Evaluating Cereal Market (Dis)Integration in Less Developed and Fragile Markets: The Case of Sudan

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Evaluating Cereal Market (Dis)Integration in Less Developed and Fragile Markets: The Case of Sudan

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Abstract

This paper evaluates spatial market integration in cereal markets in Sudan, focusing on wheat and sorghum, two major cereal crops. Sudan's context provides important insights on the functioning of markets in economies marred by sanctions, conflicts, soaring inflation, and macroeconomic imbalances. We use long-ranging monthly cereal price data and a vector of error-correction cointegration model (VECM) to characterize both short-term and long-term spatial price adjustment across cereal markets. Among the 15 wheat and 18 sorghum markets considered, we can only detect significant spatial market integration among 6 wheat and 11 sorghum markets. Despite some strong spatial market integration among a few neighboring markets, there is no spatial market integration between several markets, including between major wheat consumption and production hotspots. For example, cereal markets in Darfur are not integrated with cereal markets in the rest of the country, despite exhibiting some level of spatial integration within the Darfur region. Finally, we also observe relatively stronger spatial market integration in sorghum markets than in wheat markets. These findings have important policy implications for improving the efficiency of cereal markets in Sudan and other comparable settings.

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

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1. Introduction

Well-functioning markets play a key role for ensuring affordable food prices and food security (e.g., Frelat et al., 2016; Headey et al., 2019). The functioning and efficiency of markets are particularly important to ensure food security during shocks and food crises. However, many markets in developing countries, especially those in fragile contexts, are characterized by poor spatial integration across domestic and international markets (e.g., Dillon and Barrett, 2016; Hastings et al., 2021). For example, agricultural markets in Sudan 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).[1] Long distances between markets, lack of road networks and protracted conflicts 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, 2016; Hastings et al., 2021). Evaluating the breadth, degree, and nature of spatial market integration in less developed and fragile contexts is particularly important because these markets are vulnerable not only to domestic shocks but also to fluctuations in global markets. For example, Abay et al. (2022) argue that food markets in Sudan are among the most vulnerable to the unfolding Russian-Ukraine crisis and associated price hikes in food and fertilizers.

Given the importance of food prices for stability and food security in general, and bread and wheat flour prices in Sudan in particular (Maystadt et al., 2014; Resnick, 2021; Dorosh, 2021), this paper evaluates the extent of spatial integration amongst Sudan's cereal markets. Sudan's economy and markets provide an interesting case for evaluating market integration 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 before a military takeover took place in October 2021. Several reform steps were taken during the transitional period (starting in 2019), including the reduction of fuel subsidies, the move towards a market-oriented exchange rate, and the

[1] 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).

introduction of a cash transfer program (IBRD, 2020). However, after the recent multiple changes in the structure of the 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 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 result in persistent variations between surplus and deficit states and regions of specific crops. Sudan is also highly dependent on imported wheat, further highlighting the importance of well-functioning markets and value chains for ensuring domestic food security. These contexts make domestic agricultural markets in Sudan particularly vulnerable both to domestic shocks and global food crises.

To capture the implications of these spatial variations in production and consumption across crops and regions, 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 between 2012/2013 and 2019/2020 (CBS, 2021). During this same period, wheat production averaged about 0.5 million tons (CBS, 2021). About 80-85 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 the demand and supply of wheat and sorghum will likely trigger a significant impact on cereal markets in Sudan, albeit with varying effects across crops and markets. Better functioning and integrated markets are therefore crucial not only for domestically produced/traded goods and services but also for imported and exported commodities. Thus, identifying potential spatial market integration across alternative markets can inform public investments in market infrastructure and value chains.

Using long-ranging monthly cereal price data, we conduct comprehensive spatial market integration 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 states. Moreover, some of these markets are in conflict-affected and remote areas while the remaining markets are located in areas with improved infrastructure and trade linkages. Few of the markets we consider are known for trading both wheat and sorghum, which facilitates the characterization of spatial market integration across similar markets with different crops or value chains.

We employ Johansen's (1988) multivariate cointegration framework to estimate short-run and long-run price elasticities. We particularly estimate multivariate vector of error-correction cointegration models (VECM) to characterize spatial price integration 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 et al., 2010; Goodwin et al., 2011; Asche et al., 1999; Asche et al., 2011; Dillon and Barrett, 2016; Svanidze and Götz, 2019a; Svanidze and Götz, 2019b; Heigermoser et al., 2021). We first identify the list of markets sharing common stochastic trend and hence those which are not well-integrated with this economic market. We then identify how and whether prices respond to changes and shocks in major consumption/production hotspot areas. We also characterize price adjustment processes across nearby (within-region) and distant markets (across regions). We finally identify some leading and follower markets by testing weak exogeneity of price series, empirical evidence that can be used for prioritizing investments to create and/or revitalize the functioning of markets.

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 considered, we can only detect significant spatial market integration among 6 wheat and 11 sorghum markets. For example, wheat and sorghum markets in Darfur (which is a region composed of several states[2]) are not integrated with several markets in the rest of the country. Secondly, among integrated markets, we observe significant variations in the strength of spatial integration as well as the speed of adjustment to long-term equilibrium across markets as well as across wheat and sorghum markets. For instance, we find some interesting commodity-specific patterns and differences in market integration. Sorghum markets exhibit stronger and broader spatial integration than wheat markets and prices. Third, markets in production-surplus states are less responsive to price changes in neighboring markets than those located in production-deficient states.

[2] Darfur region is administratively divided into five states: North, South, Central, East and West. The capital of each of these states are El Fasher, Nyala, Zalingei, Dain, and El Geneina, respectively (UNOCHA, 2022).

These findings have important policy implications for improving the efficiency of cereal markets in Sudan as well as other similar settings. 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 adjustment elasticities as well as the 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 with relatively weakly developed roads and related infrastructure, necessitates understanding and supporting local institutions or mechanisms facilitating integration of markets (De Matteis et al., 2021; Hastings et al., 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 market integration in conflict-affected economies such as Sudan. An exception to this is a recent study by Hastings (2021) who show that conflict intensity inhibits spatial market integration across Somalia's markets. Besides identifying the breadth and degree of spatial market integration across markets, we also show how and whether prices respond to changes and shocks in major consumption/production hotspot areas for both domestically produced and imported food items. For example, the evidence that consumption hotspots are more responsive to price shocks than production hotspots can inform price stabilization policies, market and road infrastructure development, and measures targeted at improving trade balances. The availability of data for two crops in the same market and associated differences in market integration helps to generate nuanced empirical evidence on whether it is the nature of markets or crops (commodities) that trigger specific market integration. Similarly, identification of markets driving spatial integration of prices can be used for prioritizing investments to revitalize the functioning of 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 cultivated 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 runs through Kassala, Gedaref, Blue Nile, White Nile, Sinnar, 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 traditional rainfed agriculture employs 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 significant variability in 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), Sudan produces surplus sorghum (mainly concentrated in the eastern Gedaref and Sinnar States), is self-sufficient in millet, and is structurally deficient in wheat. 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 Sudanese 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 consumer preferences.

[3] Sorghum accounts for 80 percent of the cultivated land.

[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 Gedaref 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 El 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 subsections, we discuss the direction and intensity of cereal 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)
Gedaref	667	253.90	413.106
Sinnar	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 15-20 percent) and through commercial imports (about 80-85 percent).[6] The rapid growth in wheat consumption is driven by changing consumer preferences for wheat bread relative to alternatives from sorghum, millet, and maize. Rural and urban households have started to shift their eating habits towards wheat-based food, and farm families in rural areas frequently sell part of their harvest of sorghum and millet to buy wheat grain or bread (FEWS NET, 2015).

Khartoum is the largest wheat (local and imported) consumption center, absorbing supply mainly from Gezira (Madani) and Northern (Dongola) states (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. Unlike imported wheat or sorghum, locally produced wheat is typically traded amongst adjacent markets. Key markets trading locally produced wheat are Dongola, Ed 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 Ed Damer in the River Nile State. Because of the existence of primary roads, trade between these markets is strongly reinforced. On the other hand, markets in Darfur have separate wheat trade channels, producing a negligible quantity of rainfed wheat, which is mostly used for local consumption.[7]

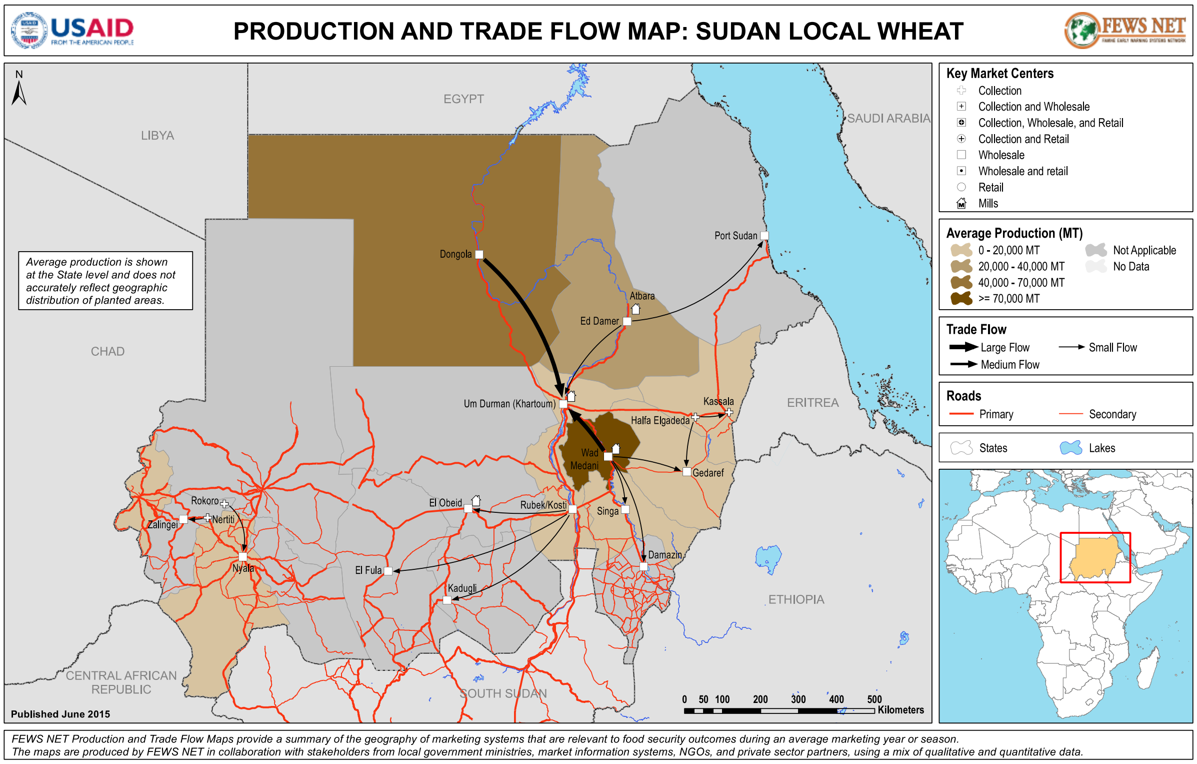
Wheat production in Sudan happens in cooler winter months (planted November-December and harvested in March) and typically requires irrigation to produce good grain quality. Harvesting is done mechanically on larger farms while smallholder farmers mostly rely on manual labor. Despite being consistently subsidized by the government, local production remains very

[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).

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).

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 irrigation and traditional rainfed systems (FAO, 2020) and is mostly planted between June and July and harvested in November-December. Overall, it is Sudan's largest crop in terms of production area, with a total

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

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

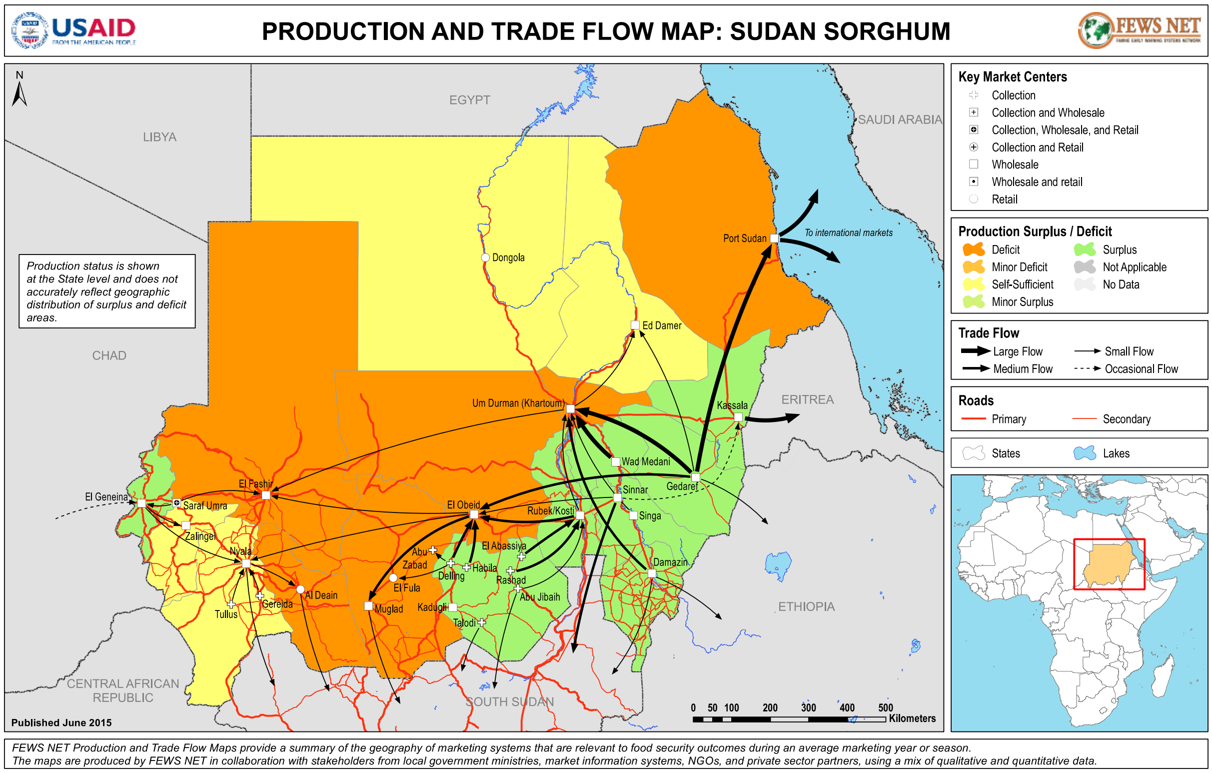
harvest of about 4 million tons in 2020, representing 68 percent of total production of all cereals (FAO, 2020).

The key wholesale sorghum markets in Sudan are Gedaref, Khartoum, and El Obeid (Figure 2). Gedaref, 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 capital and vital transit point for sorghum, and for all other commodities bought and sold in Sudan. El 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 Sinnar in the eastern and central parts of the country, respectively, as well as South Kordofan and West Darfur in the west. These surplus markets are also major sources and routes of sorghum export to neighboring countries such as Eritrea, Ethiopia, and South Sudan.

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

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

Figure 2: Production and Trade Flow Map: Sorghum



Source: FEWS NET (2015).

3. Data and Descriptive Statistics

We use monthly wholesale cereal price data collected by FEWS NET for Sudan to conduct a comprehensive multivariate market integration analysis, focusing on local wheat and sorghum markets spread throughout the country. To observe the evolution of real prices, we deflated nominal prices by Sudan's consumer price index for each corresponding period. 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. Most of these markets are known for trade in both commodities while some of them specialize in sorghum trade. Table 2 provides a list of these markets. The monthly wholesale wheat price data covers the period from January 2012 to August 2021, while the wholesale sorghum price data cover the period from January 2015 to August 2021.

Table 2: Markets and States Covered by Crop

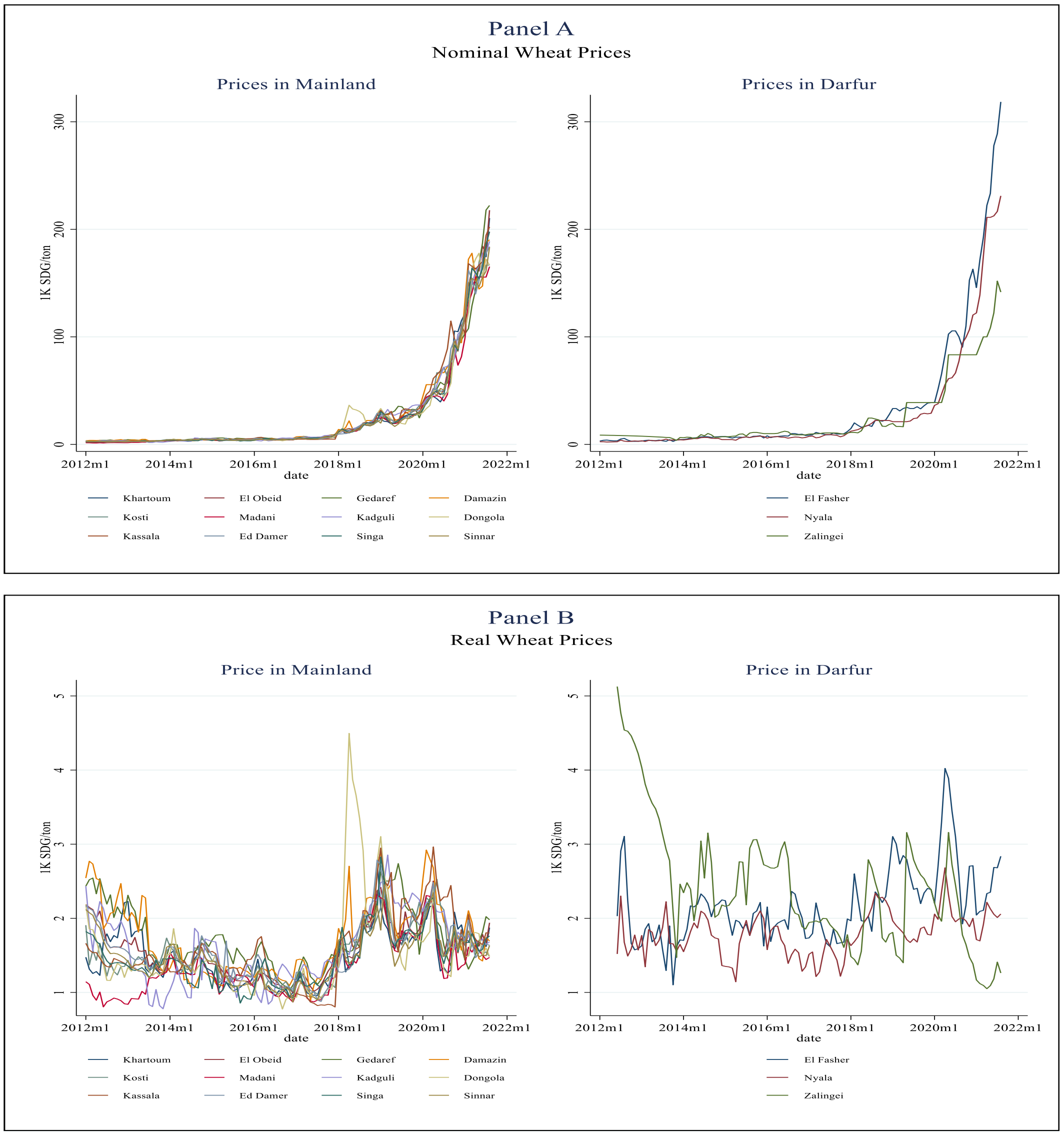
Market	State/region	Crop data available for
Khartoum	Khartoum	Wheat and Sorghum
El Obeid	North Kordofan	Wheat and Sorghum
El Fasher	Darfur	Wheat and Sorghum
Gedaref	Gedaref	Wheat and Sorghum
Damazin	Blue Nile	Wheat and Sorghum
Kosti	White Nile	Wheat and Sorghum
Madani	Gezira	Wheat and Sorghum
Kadugli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

Source: FEWS NET.

3.1 Wheat Prices

Figure 3 shows the evolution of wheat prices, both in nominal (Panel A) and real (Panel B) terms. To uncover potential differential trends, we separately plot the evolution of prices for Darfur and the rest of the country (mainland hereafter). Wheat prices (especially in nominal terms) 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 nominal wheat prices across markets and periods. Across all markets (except in Darfur), on average, wheat prices jumped from 4 thousand SDG per ton in the period before 2018 to 17 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 greatly dispersed compared to markets outside Darfur (see Appendix Table 1A and Figure 5). 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.

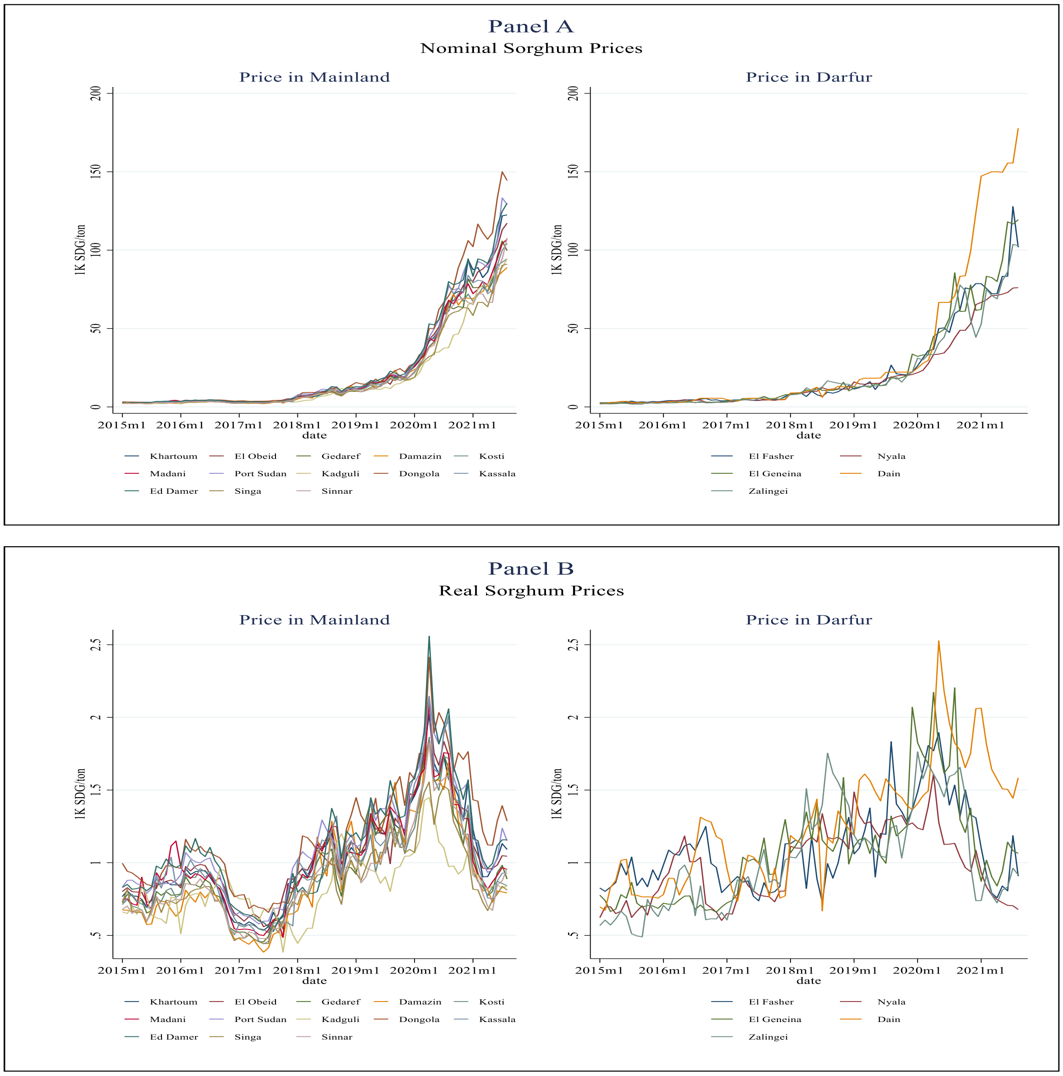
3.2 Sorghum Prices

Figure 4 provides the evolution of nominal and real sorghum prices while Appendix Table A2 provides average prices across markets and periods. Like wheat prices, nominal 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, nominal prices in surplus-producing markets such as

[11] The average nominal price for a ton of sorghum across all markets under study (except those located in Darfur) jumped from almost 3.2 thousand SDG per ton during 2012-2017 to 8.9 in 2018 (see Figure 4).

Gedaref are among the lowest, while prices in deficit states and markets such as Port Sudan are among the highest (see Figure 4). 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 increasing on average at a rate slightly like markets outside of Darfur (see also Figure 5).

Figure 4: Trends in wholesale sorghum price data

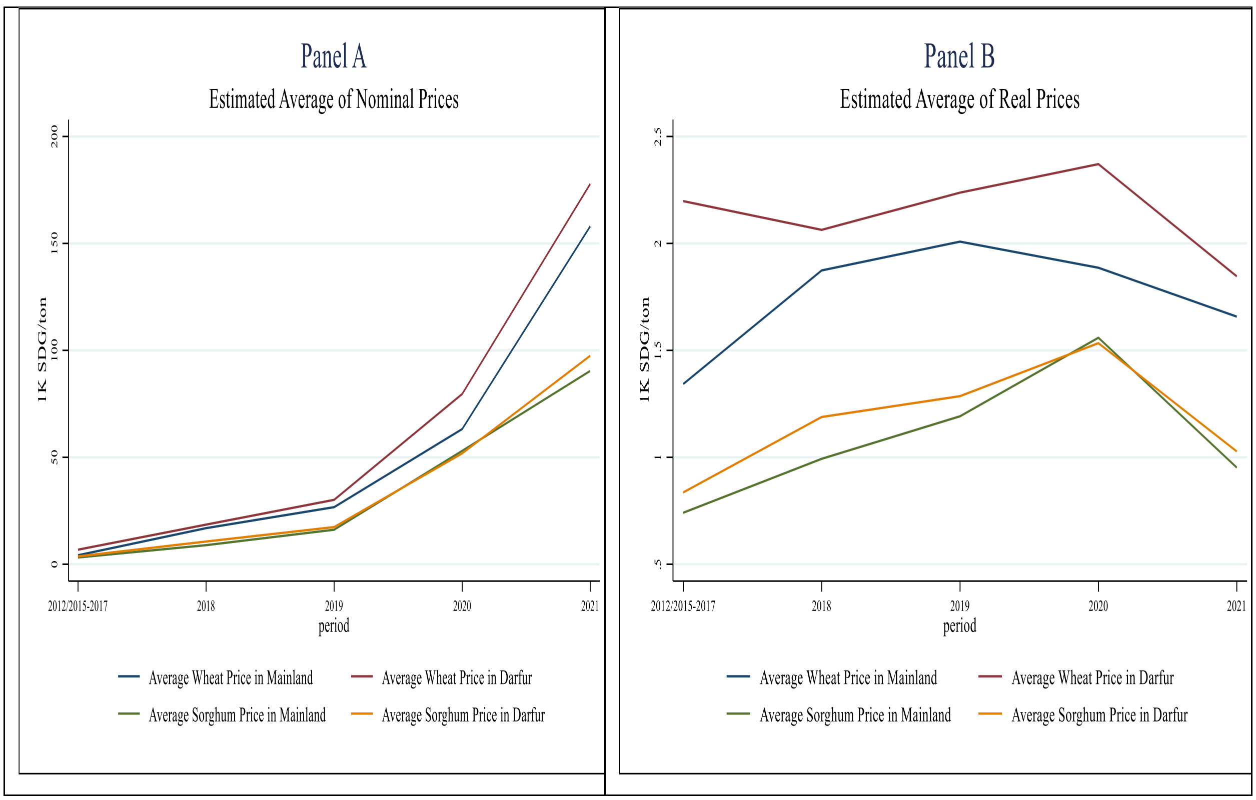


Source: Authors' computation based on FEWS NET data.

3.3 Wheat and Sorghum Prices Compared

On average, nominal wheat prices (per ton) are 56 percent higher than sorghum prices in markets outside of Darfur and are as much as 74 percent higher than sorghum prices in markets inside the Darfur region. 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 shows that the gap between wheat and sorghum prices have significantly increased. These increasing differences may also arise from a disproportional increase (or shift) in demand for wheat and associated differential implication of inflation. Indeed, the divergence in average price between wheat and sorghum appears to be more visible in nominal terms than in real terms, suggesting the differential implication of inflationary trends. Generally, there is significantly higher dispersion between wheat prices across markets in the mainland and those in Darfur, while the corresponding dispersion for sorghum appears to be negligible. This is not surprising given that some of the states in the Darfur region also produce sorghum unlike wheat, which is negligibly produced in the western states. This evidence hints that spatial market integration may be higher in sorghum markets than wheat markets.

Figure 5: Estimated 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 first differences. To circumvent the effect of CPI deflator, which can generate a stochastic common trend by itself, we rely on nominal prices for our main analysis. 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 nominal 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 spatial market 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 (e.g., González-Rivera and Helfand, 2001; Barrett and Lin, 2002). In spatially integrated markets, price differences (across locations) above the cost of transporting a tradable commodity are 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 and long-run price adjustment 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 equations (Johansen and Juselius, 1994; Asche et al., 1999).

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.

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

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

Where P_t contains 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 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 is a $n \times$ *n-1* matrix short-run adjustment coefficients while β contains normalized matrix of $n \times$ *n-1* coefficients capturing the extent of co-integration and long-run relationship between 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 is a vector of stochastic error terms.

If all markets included in equation (2) 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 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 et al., 1990; Asche et al., 1999; Asche et al., 2011). The coefficients, α, capture short-run adjustments to correct short-run disequilibria (deviations from equilibrium). 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, 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. Thus, 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 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. The fact that these markets do not cointegrate with the main economic system does not mean they do not react to price developments in other markets. Thus, and in replication of González-Rivera and Helfand (2001) approach, 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 among themselves. Thus, we also examine cointegration patterns within markets located in the Darfur region.

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 staple food. We have a total of 15 wheat markets and 18 sorghum markets spread throughout the country. We start with 3 core wheat markets, including Khartoum (located in Khartoum), Kosti (located in White Nile), and Ed Damer (River Nile). These markets are major wheat consuming and trading centers, which are mostly located close to major wheat producing states. Markets like Khartoum and Ed Damer also host large milling companies and mills. The trade flow in Figure 1 shows that Kosti serves as a source of for wheat trade to markets such as El Obeid and Kadugli. Similarly, we start with 7 most important sorghum markets, including: Khartoum, Gedaref, Kosti, Ed Damer, El 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 A4 we find two cointegrating relationships among the core wheat markets. We then include Kadugli and test if it belongs to the system or economic market. The trace test statistics suggest three cointegration relationships, which shows that Kadugli belongs to the system of equations and hence brings an additional long-run relationship because we cannot reject the null of three or less cointegrating relationships. Figure 1 shows that there is significant trade flow from Kosti to Kadugli which may explain this spatial integration. The next stage includes Damazin, and corresponding trace statistics shows that this market belongs to a bigger system. Similar result appears when we add Gedaref. After we identify five cointegration relationships, adding another market does not generate additional cointegrating relationship (as shown in Panel A of Table A4). Thus, among the 15 wheat markets in our full sample, only 6 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. Despite the trade flows between major wheat production (e.g., Dongola and Madani) and consumption markets (e.g., Khartoum) shown in Figure 1, prices in these markets are not cointegrating. This is somehow surprising and suggests that there exists significant market inefficiency in domestic wheat markets. As noted by Barrett and Li (2002) this implies that tradability may not necessarily trigger competitive market equilibrium. This suggests that differences in commodity prices between these markets are likely to be greater than transportation and transaction costs between these markets. For example, differences between average prices in Khartoum (161,270 SDG per ton) and Madani (144,900 SDG) appear to be significantly higher than the cost of transporting a tone of wheat from Madani to Khartoum. This Furthermore, wheat markets in Darfur do not cointegrate with the above main economic system, reinforcing the prevalence of significant spatial market disintegration.

Moreover, we explore whether there exists a second stochastic trend shared by those markets not integrating with the main economic zone. This relaxes the assumption that all markets follow single economic market and allows for multiple commonly shared stochastic trends. 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. 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. Most of the markets located in Darfur do not cointegrate among each other or belong to the main market. The only cointegration within Darfur markets is between El Fasher and Zalingei (see Panel B of Table 3). This is not surprising given that internal conflicts and political fragmentation can impede market interaction and trade between Darfur and the rest of Sudan (e.g., Dorosh and Subran, 2011; De Matteis et al., 2021). In Panel C of Table A4, we provide similar tests of cointegration across sorghum markets in Sudan (while Panel C of Table 3 shows final tests and cointegration ranks). 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 ten cointegration relationships, the rest of the markets do not belong to the system (as shown in Panel B of Table A4). Out of the 18 sorghum markets, 11 of them share a common stochastic trend and cointegrate with the major sorghum market system. These eleven markets are mostly located in the Southeastern and the Northern part of Sudan. The breadth of trade flows in Figure 2 may explain the relatively larger number of sorghum markets sharing a common stochastic trend and long-run price equilibrium.

As shown in Panel D of Table 3, we find that four sorghum markets located in Darfur (El Fasher, Nyala, El Geneina and Dain) share another common stochastic trend. The trace statistics and associated critical values show that after reaching three cointegration relationships, the rest of the markets do not belong to the system, as shown in Panel D of Table A4. This is intuitive and consistent with the trade flow shown in Figure 2, which indicates Nayala as a center of trade flows from several sorghum markets in Darfur and adjacent markets.

Table 3: Johansen Tests for Cointegration for Wheat and Sorghum

Series Included	**Rank (r) of Matrix**	**Trace statistics**	**Critical Value**
Panel A: Wheat (2012:01 - 2021:08)			
Core markets + Kadugli + Damazin + Gedaref = 6	5	1.98	3.76
Panel B: Wheat (Among Darfur Markets) (2012:01 - 2021:08)			
El Fasher + Zalingei = 2	1	3.29	3.76
Panel C: Sorghum (2015:01 - 2021:08)			
Core markets + Kadugli + Sinnar + Singa + Damazin = 11	10	1.53	3.76
Panel D: Sorghum (Among Darfur Markets) (2015:01 - 2021:08)			
El Fasher + Nyala + El Geneina + Dain = 4	3	1.13	3.76

Notes: Core wheat markets in Panel A include Khartoum, Ed Damer, and Kosti. Core sorghum markets in Panel B include Khartoum, El Obeid, Kosti, Ed Damer, Gedaref, Kassala, and Madani. We use 4 lags in the case of wheat (Panel A) and 1 lag in the case of wheat (Panel B) and sorghum (Panels C and D). The trace test reported concludes the number of cointegrating vectors in the system. Full procedure and stepwise inclusion tests are results are reported in Table A4. The null hypothesis for the trace test is rank=r against the alternative of rank>r.

Once we identify that 6 wheat markets share one common stochastic trend and 11 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 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 elasticities associated with wheat (Panel A and B) and sorghum markets (Panel C and D). The relative lack of spatial integration in wheat markets, relative to sorghum markets, is worth noting. Despite the strong trade link between wheat producing states like Dongola and Madani prices are not sufficiently comoving with those in major consumption hubs such as Khartoum, showing a major lack of market integration. However, the strength of spatial market integration among those markets cointegrating appears to be strong. Among those wheat markets exhibiting spatial integration, the price elasticities associated with wheat markets range from 0.82 in Kadugli to 0.97 in Ed Damer. The strongest cointegration appears to be between Khartoum and Ed Damer, which is located close to Khartoum and connected with a strong trade link and a road network. 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. This pattern extends even to the two wheat markets in Darfur (El Fasher and Zalengei) sharing another stochastic trend between them.

The long-run price elasticity estimates for sorghum range from 0.89 in Damazin to 1.05 in Ed Damer. This is intuitive and consistent with the trade flows shown in Figure 2. Damazin lacks a direct trade link and road network with Khartoum while Ed Damer and Khartoum are connected through a primary road. More generally, sorghum markets appear to be more elastic and sensitive to price increases in Khartoum implying that they are slightly more integrated than wheat markets. For most markets, likelihood ratio tests associated with the LOP cannot be rejected, although a joint test for all markets can be rejected, likely to be driven by the large number of markets. Within Darfur, we find that the four sorghum cointegrating markets located in Darfur (El Fasher, Nyala, El Geneina and Dain) generate three long-run relationships. Long-run price elasticities (Panel D of Table 4) show strong spatial market integration in sorghum markets even within the Darfur region.

The relatively larger breadth of spatial market integration and 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.

The differences in the number of wheat and sorghum markets sharing common trends also raises a question of whether it is the nature of the staple food or specific features of markets that are driving spatial market integration. While specific features of wheat and sorghum value chains may drive some of the differences, the markets exhibiting spatial market integration remain similar across both crops. This suggests physical infrastructure and trade networks associated with these markets may be major sources of spatial market integration across these markets.

Table 4: Long Run Price Elasticities

Panel A: Wheat

State	Blue Nile	River Nile	White Nile	Gedaref	South Kordofan
Market	Damazin	Ed Damer	Kosti	Gedaref	Kadugli
Khartoum	0.899***	0.970***	0.935***	0.929***	0.816***
	(0.06)	(0.06)	(0.06)	(0.06)	(0.08)
Individual LOP test (β_i= 1), p-values	0.07	0.59	0.31	0.22	0.03
Joint LOP test (β_1 = β_i = 1), p-value			0.13		

Panel B: Wheat (Among Darfur Markets)

Market	Zalingei
El Fasher	0.970***
	(0.12)
Individual LOP test (β_i= 1), p-values	0.81

Panel C: Sorghum

State	Blue Nile	River Nile	North Kordofan	Gedaref	South Kordofan	Kassala	White Nile	Gezira	Sinnar	Sinnar
Market	Damazin	Ed Damer	El Obeid	Gedaref	Kadugli	Kassala	Kosti	Madani	Singa	Sinnar
Khartoum	0.885***	1.049***	0.963***	0.954***	0.915***	0.996***	0.917***	0.948***	0.936***	0.949***
	(0.07)	(0.06)	(0.02)	(0.04)	(0.11)	(0.05)	(0.04)	(0.05)	(0.04)	(0.03)
Individual LOP test (β_i= 1), p-values	0.11	0.45	0.15	0.3	0.51	0.94	0.06	0.32	0.12	0.14
Joint LOP test (β_1 = β_i = 1), p-value					0.01					

Panel D: Sorghum (Among Darfur Markets)

Market	El Fasher	El Geneina	Dain
Nyala	1.484***	1.163***	1.649***
	(0.21)	(0.22)	(0.26)
Individual LOP test (β_i= 1), p-values	0.04	0.54	0.03
Joint LOP test (β_1 = β_i = 1), p-value		0.11	

Notes: Standard errors are in parentheses. We use 4 lags in the case of wheat (Panel A and B) and 1 lag in the case of sorghum (Panels C and D). * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

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 (deviations) across other markets. Panel A and B provide short-run adjustment coefficients for wheat markets while Panel C and D report 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 26 percent in Kosti to 61 percent in Ed Damer. That means Kosti prices adjust 26 percent of disequilibrium in one month, while wheat prices in Ed Damer correct 61 percent of disequilibrium in one month. Ed Damer is located close to Khartoum, with strong trade links and road networks, which may help prices in Ed Damer to quickly adjust in response to deviation with Khartoum prices. Kadugli is relatively located far away from Khartoum and prices in Kadguli will need more time to adjust in response to changes in prices in Khartoum. Furthermore, the trade flow in Figure 1 shows that Kadguli is directly connected with Khartoum, rather through Kosti. The short-term adjustment coefficients within Darfur markets show even lower speed of adjustment. Wheat price in Zalingei adjusts 21 percent of the deviation from equilibrium prices with El Fasher prices. This suggests that spatial market adjustment within Darfur markets is slower than those within markets in the mainland.

Similarly, the short-run adjustment coefficients for sorghum markets range from 0 percent in Sinnar and Gedaref to 0.96 percent in Damazin. These results are intuitive because Sinnar and

Gedaref 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. Gedaref and Sinnar are major sources of sorghum for Khartoum and the long-run elasticities show that long-run prices in these markets are well-integrated with those in Khartoum. Production statistics for 2016/2017 show that 31 percent of sorghum produced in in Sudan was grown in Gedaref state while 12 percent of sorghum produced in Sudan was grown in Sinnar state, where Sinnar market is located (MoAF, 2021). The fact that these markets are not responding strongly in the short-term may imply that these markets are leading the relationship and cointegration rather than following trends, a hypothesis we test in the following section. Within Darfur, the short-run adjustment coefficients are given in Table 5 (Panel D). The long-run relationship and the short-run adjustment within Darfur are consistent with the findings by De Matteis et al. (2021) and generally highlight some resilience of markets even during conflict. However, the evidence that these spatial integrations are limited to short distances and within-region insinuates the potential role of conflicts and related infrastructural deficiencies in triggering cross-region spatial disintegration of markets. Finally, the significant differences in long-run elasticities (Table 4) and short-run adjustment coefficients are worth highlighting.

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

Panel A: Wheat										
State	Blue Nile	River Nile	White Nile	Gedaref	South Kordofan					
Market	Damazin	Ed Damer	Kosti	Gedaref	Kadugli					
(Market X, Khartoum)	-0.312***	-0.605***	-0.256**	-0.479***	-0.256***					
	(0.09)	(0.15)	(0.12)	(0.09)	(0.09)					
R-squared	0.48	0.42	0.47	0.56	0.42					
Panel B: Wheat (Among Darfur Markets)										
Market	Zalingei									
(Market X, El Fasher)	-0.205***									
	(0.05)									
R-squared	0.17									
Panel C: Sorghum										
State	Blue Nile	River Nile	North Kordofan	Gedaref	South Kordofan	Kassala	White Nile	Gezira	Sinnar	Sinnar
Market	Damazin	Ed Damer	El Obeid	Gedaref	Kadugli	Kassala	Kosti	Madani	Singa	Sinnar
(Market X, Khartoum)	-0.963***	-0.272**	-0.388**	-0.103	-0.404***	-0.888***	-0.757***	-0.716***	-0.817***	-0.157
	(0.15)	(0.12)	(0.16)	(0.20)	(0.07)	(0.18)	(0.18)	(0.16)	(0.20)	(0.24)
R-squared	0.54	0.52	0.49	0.43	0.48	0.48	0.51	0.50	0.48	0.49
Panel D: Sorghum (Among Darfur Markets)										
Market	El Fasher	El Geneina	Dain							
(Market X, Nyala)	-0.373***	-0.268***	-0.472***							
	(0.11)	(0.09)	(0.09)							
R-squared	0.27	0.22	0.37							

Notes: X is the list of markets cointegrating within Sudan (6 wheat markets and 10 sorghum markets) and within Darfur (1 wheat market and 3 sorghum markets). Standard errors are in parentheses. We use 4 lags in the case of wheat (Panel A) and 1 lag in the case of wheat (Panel B) and sorghum (Panels C and D). * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

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 0.75 months for Ed Damer to about 2.3 months for Kadugli and Kosti, suggesting substantial differences in the spatial market adjustments across markets. Similarly, the half-time coefficients for Sorghum (Panel C) range from 0.2 months for Damazin to about 6 months for Gedaref. Overall, quick adjustments in response to temporary disequilibrium are found for those markets with well-established trade linkages with the reference markets (Ed Damer). 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 the weak exogeneity of any of the wheat markets, but sorghum prices in Gedaref and Sinnar appear to be weakly exogenous to the system. This is not surprising, given that Gadaref and Sinnar are major sorghum producing states. These pieces of evidence are important for prioritizing short-term and long-term interventions. For example, policies aiming at long-term price stabilization in consumption hubs and large cities like Khartoum may need to boost production in these production hubs.

[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					
State	Blue Nile	River Nile	White Nile	Gedaref	South Kordofan
Market	Damazin	Ed Damer	Kosti	Gedaref	Kadugli
(Market X, Khartoum)	1.85	0.75	2.34	1.06	2.34

Panel B: Wheat (Among Darfur Markets)	
Market	Zalingei
(Market X, El Fasher)	3.03

Panel C: Sorghum										
State	Blue Nile	River Nile	North Kordofan	Gedaref	South Kordofan	Kassala	White Nile	Gezira	Sinnar	Sinnar
Market	Damazin	Ed Damer	El Obeid	Gedaref	Kadugli	Kassala	Kosti	Madani	Singa	Sinnar
(Market X, Khartoum)	0.21	2.18	1.41	6.38	1.34	0.32	0.49	0.55	0.41	4.06

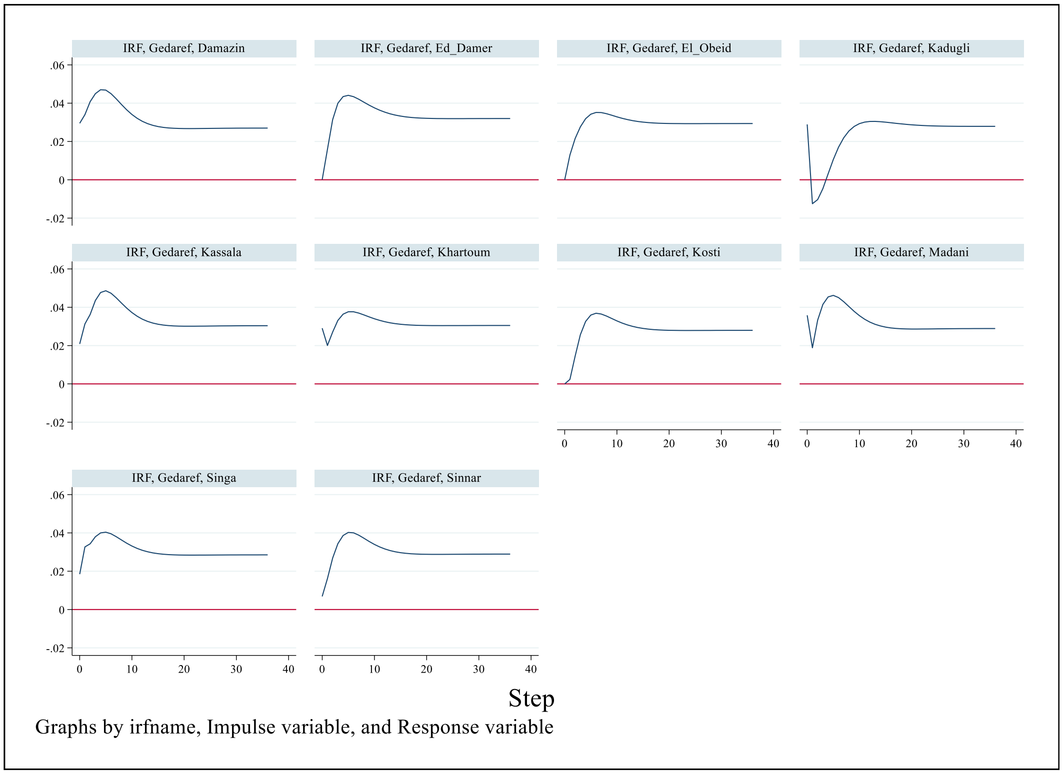
Panel D: Sorghum (Among Darfur Markets)			
Market	El Fasher	El Geneina	Dain
(Market X, Nyala)	1.48	2.22	1.09

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 $H_c = \frac{\ln(0.5)}{\ln(1-\rho)}$, where ρ is the total speed of adjustment parameter provided in Table 5. X is the list of markets cointegrating within Sudan (6 wheat markets and 10 sorghum markets).

5.3 Impulse Response Function Analyses

To further uncover price adjustment 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 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. As major wheat producing states and markets are not sufficiently integrated to wheat consumption markets, we focus on sorghum markets. Figure 6 shows the implication of one unit shock to sorghum prices in Gedaref, a major source of sorghum for Sudan and export markets. We can clearly see those 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 Gedaref. These trends show slightly distinct patterns in the short-run before settling in the long-run equilibrium, implying that these markets need a few months to transmit effect to other markets.

Figure 6: Impulse Response Functions: Sorghum



Source: Authors' computation based on FEWS NET data.

5.4 Policy Implications and Potential Avenues to Improve Market Integration

Our results are relevant for informing market policies and interventions in Sudan and other comparable contexts. Most importantly, the results suggest that improving the functioning and efficiency of markets in Sudan requires region-specific market interventions. States with high production potential require a different set of interventions compared to those states with high consumption. To identify state-specific interventions, Table 7 shows a typology of states according to their market integration conditions and production potential. Our findings point to three different sets of interventions. 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 especially benefit 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 when markets are well-integrated. However, as prices in production hubs are not sufficiently responding to changes in prices in consumption hubs, there is a 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 infrastructure are sufficiently responsive to changes in prices and shocks in neighboring states. But these markets are likely to be vulnerable to price shocks. For example, a reduction in wheat imports and related increase in domestic wheat prices, as modeled by Dorosh (2021), is likely to have different implications across states. States with high consumption levels (e.g., Khartoum) are likely to be more affected by price shocks than states with low levels of wheat consumption (e.g., Abay et al., 2022). These cereal deficit states can benefit from further spatial integration and diversification of trade networks, particularly with more cereal surplus states and markets in Sudan. They may also benefit from a better 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 also reduce producers' incentives and lower domestic production.

Table 1: Cereal Production Potential and Market Integration

Cereal	Production Potential	Market Integration	
		High	**None**
Wheat	**High**	Ed Damer	Dongola Madani
	Low	Khartoum Gadaref Kosti Kadugli Damazin	El Fasher Kassala Nyala El Obeid Zalingei Sinnar Singa
Sorghum	**High**	Gadarif Kassala Sinnar Madani Damazin	Sinnar Singa
	Low	Ed Damer Khartoum Kadugli Kosti El Obeid	Dain El Fasher El Geneina Zalingei Nyala Port Sudan

Source: Authors' compilation based on cointegration analysis.

6. Concluding Remarks

This paper evaluates spatial market integration in cereal markets in Sudan, focusing on wheat and sorghum, two major cereal crops. in the country 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 adjustment 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 among 6 of the 15 local wheat markets and 11 of the 18 sorghum markets. Despite strong spatial market integration among some neighboring markets, there is no market integration between several states and markets. For example, cereal markets in Darfur are not spatially integrated with several markets elsewhere in Sudan, despite exhibiting some spatial integration within the Darfur region. This may be explained by the frequent conflicts, political fragmentation, and lack of infrastructure that connects Darfur with the other main markets in other parts of Sudan. Among integrated markets, we observe significant variations in the strength of spatial integration 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 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. 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.

These findings have important policy implications for improving the efficiency and functioning of cereal markets in Sudan and other comparable settings. The lack of market integration between different regions and markets in Sudan suggests the need for investments in market infrastructure to ensure food security in Sudan. The strong market integration within (neighboring) states, even in contexts where road and related infrastructure are not well-developed, has two important implications. First, price related policies, including subsidies and stabilization policies, that target few markets and states will have major spillover effects into neighboring markets. Similarly, production shocks in some of these markets are likely to generate significant price hikes in neighboring states. The specific features of spatial integration and associated mechanisms we identify in this paper can inform targeting of interventions. Second, the strong spatial integration among some markets necessitates understanding and supporting local institutions or mechanisms facilitating integration of markets (De Matteis, et al., 2021; Hastings et al., 2021). Exploring these mechanism goes beyond the scope of this paper, but Hastings (2021) argues that informal institutions may help bridging the divide created by conflict, political fragmentation, and poor infrastructures. Finally, our approach relies on price-based adjustments to infer about spatial market integration. Future studies may complement this analysis with additional trade-volume data to distinguish specific features of spatial integration and market equilibrium in less developed and fragile markets (e.g., Barrett and Li, 2002).

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Appendix

Table A1: Average Domestic Nominal 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	4.08	15.53	23.68	60.25	161.27
Blue Nile					
Damazin	4.63	18.58	28.58	69.17	163.54
Darfur					
El Fasher	6.43	19.71	34.45	97.39	231.34
Nyala	5.41	18.27	24.16	71.97	189.83
Zalingei	8.57	17.59	31.69	69.44	112.38
Gadaref					
Gedaref	5.02	15.91	30.69	60.37	159.77
Gezira					
Madani	3.60	15.59	24.34	55.32	144.90
Kassala					
Kassala	4.04	17.01	29.38	75.62	166.59
North Kordofan					
El Obeid	4.34	15.99	25.68	62.25	166.31
Northern					
Dongola	3.92	24.46	25.29	56.82	154.51
River Nile					
Ed Damer	4.33	16.29	26.22	64.28	157.52
Sinnar					
Singa	3.98	15.63	25.54	60.59	160.19
Sinnar	4.09	15.21	23.34	61.43	152.80
South Kordofan					
Kadugli	4.29	16.39	31.22	66.33	160.80
White Nile					
Kosti	4.08	15.90	26.32	66.07	148.13

Source: Authors' calculations based on FEWS NET data.

Table A2: Average Domestic Nominal 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	3.22	9.17	16.40	54.87	98.96
Blue Nile					
Damazin	2.64	8.84	16.17	50.20	77.88
Darfur					
El Fasher	4.04	9.21	17.34	52.41	86.86
Nyala	3.44	10.31	17.34	39.38	71.77
El Geneina	3.62	10.66	16.84	53.67	94.44
Dain	3.99	10.62	19.73	65.16	154.30
Zalingei	3.31	12.29	15.68	48.46	80.12
Gedaref					
Gedaref	2.96	8.47	16.59	51.04	85.56
Gezira					
Madani	3.21	9.44	16.84	53.35	87.08
Kassala					
Kassala	3.05	9.60	15.74	56.53	85.19
North Kordofan					
El Obeid	3.38	9.45	16.36	54.89	96.58
Northern					
Dongola	3.77	9.68	19.00	63.63	121.98
Red Sea					
Port Sudan	3.49	9.92	17.76	59.92	102.60
River Nile					
Ed Damer	3.56	9.18	18.31	61.43	103.98
Sinnar					
Singa	2.78	7.78	14.52	45.16	73.96
Sinnar	2.82	8.33	14.47	49.32	79.07
South Kordofan					
Kadugli	3.03	7.38	12.81	37.99	81.42
White Nile					
Kosti	3.07	8.66	14.88	50.91	81.03

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	1.87	-0.26	-9.67***	1.74	-1.47	-8.13***
Blue Nile						
Damazin	1.55	-1.12	-10.77***	0.54	-2.14	-9.75***
Darfur						
El Fasher	1.38	-0.99	-11.85***	0.32	-2.27	-12.40***
Nyala	1.67	-0.57	-11.22***	0.37	-2.17	-9.57***
Zalingei	0.74	-1.69	-10.25***	0.25	-2.94	-9.36***
El Geneina	-	-	-	0.65	-2.83	-11.95***
Dain	-	-	-	0.48	-2.01	-10.18***
Gedaref						
Gedaref	3.12	0.25	-9.16***	1.16	-1.76	-8.08***
Gezira						
Madani	1.46	-0.92	-9.15***	0.93	-1.66	-10.14***
Kassala						
Kassala	1.28	-1.03	-10.75***	0.65	-1.76	-8.92***
North Kordofan						
El Obeid	3.69	0.24	-8.24***	1.84	-1.51	-8.02***
Northern						
Dongola	1.22	-1.47	-7.78***	1.82	-1.66	-8.09***
Red Sea						
Port Sudan	-	-	-	1.75	-1.47	-6.92***
River Nile						
Ed Damer	2.23	-0.63	-9.99***	1.597	-1.348	-7.56***
Sinnar						
Singa	2.22	-0.60	-9.27***	1.35	-1.80	-8.25***
Sinnar	2.31	-0.60	-10.05***	1.73	-1.46	-7.39***
South Kordofan						
Kadugli	1.36	-1.63	-10.71***	0.91	-1.72	-10.53***
White Nile						
Kosti	1.96	-0.89	-11.53***	1.25	-1.66	-8.08***

Notes: The null hypothesis for the ADF test is the 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 Wheat and Sorghum

Series Included	Rank (r) of Matrix	Trace statistics	Critical Value
Panel A: Wheat (2012:01 - 2021:08)			
Core markets = 3	2	2.72	3.76
Core markets + Kadugli = 4	3	2.44	3.76
Core markets + Kadugli + Damazin = 5	4	3.02	3.76
Core markets + Kadugli + Damazin + Gedaref = 6	**5**	**1.98**	**3.76**
Core markets + Kadugli + Damazin + Gedaref + Kassala = 7	5	13.69	15.41
Core markets + Kadugli + Damazin + Gedaref + Singa = 7	5	14.17	15.41
Core markets + Kadugli + Damazin + Gedaref + Madani = 7	5	14.21	15.41
Core markets + Kadugli + Damazin + Gedaref + Nyala = 7	5	14.07	15.41
Core markets + Kadugli + Damazin + Gedaref+ El Obeid = 7	4	10.72	15.41
Core markets + Kadugli + Damazin + Gedaref + Sinnar = 7	4	9.45	15.41
Core markets + Kadugli + Damazin + Gedaref + Dongola = 7	4	13.18	15.41
Core markets + Kadugli + Damazin + Gedaref + El Fasher = 7	4	10.68	15.41
Panel B: Wheat (Among Darfur Markets) (2012:01 - 2021:08)			
El Fasher + Zalingei = 2	**1**	**3.29**	**3.76**
El Fasher + Nyala = 2	-	6.09	3.76
Zalingei + Nyala = 2	-	4.99	3.76
El Fasher + Zalingei + Nyala = 3	-	24.33	15.41
Panel C: Sorghum (2015:01 - 2021:08)			
Core markets = 7	6	1.77	3.76
Core markets + Kadugli = 8	7	0.79	3.76
Core markets + Kadugli + Sinnar = 9	8	0.98	3.76
Core markets + Kadugli + Sinnar + Singa = 10	9	0.97	3.76
Core markets + Kadugli + Sinnar + Singa + Damazin = 11	**10**	**1.53**	**3.76**
Core markets + Kadugli + Sinnar + Singa + Damazin + Dongola = 12	0	16.02	15.41
Core markets + Kadugli + Sinnar + Singa + Damazin + El Fasher = 12	0	15.58	15.41
Core markets + Kadugli + Sinnar + Singa + Damazin + El Geneina = 12	0	14.70	15.41
Core markets + Kadugli + Sinnar + Singa + Damazin + Dain = 12	0	15.70	15.41
Core markets + Kadugli + Sinnar + Singa + Damazin + Nyala = 12	0	9.32	15.41
Core markets + Kadugli + Sinnar + Singa + Damazin + Zalingei = 12	0	10.15	15.41
Core markets + Kadugli + Sinnar + Singa + Damazin + Port Sudan = 12	0	12.23	15.41
Panel D: Sorghum (Among Darfur Markets) (2015:01 - 2021:08)			
El Fasher + Nyala = 2	1	0.71	3.76
El Fasher + Nyala + El Geneina = 3	2	1.74	3.76
El Fasher + Nyala + El Geneina + Dain = 4	**3**	**1.13**	**3.76**
El Fasher + Nyala + El Geneina + Dain + Zalingei = 5	3	14.54	15.41

Notes: Core wheat markets in Panel A include Khartoum, Ed Damer, and Kosti. Core sorghum markets in Panel B include Khartoum, El Obeid, Kosti, Ed Damer, Gedaref, Kassala, and Madani. We use 4 lags in the case of wheat (Panel A) and 1 lag in the case of wheat (Panel B) and sorghum (Panels C and D). The trace test reported concludes the number of cointegrating vectors in the system. The null hypothesis for trace test is rank=r against the alternative of rank>r.