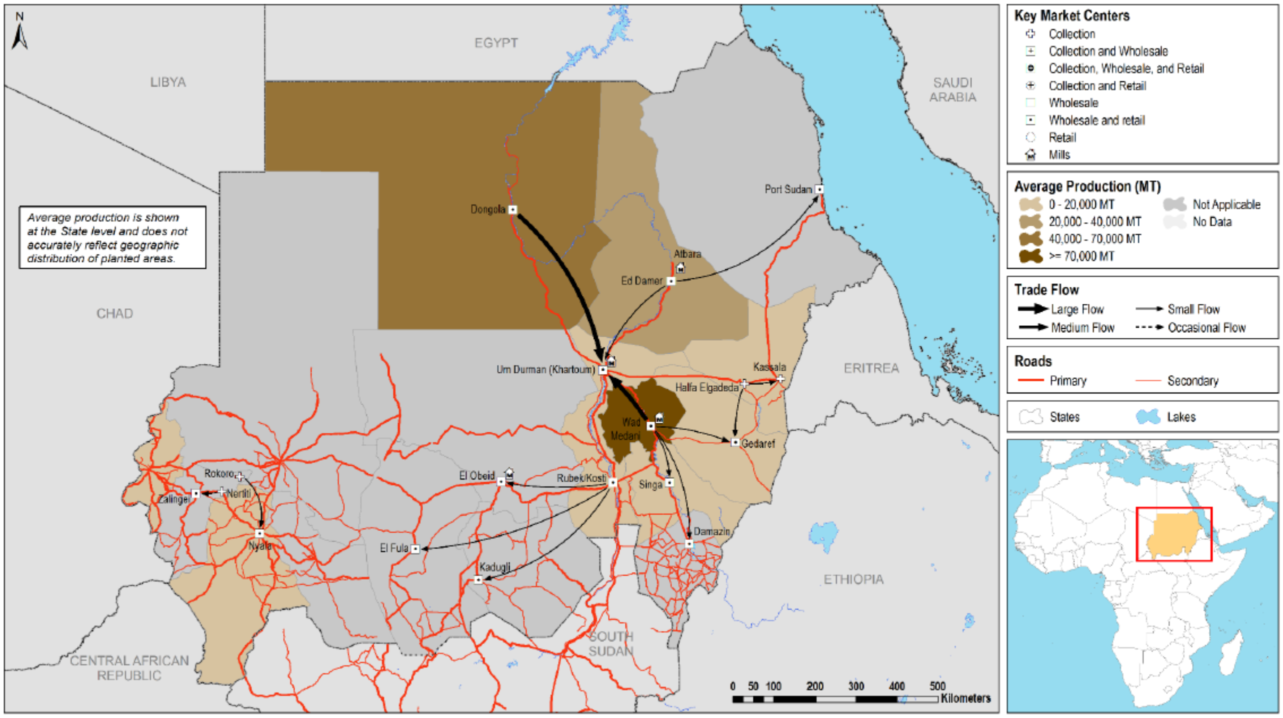
Wheat production in Sudan happens in cooler winter months (planted November-December and then harvested in March), and typically requires irrigation to produce good grain quality. Harvesting is done mechanically on larger farms while smallholder farmers mostly rely on manual labor. Despite being consistently subsidized by the government, local production remains very limited.[8] The average national yield is also low, around two tons per hectare only (MoAF, 2021), and can frequently be much lower (ICARDA, 2015).

[6] A significant portion of imported wheat is reportedly leaked outside the official trading channels. There has also been rising concerns among local producers who are discouraged by inefficient targeting for subsidized fuel.

[7] Recent improvements in road networks are facilitating direct wheat flour trade flows from Khartoum to North Darfur State (FEWS NET, 2015).

[8] Rainfall and associated climate and weather conditions are important factors that affect production and productivity in Sudan. Other factors that affect agricultural production and productivity include civil unrest (mainly in Darfur and Kordofan States); lack of agricultural finance and credit; agricultural input; and pests and diseases (FAO, 2020).

Figure 1: Production and Trade Flow Map: Wheat



Source: FEWS NET (2015).

2.2 Sorghum Markets and Trade in Sudan

Sorghum is the most important staple food produced in Sudan and consumed by both people and livestock.[9] It is consumed more in central and eastern Sudan compared to western parts of the country. Around 45 percent of its production takes place in the semi-mechanized, rainfed systems, 25 percent in the irrigated sector, and 30 percent in traditional rainfed (FAO, 2020) and is mostly planted between June and July with harvest in November-December. Overall, it is Sudan's largest crop in terms of production area, with a total harvest of about 4 million tons in 2020, representing 68 percent of total production of all cereals (FAO, 2020).

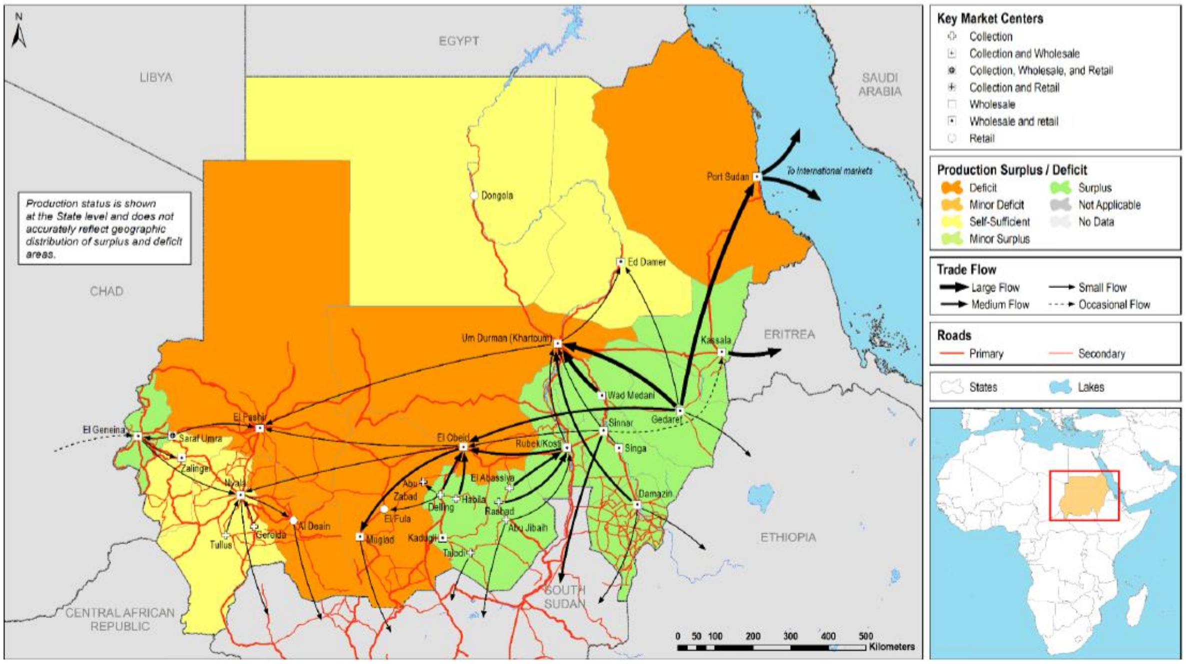
The key wholesale sorghum markets in Sudan are Gedarif, Khartoum, and Obeid (Figure 2). Gedarif, one of the largest grain markets in Sudan, is a surplus-producing state where the largest quantity of sorghum is traded.[10] Khartoum is the country's vital transit point for sorghum, and for all other commodities bought and sold in Sudan. Obeid plays a central role in sorghum trade between surplus-producing markets (in eastern Sudan) and deficit areas (in central and western Sudan). Other key trade markets include El Fasher, Madani, Rabak, Kosti, and Nyala (FEWS NET, 2015). Surplus-producing markets for sorghum also include Kassala and Sennar in the central and eastern parts of the country, respectively, as well as South Kordofan and

[9] Globally, Sudan is one of the top sorghum producers, ranked fifth after China, India, USA and Nigeria (Frah, 2016).

[10] Gedaref supplies sorghum to markets throughout Sudan, and exports to Gulf States as well as neighboring South Sudan and Ethiopia (FEWS NET, 2015)

West Darfur in the west. These markets are major sources and routes of sorghum export to neighboring countries such as Eritrea, Ethiopia, and South Sudan.

Figure 2: Production and Trade Flow Map: Sorghum



Source: FEWS NET (2015).

As shown in Figure 2, Port Sudan, Khartoum, and Obeid are the main consumption centers for sorghum. Port Sudan (located in Red Sea State) receives sorghum from Gadarif. Khartoum absorbs supply mainly from Gadarif, Madani, and Damazin, and to a lesser extent from Sennar and Kosti (which sources sorghum from other markets in South Kordofan). Obeid receives sorghum mainly from Gadarif, Kosti, and two other markets in South Kordofan. Khartoum and Obeid then provide sorghum for El Fasher market in Darfur. Obeid also serves as a trade hub and facilitates trade to Muglad market in West Kordofan, some of which are then exported to South Sudan. Unlike wheat, there are occasional sorghum trade links between Darfur and other states in Sudan.

3. DATA AND DESCRIPTIVE STATISTICS

We use long-ranging monthly cereal price data collected by FEWS NET for Sudan to conduct a comprehensive multivariate market integration and price transmission analysis, focusing on local wheat and sorghum markets spread throughout the country. The FEWS NET data cover 15 wheat and 18 sorghum markets that are major cereal markets in Sudan. These markets significantly vary in terms of size and trading volume as shown in Figure 1 and 2. Table 2 provides a list of these markets. The monthly wholesale wheat price data cover from January 2012 to August 2021 while the wholesale sorghum price data cover from January 2015 to August 2021.

Table 2: Markets and States Covered by Crop

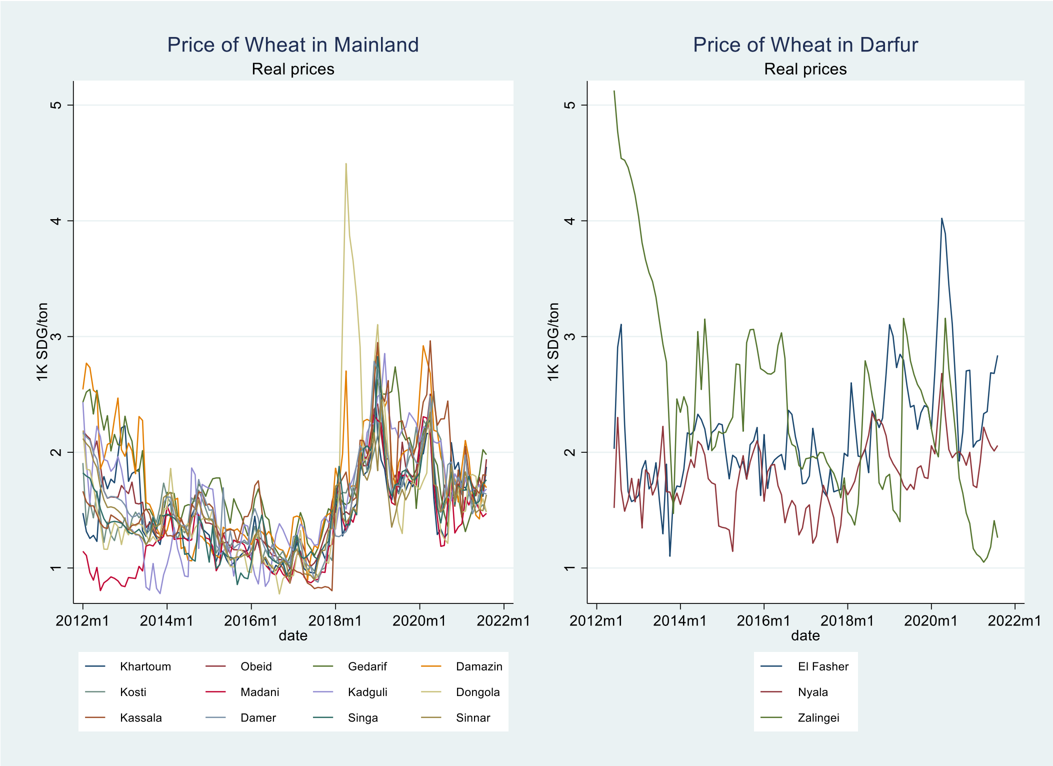
Market	State/region	Crop data available for
Khartoum	Khartoum	Wheat and Sorghum
Obeid	North Kordofan	Wheat and Sorghum
El Fasher	Darfur	Wheat and Sorghum
Gedarif	Gedarif	Wheat and Sorghum
Damazin	Blue Nile	Wheat and Sorghum
Kosti	White Nile	Wheat and Sorghum
Madani	Gezira	Wheat and Sorghum
Kadugli	South Kordofan	Wheat and Sorghum
Dongola	Northern Sudan	Wheat and Sorghum
Nyala	Darfur	Wheat and Sorghum
Kassala	Kassala	Wheat and Sorghum
Damer	River Nile	Wheat and Sorghum
Singa	Sennar	Wheat and Sorghum
Sennar	Sennar	Wheat and Sorghum
Zalingei	Darfur	Wheat and Sorghum
Port Sudan	Red Sea	Sorghum only
Genina	Darfur	Sorghum only
Dain	Darfur	Sorghum only

Source: FEWS NET.

3.1 Wheat Prices

To observe the evolution of real prices, we deflated nominal prices by Sudan's consumer price index for each corresponding period. Figure 3 shows the evolution of real wheat prices. To uncover potential differential trends, we separately plot the evolution of prices for Darfur and the rest of the country. Wheat prices were largely stable in all markets up until early 2018 when a sudden sharp spike was witnessed across Sudan. Since then, consecutive government reforms (e.g., cutting bread subsidies) and macroeconomic imbalances (shortage of foreign exchange reserves) have driven inflation as high as 413 percent in August 2021. In Appendix Table 1A we provide average real wheat prices across markets and different periods. Across all markets (except in Darfur), on average, real wheat prices jumped from 1.3 thousand SDG per ton in the period before 2018 to 1.9 thousand SDG per ton in 2018. Overall, the trends in Figure 3 and Table 1A show considerable price variation across markets and across time. Wheat prices in Darfur are higher and suffer from greater dispersion compared to markets outside Darfur (see Appendix Table 1A and Figure 3). This unique dispersion and evolution of prices in markets located in Darfur may generate specific stochastic trends that may not integrate with the main market system in other parts of Sudan.

Figure 3: Trends in wholesale wheat price data



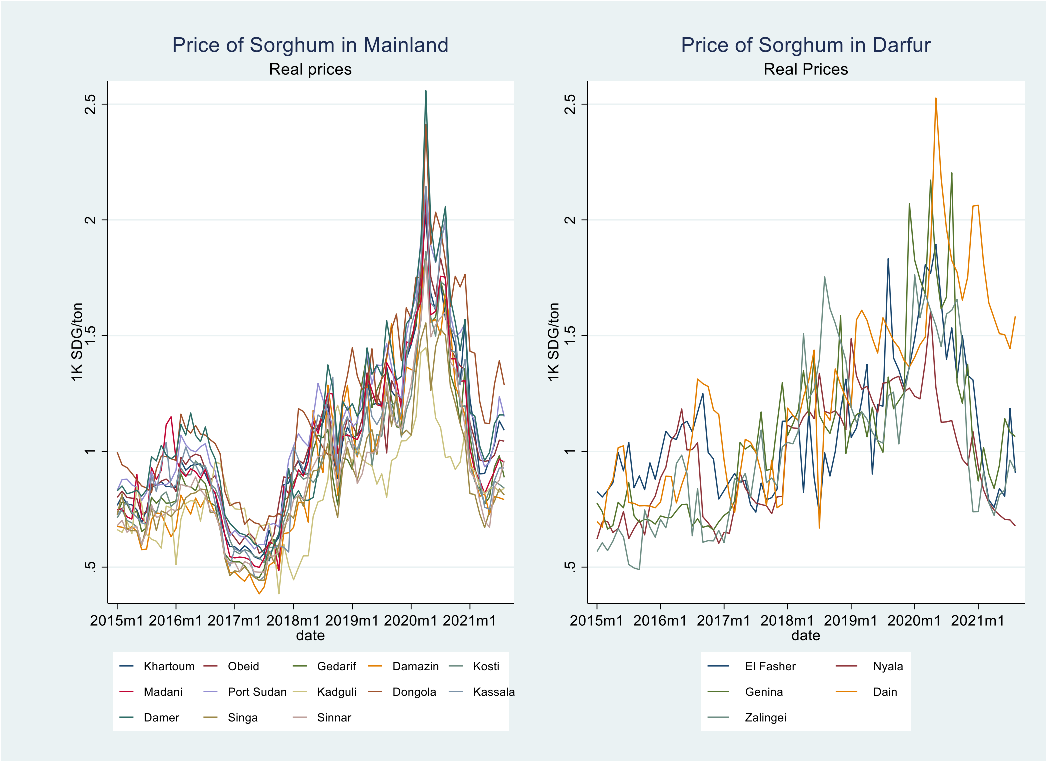
Source: Authors' computation based on FEWS NET data.

3.2 Sorghum Prices

Figure 4 provides the evolution of sorghum prices while Appendix Table A2 provides average prices across markets and different periods. Like wheat prices, sorghum prices have been largely stable in all markets until 2018 when a sudden sharp jump occurred.[11] Even without such exceptional shocks, sorghum price trends vary considerably from year to year and across markets in Sudan. For example, prices in surplus-producing markets such as Gedarif are among the lowest, while prices in deficit states and markets such as Port Sudan are among the highest. Market prices in Darfur are slightly higher on average compared to markets in the mainland. However, unlike the case of wheat, sorghum prices in Darfur markets are slightly increasing on average, similar to markets outside of Darfur (Figure 5).

[11] The average price for a ton of sorghum across all markets under study (except those located in Darfur) jumped from almost 0.7 thousand SDG per ton during 2012-2017 to 1.0 in 2018 (see also Figure 5).

Figure 4: Trends in wholesale sorghum price data



Source: Authors' computation based on FEWS NET data.

3.3 Wheat and Sorghum Prices Compared

On average, wheat prices (per ton) are 61 percent higher than sorghum prices in markets outside of Darfur and are as much as 83 percent higher than sorghum prices in markets inside Darfur. They also follow slightly different trends, insinuating that Sudan's skyrocketing inflation may be affecting wheat and sorghum prices differently. For example, compared to the period before 2018, the trend post-2018 for wheat shows some decline in price while sorghum prices continue to increase. Generally, there is significantly higher dispersion between wheat and sorghum prices in the rest of Sudan compared to Darfur, while the corresponding dispersion for sorghum appears to be less significant.

Figure 5: Average Price of Wheat and Sorghum in Sudan

Source: Authors' computation based on FEWS NET data.

3.4 Stationarity Test Results

Before implementing our cointegration analyses, we first examine the properties of each price series and test the order of integration at the levels and differences. We employ the Augmented Dickey-Fuller test to investigate whether variables follow a unit-root process (i.e., non-stationary). Test results (in Appendix Table A3) indicate that real prices of all markets contain a unit-root process in levels when including an intercept and a trend. Prices become stationary after first differencing, suggesting price transmission analysis with a cointegration and multivariate framework.

4. ECONOMETRIC ESTIMATION APPROACH: VECTOR OF ERROR CORRECTION MODEL (VECM)

We employ a multivariate cointegration framework building on previous spatial market integration analyses. Spatial integration of markets holds when prices of homogenous and tradable commodities across multiple markets share similar long-run patterns (González-Rivera and Helfand, 2001). In spatially integrated markets, price differences (across locations) above the cost of transporting a tradable commodity is only likely to exist in the short-run until market actors react to these deviations. Cointegration models are well-suited for modeling these short-term adjustments and long-run price transmission mechanisms in a unified framework. Multivariate cointegration models allow prices in multiple locations to develop simultaneously and endogenously. A fully integrated market with *n* locations generates $n - 1$ cointegration price transmission equations.

We estimate the following multivariate vector error correction model (VECM) that characterizes temporal changes in prices as a function of lagged deviations from long-run equilibria as well as lagged temporal changes in prices.

$$\Delta P_t = \mu + \pi P_{t-1} + \sum_{i=1}^{k-1} \theta \Delta P_{t-i} + \delta t + \epsilon_t \quad (1)$$

$$\Delta P_t = \mu + \alpha\beta' P_{t-1} + \sum_{i=1}^{k-1} \theta \Delta P_{t-i} + \delta t + \epsilon_t \quad (2)$$

Where P_t stands for an *n*-dimensional vector of log-transformed prices associated with *n* different markets. ΔP_t represents price changes from month *t-1* to month *t*, and μ represents a vector of constant terms. If all markets and price share one common trend, the $n \times n$ matrix π has reduced rank of *n-1* and this matrix can be decomposed as $\pi = \alpha\beta'$, where α stands for n × *n-1* matrix short-run adjustment coefficients while β contains normalized matrix of n × *n-1* coefficients capturing the extent of co-integration and long-run relationship between market prices across different markets. In other words, the α parameters capture the speed of adjustment to equilibrium prices or the response of ΔP_t to deviations from equilibrium. θ captures additional responses to changes in lagged prices. The prices in our data exhibit some trending patterns and hence we include linear trend, t, and a corresponding coefficient, δ, to capture this pattern. ϵ_t stands for a vector of stochastic error terms.

If all markets included in equation (2) cointegrate and share a single common price trend, we can identify *n-1* cointegrating relationships. Estimating and identifying the vector of parameters associated with each cointegration relationship requires further restrictions and normalizations. However, if all markets included in the VECM above share a common stochastic trend, the vector of cointegration parameters can be normalized to represent pairwise relationships between two markets (Johansen and Juselius, 1994). These normalized parameters, β, represent pairwise relationships and hence long-run price transmission elasticities, which measures the extent of spatial market integration. In spatially integrated markets, these long-run price elasticities are closer to one while lack of integration implies a lower value of β. Indeed, we can test whether these elasticities are statistically equal to one and hence whether the Law of One Price (LOP) holds (Goodwin, Grennes and Wohlgenant, 1990; Asche, Gjølberg and Guttormsen, 2011). The adjustment coefficients, α, capture short-run adjustments to correct short-run disequilibria. The closer these coefficients are to one the quicker a specific market responds to disequilibria and changes in other markets. The optimal number of lags (*k*) associated with each market in equation (2) was chosen based on the Akaike Information Criterion (AIC) and Schwarz Information Criterion (SIC). Using these criteria four lags and one lag appear to be the optimal lag lengths for modelling wheat and sorghum prices, respectively.

Estimating the VECM entails identifying the largest possible economic market that is shared by as many markets as possible. Searching for the largest set of markets that share one common stochastic trend is equivalent to identifying the maximum rank or cointegrating vectors and long-run relationships. This is done by performing Johansen's likelihood ratio test based on the trace statistics (Johansen, 1988; Johansen, 1991). To identify the maximum markets that share a common economic market and price transmission, we follow González-Rivera and Helfand's (2001) approach of starting with few "core markets" for each crop and gradual expansion and testing of the maximum number of cointegrating relationships. These core markets are selected using economic intuitions, trade flow information (see Figures 1 and 2), and the location of markets. If the number of cointegrating relationships in the core markets appears to be less than *n-1* we remove the market that is not contributing any cointegrating relationship. We then gradually expand these core markets to include one new market at a time and conduct loglikelihood ratio test using the trace statistics. This sequential inclusion and exclusion may suffer from ordering issues and hence we also experiment with a slightly different approach. Instead of starting with multiple core markets, we also start with one core market which is believed to be a major origin of trade flows and price transmission and then gradually expand the system to include more markets. Both mechanisms generate similar maximum cointegrating relationships and markets belonging to a common trend.

We note that all markets in Sudan may not share a single economic market and price transmission system. The fact that these markets do not cointegrate with the main economic system does not mean they do not react to other market and price developments. Thus, we also explore and examine potential cointegration relationships among markets which are not part of the bigger economic market. For example, markets in the Darfur region are isolated from the main markets in Sudan and these markets may share a separate economic system and stochastic trend. Thus, we also examine cointegration patterns within markets located in the Darfur region.

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5. RESULTS AND DISCUSSION

5.1 Cointegration tests and extent of spatial market integration

Before quantifying the extent of spatial market integration, we need to identify the maximum set of markets that share a common stochastic trend or economic market. As described in Section 4, we did this using a gradual inclusion and exclusion of markets for each crop. We have a total of 15 wheat markets and 19 sorghum markets spread throughout the country. We start with 4 core wheat markets, including: Khartoum (located in Khartoum), Kosti (located in White Nile), Damer (River Nile), and Obeid (North Kordofan). These markets are major wheat consuming and trading centers, which are mostly located close to major wheat producing states. Similarly, we start with 7 most important sorghum markets, including: Khartoum, Gedarif, Kosti, Damer, Obeid, Madani, and Kassala. The choice of these core markets is informed by the trade flows shown in Figure 1 and 2.

As shown in Panel A of Table 3 we find three cointegrating relationships among the four core wheat markets. In the next line, we include Sennar and test if it belongs to the system or economic market. The trace test statistics suggest four cointegration relationships, which shows that Sennar belongs to the system of equations and hence brings an additional long-run relationship because we cannot reject the null of four or less cointegrating relationships. The next stage includes Kassala, and corresponding trace statistics shows that this market belongs to bigger system. After we identify six cointegration ranks (relationships) adding another market does not generate additional cointegrating relationship. Thus, among the 15 wheat markets in our full sample only 7 of them belong to the main economic market shared by the largest number of markets. Most of these cointegrating markets are clustered in the Southeastern part of Sudan.

In Panel B of Table 4, we provide similar tests of cointegration across sorghum markets in Sudan. We initially find six cointegrating relationships among the seven core markets. We then gradually extend the system to include more markets. The trace statistics and associated critical values show that after reaching nine cointegration relationships, the rest of the markets do not belong to the system. Out of the 19 sorghum markets 10 of them share a common stochastic trend and cointegrate with the major sorghum market system. These ten markets are mostly located in the Southeastern and the Northern part of Sudan.

Despite some variations across wheat and sorghum markets, most of the markets located in Darfur do not cointegrate with or belong to the main market. This is not surprising given that internal conflicts and political fragmentation can imped market interaction and trade between Darfur and the rest of Sudan (e.g., Dorosh and Subran, 2011; De Matteis, Turkmen Ceylan and Kebede, 2021). However, this does not imply that markets within Darfur do not cointegrate among each other or are not competitive. Thus, we also examine intra-state cointegration across markets in Darfur and those markets not sharing the common stochastic trend in the rest of Sudan. For those markets located in Darfur we run additional cointegration tests for each crop. These results are discussed in Section 5.3 and results are given in Appendix Tables A4-A6.

Table 3: Johansen Tests for Cointegration for Wheat and Sorghum

Series Included	Rank (r) of Matrix	Trace statistics	Critical Value
Panel A: Cointegration tests for wheat markets			
Core markets = 4	3	2.24	3.76
Core markets + Sennar = 5	4	2.76	3.76
Core markets + Sennar + Kassala = 6	5	2.74	3.76
core markets + Sennar + Kassala + Dongola = 7	**6**	**3.15**	**3.76**
Core markets + Sennar + Kassala + Dongola + Madani = 8	6	14.29	15.41
Core markets + Sennar + Kassala + Dongola + Nyala = 8	6	14.95	15.41
Core markets + Sennar + Kassala + Dongola + El Fasher = 8	5	11.38	15.41
Core markets + Sennar + Kassala + Dongola + Singa = 8	5	12.51	15.41
Core markets + Sennar + Kassala + Dongola + Damazin = 8	5	14.18	15.41
Core markets + Sennar + Kassala + Dongola + Zalingei = 8	4	9.10	15.41
Core markets + Sennar + Kassala + Dongola + Kadugli = 8	4	12.99	15.41
Core markets + Sennar + Kassala + Dongola + Gedarif = 8	4	13.18	15.41
Panel B: Cointegration tests for sorghum markets			
Core markets = 7	6	2.93	3.76
Core markets + Port Sudan = 8	7	2.85	3.76
Core markets + Port Sudan + Kadugli = 9	8	3.70	3.76
core markets + Port Sudan + Kadugli + Sennar = 10	**9**	**3.56**	**3.76**
Core markets + Port Sudan + Kadugli + Sennar + Singa = 11	7	13.57	15.41
Core markets + Port Sudan + Kadugli + Sennar + Damazin = 11	7	16.18	15.41
Core markets + Port Sudan + Kadugli + Sennar + Dongola = 11	7	15.42	15.41
Core markets + Port Sudan + Kadugli + Sennar + El Fasher = 11	7	16.03	15.41
Core markets + Port Sudan + Kadugli + Sennar + Genina = 11	6	15.20	15.41
Core markets + Port Sudan + Kadugli + Sennar + Dain = 11	6	14.12	15.41
Core markets + Port Sudan + Kadugli + Sennar + Nyala = 11	6	11.79	15.41
Core markets + Port Sudan + Kadugli + Sennar + Zalingei = 11	6	12.60	15.41

Notes: Core wheat markets include Khartoum, Damer, Obeid, and Kosti. Core sorghum markets include Khartoum, Obeid, Kosti, Damer, Gedarif, Kassala, and Madani.

Once we identify that 7 wheat markets share one common stochastic trend and 10 sorghum markets share another common trend, we now turn to evaluating the extent of spatial integration across markets. The extent of spatial integration across markets can be expressed as pairwise long-run price transmission and hence elasticities across markets. For the purpose of interpretation, we normalize the $n - 1$ parameter estimates of the cointegration relationships with respect to Khartoum prices, the major consumption hub and a core wheat and sorghum market. This choice of normalization is innocuous but can facilitate interpretation. By doing so, we can quantify long-run elasticities and understand how consumption related shocks in major wheat/sorghum consuming markets affect price developments in neighboring states and markets.

Table 4 provides the long-run price transmission elasticities associated with wheat (Panel A) and sorghum markets (Panel B). The price elasticities associated with wheat markets range from 0.65 in Dongola to 0.91 in Kassala. We note that the long-run price transmission is driven by the interaction between the supply and demand side of the market. For example, when the price of wheat increases in Khartoum, we may expect two types of long-run responses across different markets. Wheat producing markets may respond to potential increase in long-run wheat prices by producing more while wheat consuming markets may simply respond by following the price increases. Consistent with this intuition, the wheat price elasticities show that the lowest elasticity, and hence weakest long-run relationship, appears to be between Dongola, a major wheat producing market, and Khartoum, a major wheat consumption hub. In most cases, likelihood ratio tests associated with the hypothesis that $\beta_i = 1$ cannot be rejected at the usual significance levels. This suggests that although not all wheat markets share a common stochastic trend, those sharing this economic market exhibit strong spatial integration.

The long-run elasticity estimates for sorghum range from 0.79 in Kadugli to 1.3 in Kassala. This is intuitive and consistent with the trade flows shown in Figure 2. Kadugli lacks a direct trade link and road network with Khartoum while Kassala and Khartoum are connected through a primary road. More generally, price transmission of sorghum markets appears to be more elastic and sensitive to price increases in Khartoum implying that they are slightly more integrated than wheat markets. Again, for many markets combinations, likelihood ratio tests for the LOP cannot be rejected, although we can reject that elasticities are larger than 1 for several markets.

The relatively strong long-run elasticities for sorghum may be explained by several factors, including: (i) existing trade links and road infrastructure between production and consumption markets; (ii) the large share of domestically produced sorghum in overall demand. As shown in Figure 2 most sorghum producing states and markets are well-connected with Khartoum while wheat is produced in limited states and markets, some of which are not well-connected with Khartoum. Furthermore, domestic wheat production covers a limited share of the total wheat demand in Sudan and consumers may substitute domestic wheat with imported wheat when the price of the former increases. This implies that domestic wheat markets may be relatively less sensitive to changes in prices in neighboring markets

Table 4: Long Run Price Transmission

Panel A: Wheat (2012:01–2021:08)

State	**River Nile**	**North Kordofan**	**White Nile**	**Sennar**	**Kassala**	**Northern**
Market	Damer	Obeid	Kosti	Sennar	Kassala	Dongola
Khartoum	0.83***	0.87***	0.80***	0.83***	0.91***	0.65***
	(0.12)	(0.09)	(0.14)	(0.13)	(0.19)	(0.21)
Individual LOP test (β_i= 1), p-values	0.26	0.23	0.28	0.34	0.69	0.15
Joint LOP test (β_1 = β_2 = … β_i = 1), p-value	0.719					

Panel B: Sorghum (2015:01–2021:08)

State	**River Nile**	**North Kordofan**	**White Nile**	**Gedarif**	**Kassala**	**Gezira**	**Red Sea**	**South Kordofan**	**Sennar**
Market	Damer	Obeid	Kosti	Gedarif	Kassala	Madani	Port Sudan	Kadugli	Sennar
Khartoum	1.22***	1.02***	1.15***	1.19***	1.30***	1.17***	1.08***	0.79***	1.17***
	(0.11)	(0.05)	(0.09)	(0.05)	(0.06)	(0.06)	(0.04)	(0.23)	(0.06)
Individual LOP test (β_i= 1), p-values	0.19	0.72	0.17	0.01	0.01	0.11	0.08	0.59	0.04
Joint LOP test (β_1 = β_2 = … β_i = 1), p-value	0.001								

Notes: Standard errors are in parentheses. We use 4 lags in the case of wheat and 1 lag in the case of sorghum. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

5.2 Spatial Market Interdependencies and Short-run Adjustments

Interpretation of the short-run adjustment coefficients requires stationarity of the residuals from the error correction (long-run relationships). After identifying and estimating all long-run relationships, we tested the stationarity and normality of the residuals from these cointegration relationships in addition to potential serial autocorrelation. The residuals associated with all long-run relationships are stationery, normally distributed, and serially uncorrelated allowing us to interpret the short-run adjustment coefficients from our multivariate VECM.

Table 5 reports short-run adjustments coefficients associated with market responses to deviations from long-run equilibrium. Our multivariate VECM estimates *n* by *n-1* vector of adjustment coefficients associated with deviations between each market and the normalizing market (Khartoum). Table 5 only reports responses associated with deviations to own market prices, suppressing coefficients associated with error corrections (deviation) across other markets. Panel A provides short-run adjustment coefficients for wheat markets while Panel B reports similar coefficients for sorghum markets. These adjustment coefficients can be interpreted as percentage adjustments associated with deviations from long-run equilibrium. Generally, the short-run adjustment coefficients in Table 5 are much smaller than the long-term elasticities, implying that markets need more time to react to changes in other markets and prices. The short-run adjustment coefficients (corrections to disequilibrium) in Panel A ranges from 24 percent in Dongola to 88 percent in Damer. That means Dongola prices adjust 24 percent of disequilibrium in one month while wheat prices in Damer correct 88 percent of disequilibrium in one month. Damer is located close to Khartoum, with strong trade links and road networks, which may help prices in Damer to quickly adjust in response to deviation with Khartoum prices. While Dongola has trade links with Khartoum, Dongola is also a major wheat producing state, implying that wheat prices are less likely to be elastic to changes in prices in Khartoum.

Similarly, the short-run adjustment coefficients for sorghum markets range from 0 percent in Sennar and Gedarif to 96 percent in Port Sudan. These results are intuitive because Sennar and Gedarif are major sorghum producing states and markets, implying that they are less likely to immediately respond to changes in market prices in Khartoum and associated deviations from equilibrium prices. On the other hand, Port Sudan is a sorghum deficit area which also serves as a trade hub for exporting sorghum. This allows Port Sudan sorghum prices to quickly adjust to potential changes in Khartoum.

Table 5: Short-Run Adjustment Coefficients (Error Correction)

Panel A: Wheat (2012:01–2021:08)

State	**River Nile**	**North Kordofan**	**White Nile**	**Sennar**	**Kassala**	**Northern**
Market	Damer	Obeid	Kosti	Sennar	Kassala	Dongola
(Market X, Khartoum)	-0.877***	-0.354**	-0.312**	-0.291	-0.420***	-0.239***
	(0.188)	(0.157)	(0.144)	(0.200)	(0.133)	(0.067)
R-squared	0.390	0.351	0.387	0.336	0.378	0.497

Panel B: Sorghum (2015:01–2021:08)

State	**River Nile**	**North Kordofan**	**White Nile**	**Gedarif**	**Kassala**	**Gezira**	**Red Sea**	**South Kordofan**	**Sennar**
Market	Damer	Obeid	Kosti	Gedarif	Kassala	Madani	Port Sudan	Kadugli	Sennar
(Market X, Khartoum)	-0.381***	-0.475***	-0.639***	0.208	-0.868***	-0.803***	-0.956***	-0.357***	-0.11
	(0.136)	(0.183)	(0.187)	(0.252)	(0.173)	(0.182)	(0.263)	(0.084)	(0.233)
R-squared	0.320	0.248	0.259	0.170	0.364	0.332	0.331	0.308	0.170

Notes: X stands for the list of markets cointegrating within Sudan (6 wheat markets and 9 sorghum markets). Standard errors are in parentheses. We use 4 lags in the case of wheat and 1 lag in the case of sorghum. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

We also compute additional parameters that capture the speed of adjustment in response to deviations from equilibrium (Table 6). These half-life coefficients measure the time required for correcting half of the deviations from equilibrium.[12] The less time that a market needs to correct half of the shocks and deviations, the larger the speed of adjustment is. The wheat half-life coefficients in Panel A range from 0.3 months for Damer to about 2.5 months for Dongola suggesting substantial differences in the spatial market adjustments across markets. Similarly, the half-time coefficients for Sorghum (Panel B) range from 0.3 months for Kassala to about 6 months for Sennar. Overall, quick adjustments in response to temporary disequilibrium are found for those markets with well-established trade linkages with the reference markets (Damer and Kassala). On the other hand, surplus producing states or those without established trade links with major consumption hubs are likely to respond and adjust slowly.

The fact that some of the adjustment coefficients in Table 5 are not statistically significant may suggest that some markets are weakly exogenous to the system. To probe this, we perform a joint test of all statistically insignificant adjustment coefficients in our VECM. This corresponds to testing whether a market responds to deviations from disequilibrium of any markets in the system. If a market is weakly exogenous it does not respond to temporary deviations from equilibrium but can be leading or causing the relationship and spatial integration between markets. We reject weak exogeneity of any of the wheat markets but sorghum prices in Gedarif and Sennar appear to be weakly exogenous to the system. This is not surprising given that Gedarif and Sennar are major sorghum producing states.

[12] Following the literature half-life coefficients are calculated via the equation $H_c = \frac{\ln(0.5)}{\ln(1-\alpha)}$ (Goodwin and Piggott, 2001).

Table 6: Half-Life Coefficients

Panel A: Wheat (2012:01–2021:08)

State	**River Nile**	**North Kordofan**	**White Nile**	**Sennar**	**Kassala**	**Northern**
Market	Damer	Obeid	Kosti	Sennar	Kassala	Dongola
(Market X, Khartoum)	0.3	1.6	1.9	2.0	1.3	2.5

Panel B: Sorghum (2015:01–2021:08)

State	**River Nile**	**North Kordofan**	**White Nile**	**Gedarif**	**Kassala**	**Gezira**	**Red Sea**	**South Kordofan**	**Sennar**
Market	Damer	Obeid	Kosti	Gedarif	Kassala	Madani	Port Sudan	Kadugli	Sennar
(Market X, Khartoum)	1.4	1.1	0.7	3.0	0.3	0.4	0.2	1.6	5.9

Notes: Table reports Sudan's half-life coefficients, defined as the number of months required for phasing out half of the deviations from equilibrium, calculated via the equation $H_c = \frac{\ln(0.5)}{\ln(1-\alpha)}$, where ρ is the total speed of adjustment parameter provided in Table 5. X stands for the list of markets cointegrating within Sudan (6 wheat markets and 9 sorghum markets).

5.3 Intra-state Market Integration

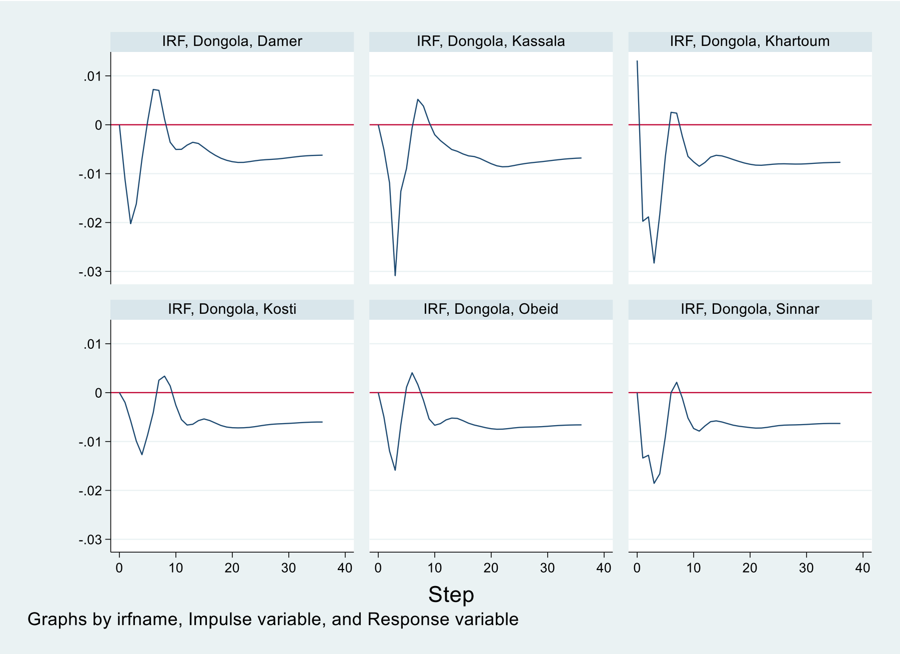
In this section, we explore whether there exists a second stochastic trend shared by those markets not integrating with the main systems of price transmission. This relaxes the assumption that all markets follow single price transmission and allows for multiple commonly shared stochastic trends. Thus, we examine whether the remaining non-cointegrating markets and those in Darfur cointegrate among each other. Markets within Darfur may integrate well among each other, despite failing to integrate with the markets elsewhere in Sudan. This is useful to understand factors contributing to lack of spatial market integration and identifying interventions to improve market efficiency. We find that wheat markets located in Darfur do not share a common trend and do not cointegrate among each other. However, three sorghum markets located in Darfur (El Fasher, Nyala, Zalingei) share a common stochastic trend and generate two long-run relationships. Long-run price transmission elasticities and short-run adjustment coefficients are given in Appendix Tables A4-A6. These markets integration results within Darfur are consistent with the findings by De Matteis, Turkmen Ceylan and Kebede (2021) and generally highlight resilience of market functions even during conflict.

5.4 Impulse Response Function Analyses

To further uncover price transmission trends across markets, we also conduct impulse response analyses. These analyses quantify the implication of a one-unit shock to a specific market. We aim to address what happens if there is a shock to the price of wheat or sorghum in a specific market and when will its impact die out. The short-run adjustments and long-run elasticities discussed in Section 5.2 and 5.3 show that surplus wheat and sorghum producing markets exhibit the weakest response to changes in prices in wheat consumption hubs. We also would like to know what happens when a production hub experiences a significant surge or shock in price. To address this question, we identify major production hub markets and examine whether shocks to these markets have transitory or permanent effects on price trends in other markets. We observe these trends for 3 years. Figure 6 shows the implication of one unit shock to wheat prices in Dongola, a major production hub, on the rest of the markets sharing a common stochastic trend. We see that the shock to prices has a short-lived impact on wheat prices in other markets. This is not surprising given that Dongola produces only a limited share of the total wheat needed to satisfy food demand in Sudan and consumers may substitute domestic wheat with imported if the price of the former increases.

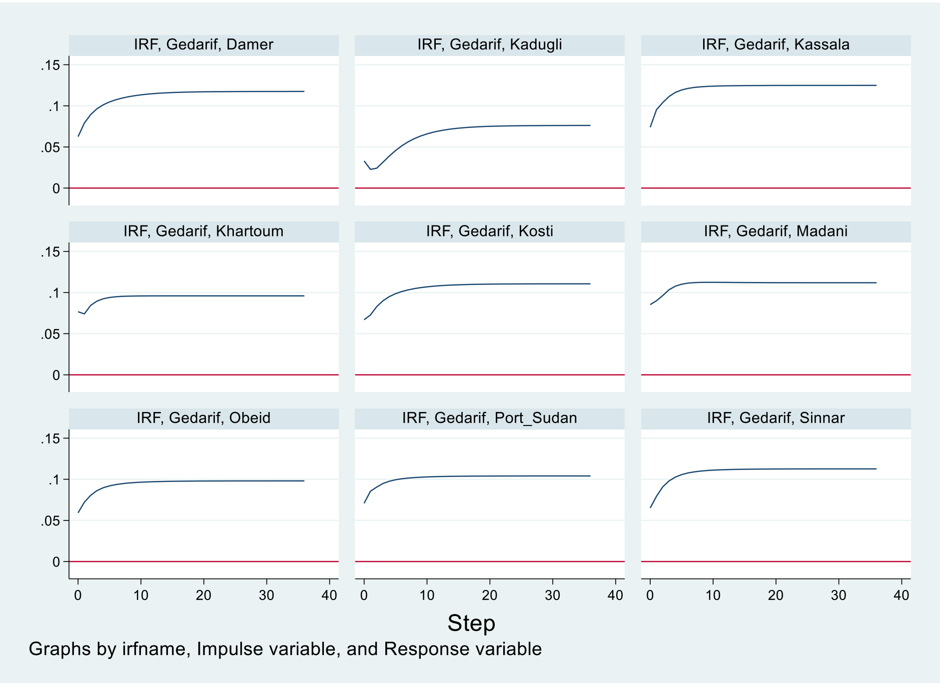
Similarly, Figure 7 provides trends on the implication of a one-unit shock to the sorghum price in Gedarif, major source of sorghum for Sudan and export markets. We can clearly see that shocks to prices in major sorghum producing markets have a permanent impact on the rest of the markets, implying an increase in demand for cereals in major cities can drive prices up permanently. The largest impact appears to be on prices in Kassala, a market located very close to and well connected with Gedarif. These trends show slightly distinct patterns in the short-run before settling in the long-run equilibrium. For example, a one unit increase in sorghum prices has larger impacts than a similar increase in wheat prices, consistent with the relatively stronger market integration in sorghum markets. Overall, the results in Figures 6 and 7 reveal important crop-specific responses. Shocks to domestic wheat prices in wheat producing markets have transitory impact while shocks to sorghum prices in sorghum surplus areas have long-lasting impacts.

Figure 6: Impulse Response Functions: Wheat



Source: Authors' computation based on FEWS NET data.

Figure 7: Impulse Response Functions: Sorghum



Source: Authors' computation based on FEWS NET data.

5.5 Policy Implications and Potential Avenues to Improve Market Integration

Our results are relevant for informing market policy and market interventions in Sudan. Most importantly, our results suggest that improving the functioning and efficiency of markets in Sudan requires region-specific market interventions and investments. Markets and states with high production potential require a slightly different set of policies and interventions compared to those states with high consumption. To identify the matrix of policies that may be considered for various regions and states, Table 7 summarizes market integration conditions and production potential of states and markets in Sudan. Our findings point to three different sets of policies and interventions that can serve the different states and markets. First, in those states with limited spatial market integration, interventions may focus on developing market infrastructure, including connecting markets with major cereal trading centers. These types of investments can benefit those markets in the Darfur region. Secondly, our findings insinuate that boosting productivity through investments in sorghum and wheat production in high potential states can benefit households residing in these states as well as neighboring states. However, these markets are not sufficiently responding to changes in prices in wheat consumption hubs, implying the need to invest in market-orientation and marketing support to wheat and sorghum producers. Finally, most markets located in cereal consumption hubs and those with relatively improved road and trade links are sufficiently integrated and responsive to changes in prices and shocks in neighboring states. These markets are likely to be vulnerable to shocks in production or cereal import prices. For example, a reduction in wheat imports as modeled by Dorosh (2021) is likely to have different implications across states depending on their wheat consumption and price transmission. States with high consumption levels (e.g., Khartoum) are likely to be more affected by potential shocks to production and prices. These states and markets can benefit from further spatial integration and diversification of trade networks, particularly with more cereal surplus states and markets in Sudan. These cereal deficit states may also benefit from coordination of domestic wheat policies (e.g., price subsidies) and related trade policies. Dorosh (2021) shows that while increasing wheat imports lowers domestic wheat prices in Sudan, such policies can reduce producers' incentives and lower domestic production.

Table 7: Cereal Production Potential and Market Integration

Cereal	Production Potential	Market Integration		
		High	**Low**	**None**
Wheat	**High**	Damer	Dongola	Madani
	Low	Khartoum Kassala Obeid Kosti Sennar		Kadugli Damazin El Fasher Gedarif Nyala Zalingei Singa
Sorghum	**High**	Gedarif Kassala Sennar Madani		Damazin Sennar Singa
	Low	Damer Khartoum Kadugli Kosti Obeid Port Sudan		Dain El Fasher Genina Zalingei Nyala

Source: Authors' compilation based on cointegration analysis.

6. CONCLUDING REMARKS

This paper evaluates spatial market integration and price transmission in cereal markets in Sudan, focusing on wheat and sorghum, two major cereal crops. Sudan provides an interesting case for assessing spatial market integration in fragmented and fragile economies. We use long-ranging monthly cereal price data covering markets spread throughout the country. We employ multivariate vector of error-correction cointegration models (VECM) to characterize both short-term and long-term price transmission across local cereal markets. Our final analysis employs impulse response functions to evaluate the implication of shocks to specific markets and the adjustment patterns of neighboring markets.

We can only detect significant spatial market integration and price transmission among 7 of 15 local wheat markets and 10 of 18 sorghum markets. Despite strong spatial market integration among some neighboring markets, there is no market integration between several regions. For example, cereal markets in Darfur are not spatially integrated with several markets elsewhere in Sudan. This may be explained by the frequent conflicts, political fragmentation, and lack of infrastructure that connects these markets with the main markets in other parts of Sudan. Among integrated markets, we observe significant variations in the strength of price transmission elasticities as well as speed of adjustment to long-term equilibrium, which implies that shocks (and price policies) in some markets can affect some but not other markets. Indeed, for some pairwise market combinations, we cannot reject perfect transmission of prices, the law of one price (LOP) hypothesis. Most of the strong price transmission and spatial market dependence follow existing trade flows and road networks, insinuating that infrastructural barriers may be obstructing spatial market integration. We also find some variations in the response of markets located in production surplus and deficit states. Markets in production surplus states are less responsive to price changes in neighboring markets than those located in production deficient states. Finally, we also find some crop-specific patterns and differences in market integration and price transmission. We generally observe stronger spatial integration and short-term adjustment in sorghum markets than wheat markets. Sorghum prices require a shorter time to correct deviations from equilibrium than wheat prices. Shocks to sorghum prices in producing markets have permanent impacts while shocks to wheat prices in producing markets endure transitory effects. This is intuitive given that domestic wheat production covers a limited share of the total wheat demand in Sudan and consumers may substitute domestic wheat with imported wheat when prices of the former increase.

These findings have important policy implications for improving the efficiency and functioning of cereal markets in Sudan and other similar settings. The lack of market integration between different regions and markets in Sudan suggest significant market inefficiency which may be improved through investments in market infrastructure. This implies that beyond the need to boost agricultural productivity, it is also essential to strengthen spatial market efficiency to ensure food security in Sudan. On the other hand, the strong market integration within (neighboring) states, even in contexts where road and related infrastructure are not well-developed, highlights two important implications. First, price related policies, including subsidies and stabilization policies, that target few markets and states will have major spillover effects in neighboring markets. Similarly, production shocks in some of these markets are likely to generate significant price hikes in neighboring markets and states. The specific features of spatial integration and the contribution of each market to the common price transmission mechanism we identify in this paper can inform targeting of price and production policies. Second, the strong spatial integration among some markets necessitates understanding and supporting local institutions or mechanisms facilitating integration of markets (De Matteis, Turkmen Ceylan and Kebede, 2021; Hastings, Phillips, Ubilava and Vasnev, 2021). Exploring these mechanism goes beyond the scope of this paper, but Hastings, Phillips, Ubilava and Vasnev (2021) argue that informal institutions may bridge the divides created by conflict, political fragmentation, and poor infrastructures.

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APPENDIX

Table A1: Average Domestic Real Price for Wheat
('000 SDG per ton)

State Market	2012:01-2018:01	2018:01-2018:12	2019:01-2019:12	2020:01-2020:12	2021:01-2021:08
Khartoum					
Khartoum	1.31	1.71	1.77	1.75	1.69
Blue Nile					
Damazin	1.52	2.07	2.16	2.15	1.73
Darfur					
El Fasher	1.98	2.20	2.60	2.90	2.39
Nyala	1.67	2.03	1.80	2.10	1.97
Zalingei	2.95	1.96	2.31	2.12	1.17
Gedarif					
Gedarif	1.64	1.77	2.32	1.82	1.65
Gezira					
Madani	1.09	1.73	1.83	1.69	1.52
Kassala					
Kassala	1.29	1.89	2.21	2.26	1.74
North Kordofan					
Obeid	1.40	1.77	1.93	1.85	1.74
Northern					
Dongola	1.25	2.76	1.93	1.67	1.62
River Nile					
Damer	1.39	1.78	1.97	1.89	1.66
Sennar					
Singa	1.26	1.74	1.93	1.79	1.68
Sennar	1.32	1.69	1.75	1.82	1.61
South Kordofan					
Kadugli	1.35	1.81	2.34	1.97	1.69
White Nile					
Kosti	1.29	1.77	1.97	1.98	1.56

Source: Authors' calculations based on FEWS NET data.

Table A2: Average Domestic Real Price for Sorghum
('000 SDG per ton)

State Market	**2015:01-2018:01**	**2018:01-2018:12**	**2019:01-2019:12**	**2020:01-2020:12**	**2021:01-2021:08**
Khartoum					
Khartoum	0.76	1.03	1.21	1.60	1.04
Blue Nile					
Damazin	0.62	0.98	1.19	1.48	0.82
Darfur					
El Fasher	0.93	1.03	1.27	1.55	0.91
Nyala	0.79	1.16	1.29	1.18	0.76
Genina	0.81	1.20	1.23	1.63	0.98
Dain	0.91	1.19	1.47	1.83	1.64
Zalingei	0.74	1.36	1.16	1.47	0.83
Gedarif					
Gedarif	0.70	0.95	1.23	1.52	0.90
Gezira					
Madani	0.76	1.05	1.24	1.58	0.92
Kassala					
Kassala	0.73	1.07	1.16	1.67	0.90
North Kordofan					
Obeid	0.79	1.06	1.21	1.62	1.02
Northern					
Dongola	0.89	1.09	1.40	1.84	1.29
Red Sea					
Port Sudan	0.82	1.11	1.31	1.76	1.08
River Nile					
Damer	0.84	1.01	1.35	1.81	1.09
Sennar					
Singa	0.65	0.87	1.07	1.32	0.78
Sennar	0.66	0.93	1.06	1.45	0.83
South Kordofan					
Kadugli	0.70	0.80	0.95	1.13	0.86
White Nile					
Kosti	0.72	0.97	1.10	1.49	0.85

Source: Authors' calculations based on FEWS NET data.

Table A3: Augmented Dickey-Fuller (ADF) Unit Root Stationarity Test

(H0: series has a unit root; H1: series does not have a unit root)

	Panel A: Wheat 2012:01-2021:08			Panel B: Sorghum 2015:01-2021:08		
State	Price in levels		Price in differences	Price in levels		Price in differences
Market	Intercept	Intercept + Trend	Intercept	Intercept	Intercept + Trend	Intercept
Khartoum						
Khartoum	-2.55	-2.74	-10.88^{***}	-1.46	-1.76	-8.5^{***}
Blue Nile						
Damazin	-2.63	-2.77	-10.91^{***}	-1.73	-1.93	-9.89^{***}
Darfur						
El Fasher	-3.79	-4.48	-12.85^{***}	-3.12	-3.27	-12.60^{***}
Nyala	-4.15	-4.57	-12.56^{***}	-1.95	-1.43	-9.47^{***}
Zalingei	-2.60	-3.33	-10.43^{***}	-2.23	-2.26	-9.52^{***}
Genina	-	-	-	-2.38	-3.16	-12.00^{***}
Dain	-	-	-	-2.49	-4.40	-10.74^{***}
Gedarif						
Gedarif	-2.33	-2.27	-9.67^{***}	-1.52	-1.62	-8.38^{***}
Gezira						
Madani	-2.06	-2.78	-9.50^{***}	-1.79	-1.89	-10.32^{***}
Kassala						
Kassala	-2.24	-2.68	-11.39^{***}	-1.76	-1.86	-9.02^{***}
North Kordofan						
Obeid	-2.15	-2.53	-9.93^{***}	-1.47	-1.63	-8.19^{***}
Northern						
Dongola	-2.51	-2.80	-8.48^{***}	-1.45	-2.08	-9.68^{***}
Red Sea						
Port Sudan	-	-	-	-1.41	-1.61	-7.55^{***}
River Nile						
Damer	-2.62	-2.85	-11.02^{***}	-1.5	-1.68	-8.59^{***}
Sennar						
Singa	-2.46	-3.09	-10.44^{***}	-1.58	-1.78	-9.13^{***}
Sennar	-2.67	-2.96	-11.12^{***}	-1.37	-1.58	-7.78^{***}
South Kordofan						
Kadugli	-2.74	-3.35	-11.09^{***}	-2.46	-2.83	-10.26^{***}
White Nile						
Kosti	-2.36	-2.83	-12.51^{***}	-1.55	-1.49	-8.67^{***}

Notes: The null hypothesis for the ADF test is a series has a unit root against the alternative of stationarity. * p<0.1, ** p<0.05, *** p<0.01.

Table A4: Johansen Tests for Cointegration for Sorghum (Among Darfur Markets)

(Trace Statistic, 2015:01 - 2021:08) H0: no cointegrating equation; H1: cointegrating equation

Series Included	Rank (r) of Matrix	Trace statistics	Critical Value
El Fasher + Nyala = 2	1	3.35	3.76
El Fasher + Nyala + Zalingei = 3	**2**	**3.36**	**3.76**
El Fasher + Nyala + Zalingei + Genina = 4	2	13.24	15.41
El Fasher + Nyala + Zalingei + Dain = 4	-	19.25	15.41

Table A5: Long Run Price Transmission for Sorghum (Among Darfur Markets)

Market	Zalingei	El Fasher
Nyala	0.96***	0.67***
	(0.18)	(0.16)

Notes: Standard errors are in parentheses. We use 1 lag. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table A6: Short-Run Adjustment for Sorghum (Error Correction) (Among Darfur Markets)

Market	Zalingei	El Fasher	Nyala
(Market X, Nyala)	-0.425***	-0.263***	0.165***
	(0.088)	(0.084)	(0.06)
R-squared	0.242	0.149	0.13

Notes: X stands for the list of markets cointegrating within Darfur (3 sorghum markets). Standard errors are in parentheses. We use 1 lag. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

ABOUT THE AUTHORS

Kibrom A. Abay is a Country Program Leader and Research Fellow in the Development Strategy and Governance Division at IFPRI, based in Cairo, Egypt. **Lina Abdelfattah** is a Senior Research Assistant with the Egypt Strategy Support Program (ESSP) of the International Food Policy Research Institute (IFPRI), based in Cairo, Egypt. **Clemens Breisinger** is the Interim Sudan SSP Leader, the MENA Program Leader and a Senior Research Fellow at IFPRI's Development Strategy and Governance Division, based in Nairobi, Kenya. **Khalid Siddig** is a Senior Researcher (Privatdozent, Associate Professor) at Humboldt-Universität zu Berlin, Berlin, Germany and Associate Professor at Khartoum University (Department of Agricultural Economics, Faculty of Agriculture), Khartoum, Sudan.

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INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE
1201 Eye St, NW | Washington, DC 20005 USA
T. +1-202-862-5600 | F. +1-202-862-5606
Email: ifpri@cgiar.org | www.ifpri.org | www.ifpri.info

IFPRI-KHARTOUM
c/o ICARDA
Agricultural Research Corporation – Shambat Research Station
P.O. Box 1302 | Khartoum North, Sudan

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