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# Market integration and asymmetric price transmission in selected domestic markets for major staple foods in Uganda

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**Abstract**

In this study, we examined the price transmission dynamics and market integration among domestic markets for Uganda's major staple foods (matoke, maize, and beans) utilizing the Granger causality analysis, bounds test, Wald test for long- and short-run asymmetry, and the nonlinear ARDL model. Among the key findings, the causal order between wholesale and retail commodity prices flows unidirectionally forward from the wholesale to the retail level across all markets. Wholesale and retail prices for Uganda's staple foods are interlinked in all markets, and spatially separated markets are also well integrated. The Wald test revealed asymmetric price transmission (APT) in speed alone for the pairs wholesale and retail prices of matoke in Kampala, and wholesale prices of matoke in Mbarara with Kampala retail prices, both APT in magnitude and APT in speed for the pairs wholesale and retail prices of beans in Kampala, wholesale and retail prices of maize in Masindi, and wholesale prices of beans in Masindi with wholesale and retail prices in Kampala. We also found that in the long run, retail prices respond more strongly to wholesale price increases than decreases, an implication of positive APT in the marketing supply chain of Uganda's major staples. This may be linked to information asymmetry between traders and consumers, traders' adjustment costs, production levels, inventory management, and the market power of retailers. We thus concluded that final consumers are more likely to experience an increase rather than a decrease in the prices of staples at the retail level, while retailers are more likely to benefit from price decreases at the wholesale level.

**Keywords** ARDL model, Asymmetric price transmission, Vertical price transmission, Spatial price transmission, Integration of markets, Nonlinear ARDL, Prices of staple foods, Uganda

## Introduction

Promoting agricultural production growth, alleviating household poverty, and enhancing food security have been top of the agenda of the Ugandan government in recent years as outlined in the Vision 2040 statement [1]. With most of the population (72%) employed in the agricultural sector [2], and more than 66% of households depending on market purchases for a large part of the food consumed [3], the efficient functioning of agricultural markets is vital for achieving the above objectives [4]. Improvements in transport infrastructure and the liberalization of agricultural trade in Uganda since the 1990s [5] may have played a role in the integration of agricultural markets in the country. However, no recent empirical studies have been carried out to examine the functioning of domestic markets for the major staple foods in Uganda. Therefore, we conducted this study to examine the relationship, price transmission dynamics, and market integration among domestic markets for Uganda's major staple foods (matoke, maize, and beans). This is aimed at addressing the following questions: (1) What is the direction of causality among markets for

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staple foods in Uganda? (2) Are there asymmetric effects in the vertical and spatial price transmission of staple food prices in Uganda's domestic markets? (3) If asymmetric effects exist in these markets, what are the likely causes? (4) How much of a shock in staple food prices in producer markets is transmitted to the consumer markets? (5) How long does it take for staple food prices in the consumer markets to adjust to a price shock in the producer markets?

Considering the available literature, the causal order is expected to flow forward from the wholesale to the retail level [6, 7] and from producer markets to consumer markets. Secondly, for markets that are well cointegrated, it is expected that prices in consumer markets will move together with those in producer markets in the long run and that shocks in prices in the producer markets will be transmitted to the consumer markets quickly and completely. As stated by Ozturk [8] and Hassanzoy et al. [4], some of the key indicators of integration in agricultural markets are the extent to which agricultural commodity prices in one market respond to changes in another market and the ability to trade agricultural commodities between spatially separated markets. Additionally, spatially separated markets are said to be integrated when price signals and information are transmitted between the markets so that the prices of commodities in the two markets move together in the long run [4, 9]. If price changes in one market are transmitted to another market quickly and completely, it implies a high transmission, and therefore the two markets are well cointegrated. On the other hand, a slow transmission of price changes between markets implies weak or no cointegration in the markets [8].

The findings generated in this study are particularly important for Uganda because most of the country's population is employed in the agricultural sector and also a great percentage of the population are net food buyers [3]. Considering the importance of staple crops in the diets of the Ugandan population and their share of household incomes, it is imperative to examine the price transmission among the different actors in the trade of these items to generate the information necessary for improving inefficiencies in the markets, thereby aiding in the alleviation of household food insecurity and poverty. Secondly, the integration of agricultural markets and the behavior of agricultural commodity prices have welfare and policy implications for both producers and consumers of food items [9, 10]. This is because producers generate a large proportion of their income from the sale of agricultural produce, and consumers benefit from the integration of agricultural markets because well-functioning agricultural markets play a role in directing food from surplus-producing areas to those with less supply. Thirdly, changes in staple food prices in different markets are likely to affect the different actors in the value chain differently based on the integration of the markets. With some markets more connected than others, changes in prices of the same staple food vary across different locations [11]. Therefore, a clear understanding of how prices of major staples interact in different markets is vital in understanding how markets behave and such information is key for any strategy to protect the welfare of the different actors in the marketing value chain of major staples. Thus, enhancing the development of the food supply value chain, boosting the performance of agricultural and food markets, expediting the integration of domestic markets with regional and global markets, and stabilizing food prices in domestic markets [4].

### Overview of the production, consumption, and trade of staple foods in Uganda

Uganda produces a sufficient quantity of staple foods to meet the domestic demand [3]. The country is among the leading producers of staple foods such as beans, maize, and matoke in the East African region and a net exporter of these items to its neighbors, majorly Kenya, South Sudan, Rwanda, and the Democratic Republic of Congo through formal and informal means, with the informal means making a large part of the interregional trade [3, 12, 13]. The crops examined in this study (matoke, maize, and beans) are among Uganda's major staple foods, with production and consumption of each commodity varying across regions in the country.

Matoke (starchy bananas that are cooked and consumed as a staple), also known as "plantains," "banana," or "cooking banana," are important both as a food and cash crop, especially in the western and central regions where production is largely concentrated. Annual production stands at 9.76 million tons as of 2020 [14]. The western and central regions contribute close to 80% of this national output [11], while the Northern and Eastern regions contribute about 9% to the national production [3]. Most of the matoke produced are consumed on the domestic market because of their high degree of perishability. However, there is also trade in the regional markets. According to the available statistics, Uganda has the highest annual per capita consumption of bananas in the world, with consumption standing at a daily per capita consumption of about 0.4–0.7 kg making 140–255 kg annual per capita consumption [3, 15]. Thus, the crop is considered the main staple food in Uganda. Within Uganda, matoke from the major producing districts in the western region flow toward the main market centers in Kampala, Jinja, and Gulu [3].

In addition to contributing a significant part of household incomes (up to 9% of household incomes), beans form a large part of the diet of the majority of Ugandan households, especially among the poor who cannot afford the relatively expensive protein products [12]. They provide 25% of the total dietary calorie intake and 45% of the protein intake in Uganda. Uganda has a higher annual per capita bean consumption compared to other East African countries at about 16 kg [3, 15]. Annual bean production stands at 0.79 million tons as of 2020 [14], placing Uganda in the second position after Tanzania among bean-producing countries in Africa [12, 16]. The greatest share of this production (44%) is contributed by Southwestern Uganda, making it the leading producer of beans in the country [12]. This is followed by the Northern region which contributes about 25% of total national production [3].

Maize is the most widely grown crop in Uganda [17]. It is grown in almost every part of the country and covers the largest cultivated land among the major food crops cultivated [18]. However, in terms of caloric intake, maize is the third most important staple food after matoke and cassava [15]. Annual per capita consumption of maize is estimated at 31 kg with daily per capita caloric intake standing at 266 kcal [15]. Maize production has increased over the years from 1.1 million tons in 2000 to 4.56 million tons in 2020 [14], with the eastern region accounting for the highest share of this production at 47%. This is followed by the Western at 21%, Central at 19%, and Northern at 13% [13]. On the domestic market, maize is delivered from the major producing regions of Busoga, Masindi, Acholi, Lango, Teso, and Mt. Elgon to the key market centers such as Kampala, which represents about 50% of the formal maize trade [3].

Seasonality plays a major role in food availability and trade of maize and beans because they have two cropping seasons in most parts of the country, i.e., planting begins in March and harvesting occurs between June and August for the first season, while crops are planted in August and September and harvested between November and December for the second season. In contrast, matoke are harvested and marketed throughout the year [3]. The value chain of these staple foods consists of several actors, namely producers, brokers, middlemen, wholesalers, processors, retailers, exporters, and consumers. These play a role in the trade of staple foods from the farm gate to the final consumer, both locally and regionally across borders [3, 12, 16]. For example, in the maize value chain, farmers sell their produce to traders (both local and urban traders), or directly in markets within their locality. Local traders either sell to processors/millers directly or to urban traders who later sell to processors/millers. Urban traders also sell to institutions and other consumers [3]. Wholesalers grade and sell agricultural produce in large quantities to processors, large traders for export, and consumers [19]. In terms of domestic trade, Kampala is the major trading center and consumption market for most staple foods [12]. Kampala markets rely on food from other areas because there is very little agricultural production. And because of the higher levels of urbanization and relatively higher levels of per capita incomes among the population in Kampala compared to other areas, food prices in Kampala are usually higher than those in other markets [19].

#### Literature review on price transmission

There exists an extensive body of literature on price transmission among agricultural commodities across markets. Table 1 provides a summary of some of these studies.

As summarized in Table 1, a considerable number of studies have examined price transmission dynamics across markets of agricultural commodities. These studies have analyzed vertical and spatial price transmission across markets. The studies examining vertical transmission have concentrated on transmission along the different levels of the marketing value chain, i.e., transmission between farm, wholesale, and retail prices. On the other hand, the studies examining spatial transmission have focused on transmission between domestic prices and global prices except for four major studies, i.e., Ojiako et al. [21], Zakari et al. [23], Wondemu [25], and Helder and Rafael [29] that have attempted to examine spatial transmission across domestic markets. Although these studies reported cointegration relationships across the examined markets, only Wondemu [25] examined price transmission in an asymmetric framework while employing the threshold vector error correction model. The authors reported the existence of asymmetric price transmission (APT) for teff, i.e., teff prices adjust more quickly to positive shocks than to negative shocks. Similarly, the current study focuses on price transmission among Uganda's major staple food across domestic markets. We focus on the price movements across domestic markets rather than on the movement with global prices because most of the major staples in Uganda are not traded on international markets but rather domestically, which makes the country partially shielded from the direct impacts of global food price movements [34].

Additionally, a considerable number of studies have employed the VEC model in their analyses. Although this approach investigates the long-run movement of prices, examining price transmission in an asymmetric framework presents more advantages over the VECM approach, i.e., such an approach provides more insights into the price transmission dynamics, enables the measurement of deviations from the long-run equilibrium and allows examining the asymmetric transmission [27]. It is

**Table 1** Summary of literature on price transmission

| Country(ies) | Author(s) | Data: econometric model(s) | Commodity: price transmission examined | Results |
|---|---|---|---|---|
| Poland and Hungary | Bakucs et al. [20] | Monthly, January 1995 to July 2007: Vector Error Correction Model (VECM) and the Johansen cointegration (JC) | Milk: Vertical transmission between farm and retail prices | Short and long-term asymmetries in Polish milk prices. No asymmetries in the Hungarian prices |
| Nigeria | Ojiako et al. [21] | Weekly, week 37 of 2004 to week 28 of 2006: JC and VECM | Gari (Cassava product): Spatial transmission between urban and rural markets | Cointegration between prices in urban and rural markets. Unidirectional Granger causal relationship from the rural to urban markets |
| Panama | Acosta et al. [22] | Monthly, January 2000 to December 2011: Asymmetric VECM (AVECM) | Milk: Spatial transmission between global and domestic producer (farm gate) prices | Long-run equilibrium and cointegration relationship between global and domestic producer prices. Price changes in global markets are transmitted to domestic markets with a lower magnitude. Asymmetric Price Transmission (APT) in global and domestic milk prices, i.e., increases in global prices are transmitted faster to producers than decreases |
| Niger | Zakari et al. [23] | Monthly, January 2006 to March 2012: Cointegration and VECM | Millet, sorghum, maize, and rice: Spatial transmission between domestic, international, and regional market prices | Domestic prices respond to negative and positive shocks in regional and international markets differently. Maize and rice prices have a high speed of adjustment to world prices compared to millet and sorghum prices |
| Dutch | Verreth et al. [24] | Weekly, January 2005 to December 2008: Houck approach and Error Correction Model (ECM) | Onion and red pepper: vertical transmission between producer, retail, wholesale, export, and import prices | Red pepper prices return to their long-term equilibria relatively more quickly than onion prices. APT in producer-wholesale and international-producer onion prices. APT between producer and retail prices for red pepper |
| Ethiopia | Wondemu [25] | Monthly, 2008 to 2012: Threshold VECM (TVECM) | White teff, red teff, and maize: Spatial transmission between Addis Ababa, Mekelle, and Dire Dawa markets | APT for teff, prices adjust more quickly to positive shocks than to negative shocks. No APT for maize |
| United States (US) | Fousekis et al. [6] | Monthly, January 1990 to January 2014: Nonlinear Autoregressive Distributed Lag (NARDL) | Beef: Vertical transmission between farm, wholesale, and retail prices | Presence of asymmetry in magnitude for the pair farm-wholesale and the presence of both asymmetry in speed and asymmetry in magnitude for the pair wholesale-retail |

**Table 1** (continued)

| Country(ies) | Author(s) | Data: econometric model(s) | Commodity: price transmission examined | Results |
|---|---|---|---|---|
| India | Shrinivas and Gómez [26] | Monthly, October 2002 to September 2012: VECM and Threshold ECM (TECM) | Cotton: vertical price transmission between international and domestic prices, and transmission from domestic to farm gate prices | Indian markets are well integrated with international markets. APT between domestic and farm gate prices. In the short run, farm gate prices respond faster to changes in domestic prices when domestic prices decrease than when they increase. The loss in revenue from a decrease in domestic price is larger than the gains from an increase in domestic price of the same magnitude |
| Afghanistan | Hassanzoy et al. [4] | Monthly, March 2004 to June 2015: Consistent Momentum Threshold Autoregressive (MTAR) and VECM | Wheat and wheat flour: Spatial transmission between domestic prices with supplier countries and global markets | Cointegration between domestic wheat and flour markets with global, Kazakh, and Pakistani markets |
| Oceania (OC), European Union (EU), and the US | Zhang et al. [27] | Monthly, January 2006 to December 2015: VECM | Whole milk powder: Spatial transmission between OC, EU, and US | Cointegration between whole milk powder prices in OC, EU, and US in the long run. A causal relationship between OC and EU prices and quick adjustment to deviations. No correlation between OC and US, Unidirectional causal relationship from the EU to the US |
| Poland, Czech Republic, Slovakia, and Hungary | Vargova and Rajcaniova [28] | Monthly, January 2005 to June 2017: Cointegration tests and VECM | Milk: Spatial transmission across the four countries | Cointegration in milk prices in the examined countries |
| Mozambique and Malawi | Helder and Rafael [29] | Monthly, 2000 to 2016: JC, Granger causality test, and ECM | White maize grain: Spatial transmission between two deficit markets (Maputo in Mozambique and Blantyre in Malawi) and two surplus markets (Chimoio and Nampula in Mozambique) | Causal relationships between market pairs, i.e., Joint long-run relationship between Chimoio with Maputo, Nampula, and Blantyre markets. Bidirectional causality between Maputo and Chimoio; Maputo and Nampula; and Chimoio and Nampula pairs |
| Turkey | Ozturk [8] | Monthly, January 2005 to March 2015: ECM | Wheat, barley, maize, soybean, and rice: Spatial transmission between producer prices and the world market prices | No cointegration between domestic rice prices and world prices. Weak cointegration of the other commodity prices with the world prices |
| Indonesia | Kamaruddin et al. [30] | 1980 to 2018: NARDL | Coffee: Spatial transmission between domestic producer prices and global prices | Cointegration between domestic and global markets. The existence of both APT in speed and magnitude. Domestic coffee producer prices respond faster to decreases in world prices than to their increases |

**Table 1** (continued)

| Country(ies) | Author(s) | Data: econometric model(s) | Commodity: price transmission examined | Results |
|---|---|---|---|---|
| US | Panagiotou [7] | Monthly, 1990 to 2018: NARDL | Pork: Vertical transmission between the farm retail and wholesale-retail pairs | APT in magnitude for the wholesale-retail pair and both APT in speed and magnitude for the farm-retail pair. In the long run, retail prices respond to positive shocks in the farm and wholesale prices faster than negative ones |
| EU, New Zealand, the US, and the Rest of the World (RoW) | Xue et al. [31] | Monthly, January 2010 to December 2019: Global Vector Autoregressive (GVAR), Global VECM, Generalized impulse response functions | Butter: Spatial transmission across the EU, New Zealand, US, and the RoW, and vertical transmission along the supply chain. Transmission of price shocks between butter export prices of the different exporting countries and changes in factors such as crude oil, palm oil, farm gate raw milk prices, exchange rates, and consumer price index (CPI) | Decreases in farm gate raw milk prices are swiftly transmitted to butter export prices of both the home country and the foreign countries. Butter export markets are not well integrated however, butter export prices in New Zealand and the US are highly integrated. Palm oil and crude oil prices only affect global butter export prices. The US dollar depreciation against the Euro caused a decline in US butter export prices |
| China | Liu et al. [32] | Monthly, November 2009 to October 2021: NARDL and Asymmetric autoregressive conditional heteroskedasticity model | Carp: vertical transmission between wholesale and retail prices | There is a nonlinear cointegration between wholesale and retail prices and APT in speed and magnitude |
| India | Sendhil et al. [9] | Monthly, July 2000 to June 2022: Bai Perron's test for structural breaks, JC, Granger causality test, and impulse response function | Rice and wheat: spatial transmission between wholesale and retail prices across domestic markets, i.e., Chennai, Delhi, Mumbai, and Patna | Existence of spatial and temporal variation price dynamics in the selected markets. Cointegration between wholesale and retail prices across markets after accounting for structural breaks |
| Kenya, Tanzania, and Uganda | Waiswa [33] | Monthly, January 2015 to September 2022: NARDL | Maize Grain: Spatial transmission across markets in Kenya, Tanzania, and Uganda | No statistically significant relationship between prices in Uganda and those in Tanzania. There exists a statistically significant relationship between prices in Uganda and Tanzania with those in Kenya |

against this background that the current study utilizes the nonlinear autoregressive distributed lag (NARDL) model to examine the asymmetric price transmission in the wholesale and retail markets of Uganda's major staple foods, similar to studies by Fousekis et al. [6], Kamaruddin et al. [30], Panagiotou [7], Liu et al. [32], and Waiswa [33]. The NARDL model presents a wide range of advantages over other cointegration approaches, i.e., the NARDL model decomposes the variables of interest into their positive and negative partial sums, allows for the analysis of nonlinearity and, for the detection of asymmetric effects in the long and short run, i.e., it allows for the differentiation of APT in magnitude from that in speed [6, 35]. Additionally, the NARDL model can detect cointegrating relationships efficiently even in small samples and it allows for the inclusion of regressors that are integrated of different orders, i.e., I(0) and I(1), but not I(2) [7, 32, 36].

We are not aware of a study that investigates the APT in the marketing value chain of Uganda's staple foods with emphasis on the speed and magnitude of asymmetric price transmission at all possible levels of Uganda's staple food supply chain despite the efforts by the Ugandan government to liberalize agricultural trade since the 1990s [5]. This study attempts to fill this gap by providing a theoretical underpinning of the price transmission of major staple foods across domestic markets (spatially and vertically) in Uganda's agri-food marketing supply chain. Moreover, the approach used in this study estimates the possible asymmetric behavior of actors (wholesalers and retailers) in the marketing of Uganda's major staple foods. This paper contributes to the available literature in the following ways: We examine the APT in wholesale and retail prices of major staples in Uganda putting into consideration the three forms of APT, i.e., in speed and magnitude, positive and negative, and vertical and spatial transmission. We further attempt to identify some of the possible causes of APT in markets of Uganda's staple foods. In terms of the research model, we utilize the NARDL model and Wald's test to examine the presence of asymmetric effects in the vertical and spatial contexts in the different markets of staple foods in Uganda.

## Material and methods

### Conceptual framework

Price transmission occurs when prices in one market change in response to price changes in another market [29]. Meyer and Von Cramon-Taubadel [37] categorized Asymmetric Price Transmission (APT) into three forms. The first form is APT in magnitude or speed. APT in magnitude, refers to the magnitude of the change in prices at a given market level in response to the price changes at another market level. And APT in speed indicates the length of time it takes for prices at a given market level to adjust to price changes at another market level [6, 30]. APT in speed causes a temporary transfer of welfare, while APT in magnitude causes a permanent transfer of welfare, i.e., from buyers of a commodity to the sellers. The size of this transfer depends on the changes in price and the volumes involved in the transaction. APT in both speed and magnitude causes a combination of the temporary and permanent transfer of welfare.

The second classification of APT is according to the sign of the price transmission, i.e., either positive or negative. Positive asymmetry happens when prices in a given market respond more fully or rapidly to an increase in another market than to a decrease. On the other hand, negative asymmetry happens when prices in a given market respond more fully or rapidly to a decrease in another market than to an increase. The third classification of APT depends on whether it affects price transmission vertically or spatially. APT in a vertical context happens when the asymmetry in price transmission occurs at different levels of the marketing chain, i.e., farm level, wholesale, and retail levels, while APT in the spatial context happens when the asymmetry in price transmission occurs in spatially separated markets [32, 37]. Integration in spatially separated markets involves the transfer of Marshallian excess demand between geographically separated markets evident in terms of the physical flow of commodities between spatially distinct markets, the transmission of price movements, or both [27, 29]. Spatial and vertical APT can be classified in terms of speed and magnitude of the price transmission, and whether price transmission is positive or negative. According to the available literature, APT is attributed to factors such as market power or imperfect competition in the market, adjustment costs faced by firms, transaction costs, government intervention, i.e., trade policies such as exchange rate policies, tariffs on imports, quotas, export taxes, export subsidies among others, asymmetric information, perishability of commodities because actors do not want to risk staying with spoiled commodities, and inventory management [22, 24, 37].

In this study, we consider APT for maize, beans, and matoke in the vertical and spatial context across Kampala, Mbarara, Masindi, and Tororo. Following Helder and Rafael [29], let $p_t^i$ denote the price of matoke, maize, and beans in the market $i$ (Kampala, Mbarara, Masindi, and Tororo) at time $t$ (monthly, January 2015 to January 2023), $r_t^{ij}$ represents transaction costs such as transport costs associated with the physical movement of commodities between spatially separated markets $i$ and $j$ at time $t$, and $q_t^{ij}$ denote trade flow of commodities from market $i$ to market $j$ at time $t$. Equation 1 represents the competitive spatial equilibrium.

$$p_t^i - p_t^j \begin{cases} \leq r_t^{ji} & \text{if } q_t^{ji} = 0 \\ = r_t^{ji} & \text{if } q_t^{ji} \in \left[0, q_t^{ji*}\right] \\ \geq r_t^{ji} & \text{if } q_t^{ji} = q_t^{ji*} \end{cases} \tag{1}$$

Equation 1 suggests three possible situations that are likely to prevail. The first situation occurs when the price difference between two geographically separated markets is smaller or equal to the transaction costs associated with the physical movement of commodities between the two markets. This implies that trade in the commodities between the two markets is not profitable, so it does not occur and even if it occurs, traders are bound to make losses. The second situation occurs when the price difference between two geographically separated markets is equal to the transaction costs associated with the physical movement of commodities between the two markets. This implies that the volume of trade in commodities between the two markets lies between zero and a trade ceiling $q_t^{ji*}$ in case it exists. Here, the two spatially distinct markets are in a competitive spatial equilibrium explained under the Law of One Price (LOP), which states that commodity prices in spatially distinct markets are the same once transaction costs are taken into account [27]. Competitive spatial equilibrium could occur with or without the physical transfer of commodities between two spatially distinct markets because when transaction costs associated with the movement of commodities between the two markets are fully covered, traders are indifferent between trading and not trading. While in the competitive spatial equilibrium state, perfect price transmission between two markets occurs when a price change in one market results in a similar change in prices in the other market. In the third situation, the price difference between two spatially separated markets is greater than or equal to the transaction costs associated with the movement of commodities between the two markets. This implies that trade in the commodities between the two markets will be equal to a trade ceiling $q_t^{ji*}$ in case it exists. This situation could be a result of trade volume restrictions between the two markets, government price supports, exchange rate risk, non-tariff barriers, tariffs, non-tradable inputs, and institutional factors impacting price [27], and markets under this pattern are associated with inefficiencies regardless of whether trade in commodities occurs between the two markets or not.

**Data, model specification, and econometric methodology**

In this study, we used monthly wholesale and retail prices from January 2015 to January 2023 to examine the price transmission and integration among domestic markets for Uganda's major staples, i.e., matoke, beans, and maize. We utilized the NARDL model to examine the APT in the wholesale and retail prices of these staples with an emphasis on the three forms of APT, i.e., in speed and magnitude, positive and negative, and vertical and spatial transmission. We examined vertical price transmission between wholesale and retail prices of staples in the different markets. We also examined the spatial price transmission in the following markets: Mbarara and Kampala for matoke, Kampala and Masindi for beans, and Kampala, Masindi, and Tororo for maize. These districts were selected based on the availability and completeness of price data (2015–2023), which is required for such analysis. Among these markets, Kampala is the major market for the three commodities. Matoke flow from Mbarara, beans flow from Masindi, and maize flows from Masindi and Tororo to Kampala [3]. This suggests that Kampala markets are very significant in contributing to price determination among staple foods in Uganda.

The wholesale and retail prices used in this study were obtained from the monthly price bulletins of the Famine Early Warning Systems Network (FEWSNET) [38] and are expressed in Ugandan Shilling (UGX) per kilogram of food item. The monthly trend in wholesale and retail prices of these crops in the studied markets are presented in Figs. 1, 2, and 3. These figures show seasonal fluctuations in the prices of the three crops across all markets. These cyclic movements are attributed to seasonality in the planting and harvesting calendar, which influences food supply to the markets [39]. The upward trends in the prices of the three crops noted in the graphs has been linked to the following factors: Firstly, low production due to changes in the weather pattern manifested in long dry spells in some regions and floods in other regions [39]. Secondly, the price transmission effects of rising food, fuel, and production input prices such as fertilizer prices in the international markets affect domestic production and transportation costs of food items [34, 39, 40]. It can also be noted that wholesale and retail prices of each food item follow the same trends and patterns across all markets, which indicates the possibility of integration of these markets and the existence of a long-term relationship among these prices across all markets.

We transformed all the prices into their natural logarithms for the empirical analysis. This was intended to reduce variability in prices and increase the possibility of stationarity of their first differences and also to allow these first differences and the estimated coefficients to be interpreted as growth rates and price transmission

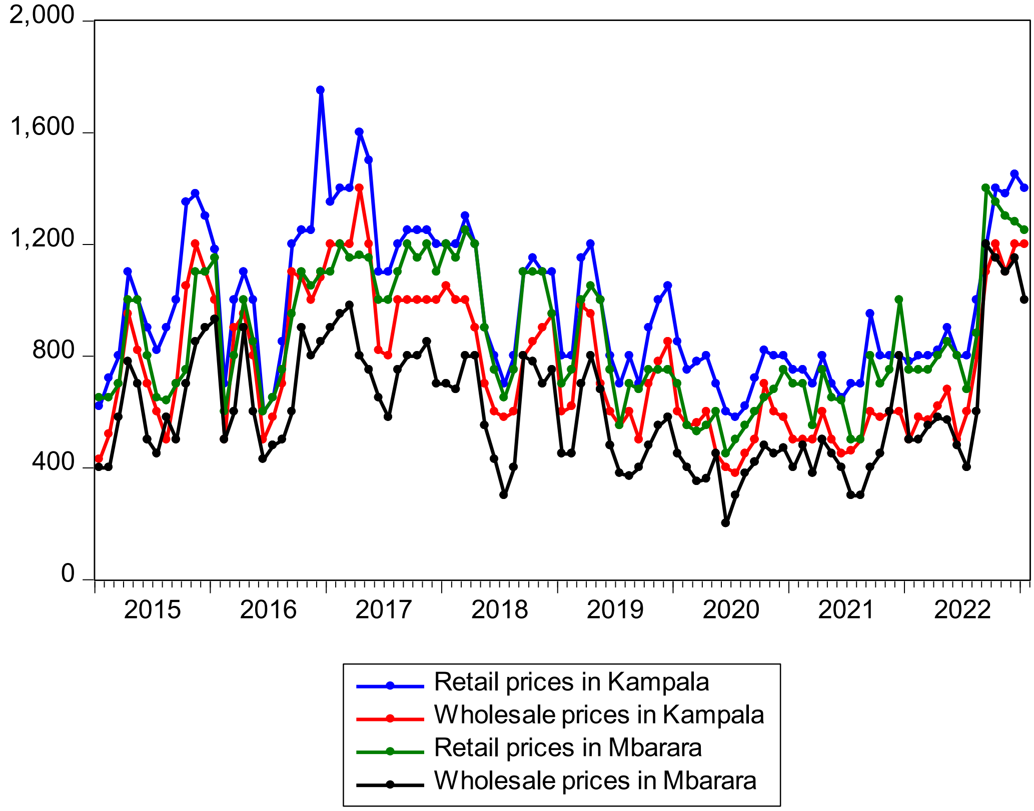


**Fig. 1** Prices of matoke in Mbarara and Kampala. Source: FEWSNET [38]

elasticities, respectively [2, 41]. We begin this study's empirical analysis by determining the order of integration of the wholesale and retail prices in the different markets. This is because the NARDL model employed in this study requires that none of the series examined is integrated of order 2. The series can be integrated of order 0 or 1 [35, 41]. Considering this, as a first step to our analysis, we conducted unit root tests, i.e., Phillips–Perron (PP) and Elliott–Rothenberg–Stock DF-GLS unit root tests, and augmented Dickey–Fuller (ADF) and Zivot–Andrews unit root tests with one structural break. Results of these tests revealed that the series were either I(0) or I(1), and none of them was I(2) as presented in Tables 3 and 4, which meets the prerequisite of the NARDL model. We proceeded with performing the Granger causality analysis to determine the causal markets.

### Granger causality analysis

The Granger causality analysis determines whether a time series variable for example $X_t$ contains sufficient information to predict future values of another time series variable $Y_t$. This suggests that if past values of $X_t$ significantly contribute to forecasting future values of $Y_t$, then $X_t$ is said to Granger cause $Y_t$, and if past values of $Y_t$ significantly contribute to forecasting future values of $X_t$, then $Y_t$ is said to Granger cause $X_t$ [42]. This analysis involves testing the null hypothesis that $X_t$ does not Granger cause $Y_t$ and vice versa by running the following regressions [42]:

$$Y_t = \alpha_0 + \sum_{i=1}^{n} a_{1i} Y_{t-i} + \sum_{i=1}^{n} b_{1i} X_{t-i} + u_{1t} \quad (2)$$

$$X_t = b_0 + \sum_{i=1}^{n} a_{2i} Y_{t-i} + \sum_{i=1}^{n} b_{2i} X_{t-i} + u_{2t} \quad (3)$$

where $u_{1t}$ and $u_{2t}$ are the white noise error processes and n denotes the number of lagged variables. The null hypothesis that $X_t$ does not Granger cause $Y_t$ is rejected if $b_{1\mathrm{i}}$ are jointly significant. Likewise, the null hypothesis that $Y_t$ does not Granger cause $X_t$ is rejected if $a_{2\mathrm{i}}$ are jointly significant. In the vertical context, results of the Granger causality analysis presented in Table 5 suggest that the causal order flows from the wholesale level to the retail level. In the spatial context, the causal order for matoke flows from wholesale prices in Kampala to wholesale prices in Mbarara, and from wholesale prices

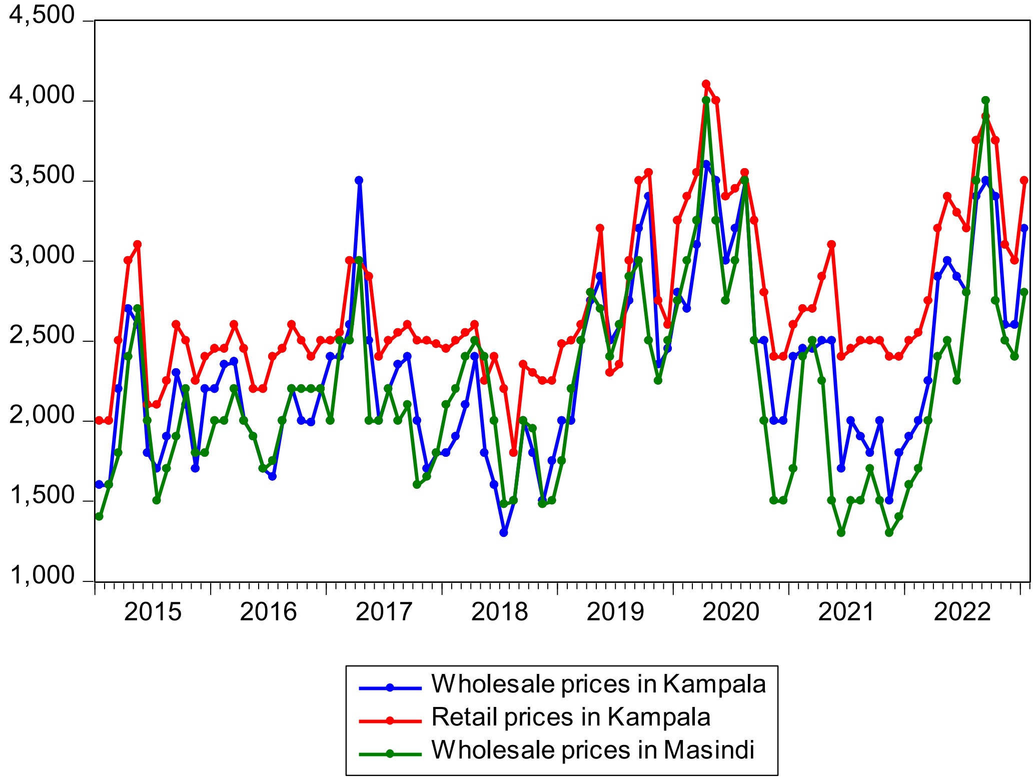


**Fig. 2** Prices of beans in Kampala and Masindi. Source: FEWSNET [38]

in Mbarara to retail prices in Kampala. For beans, the causal order flows from wholesale prices in Masindi to wholesale and retail prices in Kampala. And for maize, the causal order flows from wholesale prices in Masindi and Tororo to retail prices in Kampala. Based on these results, we specified the models as shown in Eqs. 4, 5, and 6.

$$\mathrm{LnRP}_t = \beta_{\mathrm{I}} + \beta_{1\mathrm{i}}\mathrm{LnWP}_t + \varepsilon_{1t} \quad (4)$$

$$\mathrm{LnWP\_Y}_t = \beta_{\mathrm{ii}} + \beta_{1\mathrm{ii}}\mathrm{LnWP\_X}_t + \varepsilon_{2t} \quad (5)$$

$$\mathrm{LnRP\_Y}_t = \beta_{\mathrm{iii}} + \beta_{1\mathrm{iii}}\mathrm{LnWP\_X}_t + \varepsilon_{3t} \quad (6)$$

where RP and WP denote retail and wholesale prices, respectively, $X$ and $Y$ denote the different markets of each staple food examined in this study, and $X$ represents the causal market based on the Granger analysis results. Equation 4 is to be interpreted as retail prices of a staple in each market are dependent on that staple's wholesale prices in that market. Equation 5 is to be interpreted as wholesale prices in market $Y$ are dependent on the wholesale prices in market $X$. Equation 6 is to be interpreted as retail prices in market $Y$ are dependent on wholesale prices in market $X$. This is intended to examine how retail prices in a consumption market (Kampala) respond to changes in the wholesale prices in the producer markets, i.e., Mbarara for Matoke, Masindi for beans, and Masindi and Tororo for maize since some retail traders in Kampala buy food commodities from wholesalers in the producing districts. Ln denotes the natural logarithm of the wholesale and retail prices, $\beta_{\mathrm{I}}$, $\beta_{\mathrm{ii}}$, and $\beta_{\mathrm{iii}}$ are intercepts, $\beta_{1\mathrm{i}}$, $\beta_{1\mathrm{ii}}$, and $\beta_{1\mathrm{iii}}$ are coefficients of their respective variables, and $\varepsilon_{1t}$, $\varepsilon_{2t}$, and $\varepsilon_{3t}$ are the error terms.

### Empirical models (ARDL and NARDL models)

The first step in the formulation of the NARDL model is the formulation of the linear ARDL model. In the linear ARDL model, the retail prices of each staple in the different markets were expressed as a function of their lagged values, the current and lagged values of each staple's wholesale price in the different markets as shown in Eq. 7. Similarly, wholesale and retail prices in market Y were expressed as a function of their lagged values, the current and lagged values of wholesale prices in market

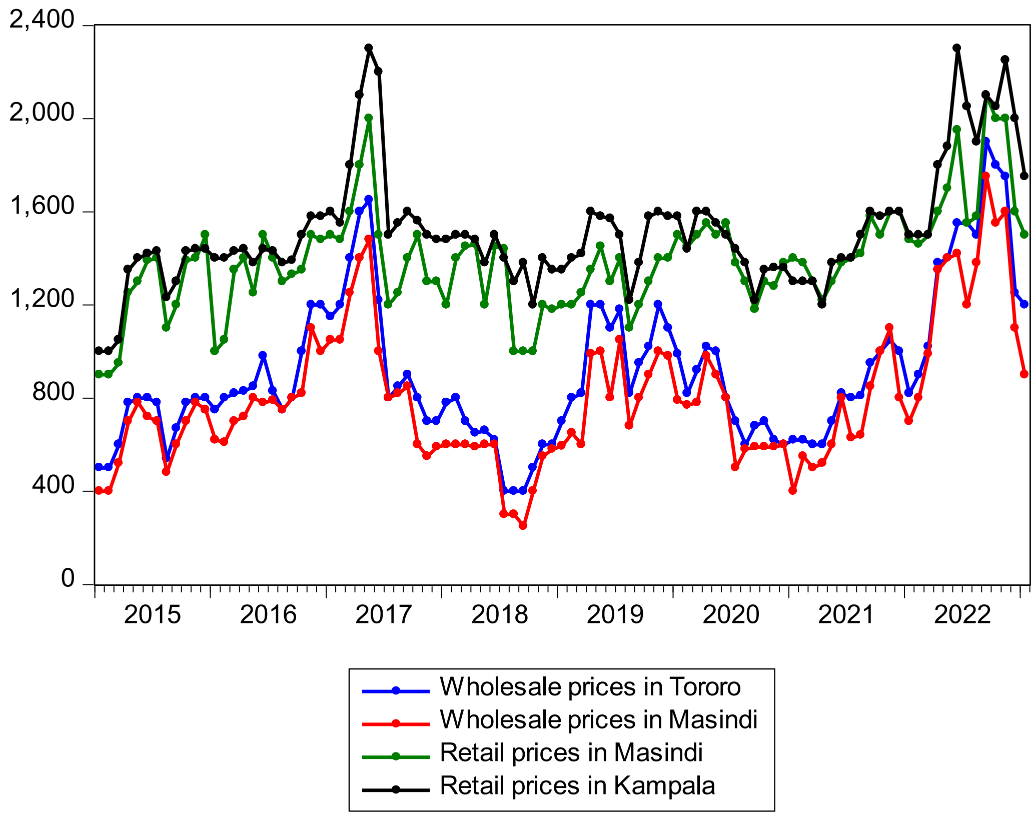


**Fig. 3** Prices of maize in Tororo, Masindi, and Kampala. Source: FEWSNET [38]

$X$ (causal markets) for each staple food item as shown in Eqs. 8 and 9. Equations 4, 5, and 6 are transformed into the following linear ARDL models.

$$\Delta \mathrm{LnRP}_t = \alpha_{\mathrm{I}} + \sum_{i=1}^{p} \theta_i \Delta \mathrm{LnRP}_{t-I} + \sum_{i=0}^{q} \beta_{1\mathrm{i}} \Delta \mathrm{LnWP}_{t-I} + \lambda_{1\mathrm{i}} \mathrm{LnRP}_{t-1} + \lambda_{2\mathrm{i}} \mathrm{LnWP}_{t-1} + u_{1t} \tag{7}$$

$$\Delta \mathrm{LnWP\_Y}_t = \alpha_{\mathrm{ii}} + \sum_{i=1}^{p} \theta_{\mathrm{ii}} \Delta \mathrm{LnWP\_Y}_{t-I} + \sum_{i=0}^{q} \beta_{1\mathrm{ii}} \Delta \mathrm{LnWP\_X}_{t-I} + \lambda_{1\mathrm{ii}} \mathrm{LnWP\_Y}_{t-1} + \lambda_{2\mathrm{ii}} \mathrm{LnWP\_X}_{t-1} + u_{2t} \tag{8}$$

$$\Delta \mathrm{LnRP\_Y}_t = \alpha_{\mathrm{iii}} + \sum_{i=1}^{p} \theta_{\mathrm{iii}} \Delta \mathrm{LnRP\_Y}_{t-I} + \sum_{i=0}^{q} \beta_{1\mathrm{iii}} \Delta \mathrm{LnWP\_X}_{t-I} + \lambda_{1\mathrm{iii}} \mathrm{LnRP\_Y}_{t-1} + \lambda_{2\mathrm{iii}} \mathrm{LnWP\_X}_{t-1} + u_{3t} \tag{9}$$

where Δ denotes the first difference operator, α represents the constant term, $\theta$ and $\beta$ are the short-run coefficients, $\lambda$ represents the long-run coefficients, $u_t$ is the error term, and $p$ and $q$ denote the lags, determined using the Akaike information criteria (AIC) in this study.

Equations 7, 8, and 9 were then transformed into the NARDL models, which incorporate the asymmetric relationship between the prices of staple foods in the different markets, unlike the ARDL models which assume a symmetric relationship between the prices [35]. In the

NARDL model, prices are decomposed into their negative and positive sums as expressed in Eqs. 10, 11, and 12.

$$\Delta \text{LnRP}_t = \alpha_1 + \rho_1 \text{LnRP}_{t-1} + \beta_1^{+} \text{LnWP}_{t-1}^{+} + \beta_2^{-} \text{LnWP}_{t-1}^{-} + \sum_{j=1}^{p-1} \varphi_j \Delta \text{LnRP}_{t-j} + \sum_{j=0}^{q} (\pi_j^{+} \Delta \text{LnWP}_{t-j}^{+} + \pi_j^{-} \Delta \text{LnWP}_{t-j}^{-}) + e_{1t} \tag{10}$$

$$\Delta \text{LnWP\_Y}_t = \alpha_2 + \rho_2 \text{LnWP\_Y}_{t-1} + \beta_{1i}^{+} \text{LnWP\_X}_{t-1}^{+} + \beta_{2i}^{-} \text{LnWP\_X}_{t-1}^{-} + \sum_{m=1}^{p-1} \varphi_m \Delta \text{LnWP\_Y}_{t-m} + \sum_{m=0}^{q} (\pi_m^{+} \Delta \text{LnWP\_X}_{t-m}^{+} + \pi_m^{-} \Delta \text{LnWP\_X}_{t-m}^{-}) + e_{2t} \tag{11}$$

$$\Delta \text{LnRP\_Y}_t = \alpha_3 + \rho_3 \text{LnRP\_Y}_{t-1} + \beta_{1ii}^{+} \text{LnWP\_X}_{t-1}^{+} + \beta_{2ii}^{-} \text{LnWP\_X}_{t-1}^{-} + \sum_{n=1}^{p-1} \varphi_n \Delta \text{LnRP\_Y}_{t-n} + \sum_{n=0}^{q} (\pi_n^{+} \Delta \text{LnWP\_X}_{t-n}^{+} + \pi_n^{-} \Delta \text{LnWP\_X}_{t-n}^{-}) + e_{3t} \tag{12}$$

where $\text{LnWP}_t^{+}$, $\text{LnWP}_t^{-}$, $\text{LnWP\_X}_t^{+}$, and $\text{LnWP\_X}_t^{-}$ are the partial sum process of positive and negative changes in $\text{LnWP}_t$ and $\text{LnWP\_X}_t$, $-\frac{\beta^{+}}{\rho}$ and $-\frac{\beta^{-}}{\rho}$ represent the asymmetric long-run coefficients, the short-run coefficients are represented by:

$$\sum_{j=0}^{q} \pi_j^{+}, \sum_{j=0}^{q} \pi_j^{-}, \sum_{m=0}^{q} \pi_m^{+}, \sum_{m=0}^{q} \pi_m^{-}, \sum_{n=0}^{q} \pi_n^{+}, and \sum_{n=0}^{q} \pi_n^{-}.$$

After estimating models 10, 11, and 12 using the standard ordinary least squares method (OLS), we test for the presence of a long-run asymmetric relationship between the prices using the bounds cointegration test. The null hypotheses of no long-run relationship are $\rho_1 = \beta_1^{+} = \beta_2^{-} = 0$, $\rho_2 = \beta_{1i}^{+} = \beta_{2i}^{-} = 0$, and $\rho_3 = \beta_{1ii}^{+} = \beta_{2ii}^{-} = 0$ for Eqs. 10, 11, and 12, respectively. The alternative hypotheses of the existence of a long-run relationship are $\rho_1 \neq \beta_1^{+} \neq \beta_2^{-} \neq 0$, $\rho_2 \neq \beta_{1i}^{+} \neq \beta_{2i}^{-} \neq 0$, and $\rho_3 \neq \beta_{1ii}^{+} \neq \beta_{2ii}^{-} \neq 0$ for Eqs. 10, 11, and 12, respectively. The null hypothesis is rejected if the computed F-statistic is bigger than the upper critical value and cannot be rejected if the computed F-statistic is below the lower critical value. The result is inconclusive if the F-statistic lies within the upper and lower bound values [41, 43].

We use the Wald test to test for APT in speed and magnitude. These can also be explained as asymmetric short-run price equilibrium and asymmetric long-run price equilibrium, respectively [6]. Symmetry, in the long run, takes the form $\beta = \beta^{+} = \beta^{-}$, while short-run symmetry can be expressed in one of the following forms: $\pi_j^{+}, \pi_m^{+}, \pi_n^{+} = \pi_j^{-}, \pi_m^{-}, \pi_n^{-}$ for all $j$, $m$, $n = 1,\ldots, q$ or.

$$\sum_{j=0}^{q} \pi_j^{+}, \sum_{m=0}^{q} \pi_m^{+}, \sum_{n=0}^{q} \pi_n^{+} = \sum_{j=0}^{q} \pi_j^{-}, \sum_{m=0}^{q} \pi_m^{-}, \sum_{n=0}^{q} \pi_n^{-}.$$

According to the Wald test results presented in Table 7, the test rejects the null hypothesis of long- and short-run symmetry for the pair wholesale and retail prices of beans in Kampala and maize in Masindi. The test also rejects the null hypothesis of both long- and short-run symmetry for the pairs wholesale prices of beans in Masindi with those in Kampala, and wholesale prices of beans in Masindi with retail prices in Kampala. Price transmission in these models is therefore estimated using the NARDL models in Eqs. 10, 11, and 12. However, the Wald test rejects the null hypothesis of short-run symmetry for the pair wholesale and retail prices of matoke in Kampala and does not reject the null hypothesis of long-run symmetry. We, therefore, re-estimate the NARDL model for this pair with long-run symmetry imposed as presented in Eq. 13 to avoid misspecifications as suggested by Fousekis et al. [6] and Panagiotou [7].

$$\Delta \text{LnRP}_t = \alpha_1 + \rho_1 LnRP_{t-1} + \beta_1 \text{LnWP}_{t-1} + \sum_{j=1}^{p-1} \varphi_j \Delta \text{LnRP}_{t-j} + \sum_{j=0}^{q} (\pi_j^{+} \Delta \text{LnWP}_{t-j}^{+} + \pi_j^{-} \Delta \text{LnWP}_{t-j}^{-}) + e_{1t} \tag{13}$$

The test also rejects the null hypothesis of short-run symmetry for the pair wholesale prices of matoke in Mbarara and retail prices in Kampala. However, it does not reject the null hypothesis of long-run symmetry. We also re-estimate the NARDL model for this pair with long-run symmetry imposed to avoid misspecifications as shown in Eq. 14.

$$\Delta \mathrm{LnRP\_Y}_t = \alpha_3 + \rho_3 \mathrm{LnRP\_Y}_{t-1} + \beta_{1ii}\mathrm{LnWP\_X}_{t-1} + \sum_{n=1}^{p-1}\varphi_n \Delta \mathrm{LnRP\_Y}_{t-n} + \sum_{n=0}^{q}(\pi_n^{+}\Delta \mathrm{LnWP\_X}_{t-n}^{+} + \pi_n^{-}\Delta \mathrm{LnWP\_X}_{t-n}^{-}) + e_{3t} \quad (14)$$

Finally, the Wald test does not reject the null hypothesis of long- and short-run symmetry between wholesale prices of matoke in Kampala and Mbarara. The model is therefore estimated using the symmetric ARDL model in Eq. 8. The test also does not reject the null hypothesis of long- and short-run symmetry between wholesale prices of maize in Masindi and Tororo with the retail prices in Kampala. We estimate these models using the symmetric ARDL model in Eq. 9.

Lastly, models 10, 11, 12, 13, and 14 are used to obtain the asymmetric cumulative dynamic multiplier effects of a unit change in $x_t^{+}$ and $x_t^{-}$ on $y_t$, where $x$ represents LnWP and LnWP_X, while y represents LnRP, LnWP_Y, and LnRP_Y.

$$m_h^{+} = \sum_{j=0}^{h}\frac{\partial y_{t+j}}{\partial x_t^{+}} (15), m_h^{-} = \sum_{j=0}^{h}\frac{\partial y_{t+j}}{\partial x_t^{-}} \quad (16)$$

where, $h$=0, 1, 2, … As $h \to \infty$, then $m_h^{+} \to \beta^{+}$ and $m_h^{-} \to \beta^{-}$, which are the asymmetric coefficients in the long run.

## Results and discussion

### Summary statistics

The mean, maximum, minimum, standard deviation, skewness, kurtosis, and coefficient of variation (CV) (expressed as the percentage of the standard deviation divided by the mean) for the original prices of staple food items in the different markets are presented in Table 2. Retail prices are higher than their wholesale counterparts for all staple foods in all markets. Based on the mean values, Kampala has the highest wholesale and retail prices of all staple commodities compared to all markets studied. This can be attributed to two reasons: (i) Kampala is a major trading center and consumption market for all staple commodities examined in this study, relying on food from other areas because there is very little agricultural production [12]. Thus, also suggesting that relatively higher prices of the examined commodities are registered in the deficit market of Kampala and relatively lower prices in surplus markets of Mbarara, Masindi, and Tororo. These price differences could imply that price signals could be transmitted between the spatially separated markets. These differences could further create profitable opportunities for traders to move their commodities from surplus markets to the deficit market if the differences in price are enough to cover at least the transaction costs associated with the movement of commodities between any two spatially separated markets [29]. (ii) Because of the higher levels of urbanization and relatively higher levels of per capita income among the population in Kampala compared to other areas, food prices in Kampala are usually higher than those in other markets [19].

The coefficient of variation, which is a measure of price variability in relation to the mean is the highest in wholesale prices compared to the retail prices of all staple food items ranging from 23.69 in wholesale prices of beans in Kampala to 37.39 in wholesale prices of maize in Masindi, while the CV for retail prices ranges from 16.27 in retail prices of maize in Masindi to 27.63 in retail prices of matoke in Mbarara. This shows a higher rate of variability in wholesale prices compared to the retail prices of staples in the period from 2015 to 2023. The CV for retail prices of matoke is lowest in Kampala at 26.92, and highest in Mbarara at 27.63. Similarly, the CV for wholesale prices is lowest in Kampala at 32.70, and highest in Mbarara at 35.71. These values suggest a high degree of price variability in both retail and wholesale prices of matoke in the two markets, although price variability is higher in Mbarara than in Kampala. The CV for wholesale prices of beans is lowest in Kampala at 23.69, and highest in Masindi at 26.21, suggesting a higher degree of price variability in Masindi. The CV for retail prices of maize is lowest in Masindi at 16.27, and highest in Kampala at 16.81, while the CV for wholesale prices is lowest in Tororo at 35.07, and highest in Masindi at 37.39, suggesting a higher degree of variability compared to the retail prices. The possible reason for Kampala's low CV values compared to other markets could be attributed to its higher rate of consumption, being the capital city and a major consumption market for almost all staple foods in Uganda, while the higher CV values in Mbarara, Masindi, and Tororo could be attributed to the higher dependence on seasonality production. The CV values for all crops were found to be consistent with those reported by FEWSNET [3] for the 2010 to 2016 period.

The lower part of Table 2 presents the Brock–Dechert–Scheinkman (BDS) test, which was conducted to detect the nonlinear structure of retail and wholesale prices of matoke, beans, and maize across the examined markets. It can be noted that the BDS test rejects the null hypothesis at all the embedding dimensions for retail and wholesale prices of matoke, beans, and maize across all the examined markets. This suggests that these variables have nonlinear characteristics and therefore examining

**Table 2** Summary statistics

| Commodity | | Matoke | | | | Beans | | | Maize | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Market | | RP_Kampala | WP_ Kampala | RP_Mbarara | WP_ Mbarara | RP_ Kampala | WP_ Kampala | WP_ Masindi | RP_ Kampala | WP_ Tororo | RP_Masindi | WP_ Masindi |
| Mean | | 978.56 | 763.4 | 861.55 | 607.22 | 2717.63 | 2324.85 | 2194.43 | 1519.07 | 911.03 | 1390.93 | 798.71 |
| Max | | 1750 | 1400 | 1400 | 1200 | 4100 | 3600 | 4000 | 2300 | 1900 | 2100 | 1750 |
| Min | | 580 | 380 | 450 | 200 | 1800 | 1300 | 1300 | 1000 | 400 | 900 | 250 |
| SD | | 263.44 | 249.62 | 238.08 | 216.82 | 483.41 | 550.65 | 575.12 | 255.35 | 319.48 | 226.34 | 298.65 |
| Skewness | | 0.59 | 0.49 | 0.33 | 0.67 | 0.92 | 0.57 | 0.81 | 1.24 | 1.03 | 0.58 | 0.98 |
| Kurtosis | | 2.48 | 2.03 | 1.93 | 2.81 | 3.18 | 2.59 | 3.66 | 4.94 | 3.78 | 4.45 | 3.84 |
| CV (%) | | 26.92 | 32.7 | 27.63 | 35.71 | 17.79 | 23.69 | 26.21 | 16.81 | 35.07 | 16.27 | 37.39 |
| *Brock–Dechert–Scheinkman (BDS) Test* | | | | | | | | | | | | |
| D2 | BDS | 0.10*** | 0.09*** | 0.09*** | 0.07*** | 0.10*** | 0.08*** | 0.10*** | 0.13*** | 0.13*** | 0.09*** | 0.12*** |
| | Z stat | 21.57 | 20.79 | 19.55 | 14.12 | 13.90 | 15.59 | 17.25 | 11.35 | 19.24 | 8.33 | 14.27 |
| D3 | BDS | 0.15*** | 0.13*** | 0.13*** | 0.11*** | 0.16*** | 0.13*** | 0.15*** | 0.21*** | 0.21*** | 0.14*** | 0.19*** |
| | Z stat | 20.45 | 18.98 | 18.10 | 12.45 | 14.32 | 15.26 | 16.46 | 11.31 | 19.04 | 7.83 | 14.10 |
| D4 | BDS | 0.17*** | 0.15*** | 0.14*** | 0.11*** | 0.21*** | 0.15*** | 0.17*** | 0.25*** | 0.25*** | 0.15*** | 0.22*** |
| | Z stat | 19.45 | 18.40 | 16.46 | 10.80 | 15.31 | 15.01 | 16.04 | 11.12 | 18.44 | 7.05 | 13.47 |
| D5 | BDS | 0.18*** | 0.16*** | 0.14*** | 0.10*** | 0.23*** | 0.15*** | 0.18*** | 0.26*** | 0.26*** | 0.14*** | 0.22*** |
| | Z stat | 19.23 | 17.95 | 15.66 | 9.40 | 15.73 | 14.27 | 15.84 | 11.17 | 18.35 | 6.19 | 12.97 |
| D6 | BDS | 0.18*** | 0.15*** | 0.13*** | 0.09*** | 0.22*** | 0.14*** | 0.16*** | 0.26*** | 0.25*** | 0.13*** | 0.21*** |
| | Z stat | 20.45 | 18.26 | 15.55 | 8.47 | 16.02 | 13.66 | 15.26 | 11.54 | 18.66 | 5.75 | 12.82 |

Observations = 97, Max, Min, and SD denote Maximum, Minimum, and Standard Deviation, respectively. Mean, Maximum, Minimum, and Standard Deviation values are in UGX/Kg, RP and WP denote retail and wholesale prices, respectively, D2, D3, D4, D5, and D6 denote Dimensions 2, 3, 4, 5, and 6, respectively, BDS and Z stat denote the Brock–Dechert–Scheinkman and the Z statistics, respectively, *** denotes significance of the BDS statistic at the 1% level

**Table 3** PP and DF-GLS unit root tests

| Commodity | Variables | Phillips–Perron test | | Elliott–Rothenberg–Stock DF-GLS test | |
|---|---|---|---|---|---|
| | | Constant T-Stat. (Prob.) | C&T T-Stat. (Prob.) | Constant T-Stat. (Prob.) | C&T T-Stat. (Prob.) |
| Matoke | WP_Kampala | − 3.372** (0.014) | − 3.569** (0.038) | − 0.935 (0.352) | − 1.636 (0.105) |
| | RP_Kampala | − 3.352** (0.015) | − 3.460* (0.050) | − 1.053 (0.295) | − 1.747* (0.084) |
| | WP_Mbarara | − 3.503** (0.010) | − 3.569** (0.038) | − 1.065 (0.290) | − 1.615 (0.110) |
| | RP_Mbarara | − 3.227** (0.021) | − 3.244* (0.082) | − 1.515 (0.133) | − 1.888* (0.062) |
| | ΔWP_Kampala | − 14.959*** (0.000) | − 15.041*** (0.000) | − 2.717*** (0.008) | − 7.003*** (0.000) |
| | ΔRP_Kampala | − 11.121*** (0.000) | − 11.214*** (0.000) | − 2.592** (0.011) | − 6.814*** (0.000) |
| | ΔWP_Mbarara | | − 11.179*** (0.000) | − 8.098*** (0.000) | − 7.999*** (0.000) |
| | ΔRP_Mbarara | − 15.165*** (0.000) | − 15.775*** (0.000) | − 7.557*** (0.000) | − 7.589*** (0.000) |
| Beans | WP_Kampala | − 3.421** (0.012) | − 3.733** (0.025) | − 1.590 (0.115) | − 2.926*** (0.004) |
| | RP_Kampala | − 3.549*** (0.009) | − 4.164*** (0.007) | − 0.758 (0.450) | − 3.041*** (0.003) |
| | WP_Masindi | − 3.387** (0.014) | − 3.428* (0.054) | − 1.189 (0.237) | − 2.274** (0.025) |
| | ΔWP_Kampala | − 11.959*** (0.000) | − 11.844*** (0.000) | − 9.269*** (0.000) | – |
| | ΔRP_Kampala | – | – | − 8.643*** (0.000) | – |
| | ΔWP_Masindi | − 12.028*** (0.000) | − 11.751*** (0.000) | − 2.460** (0.016) | − 4.865*** (0.000) |
| Maize | WP_Tororo | − 2.616* (0.093) | − 2.678 (0.248) | − 1.697* (0.093) | − 2.714*** (0.008) |
| | RP_Kampala | − 3.385** (0.014) | − 3.502** (0.045) | − 0.029 (0.977) | − 2.556** (0.012) |
| | WP_Masindi | − 3.026** (0.036) | − 3.044 (0.126) | − 1.778* (0.078) | − 2.711*** (0.008) |
| | RP_Masindi | − 4.355*** (0.001) | − 4.724*** (0.001) | − 0.151 (0.880) | − 2.164** (0.033) |
| | ΔWP_Tororo | − 8.001*** (0.000) | − 7.957*** (0.000) | − 3.768*** (0.000) | – |
| | ΔRP_Kampala | − 9.963*** (0.000) | − 9.905*** (0.000) | − 4.790*** (0.000) | − 4.324*** (0.000) |
| | ΔWP_Masindi | − 9.919*** (0.000) | − 9.838*** (0.000) | − 7.164*** (0.000) | – |
| | ΔRP_Masindi | – | – | − 7.532*** (0.000) | − 7.387*** (0.000) |

Δ denotes the first difference operator, ***, **, and * denote rejection of the null hypothesis of unit root at the 1%, 5%, and 10% levels, respectively. The optimal lag structure of the ADF and DF-GLS tests was selected based on the AIC, while the optimal bandwidth of the PP test was selected based on the Newey–West Bartlett kernel method. C&T denotes constant and trend

price transmission dynamics should be conducted by utilizing nonlinear approaches, considering that utilizing linear approaches may produce inaccurate results.

### Unit root test results

We performed the unit root tests on the wholesale and retail prices of staple food commodities in the different markets using the Phillips–Perron (PP) and Elliott–Rothenberg–Stock DF-GLS unit root tests, together with the augmented Dickey–Fuller (ADF) and Zivot–Andrews unit root tests with one structural break. Results from these four tests are presented in Tables 3 and 4. Although the tests give mixed results concerning the order of integration of the prices, the four tests reveal that none of the prices is I(2). According to the PP test results at the 5% level, prices of the three commodities in all markets are I(0), except for the wholesale prices of maize in Tororo which is I(1). The DF-GLS test results reveal that prices of matoke in the two markets are I(1), while prices of beans and maize in all markets are I(0) at the 5% level. Results of the ADF test with one structural break reveal that wholesale prices of matoke in Kampala and Mbarara and the retail prices of maize in Masindi are I(0), while all the other prices are I(1) at the 5% level. On the other hand, the Zivot–Andrews test with one structural break reveals that prices of all commodities across all markets are I(1) except for the retail prices of maize in Masindi which are I(0) at the 5% level.

### Granger causality tests

After establishing the order of integration of the variables, we proceed with determining the direction of causality of wholesale and retail prices for each staple commodity in the vertical context and spatial context, i.e., between the different markets for each commodity using the Granger causality analysis. In the vertical context, the available literature shows that the causal order in markets for agricultural commodities flows forward from the wholesale to the retail level, i.e., retailers adjust to shocks at the wholesale level [6, 7]. Similarly, based on the results presented in the upper part of Table 5, the causal order between wholesale and retail prices of

**Table 4** ADF and Zivot–Andrews unit root tests with one structural break

| Commodity | Variables | Augmented Dickey–Fuller test | | Zivot–Andrews unit root test | |
|---|---|---|---|---|---|
| | | T-Stat. (Prob.) | Break date | T-Stat | Break date |
| Matoke | WP_Kampala | − 5.3655*** (< 0.01) | 2022M08 | − 3.1337 | 2021M11 |
| | RP_Kampala | − 3.3464 (0.7794) | 2015M07 | − 3.1782 | 2021M10 |
| | WP_Mbarara | − 6.0616*** (< 0.01) | 2022M07 | − 3.3154 | 2021M07 |
| | RP_Mbarara | − 4.5209 (0.1240) | 2019M05 | − 3.3705 | 2019M06 |
| | ΔWP_Kampala | – | – | − 9.3520*** | 2017M05 |
| | ΔRP_Kampala | − 9.5221*** (< 0.01) | 2016M02 | − 8.8490*** | 2017M01 |
| | ΔWP_Mbarara | – | – | − 8.6027*** | 2020M07 |
| | ΔRP_Mbarara | − 10.1144*** (< 0.01) | 2016M02 | − 8.1372*** | 2018M05 |
| Beans | WP_Kampala | − 4.3819 (0.1742) | 2018M11 | − 3.8754 | 2021M06 |
| | RP_Kampala | − 4.0804 (0.3228) | 2015M07 | − 3.9967 | 2021M06 |
| | WP_Masindi | − 4.1430 (0.2906) | 2021M04 | − 3.7083 | 2021M05 |
| | ΔWP_Kampala | − 10.0850*** (< 0.01) | 2015M06 | − 5.4599** | 2020M09 |
| | ΔRP_Kampala | − 10.0783*** (< 0.01) | 2020M11 | − 5.9161*** | 2020M06 |
| | ΔWP_Masindi | − 9.2542*** (< 0.01) | 2020M09 | − 9.5107*** | 2020M09 |
| Maize | WP_Tororo | − 3.5508 (0.6608) | 2022M02 | − 4.1511 | 2017M06 |
| | RP_Kampala | − 4.5804 (0.1076) | 2022M03 | − 4.6489 | 2017M07 |
| | WP_Masindi | − 3.7460 (0.5348) | 2017M09 | − 4.2439 | 2017M06 |
| | RP_Masindi | − 6.3759*** (< 0.01) | 2018M07 | − 6.0524*** | 2017M06 |
| | ΔWP_Tororo | − 8.4381*** (< 0.01) | 2015M08 | − 7.1029*** | 2018M10 |
| | ΔRP_Kampala | − 11.2346*** (< 0.01) | 2017M07 | − 6.0577*** | 2017M07 |
| | ΔWP_Masindi | − 9.9733*** (< 0.01) | 2020M07 | − 7.3002*** | 2018M10 |

Δ denotes the first difference operator, critical values for the PP test are − 6.32, − 5.59, and − 5.29 at the 1%, 5%, and 10% levels, respectively, *** and ** denote rejection of the null hypothesis of unit root at the 1% and 5% levels, respectively. Critical values for the Zivot–Andrews unit root test are − 5.57, − 5.08, and − 4.82 at the 1%, 5%, and 10% levels, respectively

matoke, beans, and maize flows unidirectionally forward from the wholesale level to the retail level in all the markets except matoke prices in Mbarara. There is no Granger causal relationship between wholesale and retail prices of matoke in Mbarara. In the spatial context as presented in the second part of Table 5, there is a unidirectional Granger causal relationship between matoke prices in Mbarara and those in Kampala. Regarding wholesale prices in the two markets, the causal order flows unidirectionally from the wholesale markets in Kampala to the wholesale markets in Mbarara. However, regarding wholesale in Mbarara and retail prices in Kampala, the causal order flows unidirectionally from the wholesale markets in Mbarara to the retail markets in Kampala. This suggests that at the wholesale level, wholesalers in Mbarara adjust to price shocks at the wholesale level in Kampala, while retailers in Kampala adjust to shocks in wholesale prices in Mbarara.

There is a unidirectional Granger causal relationship between the prices of beans in Masindi and prices in Kampala, with the causal order flowing unidirectionally from the wholesale markets in Masindi to the wholesale and retail markets in Kampala. This suggests that wholesale and retail prices of beans in Kampala adjust to shocks in wholesale prices in Masindi. There is a unidirectional Granger causal relationship between wholesale prices of maize in Masindi and Tororo and the retail prices in Kampala, with the causal order flowing unidirectionally forward from the wholesale markets in Masindi and Tororo to the retail markets in Kampala. One may conclude that retail prices of maize in Kampala adjust to shocks in wholesale prices in Masindi and Tororo. This unidirectional flow of prices between the different regions depends to a large extent on seasonality and the differences in production and consumption between the regions. These findings are consistent with findings by FEWSNET [3] which reported high and statistically significant correlation coefficients above 0.7 between matoke prices in Mbarara and Kampala, beans prices in Masindi and Kampala, and maize prices in Masindi and Tororo with those in Kampala, thus suggesting a high level of co-movement in prices of these staple commodities across markets in Uganda. Based on these findings, we confined this study's analysis of vertical price transmission to one direction, namely wholesale to retail, and for both the vertical and spatial transmission, we

**Table 5** Results of granger causality tests

**Vertical transmission (wholesale and retail prices)**

| Commodity | Market | Null hypothesis | Chi-sq | Prob | Type of causality |
|---|---|---|---|---|---|
| Matoke | Kampala | WP ≠ > RP | 3.5421* | 0.0598 | Unidirectional |
| | | RP ≠ > WP | 0.1702 | 0.6799 | |
| | Mbarara | WP ≠ > RP | 4.2169 | 0.1214 | None |
| | | RP ≠ > WP | 2.9692 | 0.2266 | |
| Beans | Kampala | WP ≠ > RP | 9.5095*** | 0.0086 | Unidirectional |
| | | RP ≠ > WP | 0.3560 | 0.8369 | |
| Maize | Masindi | WP ≠ > RP | 28.6944*** | 0.0000 | Unidirectional |
| | | RP ≠ > WP | 5.1383 | 0.1619 | |

**Spatial price transmission**

| Commodity | Null hypothesis | Chi-sq | Prob | Type of causality |
|---|---|---|---|---|
| Wholesale and wholesale prices | | | | |
| Matoke | WP_Kampala ≠ > WP_Mbarara | 24.8592*** | 0.0000 | Unidirectional |
| | WP_Mbarara ≠ > WP_Kampala | 0.6502 | 0.7224 | |
| | WP_Mbarara ≠ > RP_Kampala | 13.8341*** | 0.0010 | Unidirectional |
| | RP_Kampala ≠ > WP_Mbarara | 0.5110 | 0.7745 | |
| Beans | WP_Kampala ≠ > WP_Masindi | 2.3957 | 0.4944 | Unidirectional |
| | WP_Masindi ≠ > WP_Kampala | 13.4921*** | 0.0037 | |
| | WP_Masindi ≠ > RP_Kampala | 21.4760*** | 0.0000 | Unidirectional |
| | RP_Kampala ≠ > WP_Masindi | 0.9678 | 0.6164 | |
| Maize | WP_Masindi ≠ > RP_Kampala | 21.11967*** | 0.0000 | Unidirectional |
| | RP_Kampala ≠ > WP_Masindi | 1.5183 | 0.4681 | |
| | WP_Tororo ≠ > RP_Kampala | 24.8015*** | 0.0001 | Unidirectional |
| | RP_Kampala ≠ > WP_Tororo | 6.7686 | 0.1486 | |

The symbol ≠ > means that A does not Granger cause B, *** and * denote rejection of the null hypothesis of no Granger causality at the 1% and 10% levels, respectively

**Table 6** Bounds test for nonlinear cointegration

| Commodity (market) | Causal direction | Linear ARDL | Nonlinear ARDL |
|---|---|---|---|
| Vertical transmission | | | |
| Matoke (Kampala) | WP = > RP | 17.7173 | 13.6787 |
| Beans (Kampala) | WP = > RP | 12.3948 | 42.9416 |
| Maize (Masindi) | WP = > RP | 31.3756 | 15.0223 |
| Spatial transmission | | | |
| Matoke | WP_Kampala = > WP_Mbarara | 56.4128 | 43.0599 |
| | WP_Mbarara = > RP_Kampala | 7.7522 | 15.5272 |
| Beans | WP_Masindi = > WP_Kampala | 4.2841 | 14.0387 |
| | WP_Masindi = > RP_Kampala | 2.9737 | 15.5779 |
| Maize | WP_Masindi = > RP_Kampala | 25.9836 | 19.4356 |
| | WP_Tororo = > RP_Kampala | 8.2750 | 6.3638 |
| Significance | | | |
| LCB | 1% | 4.94 | 4.13 |
| | 5% | 3.62 | 3.10 |
| UCB | 1% | 5.58 | 5.00 |
| | 5% | 4.16 | 3.87 |

= > denotes a unidirectional relationship confined the analysis to only those markets with a causal relationship that flows unidirectionally.

### Bounds test for linear and nonlinear cointegration

Table 6 presents the results of the bounds test for linear and nonlinear cointegration. The null hypothesis of no cointegration is rejected at the 1% significance level for all models, i.e., the F-statistic is greater than the upper critical bound in all models at all levels of significance, except for the linear models of the pair wholesale prices of beans in Masindi and retail prices in Kampala and the pair wholesale beans prices in Masindi and Kampala. In the vertical context, this implies that wholesale and retail prices for matoke, beans, and maize are interlinked in all the markets under study, i.e., there is a long-run relationship between the wholesale and retail prices of these staple commodities. In the spatial context, these findings suggest that matoke markets in Kampala and Mbarara, beans markets in Kampala and Masindi, and maize markets in Masindi, Tororo, and Kampala are interlinked, i.e., price changes (increases or decreases) in one market are transmitted to the other market. The literature outlines good infrastructure, quick dissemination of information about price changes, higher volume of trade, and low transaction costs as some of the causes of such integration in agricultural markets [9]. The null hypothesis of no linear cointegration is not rejected for the pair wholesale prices of beans in Masindi and retail prices in Kampala at all levels of significance and the pair wholesale beans prices in Masindi and Kampala at the 1% level of significance, i.e., the F-statistic is lower than the lower critical bound. However, the models are cointegrated in the nonlinear model, which suggests that the absence of cointegration in the linear model could be because of misspecification. These cointegration results also imply that wholesale and retail prices of staple commodities in the examined markets will converge toward a common behavior in the long run even if they behave differently in the short run. The presence of cointegration relationships could also suggest the presence of trade of the examined commodities across the markets in this study. Since Kampala is a major trading center and consumption market for all staple commodities examined in this study, these cointegration results are consistent with the strong interdependent relationship observed between Kampala prices and those of other markets for each staple commodity.

### Wald test for long- and short-run asymmetry

We utilized the Wald test to verify the appropriateness of an asymmetric model and to separate APT in magnitude from APT in speed, and the results are reported in Table 7. In the vertical context, the Wald test rejects the null hypothesis of short-run symmetry for wholesale and retail prices of matoke in Kampala at the 10% significance level; it does not, however, reject the null hypothesis of long-run symmetry. This suggests that APT in speed is relevant to the relationship between wholesale and retail prices of matoke in Kampala, but APT in magnitude is not. Regarding prices for beans, the test strongly rejects the null hypothesis of long-run symmetry for wholesale and retail prices of beans in Kampala at the 1% significance level; it also rejects the null hypothesis of short-run symmetry at the 10% significance level. This suggests that both APT in magnitude and APT in speed are relevant to the relationship between wholesale and retail prices of beans in Kampala. Regarding wholesale and retail prices of maize in Masindi, the test rejects the null hypothesis of

**Table 7** Testing for asymmetric effects

| Commodity (market) | Causal direction | Short run | | Long run | |
|---|---|---|---|---|---|
| | | Chi-square | Prob | Chi-square | Prob |
| Vertical transmission | | | | | |
| Matoke (Kampala) | WP = > RP | 3.0555* | 0.0805 | 0.0109 | 0.9167 |
| Beans (Kampala) | WP = > RP | 2.9407* | 0.0864 | 8.8542*** | 0.0029 |
| Maize (Masindi) | WP = > RP | 6.0440** | 0.0140 | 5.4820** | 0.0192 |
| Spatial transmission | | | | | |
| Matoke | WP_Kampala = > WP_Mbarara | 0.1834 | 0.6685 | 1.9309 | 0.1647 |
| | WP_Mbarara = > RP_Kampala | 2.8692* | 0.0903 | 1.9599 | 0.1615 |
| Beans | WP_Masindi = > WP_Kampala | 24.1099*** | 0.0000 | 9.3313*** | 0.0030 |
| | WP_Masindi = > RP_Kampala | 2.8830* | 0.0895 | 11.7918*** | 0.0006 |
| Maize | WP_Masindi = > RP_Kampala | 0.0108 | 0.9174 | 0.2362 | 0.6270 |
| | WP_Tororo = > RP_Kampala | 0.0677 | 0.7947 | 0.0236 | 0.8780 |

= > denotes unidirectional relationship, *, **, *** denote rejection of the null hypothesis of long -and short-run symmetry at the 10%, 5%, and 1% levels, respectively both long- and short-run symmetry for the wholesale and retail prices at the 5% significance level. Therefore, one may conclude that both APT in magnitude and APT in speed are relevant to the relationship between wholesale and retail prices of maize in Masindi.

In the spatial context, the Wald test does not reject the null hypothesis of long- and short-run symmetry between wholesale prices of matoke in Kampala and Mbarara. The test, however, rejects the null hypothesis of short-run symmetry for wholesale prices of matoke in Mbarara and retail prices in Kampala at the 10% significance level; it does not, however, reject the null hypothesis of long-run symmetry. This suggests that APT in speed is relevant to the relationship between wholesale prices of matoke in Mbarara and their retail prices in Kampala, but APT in magnitude is not. Regarding markets for beans, the test strongly rejects the null hypothesis of both long- and short-run symmetry for the wholesale prices of beans in Masindi with those in Kampala, at the 1% significance level. The test also rejects the null hypothesis of both long- and short-run symmetry for the pair wholesale prices of beans in Masindi and retail prices in Kampala, at the 1% significance level for long-run symmetry and at the 10% level for short-run symmetry. Therefore, one may conclude that both APT in magnitude and APT in speed are relevant to the relationship between wholesale prices of beans in Masindi and the prices (wholesale and retail prices) in Kampala. Regarding maize markets, the Wald test does not reject the null hypothesis of long- and short-run symmetry between wholesale prices of maize in Masindi and Tororo with the retail prices in Kampala.

## Asymmetric vertical price transmission

In addition to providing insight into the price relationships and movements between the different levels of the marketing supply chain, examining vertical asymmetric price transmission in different commodities reveals how changes in a specific stage of the marketing supply chain

**Table 8** Asymmetric vertical price transmission

| Market | Long-run estimates | | Estimates from the ECM | |
|---|---|---|---|---|
| **MATOKE [ARDL (1, 1, 2)]** | | | | |
| Kampala | **LR symmetry imposed** | | ΔWP_Kampala$^{+}$ | 0.6753*** (13.7032) |
| | WP_Kampala | 0.8031*** (25.3141) | ΔWP_Kampala$^{-}$ | 0.7582*** (15.4669) |
| | C | 1.5638*** (7.4771) | ΔWP_Kampala$^{-}$(− 1) | 0.1162** (2.2510) |
| | | | ECT(− 1) | − 0.6916*** (− 7.5234) |
| | | | R− squared | 0.9422 |
| | | | DW stat | 2.0357 |
| **BEANS [ARDL (3, 0, 0)]** | | | | |
| Kampala | WP_Kampala$^{+}$ | 0.6300*** (13.8449) | ΔRP_Kampala(− 1) | 0.1515*** (2.6978) |
| | WP_Kampala$^{-}$ | 0.6102*** (12.7834) | ΔRP_Kampala(− 2) | − 0.0825 (− 1.3751) |
| | C | 7.6196*** (380.4755) | ECT(− 1) | − 0.7603*** (− 13.327) |
| | | | R− squared | 0.8713 |
| | | | DW stat | 1.9016 |
| **MAIZE [ARDL (2, 5, 4)]** | | | | |
| Masindi | WP_Masindi$^{+}$ | 0.3118*** (10.1164) | ΔRP_Masindi(− 1) | 0.1766* (1.7860) |
| | WP_Masindi$^{-}$ | 0.2895*** (8.9469) | ΔWP_Masindi$^{+}$ | 0.2049** (2.6186) |
| | C | 7.0720*** (231.6469) | ΔWP_Masindi$^{+}$(− 1) | − 0.2118** (− 2.4495) |
| | | | ΔWP_Masindi$^{+}$(− 2) | − 0.1299* (− 1.6996) |
| | | | ΔWP_Masindi$^{+}$(− 3) | − 0.1846** (− 2.5343) |
| | | | ΔWP_Masindi$^{+}$(− 4) | − 0.2906*** (− 4.1340) |
| | | | ΔWP_Masindi$^{-}$ | 0.2239*** (3.7842) |
| | | | ΔWP_Masindi$^{-}$(− 1) | 0.1365** (2.0404) |
| | | | ΔWP_Masindi$^{-}$(− 2) | 0.0767 (1.1843) |
| | | | ΔWP_Masindi$^{-}$(− 3) | 0.1556** (2.3420) |
| | | | ECT(− 1) | − 0.8816*** (− 7.9013) |
| | | | R-squared | 0.7803 |
| | | | DW stat | 2.1728 |

LR denotes long run, the causal order is WP = > RP across all markets for all commodities, the superscripts "+" and "−" denote positive and negative partial sums, respectively, Δ denotes the first difference operator, *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively, ECT is the Error Correction Term, figures in parentheses () are t-statistics are transmitted to downstream and upstream stages. The magnitude and speed at which price shocks are transmitted from one level of the supply chain to another may be indicative of the competition level in the market [24]. Table 8 presents the long- and short-run estimates of the asymmetric vertical price transmission of matoke, beans, and maize prices in the selected markets. The long-run coefficients of the three commodities in the selected markets are highly significant at the 1% level of significance. For the pair wholesale and retail prices of matoke in Kampala, the Wald test results for long-run symmetry revealed that in the long run, positive shocks in the wholesale prices of matoke in Kampala are transmitted to the retail level with equal intensity as the negative ones. Therefore, after imposing long-run symmetry on the model, the long-run coefficient suggests that a 1% increase in the wholesale prices of matoke in Kampala leads to a 0.803% increase in retail prices. Regarding bean prices in Kampala, the long-run coefficients suggest that a 1% increase (decrease) in the wholesale prices of beans in Kampala leads to a 0.63% (0.61%) increase (decrease) in retail prices. These values imply that in

**Table 9** Asymmetric spatial price transmission

| Causal direction | Long-run estimates | | Estimates from the ECM | |
|---|---|---|---|---|
| MATOKE | | | | |
| WP_Kampala = > WP_Mbarara [ARDL(2, 0)], LR and SR symmetry imposed | WP_Kampala | 0.9805*** (14.3259) | ΔWP_Mbarara(− 1) | 0.1788*** (2.8692) |
| | C | − 0.1122 (− 0.2488) | ECT(− 1) | − 0.7941*** (− 13.1513) |
| | | | R-squared | 0.8208 |
| | | | DW stat | 2.0308 |
| WP_Mbarara = > RP_Kampala [ARDL (4, 0, 1)] | **LR symmetry imposed** | | ΔRP_Kampala(− 1) | − 0.0322 (− 0.4785) |
| | WP_Mbarara | 0.7320*** (8.1315) | ΔRP_Kampala(− 2) | − 0.0453 (− 0.6799) |
| | C | 2.2176*** (3.8883) | ΔRP_Kampala(− 3) | − 0.1906*** (− 2.8575) |
| | | | $\Delta WP\_Mbarara^{-}$ | 0.6144***(9.2364) |
| | | | ECT(− 1) | − 0.5340***(− 8.0188) |
| | | | R-squared | 0.8476 |
| | | | DW stat | 1.9903 |
| BEANS | | | | |
| WP_Masindi = > WP_Kampala [ARDL (1, 0, 3)] | $WP\_Masindi^{+}$ | 0.8400*** (10.2231) | $\Delta WP\_Masindi^{-}$ | 0.6249***(7.1565) |
| | $WP\_Masindi^{-}$ | 0.8054*** (9.5742) | $\Delta WP\_Masindi^{-}(-1)$ | 0.1194 (1.2747) |
| | C | 7.2774***(132.3281) | $\Delta WP\_Masindi^{-}(-2)$ | − 0.2407*** (− 2.6524) |
| | | | ECT(− 1) | − 0.5907***(− 7.6232) |
| | | | R-squared | 0.8248 |
| | | | DW stat | 1.9613 |
| WP_Masindi = > RP_Kampala [ARDL (3, 0, 2)] | $WP\_Masindi^{+}$ | 0.5264*** (9.6489) | ΔRP_Kampala(− 1) | 0.1191 (1.5956) |
| | $WP\_Masindi^{-}$ | 0.4884*** (8.7823) | ΔRP_Kampala(− 2) | − 0.1465* (− 1.9637) |
| | C | 7.5714***(217.6952) | $\Delta WP\_Masindi^{-}$ | 0.2221***(3.2310) |
| | | | $\Delta WP\_Masindi^{-}(-1)$ | 0.1300* (1.8033) |
| | | | ECT(− 1) | − 0.6539*** (− 8.0303) |
| | | | R-squared | 0.8180 |
| | | | DW stat | 1.9500 |
| MAIZE (LR and SR symmetry imposed in both models) | | | | |
| WP_Masindi = > RP_Kampala [ARDL (1, 0)] | WP_Masindi | 0.4036*** (9.3802) | ECT(− 1) | − 0.4552*** (− 8.9234) |
| | C | 4.6513*** (16.3322) | R-squared | 0.8230 |
| | | | DW stat | 1.9583 |
| WP_Tororo = > RP_Kampala [ARDL (1, 1)] | WP_Tororo | 0.4581*** (8.3507) | ΔWP_Tororo | 0.3389*** (8.2747) |
| | C | 4.2247*** (11.3934) | ECT(− 1) | − 0.3558*** (− 5.0363) |
| | | | R-squared | 0.8575 |
| | | | DW stat | 2.0582 |

LR and SR denote long run and short run, respectively. The superscripts "+" and "−" denote positive and negative partial sums, respectively, Δ denotes the first difference operator, * and *** denote significance at the 10% and 1% levels, respectively, ECT is the Error Correction Term signifying the proportion of the long-term imbalance of the dependent variable that is corrected in each short-run period, figures in parentheses () are t-statistics the long run, positive shocks in the wholesale prices of beans in Kampala are transmitted to the retail level with greater intensity compared to the negative ones. Specifically, the transmission elasticity of positive price shocks at the wholesale level is 2 percentage points higher than that of negative price shocks. Regarding maize prices in Masindi, the long-run coefficients suggest that a 1% increase (decrease) in the wholesale prices of maize in Masindi leads to a 0.312% (0.289%) increase (decrease) in retail prices. These values imply that in the long run, positive shocks in the wholesale prices of maize in Masindi are transmitted to the retail level with greater intensity compared to the negative ones. Specifically, the transmission elasticity of positive price shocks at the wholesale level is 2.3 percentage points higher than that of negative price shocks.

#### Asymmetric spatial price transmission

In addition to vertical price transmission, we examined spatial price transmission across markets. Examining price transmission across spatially separated markets aids in understanding the dynamic behavior of prices across markets, thus enabling tracking of the potential economic implications [9]. Table 9 presents the long- and short-run estimates of the asymmetric spatial price transmission in wholesale and retail prices of matoke, beans, and maize in the selected markets. The long-run coefficients of the three commodities in the selected markets are highly significant at the 1% level of significance. Regarding matoke prices for the pair wholesale prices in Kampala and Mbarara, the Wald test revealed short- and long-run symmetry in the wholesale prices of matoke in Kampala with the wholesale prices in Mbarara. Therefore, after imposing long- and short-run symmetry on the model, the long-run coefficient suggests that a 1% increase in the wholesale prices of matoke in Kampala leads to a 0.98% increase in wholesale prices in Mbarara. Regarding the pair wholesale prices of matoke in Mbarara and retail prices in Kampala, the Wald test revealed long-run symmetry in the wholesale prices of matoke in Mbarara with the retail prices in Kampala. Therefore, after imposing long-run symmetry on the model, the long-run coefficient suggests that a 1% increase in the wholesale prices of matoke in Mbarara leads to a 0.732% increase in the retail prices in Kampala. The short-run coefficients show that the pass-through from wholesale prices of matoke in Mbarara to retail prices in Kampala is larger when wholesale prices in Mbarara decrease than when they increase in the short run, an implication of negative APT. This could be attributed to the high perishability nature of matoke where retailers are hesitant to raise prices for fear of reduced sales that could lead to losses as a result of spoilage [37].

Regarding wholesale bean prices for the pair Kampala and Masindi, the long-run coefficients suggest that a 1% increase (decrease) in the wholesale prices of beans in Masindi leads to a 0.84% (0.805%) increase (decrease) in the wholesale prices in Kampala. These values imply that in the long run, positive shocks in the wholesale prices of beans in Masindi are transmitted to the wholesale prices in Kampala with greater intensity compared to the negative ones. Specifically, the transmission elasticity of positive price shocks at the wholesale level in Masindi is 3.5 percentage points higher than that of negative price shocks. Regarding the pair wholesale bean prices in Masindi and retail prices in Kampala, the long-run coefficients suggest that a 1% increase (decrease) in the wholesale prices of beans in Masindi leads to a 0.5264% (0.4884%) increase (decrease) in the retail prices in Kampala. These values imply that in the long run, positive shocks in the wholesale prices of beans in Masindi are transmitted to the retail prices in Kampala with greater intensity compared to the negative ones. Specifically, the transmission elasticity of positive price shocks at the wholesale level in Masindi is 3.8 percentage points higher than that of negative price shocks.

Regarding maize prices for the pairs wholesale prices in Masindi and Tororo and the retail prices in Kampala, the Wald test revealed short and long-run symmetry in the wholesale prices of maize in Masindi and Tororo with the retail prices in Kampala. Therefore, after imposing long- and short-run symmetry on the two models, the long-run coefficients suggest that a 1% increase in the wholesale prices of maize in Masindi and Tororo leads to a 0.404% and 0.458% increase in retail prices of maize in Kampala, respectively.

The presence of positive asymmetric price transmission for the pairs wholesale and retail prices of beans and maize in Kampala and Masindi, respectively (vertical context), wholesale prices of beans in Masindi with wholesale prices in Kampala, and wholesale prices of beans in Masindi with retail prices in Kampala (spatial context) suggests that while price increases at the wholesale level are fully passed on to the consumers, price reductions at the wholesale level are not fully passed on to the consumers by the retailers. Given these patterns of price transmission, one may conclude that final consumers of Uganda's major staples are more likely to experience an increase rather than a decrease in prices at the retail level, i.e., the positive asymmetric price transmission reported in this study is associated with welfare losses to the consumers [7, 37, 44]. This should cause concern among policymakers, especially in the context of the growing concerns about high food prices, high poverty levels, and increasing levels of food insecurity. However, for policymakers to act, it is imperative to first understand the underlying causes of asymmetric price transmission in markets of Uganda's staple foods. The commonly reported causes of APT in the literature are market power, adjustment costs, transaction costs, government intervention, price support policies, asymmetric information, perishability of commodities, and inventory management [22, 24, 37].

In the context of Uganda's staple food marketing supply chain, the asymmetric behavior of prices obtained in this study may be linked to information asymmetry between traders and consumers [4], asymmetry of traders' adjustment costs, i.e., transport costs with respect to increasing or decreasing prices, asymmetry in production, i.e., decreases in production do not happen in the same rates as increases [44]. Unlike traders, a large proportion of consumers lack information about the movement of prices of staples along the supply marketing chain. The positive APT could also be attributed to inventory management as a way of traders' adjustment to exogenous shocks, i.e., in periods of surplus production, which is always associated with low prices of staples, traders store produce in warehouses rather than selling at low prices. And in periods of high demand, traders sell the produce at high prices [37]. The positive APT in this study may also reflect the market power of retailers of staple foods in Uganda, which is consistent with the perception that retailers in the food marketing supply chain have more market power than wholesalers [7].

Regarding the actors along the supply marketing chain of Uganda's major staples, retailers are more likely to benefit from price decreases at the wholesale level, i.e., their gross margin is more likely to expand following a price decrease at the wholesale level. This study's findings are consistent with the typical pattern reported in the literature which indicates that food prices in the downstream markets (retail level) respond more quickly to price increases in the upstream markets (producer and wholesale level) than to decreases in many agricultural markets [7, 44].

Finally, the coefficients of the error correction terms of all commodities across all markets have negative signs, which implies that their short-term fluctuation can be brought back to equilibrium by market forces when deviating from their long-term equilibrium [27]. The P-values of all error correction terms are statistically significant even at the 1% level, which may imply that the adjustment capability of the prices across all markets in this study is effective enough due to the liberalization of trade or the lack of restrictions on trade in staple foods across all markets in Uganda. The large absolute values of the ECT coefficients for matoke (the pairs Kampala–Mbarara) and beans (the pairs Masindi–Kampala) suggest that the speed of adjustment is very rapid, while the low absolute values for maize (for the pairs Masindi–Kampala and Tororo–Kampala) suggest a slow speed of adjustment toward equilibrium.

In addition to the long- and short-run estimates, we obtained the asymmetric cumulative dynamic multipliers for each model, and these are presented in Figs. 1a, b, 2a–c, and 3a among the Additional file 1. The dynamic multipliers enable tracing out the evolution of a price in each market in response to a price shock in another market, thus providing a picture of the path to the new equilibrium [6]. In all figures, we observe that the behavior of the dynamic multipliers is consistent with asymmetry in both the short and long run as reported in Tables 8 and 9. For the pair wholesale and retail prices of matoke in Kampala in Fig. 1a, retail prices do not respond at the same rate to increases and decreases in wholesale prices in the short run; however, they respond at the same rate to increases and decreases in wholesale prices in the long run and equilibrium correction is achieved after around 3 months. In the short run, negative shocks in the wholesale prices of matoke in Kampala are transmitted to the retail level with greater intensity compared to positive ones. Regarding the pair wholesale prices of matoke in Mbarara and retail prices in Kampala in Fig. 1b, retail prices of matoke in Kampala do not respond at the same rate to increases and decreases in wholesale prices in Mbarara in the short run; however, in the long run, they respond at the same rate to increases and decreases in wholesale prices in Mbarara and equilibrium correction is achieved after around 8 months.

Regarding bean prices in Kampala in Fig. 2a, retail prices do not respond at the same rate to wholesale price increases and decreases, both in the short and long run and equilibrium correction is achieved after around 6 months. Regarding wholesale bean prices for the pair Kampala and Masindi in Fig. 2b, wholesale prices in Kampala do not respond at the same rate to increases and decreases in wholesale prices in Masindi, both in the short and long run and equilibrium correction is achieved after around 5 months. Similarly, regarding the pair wholesale bean prices in Masindi and retail prices in Kampala, retail prices in Kampala do not respond at the same rate to increases and decreases in wholesale prices in Masindi, both in the short and long run and equilibrium correction is achieved after around 5 months. Finally, regarding maize prices in Masindi, we observe in Fig. 3a that retail prices of maize in Masindi do not respond at the same rate to increases and decreases in wholesale prices, both in the short and long run and equilibrium correction is achieved after around 7 months. The diagnostic test results presented in Table 10 illustrate

**Table 10** Diagnostic tests

| Commodity (market) | Causal direction | Tests | | |
|---|---|---|---|---|
| | | BG–LM test | BPG-Het test | Ramsey RESET test |
| Vertical transmission | | | | |
| Matoke (Kampala) | WP = > RP | 0.1098 (0.8961) | 0.7126 (0.6403) | 0.0005 (0.9827) |
| Beans (Kampala) | WP = > RP | 0.2860 (0.9195) | 0.6665 (0.6498) | 0.2247 (0.6366) |
| Maize (Masindi) | WP = > RP | 1.3679 (0.2465) | 1.5302 (0.1258) | 0.6323 (0.4290) |
| Spatial transmission | | | | |
| Matoke | WP_Kampala = > WP_Mbarara | 0.2891 (0.7497) | 1.7687 (0.1421) | 0.1364 (0.7127) |
| | WP_Mbarara = > RP_Kampala | 0.0338 (0.9978) | 1.2305 (0.2953) | 0.6337 (0.4283) |
| Beans | WP_Masindi = > WP_Kampala | 0.1579 (0.9243) | 1.9954 (0.0750) | 0.0529 (0.8186) |
| | WP_Masindi = > RP_Kampala | 0.0321 (0.9980) | 1.4760 (0.1866) | 3.4610 (0.0663) |
| Maize | WP_Masindi = > RP_Kampala | 1.0581 (0.3522) | 1.6095 (0.0955) | 3.4825 (0.0659) |
| | WP_Tororo = > RP_Kampala | 0.5553 (0.5760) | 1.1017 (0.3695) | 0.3797 (0.5394) |

BPG-Het: Breusch-Pagan-Godfrey Heteroskedasticity Test, BG – LM: Breusch-Godfrey Serial Correlation LM Test, Figures in brackets are probabilities, values for LM, Het, and Ramsey tests are F-statistics

the absence of serial correlation and heteroscedasticity in the estimated models as pointed out by LM and Breusch–Pagan–Godfrey test results. The correct specification of the models is evident from the outcomes of the Ramsey RESET tests. The CUSUM tests presented in Figs. 1c–e, 2d–f, 3b–d among the Additional file 1 show that the CUSUM in all models is within critical bounds, which signifies the constancy of the parameters and stability of the models.

## Conclusion

We conducted this study to examine the relationship, price transmission dynamics, and market integration among domestic markets for Uganda's major staple foods (matoke, maize, and beans). Our study was confined to addressing the following questions: (1) What is the direction of causality among markets for staple foods in Uganda? (2) Are there asymmetric effects in the vertical and spatial price transmission of staple food prices in Uganda's domestic markets? (3) If asymmetric effects exist in these markets, what are the likely causes? (4) How much of a shock in staple food prices in producer markets is transmitted to the consumer markets? (5) How long does it take for staple food prices in the consumer markets to adjust to a price shock in the producer markets? To answer these questions, we utilized the Granger causality analysis, the bounds test for nonlinear cointegration, the Wald test for long- and short-run asymmetry, and the NARDL model, which decomposes the variables of interest into their positive and negative partial sums, allowing for the differentiation of APT in magnitude from that in speed.

The Granger causality analysis results revealed that the causal order between wholesale and retail prices of matoke, beans, and maize flows unidirectionally forward from the wholesale level to the retail level across all markets. The bounds test for nonlinear cointegration revealed that wholesale and retail prices for matoke, beans, and maize are interlinked in all the markets in the vertical context. In the spatial context, matoke markets in Kampala and Mbarara, beans markets in Kampala and Masindi, and maize markets in Masindi, Tororo, and Kampala are interlinked. This suggests that markets for Uganda's major staple foods are well integrated. Thus, wholesale and retail prices in the different markets respond quickly to restore their long-run equilibrium in response to price shocks. The Wald test revealed APT in speed and no APT in magnitude for the pairs wholesale and retail prices of matoke in Kampala and wholesale prices of matoke in Mbarara and the retail prices in Kampala, both APT in magnitude and APT in speed for the pairs wholesale and retail prices of beans in Kampala, wholesale and retail prices of maize in Masindi, and wholesale prices of beans in Masindi with the prices (wholesale and retail prices) in Kampala. We also found that in the long run, retail prices respond more strongly to wholesale price increases than decreases. Hence, our findings demonstrate the presence of positive asymmetric price transmission in the marketing supply chain of Uganda's major staples. The asymmetric behavior of prices obtained in this study may be linked to information asymmetry between traders and consumers, asymmetry of traders' adjustment costs, asymmetry in production, inventory management as a way of traders' adjustment to exogenous shocks, and market power of retailers of staple foods in Uganda.

## Limitations of the study

Uganda's marketing value chain for staple foods flows through several channels/actors namely producers, brokers, middlemen, wholesalers, processors, retailers, exporters, and consumers. Secondly, the marketing supply chain of Uganda's staple foods involves several districts far more than the four considered in this study. For example, according to the FEWSNET [3] beans majorly flow from Kasese, Mbarara, Masaka, Mubende, Iganga among other districts to Kampala, from Soroti, Lira, and Arua to Gulu, from Soroti, Mbale, Iganga to Busia, and from Busia to Kenya. Matoke majorly flow from Bushenyi, Mbarara, Masaka to Kampala, from Kampala to Gulu, Iganga, Mbale, and Busia and then to Kenya. They also flow from Mbale to Soroti, Lira, Kotido, and Moroto and from Mbarara to Kabale and then to Rwanda. Maize majorly flows from Fort Portal, Mubende, Kamuli, Iganga among other districts to Kampala, from Iganga, Soroti, Amudat, Mbale to Busia and then to Kenya. This explains the complex nature of the marketing supply chain for Uganda's staple foods. Bearing in mind that it is imperative to cover all stages of the marketing supply chain while examining price transmission (because price transmission depends on competition across all markets and actors in all stages of the marketing supply chain [24]), examining price transmission across all the actors involved in the marketing of Uganda's major staples and across all the major districts involved would give a clearer view of the integration of these markets and the welfare losses/gains across these actors. However, such an analysis was not possible in this study because of the lack of price data for each actor and all the major markets involved. This study analyzed only those markets whose prices were available on the FEWSNET website. Therefore, future empirical work on Asymmetric Price Transmission in Uganda's agro-food marketing supply chain should aim at a more comprehensive analysis to include more actors along the supply chain and more markets across the country. Despite these limitations, the analyses conducted in this study provide an overview of the price transmission between the two major actors (retailers and wholesalers) in the marketing of Uganda's major staple foods and the integration of the analyzed markets with Kampala, Uganda's major consumption market for the staple foods.

### Abbreviations

| | |
|---|---|
| ADF | Augmented Dickey-Fuller unit root test |
| ARDL | Autoregressive Distributed Lag |
| APT | Asymmetric Price Transmission |
| ECT | Error Correction Term |
| FAO | Food and Agriculture Organization of the United Nations |
| FEWSNET | Famine Early Warning Systems Network |
| NARDL | Nonlinear Autoregressive Distributed Lag |
| PP | Phillips–Perron unit root test |
| RP | Retail prices |
| WP | Wholesale prices |

## Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s43093-023-00281-6.

**Additional file 1.** Asymmetric cumulative dynamic multipliers and CUSUM of Squares for the examined models.

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### Author contributions
Both authors contributed to the conceptualization of the study. DW contributed to the extraction of the data from the respective websites, analysis of the data in the EViews statistical program, and writing, reviewing, and editing of the manuscript. FY contributed to the supervision of the study, reviewing, validation, and proofreading of the final manuscript. Both authors read and approved the final manuscript.

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## Declarations

### Ethics approval and consent to participate
Not applicable.

### Consent for publication
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The authors declare that they have no competing interests.

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