Hungarian University of Agriculture and Life Sciences

Factors of food security: agricultural price transmission and volatility spillovers

Doctoral (PhD) thesis

by

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2024

Hungarian University of Agriculture and Life Sciences

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1. INTRODUCTION

It is evident that food security always presents a challenge for most countries, mainly in the African continent. Despite, the endeavors that aim to develop the agriculture sector and provide enough food to the increasing population, governments still struggle to face this concern.

Due to the constraints of a rising population and limited arable area, food security has attracted considerable awareness for many years. The food situation has been altered as a result of some factors, such as the increased urbanization and changes in the food system, that cause enormous issues for the expanding populations (Ritchie and Roser, 2018). Food systems could boost human well-being as well as the green environment. Nonetheless, they are now jeopardizing both of these.

It is an acute problem to provide a rising global population with nutritious meals derived from sustainable agricultural systems. A gap appeared between the global food production and the population expansion, showing a marked growth of the accounted people who are facing serious food insecurity. Hunger depicts an acute issue, approximately 8 million people, yearly, pass away of hunger that means more than 20,000 people per day. In 2015, the number was counted at 80 million, it jumped to 108 million in 2016, and 124 million in 2017. The demand for food is flourishing, FAO estimated that there will be a food demand upward in 2050 by fifty percent of the total food amount in 2013. Meat products are predicted to witness the highest demand increase, in 2050, of 76%, while dairy products will mark an increase of 65 percent, as long as grain products with 40 percent. Developing countries are the most concerned by this increase, they will register greater than 80 percent of food and beverage demand by 2030. We cannot deny that to feed the population, governments should focus on the production input expenses because they reflect food prices later on. Any increase in agriculture input price will be reversed to an augmentation in food prices (Fróna et al., 2019). To comprehend such circumstances, it needs to understand the risk that can agricultural price contributes to aggravating food insecurity status.

These facts lead to the emergence of food security debate. As a consequence, consumers face the effect of increasing food prices, as well as producers, feel the pressure from the increasing input costs. Agricultural price changes are caused by a number of determinants. The increasing food demand joined with the slowed agricultural productivity growth and the dependence between the agriculture and the fluctuating energy price are among the identified reasons.

Food price increase impedes food security and restricts the access to the food. Also, price volatility menaces farmers from having stable income. The increased prices which happened between 2007 and 2008 led to 40 million more undernourished people in Asian and Pacific regions, and more than 20 million in Sub-Sahara Africa. In general, high food prices could affect the currency which could lose its value by the high inflation. The merger of the economic stagnation and the increased inflation form a detriment for economic recovery. More recently, prices move to drop again, but they remain significantly above the pre-crisis level.

Achieving the answer for this upward deviation in food price level and volatility are still the interest of many scientific researches. Some researchers focus on finding an explanation of the disequilibrium which exists between supply and demand, with demand trend rising faster than supply trend, through the concentration on the food demand strength which launched a considerable shifting in the world, which could explain this quickly and unexpected movement in price levels. Trade policies are implemented in order to protect the markets from the price fluctuation, such as the trade restrictions which is considered as a measure among others. The higher cost of production as a result of price fluctuations in certain production elements, particularly energy, was also a key factor in explaining the upward trend in commodity prices, indicating an imbalance between global demand for and supply of limited resources.

Regardless of these achievements, Africa has attracted global attention for significant issues including social inequality, food insecurity, poverty and unemployment (World Bank, 2020). Agriculture has heavily relied on the petroleum industry for inputs such as fuel and fertilizer, but aggressive biofuel regulations in petroleum refining have strengthened ties between the energy and agricultural commodities markets. Countries regularly interfere in the case of major oscillations in global food prices to mitigate the effects of world food price rises on domestic prices and to ease the adjusting pressure on vulnerable populations.

1.1. Problem Statement

Food price volatility and spikes provoke governmental, professional, and public concerns about food security across the world. Food price volatility in 2007/2008 harmed millions of individuals, undermining their nutritional condition and food security. The Food and Agriculture Organization (FAO) has foreseen that the 2007/08 price increase raised the number of undernourished people (Bouis, 2008). It went from about 850 million in 2007 to about 1023 million in 2009.

According to FAO in 2011, because of price fluctuations in staple foods, such as wheat and maize, the African continent has a significant number of undernourished individuals, which has reached 240 million. In addition, the appearance of the Covid-19 pandemic, has aggravated the situation of food security because of the restrictions that have been imposed imposed (De Bakker et al., 2005. De Paulo Farias and de Araújo, 2020 and Arndt et al., 2020). The uncertainty has been developed which harms further the food availability, thus food price. Commodity price volatility, unpredictable supply chain interruptions, and weather and climate change all pose a significant risk to food markets, making the mission harder for the government to assure consistently and regularly accessible food, putting food security at risk.

Household earnings and buying power decline as price volatility increases. Price change is linked to the idea of food security. A shock price could disrupt the four pillars of food security (i.e. availability, access, utilization, and stability) (FAO 1996, 2015). Although, price volatility disrupts the different level of supply chain, upstream and downstream. Also, the price volatility magnitude could undermine the economic growth and the poverty reduction (HLPE, 2011). An enormous food price increase aggravates the poverty, especially in low income countries (Ivanic and Martin, 2008 ; Ivanic, Martin and Zaman, 2011).

The price spike affects all stages of the supply chain. Unexpected price volatility decreases the farmer productivity; thus, they reduce their investment. (Rezitis and Stavropoulos, 2009; Piot-Lepetit and M'Barek, 2011; Taya, 2012). Also, agricultural inputs became subject to the price volatility, driving retailers and processors to adjust their supply strategies to mitigate the supply uncertainty (Rabobank, 2011). Unexpected price increases also pose food security risks, particularly to consumers who spend a large share of their income on food items (Hernandez et al., 2014). All this implies that managing the risk from price volatility is necessary for the smooth functioning of food supply chains. The price boom launches the debate about the position of commodities in future market.

Due to the market interconnections, it is crucial to understand the price dynamics within the market. To analyze the link between the food prices and food security, a research study has been established in Kenya. The aim of the study was to assess the link between the maize price and the low birth weight as an indicator of food security and account its effect. A positive correlation has been detected. This result could not be generalized for all Kenyan households. In other word, some households got advantages from maize price increase (Grace et al, 2014).

The food price increase could worsen the health status of poor households by preventing them to have the access to sufficient nutritional food (Mkhawani et al, 2016). Food instability and price volatility will be major concerns in the future.

For long-term growth, governments must adopt clearer policies that address agricultural risk management effectively. It is critical to have the tools and information necessary to recognize and identify the factors of food security, as well as to be aware of the interventions available to protect individuals from food deprivation. Therefore, it is pivotal that the government should undertake a background study of the forecast of a food security index. In this regard, the results of this study would be a useful reference for the government in intending to practice a global model forecast of food security index.

1.2. Significance of the Study

Crude oil has long been acknowledged as the world's most valuable raw material and vital energy resource. It has now become a critical component of socioeconomic progress and sustainability.

Petroleum products, such as diesel, gasoline, and other fuels, are also an essential source of energy for farming machinery, since they are used by fleets of agricultural transportation equipment vehicles that are employed in the production chain in agricultural areas.

Agricultural sector plays an important place in the economic growth. However, the agricultural development, the poverty decrease, and the food security are subject to risks. Unexpected shocks such as climate change, crude oil price, pandemic spread, input price increase, and the appearance of new plant diseases imply a real harm for food yield. Also, they interrupt the food supply and burden people from having access to suitable quantity and quality of food. Furthermore, the decrease of rural population creates a gap between the rural production (supply) and the demand from the rising urban population, leading to price shocks mainly for importer countries which are more sensitive to the price change (Alem and Söderbom, 2012).

For this purpose, forecasting price transmission and volatility spillovers between the global and domestic food price help to understand the speed and magnitude of price dynamic between domestic and international prices. It plays a pivotal role for policy makers to manage and understand the responsiveness of domestic market to international shocks. The food price changes count on the vulnerability of the country and the agricultural product upon a price shock (Galtier, 2013). Firstly, my thesis examines the volatility spillover between the domestic and global food prices. Energy products, such as crude oil, represent important energy source for farming machinery, being consumed by fleets of agricultural machinery and transport vehicles used for the production process in agriculture fields (Rafi et.al, 2009 and Adam et.al,2016). Therefore, examining the price spillover between crude oil and food price gives a clear image about the vulnerability of food price face to a change of fuel price. My research contributes to establish an updated price investigation based on recent price series.

On the other hand, the food security index is always a primordial subject, especially, after the pandemic of Covid-19 spread, causing an unexpected shock for the food supply, the food consumption, and the trade restrictions. It creates a disruption the food supply due to the lockdown which harms the planting season, therefore a lower production could be the consequence. A bibliometric analysis was elaborated, since it reveals the importance of previous research have been done in this field (Eck and Waltman, 2014). After the elaboration a bibliometric analysis to discover the link between food security and food price, an important interest was focused to this research idea, especially with the lack of previous studies that forecasted the food security. Based on highlighted keywords, mainly supply and food intake, and to fill the gap, the food security index based on the gap of food supply should be a contributive finding for food security topic.

Domestic price volatility, which is associated with international price volatility to varying degrees in various nations, has an impact on food security at the national level. Various indicators (e.g. local regulations, high shipping costs, inadequate infrastructure, consumption patterns, and exchange rate fluctuations, etc.…) might hinder price transmission from global to national prices.

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1.3. Research questions and hypotheses

The main question of my research is there interconnectedness between agricultural producer price and food security? Food security is perceived as the sufficient supply of the required food for people. Here, the question is how to estimate the aggregated food insecurity index based on the supply gap of food subcategories? And How to weight each food subcategory?

Four main ideas are considered in my study:

- Firstly, global food price examination: Assessing the magnitude of the global food price volatility transmissions of food and food subcategories:1. Own price volatility: How an occurred past price shock is transmitted to the present value? Energy, particularly crude oil, , is regarded as a crucial input in different sectors (e.g transportation, industry, agriculture, etc.). It is extensively utilized to supply agriculture as a raw input; thus, it has a high value and influences the pricing of agricultural commodities. 2. Interdependence between the global food prices and crude oil price: Is there a significant interdependence between crude oil and world food prices?
  - Secondly, spatial volatility spillovers:1. from one side we estimated the extent of the price volatility that could transmit from the global level to the domestic level. How much

the domestic food price is vulnerable to a global food price shock? 2.From the other side, the connectedness between the global crude oil price and the domestic food price has been estimated. How much the domestic food price is vulnerable to a crude oil price shock?

- Thirdly, quantitatively assessing the food security index: it aims to build food security index based on food supply indicators: The gap between the supplied food intake and the required food intake. A food security index will be forecasted based on deficit food subcategories supply: The weighting method is determined from the DALY (Disability-Adjusted Life Years) value (World Health Organization, 2020a). Each food subcategories have been weighted based on its rate of the Disability-Adjusted Life year.
- Fourthly, implication of price dynamic and macroeconomic variables on national food security and sustainability: how vulnerable nations and populations can ensure the food availability when volatility causes market disruptions.

Hypothesis:

- **H1:** Food prices are significantly impacted by its own past values: a past volatility is significantly transmitted to the present value.
- **H2:** Crude oil price is significantly impacted by its own past values: a past volatility is significantly transmitted to the present value.
- **H3:** Crude oil price has a significant volatility spillover on the global food price.
- **H4:** Highly perishable agricultural commodity price (meat price) has the highest own price volatility among other commodities.
- **H5:** The global food price volatility is significantly transmitted to the domestic food price.
- **H6:** The crude oil has a significant influence on the global and domestic food prices: energy and food price and highly interdependent.
- **H7:** The agricultural producer price has a significant negative effect on forecasted food security index

- **H8:** Macroeconomic variables (i.e. Trade openness, Exchange rate between local currency and USD, Inflation rate, Interest rate (long term real interest rate),Employment rate, Crude oil price) have a significant effect on food security index.

1.4. Theoretical framework

Prior to assessing agricultural price effect on the national food security, it is quite important to understand how much the domestic food price is correlated to the international food and the energy (crude oil) prices. The magnitude of the price volatility transmission from the global food price to the national prices is constrained to different factors, such as, the implemented trade policies, and the exchange rate. African countries are most vulnerable to an increase of food prices. They have the large share of income expenditure on food. However, the two first countries with the highest income share spent on food are Nigeria and Kenya with 59% and 52% respectively. Algeria and Egypt as well have a high share of income expenditure on food, with 38% and 37% respectively (give references for the data). Figure 1 described the general theoretical background of my dissertation.

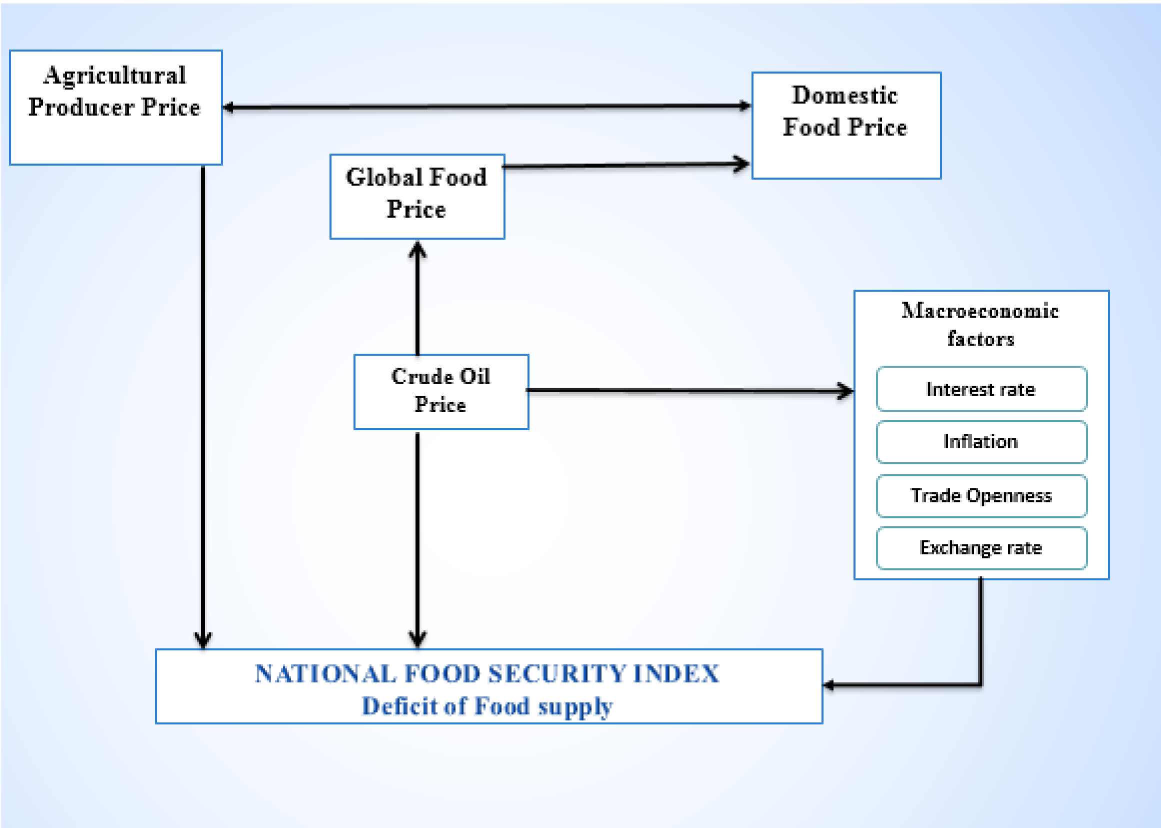

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Figure 1. Conceptual model of the research: Connections between food prices, crude oil price, macroeconomic indicators, and food security index

Source: Author's own construction

At the beginning, my research tried to examine vertical price volatility of selected agricultural commodities (i.e. meat, milk, and wheat) in the selected 8 African countries (Tunisia, Algeria, Morocco, Egypt, Kenya, Nigeria, Congo, and Uganda), to understand the characteristics of the domestic market. Because of lack of data, especially the producer price, we could not examine the relationship between the producer and the consumer. As mentioned in Figure 1, the arrow linking the agricultural producer price and the domestic food price is not going to be taken in consideration.

Figure 2 illustrates the modified theoretical framework of my dissertation, showing the relationships that were incorporated in the analysis.

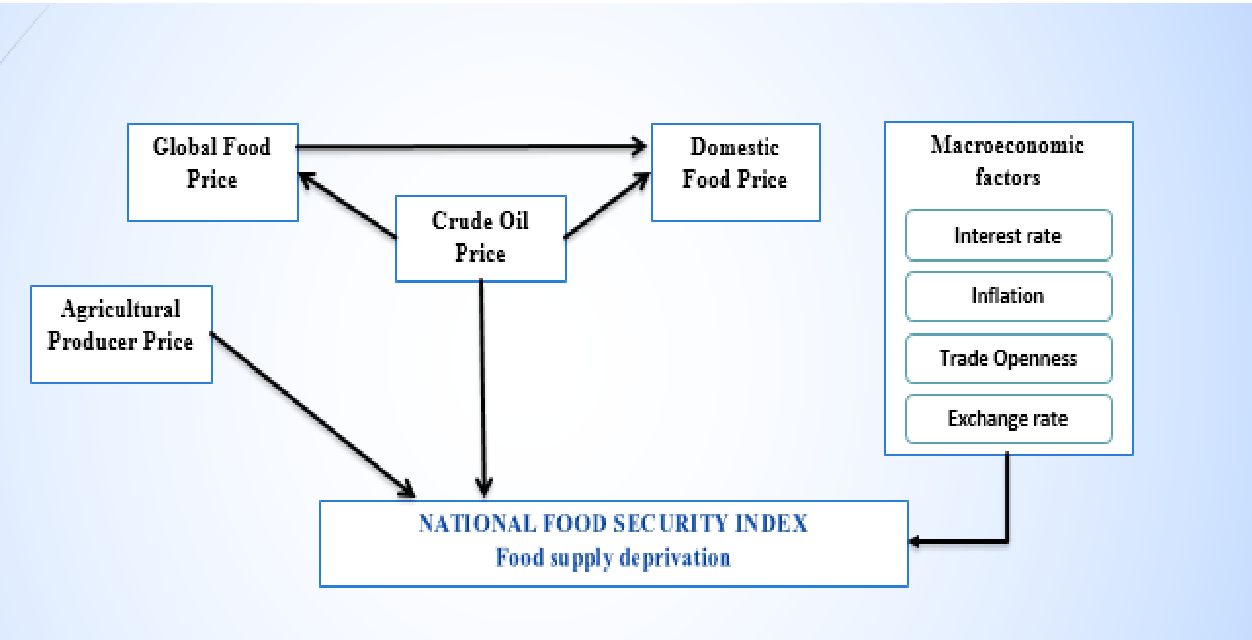

Figure 2. The modified Conceptual model of the research: Connections between food prices, crude oil price, macroeconomic indicators, and food security index Source: Author's own construction

The increasing concern in investigating the co-movement of fuel and food prices was ascribed to the capability of agricultural commodities financialization. Mainly, after the financial crises, and with the era of food crisis between 2006 and 2008. Energy, particularly crude oil, is a critical component of every economy's development. It is widely used to supply many sectors like as transportation, agriculture, industry, and households.

As a result, it has a high value and influences the prices of other commodities. After1973, oil price shock is one of the most important concerns in energy economics. Many studies (Wang, Wu, and Yang, 2014; Ahmadi, Behmiri, and Manera, 2016; Bhat, Ganaie, and Sharma, 2018) evaluate its implications on other sectors that are related. Price volatility may lead to the uncertainty and the fluctuation in agricultural markets and generate crucial unpredictability between stakeholders. Though some countries utilize trade measures to protect their domestic markets from variations in international food prices, the volatility is exacerbated.

As a result, more countries will follow similar measures. Countries should intervene in the case of major world food price fluctuations to mitigate the impact of international food price spikes on domestic prices and to ease the adjustment burden on disadvantaged population groups. The international pricing instability is exacerbated by fluctuations in trade barriers, especially food products, which may cause crucial effect on the national food security status. To determine to which extent the international food price volatility may be transmitted to the domestic food price help policy makers to intervene and stabilize the market. The food price has been linked to food security in some research papers (Amolegbe et al., 2021). Prior to examine this relationship, we notice that there is different method to weight different indicators to estimate the national food security index. It is quite important to forecast food security index and to provide a mathematical and scientific weighting method. Finally, explaining the link between the food price and national food security with some selected macroeconomic indicators could draw a clear image for the governments to implement the suitable policy measures.

2. OBJECTIVES

My dissertation focuses on quantifying the speed and the extend of price adjustment relationship between international and domestic prices of food and some food subcategories (i.e. meat, cereal, and milk). African countries have been selected for this examination of market interaction. GARCH family models haven used because of their ability to catch the dynamic volatility and its transmission.

In the dissertation the examination of global food and sub-categories prices was highlighted. The dissertation follows this line and focuses on the national food security. It aims to forecast the national food security index based the gap in food supply. My research work aims to suggest a food security index based on the gap in food supply, and introducing a weighting method based on the DALY indicators.

- ***Main objectives:***
    1. Measuring the interdependence and the dynamic correlation, firstly between global food price and crude oil price, secondly between domestic and international food prices, and thirdly between the domestic food and crude oil prices.
    2. Forecasting a national food security index, based on the deficit in the food supply (food subcategories).
    3. Determination of the relationship between the forecasted food security, agricultural producer price and macroeconomic indicators.

The United Nations' Vision 2050 for food security calls for doubled food output by 2050 to ensure adequate food availability (McKenzie and Williams).. To achieve this goal, an appropriate planning at the national level is required.

The price fluctuation of agricultural commodities has raised a concern for studying the volatility of different agricultural products. A persistent volatility in prices causes continued uncertainty in the market. It causes an increased management costs which is converted into higher producer prices.

My thesis considers the examination of the relationship between, crude oil price shocks, food price, and agricultural commodities. Crude oil is a key element for socio-economic development and stability.

The data used for volatility examination covers the two global crises: Global Financial Crisis (2007-2008) and Covid-19 pandemic crisis (2020). International agricultural prices and fluctuations are spilled-over horizontally to domestic markets, thus affecting the national food security. It is important for countries to have enough knowledge concerning the co-movement between crude oil and food prices.

For this purpose, and to fill the gap of the existing studies, my dissertation is going to examine firstly, the dynamic relation between crude oil and international food prices, secondly between the global food price and selected African countries (Tunisia, Morocco, Algeria, Egypt, Kenya, Congo, Uganda) domestic food prices, and thirdly, between the crude oil and domestic food prices of the selected developing countries. These examinations are aiming to determine the magnitude of interdependence between different prices during food crisis and Covid-19 periods.

3. MATERIAL AND METHODS

To investigate the price dynamic along the supply chain, there are two principal concepts: price volatility and price transmission. Price transmission and price volatility transmission handle the price relations along the supply chain.

However, price transmission designs to the interconnections between the conditional mean prices, but price volatility transmission concerns the links between the conditional variance of prices (Natcher and Weaver, 1999).

Price transmission investigates the relation between the foreseeable parts of price information whereas price volatility transmission examines the connection between the unforeseeable part of prices. Price volatility spillover is also interpreted as the magnitude of price uncertainty in one market affects price uncertainty in other markets (Apergis and Rezitis, 2003).

3.1. Area of study

Our study deal with African countries. Africa is a vulnerable continent to food security. It accounts 821 million of food-insecure person, which presents 31% of the global people in 2017 (Fan, 2019). Africa, due to its vulnerability, is exposed to many factors that threaten its food security.

First, it witnessed a decreasing animal husbandry and rangelands (Nardone et al., 2010). In addition, to the expanded desertification, that alters 46 African countries and raised dangerous effect of droughts(Intergovernmental Panel on Climate Change, 2020).

3.2. ARCH/GARCH models

For dealing with time series heteroskedastic models, ARCH and GARCH models have become standard tools; these models give a volatility measure that may be used in price analysis. The ARCH (Engle, 1982) and GARCH (Bollerslev, 1986) models were created to capture such data volatility characteristics. The time-series approach GARCH, in particular, enables for simulating the serial dependency of the volatility. Engle was the first to present ARCH models (1982).

The models aim to explain variance transmission in the residuals.

The basic form of ARCH proposed by Angle (1982) is presented in two equations - the conditional mean and the conditional variance:

$$Z_t = w_t\beta + \varepsilon_t \quad (1)$$

$$\tau_t^2 = \varphi_0 + \varphi_1 \varepsilon^2_{t-1} + \varphi_2 \varepsilon^2_{t-2} + \varphi_3 \varepsilon^2_{t-3} + \ldots\ldots + \varphi_p \varepsilon^2_{t-n} \quad (2)$$

ε^2_t is the squared residual,

φ_p are the ARCH coefficients that quantify the past deviation of conditional variance τ_t.

The Generalized Autoregressive Conditional Heteroscedasticity is abbreviated as GARCH. Conditional heteroscedasticity implies variable conditional variance, while heteroscedasticity means variable variance.

The GARCH model has four main specifications: conditional covariance matrix models, factor models, conditional variances and correlations models, as well as non-parametric and semi-parametric models. (Silvennoinen and Terisvirta, 2008).

The GARCH(p,q) model performs the conditional variance and it is explained by the lagged squared errors and past conditional variance.

$$\tau_t^2 = \varphi_0 + \varphi_1 \varepsilon^2_{t-1} + \varphi_2 \varepsilon^2_{t-2} + \varphi_3 \varepsilon^2_{t-3} + \ldots + \varphi_p \varepsilon^2_{t-p} + \theta_1 \tau^2_{t-1} + \theta_2 \tau^2_{t-2} + \ldots + \theta_q \tau^2_{t-q} \quad (3)$$

where φ_q are the GARCH coefficients which reflect the effect previous variance information on the present value.

3.2.1. The univariate GARCH

Bollerslev (1986) developed a methodology based on Engle's ARCH models (1982). Engle introduced a conditional variance formula for time series that is dependent on the realized error of the previous period. Bollerslev built the GARCH model by considering his own volatility history, similar to the expansion from AR to ARMA models.

However, the constraints on univariate time series in this paradigm do not account for volatility spillover.

The following is the univariate GARCH (1,1) model:

$$\sigma_t^2 = \gamma_0 + \gamma_1 \varepsilon^2_{(t-1)} + \gamma_2 \sigma^2_{(t-1)} \quad (4)$$

$\sigma_t^2$is the variation of t, based on information up to period t. (conditional error term). Univariate GARCH models do not appear to be appropriate, hence multivariate generalization appears to be the preferable option.

Modeling multivariate time series may be done in two ways: direct estimating the variance–covariance matrix or indirectly modeling the correlation between the timeseries

3.2.2. Multivariate GARCH model

While univariate GARCH models are good at modeling the conditional variance of a single time series, they are enabling when it comes to simulating connectedness between two or more-time series.

Multivariate GARCH models provide the benefit of specifying equations for the movement of variances and covariances of many time series across time. Multivariate Generalized Autoregressive Heteroskedasticity models are the most often utilized price volatility transmission models (MGARCH). Multivariate GARCH models are effective for forecasting multivariate time series volatility and volatility co-movement (Zivot andWang2006).

Consider a vector of price x_t of dimension a*1:

$$x_t = (x_{1t}, \ldots, x_{a,t})' \quad (5)$$

$$x_t - \mu_t = £_t = A^{-1/2} y_t \quad (6)$$

$\{y_t\}$= a sequence of (a*1) i.i.d random vector with the following characteristics:

$$E[y_t] = 0 \quad (7)$$

$$E[y_t y'_t] = B_a(10) \quad (8)$$

$$y_t \sim G(0, B_a) \quad (9)$$

G is a continuous density function:

$$E_{t-1}(£) = 0 \quad (10)$$

$$E_{t-1}(£t\ £'t) = A_t \quad (11)$$

The correlation matrix is :

$Corr_{t-1}$ ($£_t$) = $R_t = D_t^{-1/2} A_t D_t^{-1/2}$ (12)

D_t= diag($A_{11,t}, \ldots, A_{aa,t}$) (13)

The general bivariate GARCH model is presented below:

$$A_t = \begin{bmatrix} b0,1 \\ b0,2 \end{bmatrix} + \begin{bmatrix} b11 & \alpha12 \\ b21 & \alpha22 \end{bmatrix} \begin{bmatrix} \varepsilon_t^2 1, t-1 \\ \varepsilon_t^2 2, t-1 \end{bmatrix} + \begin{bmatrix} c11 & c12 \\ c21 & c22 \end{bmatrix} \begin{bmatrix} A1, t-1 \\ A2, t-1 \end{bmatrix} \quad (14)$$

where:

$b0,1$ and $b0,2$ are the constants that present the mean equation of the model.

$A_{1,t-1}$ and $A_{2,t-1}$ are the conditional variance at time t-1 for the price series.

$\varepsilon^2_{1,t-1}$ and $\varepsilon^2_{2,t-1}$ are the errors at time t - 1 of the price series.

b_{11} b_{12} b_{21} b_{22} are the coefficients of the autoregressive errors $\varepsilon^2_{1,t-1}$ $\varepsilon^2_{2,t-1}$. The "b" matrix represents the sensitivity to short-term shocks of the conditional volatility.

b_{11} measures the own short-term shock of the first price vector, b_{12} measures the volatility transmission from the first price to the second price. b_{21} b_{12} measures the short-term shock transmission from the second price to the first price. And finally, b_{22} measures the own short-term shock of the second price vector

c_{11}, c_{12}, c_{21}, c_{22} are the coefficients of the conditional variance $A_{1,t-1}$ and $A_{2,t-1}$.The matrix "c" indicates the persistence of the conditional volatility. $c_{11}$and c_{22} present the magnitude of the conditional volatility of the price series while c_{12} and c $_{21}$indicates the volatility transmission between the two prices.

3.2.3. DCC-GARCH model (Dynamic Conditional Correlation model)

The DCC-GARCH model is used in order to model the correlation between two price levels. Engle(2002)has introduced the dynamic conditional correlation model, the DCC GARCH, enabling the matrix of conditional correlations that vary in time. This model is a generalization of the CCC-GARCH model Bollerslev (1990).

$Y_t = \mu_t + \varepsilon_t$ (15)

$\varepsilon_t = \sqrt{H_t}\, \xi_t$ (16)

$H_t = D_t R_t D_t$ (17)

Y_t is n*1 vector of n returns at time t

μ_t is n *1 vector of n expected returns at time t

ε_t is n*1 vector of independent, and identically distributed errors with $E[\varepsilon_t] = 0$ and $cov[\varepsilon_t]$ = Ht

H_t is n*n matrix of conditional variance of ε_t, time t

D_t is n*n diagonal matrix of conditional standard deviation of ε_t time t.

R_t is n*n matrix of conditional correlation of ε_t time t

ξ_t is n x 1 vector of i.i.d errors with $E[\xi_t] = 0$ et $E[\xi_t\xi'_t] = I_n$

This is an estimation model in two stages. The first step is to estimate the conditional variance with univariate GARCH for each series. The second step uses the standardized residuals obtained in the first step to estimate the parameters of the matrix of dynamic correlations.

This model includes conditions allowing the covariance matrix to be definite positive at all times and the covariance to be stationary.

The H_t matrix is divided into two matrixes, D_t and R_t. The D_t matrix elements are derived from univariate GARCH estimated for each series:

$$\begin{bmatrix} \sqrt{h1}, t & 0\ 0\ 0\ \cdots & 0 \\ 0\ \vdots & \sqrt{h2}, t\ \ddots & \vdots\ 0 \\ 0 & 0\ 0\ 0\ \cdots & \sqrt{hN}, t \end{bmatrix} \quad (18)$$

where $h_{i,t}= \alpha_{0,i}+ \sum_{q=1}^{Qi} \alpha_{iq}\varepsilon^2_{i,t-q}+ + \sum_{p=1}^{Pi} \beta_{ip}h_{i,t-p}$ (19)

Univariate GARCH could be with a different order, which enables analysis of sets with different numbers of lags.

The Rt matrix is that of standardized residual conditional correlations ε_t and it is now dynamic:

$$\begin{bmatrix} 1 & \rho 12, t\rho 13, t \cdots & \rho 1n, t \\ \rho 21, t\ \vdots & 1\ \ddots & \rho 2n, t\ \vdots \\ \rho n1, t & \rho n2, t\rho n3, t \cdots \rho nn-1, t & 1 \end{bmatrix} \quad (20)$$

The Ht matrix must be definite positive, because it is a variance-covariance matrix.

In order to ensure that Ht be definite positive, Dt must be definite positive. The matrix Rt is always positive because Dt= diag($\sqrt{h_{1,t}}$, $\sqrt{h_{2,t}}$, ….., $\sqrt{h_{N,t}}$) so these elements are always positives. We also have to ensure that R_t elements are smaller or equal to 1, because they are correlations. Then in order to ensure that Rtis positive, it has to be decomposed in two matrixes:

$Rt= Q_t^{*-1} Q_t Q_t^{*-1}$ (21)

and $Q_t=(1- \alpha_{DCC} - \beta_{DCC}) \overline{Q} + \alpha_{DCC}\ \varepsilon_{t-1}\ \varepsilon'_{t-1}+ \beta_{DCC}\ Q_{t-1}$ (22)

where

$$Q_t^* = \begin{bmatrix} \sqrt{q11}, t & 0\ 0\ 0 & 0 \cdots & 0 \\ 0 & \sqrt{q22}, t \ddots & & O \\ 0 & 0\ 0\ 0 & 0 \cdots & \sqrt{qNN}, t \end{bmatrix} \quad (23)$$

and where $$Q_t = \begin{bmatrix} q11, t & \sqrt{q11}, tq22, t \cdots & \sqrt{q11}, tqNN, t \\ \sqrt{q11}, tq22, t & q22, t \ddots & \sqrt{q22}, tqNN, t \vdots \\ \sqrt{q11}, tqNN, t & \sqrt{q11}, tqNN, t \cdots & qNN, t \end{bmatrix} \quad (24)$$

The Qt matrix must be definite positive to ensure that Dt is positive too.

Q = Cov [$\varepsilon_t \varepsilon'_t$] =E[$\varepsilon_t \varepsilon'_t$], presents the non-conditional covariance of the standardized residuals obtained by univariate GARCH. α_{DCC} and β_{DCC} are scalars. In order to ensure that His definite positive:

$\alpha_{DCC} \geq 0$,

$\beta_{DCC} \geq 0$

and ($\alpha_{DCC} + \beta_{DCC}$) < 1.

The general structure of DCC dynamic correlation (p, q) is as follows:

$$Q_t = (1- \sum^{P}_{i=1} \alpha_{DCC,i} - \sum^{Q}_{j=1} \beta_{DCC,j}) \bar{Q} + \sum^{P}_{i=1} \alpha_{DCC,i}(\varepsilon_{t-i} \varepsilon'_{t-i}) + \sum^{Q}_{j=1} \beta_{DCC,j} Q_{t-j} \quad (25)$$

The DCC-GARCH (l,l) bivariate model is:

$$h_{11,t} = \alpha_{0,1} + \alpha_{11} \varepsilon^2_{1,t-1} + \beta_{11} h_{11,t-1} \quad (26)$$

$$h_{22,t} = \alpha_{0,2} + \alpha_{21} \varepsilon^2_{2,t-1} + \beta_{21} h_{22,t-1} \quad (27)$$

$$Rt = Q_t^{*-1} Q_t Q_t^{*-1} \quad (28)$$

$$Q_t = (1- \alpha_{DCC} - \beta_{DCC}) \bar{Q} + \alpha_{DCC} \varepsilon_{t-1} \varepsilon'_{t-1} + \beta_{DCC} Q_{t-1} \quad (29)$$

where equations (33) and (34) are the conditional variance equations obtained from equation

$$H_t = \begin{bmatrix} h11, t & h12, t \\ h21, t & h22, t \end{bmatrix} \quad (30)$$

3.3. Food security index forecast

Food security measures have changed in recent decades from bridging the dietary energy gap through greater staples production to making diets more economically feasible (World Health Organization, 2017). To estimate the food security index, the gap of supply of different staple food has been used. The daily food allocation for a person is considered based on the eat lancet commission in 2019. They introduced the recommended macronutrient intake in grams per day per person. The following table present the amount of each food category that should be consumed.

Table 1. Macronutrient Intake (grams/ day)

Food categories	Required quantity in grams/ person/day/
Vegetables	300
Fruits	200
Whole grain	232
Nuts	50
Dairy products	250
Fish and sea products	28
Legumes	75

Source: Eat lancet commission (2019)

DALYs are defined as the sum of “years of life lost due to premature mortality and years lived with disability” (Murray et al., 2012). DALYs measures are included from food deficiencies (Sulser et al., 2021). Dalys have been used to measure the hunger and highlight the linked trends (Gödecke et al., 2018). In our study, DALYs for food subcategories have been employed.

The difference of the supplied food and the recommended has been used to quantify the food security. The weight of each items is based on the DALY (disability-adjusted life year) indicator given by the Global burden of disease. DALY indicator involved in our study considers the dietary risks. The dietary risks included in our thesis are; diet low in fruits, vegetables, nuts, milk, fish and sea food, cereals, and legumes. the DALY indicator weight of each item has employed to measure its magnitude in the estimated food security index.

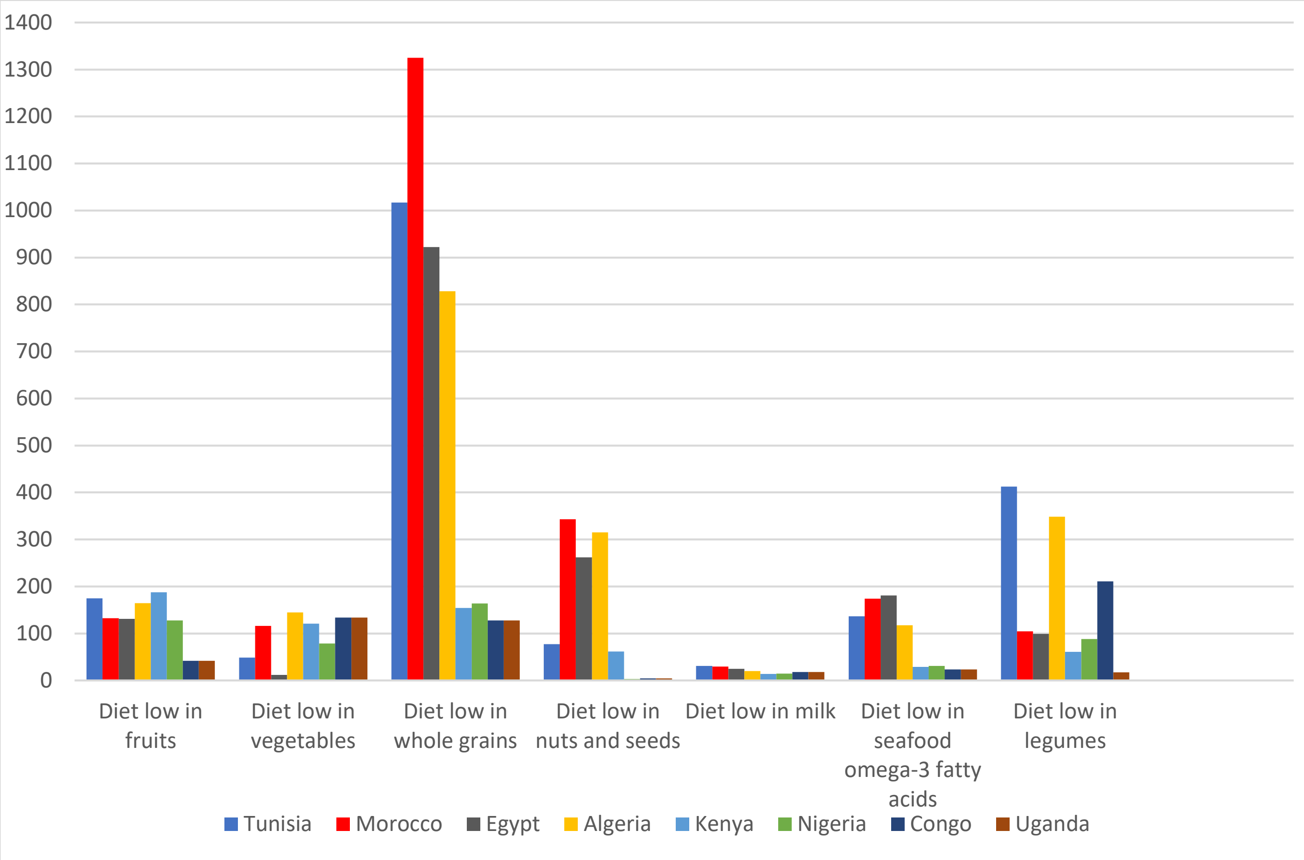

Figure 3. DALY rates presenting the diet low in food subcategories (fruits, vegetables, milk, seafood, legumes, whole grains, and nuts and seeds)

Source: Author's own work based on Global Burden Disease Database

DALYs for a specific cause are calculated as the sum of the years of life lost due to premature mortality (YLLs) from that cause and the years of years of healthy life lost due to disability (YLDs) for people living in states of less than good health resulting from the specific cause.
After the determination of the weight. Figure 3 shows the DALYs of the selected African countries. The disability life lost due to the deficit diet in cereals has the highest rate for all countries, except Congo, where the shortage of legumes has the highest rate.

3.4. PANEL data analysis: GMM approach

The composite food security, agricultural producer price, and macroeconomic factors relationship is estimated applying a two-step system GMM approach.in order to avoid the endogeneity, the difference GMM, suggested by Arellano and Bond in 1991, has been utilized. It uses the first differences of the variables, and considers the lagged value of regressors as instruments to remove the country specific effect.

$$\text{Log}(FSI_{it}) = \mu + \alpha \log(FSI_{it-1}) + \beta \log(X_{it}) + \tau_i + \varepsilon_i \quad (31)$$

We introduced the natural logarithms to the variables considered in our model, in order to reduce the occurrence of heteroscedasticity Where FSI_{it} is the dependent variable of country i for period t, X_{it} t is the matrix of explanatory (independent) variables that detect the effect of the macroeconomic characteristics of countries. μ is a constant, α and β are the coefficients of the lag value of food security index and the independents variables respectively. τ_i presents the fixed effect of the country (country control), ε_i is the error terms.

3.5. Data sources and description

To examine the price volatility time series database has been used. For the examination of the price volatility between the global food price and crude oil price, a monthly price index of food and food subcategories have been taken from FAOSTAT and mundi index from January 1992 till October 2021.

To calculate the gap in food supply, we used the database from FAOSTAT. It has a yearly value of the quantity supplied of food subcategories from 1995 till 2018.

We employed a panel data of eight selected African countries covering the period between 1995 and 2018. The choice of the variables and time frame, employed in our dissertation, is based on previous research works and data availability. Data used in the study are taken mainly from the Word Bank database and FAO's FAOSTAT.

The retail monthly prices of Tunisia, Morocco, and Algeria of the different commodities are retrieved from Food Price and Monitoring Analysis (FPMA) provided by FAO, which contains time series of agricultural commodity retail prices. Based on the data availability, we illustrate the data frame used in our research. For Tunisia, we used monthly retail prices from January 1994 till February 2018 for milk price, monthly data from January 1994 till March 2022 for chicken and beef meat, and for lamb meat price is from January 1994 till October 2021. For Algeria, price series are from January 2005 till April 2018. And for Morocco, retail prices are between January 2010 and June 2020.

4. RESULTS AND DISCUSSIONS

Data analysis is the part of presenting research findings. This section describes the specific analyses realized to respond the research problem and decide whether to support or reject the hypotheses. The used software for all findings is R studio version 4.1.2 (2021-11-01) (R Core team,, 2013).

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4.1. Analysis of global crude oil, global food prices volatility and their dynamic correlations

To understand the movement of global food price index and the staple food prices (i.e. meat, dairy, and cereal), the price volatility of each price series has been analyzed. A univariate GARCH model has been employed to measure the magnitude of the past effect (shocks and volatility) of each own price series.

Table 2 presents the descriptive statistics of the variables. It points out the value of minimum, maximum, average, median, and the standard deviation. It gives an image about the price range of each item. Crude oil price has registered the highest standard deviation that explains its important fluctuation around the average price.

Table 2. Descriptive statistics of the variables

	Min	mean	Median	Standard deviation	Max
Food Price Index	50.47	85.06	80.42	24.34	137.62
Meat Price Index	51.10	83.14	81.77	16.63	119.17
Dairy Price Index	40.08	84.90	77.12	31.19	156.49
Cereal Price Index	48.62	86.49	86.21	29.59	163.33
Crude oil price index	24.09	110.54	103.81	63.57	264.61

Source: Author’s own work based on R studio results

Prior to estimate the GARCH model, it is mandatory to determine the optimal lag number of the variables. For this purpose, the optimal lag number determined using “Varselect” command from Vars package in R studio software. The optimal lag is equal to 1 for our variables.

Based Schwartz Information Criteria (SIC), Lag 1 is considered the optimal lag length for all test and the model estimation.

4.1.1. Unit root tests

Unit roots in non-stationarity in price series are investigated using two alternative unit root tests. Said and Dickey (1984) established the Augmented Dickey-Fuller (ADF) test, while Phillips and Perron (PP) established the Phillips-Perron (PP) test (Phillips and Peron, 1988).

The acceptance of the null hypothesis in these tests means that the price series are non-stationary,as they do not have a unit root. The results of the tests show that all price series have a unit root, indicating that they are all stationary at first level.

Table 3. Unit root tests (ADF test values with p-values in parentheses)

	Level of price indices				
Variables	Food price index	Meat price index	Dairy price index	Cereal price index	Crude oil price index
Value	-1.14(0.915)	-1.56 (0.764)	-1.69 (0.709)	-1.7 (0.701)	-2.46 (0.381)
	First difference of price indices				
Variables	Food price index	Meat price index	Dairy price index	Cereal price index	Crude oil price index
Value	-10.5(0.01)	-14.1 (0.01)	-10.7 (0.01)	-12 (0.01)	-7.08 (0.01)

Source: Author’s own work based on R studio results

Firstly, we performed the ADF test for unit roots, as presented in table 3, to determine if the price series are non-stationary. The test has been applied on price series and first difference price series. Our data are stationary at first level.

Table 4. Phillips Perron unit root test results (test values, and p-values in parentheses)

	Level of price indices

Variables	Food price index	Meat price index	Dairy price index	Cereal price index	Crude price index
Value	-9.26 (0.491)	-9.07 (0.5)	-15.4 (0.217)	-13.5 (0.301)	-13.98 (0.327)
	First difference of price indices				
Variables	Food price index	Meat price index	Dairy price index	Cereal price index	Oil price index
Value	-181 (0.01)	-265 (0.01)	-189 (0.01)	-218 (0.01)	-227 (0.01)

Source: Author's own work based on R studio results

Phillips Perron (PP) proposed another theory of unit root non-stationarity, as seen in Table 4. The tests are similar to ADF tests, except they include an automated DF process adjustment to account for autocorrelated residuals.

Table 5. ARCH test result: aTSA package- A better title can be: ARCH LM test for heteroscedasticity (p-values in parentheses)

	Porte-manteau	**Lagrange Multiplier**
Crude Oil	99.7 (0.0000)	137.4 (0.0000)
Cereal	26.5 (0.00002)	419.9 (0.0000)
Dairy	77.3 (0.00000)	210.3 (0.0000)
Meat	10.4 (0.033581)	165.8 (0.0000)
Food price index	50.5 (0.00000)	234.7 (0.0000)

Source: Author's own work based on R studio results

The residuals should perform an autoregressive conditional heteroscedasticity to support the use of the GARCH model. The ARCH LM test for conditional heteroscedasticity, as mentioned in Table 5, reveals a high existence of the ARCH structure across the different price series, confirming the feasibility of using GARCH models to study volatility dynamics.

4.1.2. GARCH model estimation

Firstly, we estimated the own price volatility for the price series using the univariate GARCH model to determine the level of own price volatility.

Table 6. Univariate GARCH model

	Mu	Ar1	Omega	Alpha	Beta
Food Price Index	0.001680 (0.27446)	0.367212 (0.0000)	0.000024 (0.16397)	0.100105 (0.01165)	0.834572 (0.00000)
Meat	0.001982 (0.228913)	0.305901 (0.00000)	0.000027 (0.255688)	0.089728 (0.046113)	0.867663 (0.000000)
Dairy	0.001898 (0.4408)	0.528247 (0.00000)	0.000055 (0.080907)	0.220968 (0.004070)	0.751703 (0.00000)
Cereal	0.000531 (0.831952)	0.368369 (0.0000)	0.000060 (0.144872)	0.042833 (0.084801)	0.9066022 (0.00000)
Crude Oil	0.002845 (0.361235)	0.292031 (0.00000)	0.000150 (0.095180)	0.119925 (0.005180)	0.823627 (0.000000)

Source: Author's own work based on R studio results

The univariate GARCH model captures the own ARCH and GARCH of each price series, as presented in table 6. Own shocks spillovers of each price series are significant, we can affirm the presence of the own volatility effect for the employed price series. The global dairy price registered the highest ARCH value (0.22), that means 22% of the past shocks are transmitted to the present value.

The lagged volatility spillover effects for all price series are significant. This suggests that previous price volatility shocks have a significant impact on future volatility. The GARCH impact is measured by beta values, which suggests that price series are heavily influenced by previous volatility.

We prove that the cereal price has a high volatility persistence of 0.90, which implies that 90% of the previous'day's volatility endures the next day. The meat price has a Beta value of 0.86, which means 86% of past volatility is spilled over the present value, which is considered also high.

Table 17 shows the magnitude of interdepended relationship between the crude oil price and the food price.

Table 7. The time-varying volatility spillover between crude oil price and global food price index (what model??)

Variables	Coefficient	Standard Error	T value	Probability
Mu (fuel)	0.0113	0.0044	2.526	0.0115
Omega (fuel)	0.0041	0.0015	2.630	0.0085
Alpha (fuel)	0.4264	0.1490	2.8613	0.0042
Beta(fuel)	0.0000	0.2591	0.0000	1.0000
Mu (food price index)	0.0014	0.0010	1.3865	0.1655
Omega (food price index)	0.00003	0.00002	1.0801	1.2801
Alpha (food price index)	0.18970	0.07523	2.5216	0.0116
Beta (food price index)	0.76037	0.1179	6.4460	0.0000
Alpha DCC	**0.1037**	**0.0300**	**3.4549**	**0.0005**
Beta DCC	**0.8151**	**0.0644**	**12.6420**	**0.0000**

Source: Author’s own work based on R studio results

To examine the strength and direction of the spillover effect of oil price fluctuation. The data used for the estimation is monthly price index from January 1992 till October 2021. The DCC model (Engle, 2002) is estimated. The GARCH (1,1) process accounts for serial correlation in squared residuals.

DCC (1, 1)-GARCH (1, 1) is adopted to examine the time varying conditional correlation between crude oil price and the food price index. The estimation results for the DCC (1, 1) model is highlighted in table 7. At first sight, Alpha DCC and Beta DCC are significant, their sums is close to 1, indicating rather high persistence in conditional variances.

The β coefficient indicates that the conditional correlation between the residuals. 0.8151 is the value of Beta DCC, that means the food price index and the fuel price are 81% conditionally correlated. The results approve the stronger positive dependence between these two prices.

This relationship is explained by reallocation of the farmer land to produce energy products instead other products, mainly cereals, which by itself will aggravate the food insecurity.

4.2. Volatility investigation between global food price index and the national food price index in 8 African countries (i.e. Tunisia, Algeria, Morocco, Egypt, Uganda, Kenya, Congo, and Nigeria)

The continent of Africa is considered a high importing continent. They import 85% of their needs in food between 2016 and 2018. A sudden increase of international food price could worsen the status, where an unexpected increase affects the amount of imported food, which may decrease.

An empirical econometric model has been estimated to quantify the magnitude of the volatility spillovers between the global food price index and the food price index of some selected African countries (i.e. Algeria, Tunisia, Morocco, Egypt, Congo, Uganda, Nigeria, and Kenya). Monthly price series have been used from January 2000 till June 2021.

Source: Author's own work based on R studio results

Table 8: ARCH-LM test results for heteroskedascity

	Portmanteau	**Lagrange Multiplier**
Food price index in Algeria	30.89 (0.003)	79.39 (0.0000)
Food price index in Tunisia	16.0 (0.003)	70.34 (0.0000)
Food price index in Egypt	46.4 (0.0000)	70.55 (0.0000)
Food price index in Congo	52.4 (0.0000)	124.4 (0.0000)
Food price index in Uganda	47.6 (0.0000)	226.3 (0.0000)
Food price index in Nigeria	15.8 (0.003)	408.8 (0.0000)
Food price index in Morocco	55.0 (0.0000)	102.00 (0.0000)
Food price index in Kenya	38.7 (0.0000)	79.10 (0.0000)
Retail milk price in Tunisia	20.8 (0.0000)	203.6 (0.0000)
Retail beef price in Tunisia	42.4 (0.0000)	158.3 (0.0000)

Retail lamb price in Tunisia	38.9 (0.0000)	126.9 (0.0000)
Retail chicken price in Tunisia	26.5 (0.0000)	118.5 (0.0000)
Retail durum wheat in Morocco	27.1 (0.0000)	98.1 (0.0000)
Retail soft wheat in Morocco	37.4 (0.0000)	93.7 (0.0000)
Retail chicken price in Algeria	19.6 (0.0000)	89.78 (0.0000)
Retail milk price in Algeria	26.8(0.0000)	187(0.0000)
Retail lamb price in Algeria	27.34(0.0000)	345(0.0000)

Source: Author's own work based on R studio results

ARCH E'gle's Test for Residual Heteroscedasticity has been employed using ARCH test function from aTSA package in R studio. This test helps to detect the heteroskedasticity of residuals, the, the use of GARCH model. As shown in table 8, all variables exhibit heteroscedasticity. In other words, conditional variance of the error terms is non constant, it varies over time.

4.2.1. Unit root tests

To check the stationarity of the variables, two tests have been employed. The first one is the Augment Dickey-Fuller (ADF) test suggested by Said and Dickey (1984), the second test is the Phillips-Perron (PP) test suggested by Phillips and Perron (1988). The null hypothesis says that variables are non-stationary, which means that they have unit root. Test results indicate that all price series contain a unit root, i.e. price series are I(1).

4.2.2. DCC-GARCH estimation

The two rows; alpha DCC and beta DCC measure the dynamic volatility transmission from the global food price index to every country (i.e. Algeria, Tunisia, Morocco, Nigeria, Egypt, Kenya, Congo, and Uganda). Mu, Omega, Alpha and Beta of each price series measure the own price volatility. Mu is a constant.

The sums of the GARCH estimates α and β are close to one and it is significant for all price series. This implies a high volatility persistency (compounded shocks to the prices) as the sum α and β and defines the decay factor of the exponentially declining autocorrelation function. A high β coefficient indicates a strong impact of the own-variance on volatility development.

Tables 24 and 25 highlight the forecasted conditional correlations of the DCC model between African food price and the international food price. Table 26 and 27 presents the conditional correlation between the crude oil price and the food price in the selected African countries. All variables have a significant β coefficient that indicates that the conditional correlation between the residuals is highly persistent. It means the existence of the conditional correlation between the two-price series.

Table 9: volatility spillovers between national food price index of selected African countries and the global food price (DCC-GARCH model)

Coefficients	GFPI	FPI Algeria	FPI Tunisia	FPI Morocco	FPI Nigeria
Mu	0.00275(0.017)	0.0017(0.200)	0.003(0.00000)	0.0011(0.000)	0.0095(0.000)
Omega	0.000036(0.34)	0.000003(0.021)	0.0000(0.9924)	0.0000(0.988)	0.000(0.0000)
Alpha	0.3154(0.040)	0.1999(0.0000)	0.2428(0.0000)	0.3299(0.0000)	0.635(0.000)
Beta	0.6511(0.0009)	0.7990(0.0000)	0.7561(0.0000)	0.6687(0.0000)	0.363(0.002)
Alpha DCC	-	**0.000(0.99)**	**0.000(0.99)**	**0.0000(0.9976)**	**0.009(0.551)**
Beta DCC	-	**0.901(0.0000)**	**0.909(0.000)**	**0.9142(0.0000)**	**0.978(0.000)**

Source: Author's own work based on R studio results

As highlighted in two tables 9 and 10, the highest conditional correlation of 0.978 is registered between the Nigerian food price and the global food price. 97.8% of the global food price volatility is transmitted to the Nigerian food price. Food price in Nigeria is highly sensitive to the perturbation of the global food price. Alpha DCC is not significant. It means that in short term a shock of the global food price is not transmitted to the domestic food price of Algeria, Tunisia, Morocco, and Nigeria.

Table 10. Volatility spillovers between national food price index of selected African countries and the global food price (DCC-GARCH model) (continuous)

Coefficients	FPI Egypt	FPI Kenya	FPI Congo	FPI Uganda
Mu	0.0054(0.046)	0.0086(0.0000)	-0.002(0.0210)	0.0038(0.001)
Omega	0.000014(0.506)	0.000029(0.009)	0.0000(0.6714)	0.0000(0.223)
Alpha	0.307(0.103)	0.567(0.0004)	0.2564(0.0000)	0.151(0.049)
Beta	0.6913(0.0000)	0.274 (0.035)	0.7425(0.0000)	0.78(0.00)
Alpha DCC	**0.168(0.035)**	**0.119(0.086)**	**0.015(0.67)**	**0.116(0.061)**
Beta DCC	**0.0000(0.999)**	**0.296(0.645)**	**0.799(0.0000)**	**0.629(0.000)**

Source: Author's own work based on R studio results

To examine the linkage between energy price and food prices over the period 2000–2021 by using DCC-GARCH model in the case of 8 African countries. Monthly prices of crude oil and food price from January 2000 till June 2021 have been used. Tables 11 and 12 present the results of the econometric model.

Table 11. Volatility spillovers between national food price index of selected African countries and the crude oil price (DCC-GARCH model)

Coefficients	FUEL	FPI Algeria	FPI Tunisia	FPI Morocco	FPI Nigeria
Mu	0.013(0.010)	0.0017(0.200)	0.003(0.0000)	0.0011(0.000)	0.0095(0.000)
Omega	0.004(0.002)	0.0000(0.021)	0.0000(0.992)	0.0000(0.988)	0.000(0.000)
Alpha	0.479(0.007)	0.1999(0.000)	0.242(0.000)	0.3299(0.000)	0.635(0.000)
Beta	0.000(0.99)	0.7990(0.000)	0.756(0.000)	0.6687(0.000)	0.363(0.002)
Alpha DCC	**-**	**0.000(0.99)**	**0.045(0.02)**	**0.058(0.051)**	**0.008(0.74)**
Beta DCC	**-**	**0.924(0.000)**	**0.870(0.000)**	**0.722(0.000)**	**0.78(0.000)**

Source: Author's own work based on R studio results

We notice that all Beta DCC are significant at 1%. It explains the significance of the volatility transmission between the crude oil and food price of the eight African countries. Our results demonstrate that energy price has a significant impact on food prices.

Table 12. Volatility spillovers between national food price index of selected African countries and the crude oil price (DCC-GARCH model) (continuous)

Coefficients	FPI Egypt	FPI Kenya	FPI Congo	FPI Uganda
Mu	0.0054(0.046)	0.0086(0.0000)	-0.002(0.0210)	0.0038(0.001)
Omega	0.000014(0.506)	0.000029(0.009)	0.0000(0.6714)	0.0000(0.223)
Alpha	0.307(0.103)	0.567(0.0004)	0.2564(0.0000)	0.151(0.049)
Beta	0.6913(0.0000)	0.274 (0.035)	0.7425(0.0000)	0.78(0.00)
Alpha DCC	**0.033(0.371)**	**0.005(0.908)**	**0.037(0.31)**	**0.00 (0.99)**
Beta DCC	**0.755 (0.000)**	**0.852(0.000)**	**0.827(0.001)**	**0.925(0.000)**

Source: Author's own work based on R studio results

According to the results, food prices respond positively, with different magnitude, to any shock from oil prices. Thus, our results show that there is a connection between energy and food security as a consequence of price volatility. The DCC-GARCH findings prove the evidence of volatility spillovers between all price series. The highest level of conditional correlation has been registered in Algeria and Uganda. They record 0.925 and 0.924. It measures the magnitude of the dynamic coefficient of the correlation between the crude oil and food price, that translates the persistence correlation feature.

An examination of price volatility between Ihe international agricultural commodity and retail prices has been realized. Based on data availability and the selected Africa countrie, I analyzed the spatial price volatility transmission across meat, wheat, and milk products in Tunisia, Algeria, and Morocco. Tables 13, 14, 15, 16, and 17 illustrate the results of the model estimation.

Table 13 exhibits the volatility spillovers across the international dairy price and the retail milk price in Tunisia and Algeria.

Table 13. Volatility spillovers between the global dairy price and the retail milk prices in Tunisia and Algeria

Variables	International dairy price	Retail milk price in Tunisia	Retail milk price in Algeria
Mu	-0.0011(0.813)	0.0032(0.736)	0.003(0.000)
Omega	0.0005(0.000)	0.0000(0.009)	0.000(0.718)
Alpha	0.3711(0.517)	0.348(0.000)	0.000(0.99)
Beta	0.571(0.001)	0.610(0.000)	0.998(0.000)
Alpha DCC		**0.257(0.000)**	**0.04(0.000)**
Beta DCC		**0.5561(0.000)**	**0.925(0.000)**

Source: Author's own work based on R studio results

As indicated in table 13, the sum of Alpha DCC and Beta DCC parameters are less than 1. It proves the model stability and suitability. The sum for Algeria is closer to 1 (0.965), it signifies the existence of continuous linkage between the global dairy price and the retail milk price. However, the beta coefficient of Algerian retail milk price is greater than Beta DCC. It indicates that the retail milk price is highly affected by its own previous value. The magnitude of the conditional volatility in Tunisia is lower, Beta DCC is 0.55, that means the retail milk price is more resistant to international dairy price fluctuation than the retail milk price in Algeria.

Table 14 summarizes the DCC-GARCH output for beef meat in Tunisia. It shows the significance of Beta values. Beta DCC is equal to 0.917, this result proves a positive long run volatility persistence that transmitted from the international price shocks.

Table 14. Volatility spillovers between the global beef and retail beef prices in Tunisia

Variables	International beef price	Retail beef price
Mu	-0.000720(0.917)	0.047(0.0006)
Omega	0.0007(0.311)	0.0023(0.156)
Alpha	0.386(0.035)	0.179(0.001)
Beta	0.612(0.0003)	0.819(0.000)
Alpha DCC	**0.000(0.99)**	
Beta DCC	**0.917(0.000)**	

Source: Author's own work based on R studio results

The significance values of alpha in both meat price (international and domestic) prove that both prices show a significance sensitively impact of their previous own shock. The significance of Beta DCC, which is high value, 0.917, indicates the persistence of volatility that transmitted from the international beef price to the retail beef price in Tunisia. It demonstrates the strong conditional correlation between two markets.

Table 15 illustrates the volatility spillovers of the chicken price in Tunisia and Algeria. It indicates the level of the conditional correlation between the global and the domestic chicken prices in these two countries.

Table 15. Volatility spillovers between the global chicken and retail chicken prices in Tunisia and Algeria

Variables	**International chicken price**	**Retail chicken price in Tunisia**	**Retail chicken price in Algeria**
Mu	-0.003(0.218)	0.006(0.0792)	0.847(0.710)
Omega	0.0001(0.339)	0.0007(0.267)	0.000(0.786)
Alpha	0.156(0.002)	0.237(0.000)	0.0176(0.223)
Beta	0.842(0.0000)	0.761(0.000)	0.981(0.000)
Alpha DCC		**0.000(0.99)**	**0.000(0.99)**
Beta DCC		**0.898(0.000)**	**0.9300 (0.000)**

Source: Author's own work based on R studio results

The international chicken price shows a significant alpha and beta coefficients. It means that the international chicken price is sensitive to its own previous shock and is persistent to previous volatility. The sum of alpha and beta is highly close to 1, it reflects the high volatility persistence. Beta DCC for both national markets are significant. It justifies the high volatility persistence between the international chicken price and the retail chicken price in Tunisia and Algeria. Own and across volatility persistence is justified for the chicken meat price.

Table 16 illustrates the volatility spillovers of the lamb price in Tunisia and Algeria. It indicates the level of the conditional correlation between the global and the domestic lamb prices in these two countries. The sum of Alpha DCC and Beta DCC parameters are less than 1. It proves the model stability and suitability. The sum for Tunisia is closer to 1 (0.911), it signifies the existence of continuous linkage between the global lamb price and the retail lamb price. However, for Algeria Beta DCC is non-significant, it indicates that the retail lamb price is not persistent to an international volatility of lamb price. Retail lamb price in Algeria is sensitive to international lamb price shock. We observe the significant of Beta value for Algeria, it indicates the own volatility persistence of retail lamb price.

Table 16. Volatility spillovers between the global lamb and retail lamb prices in Tunisia and Algeria

Variables	International lamb price	Retail lamb meat price in Tunisia	Retail lamb meat price in Algeria
Mu	0.010(0.329)	0.037(0.000)	0.003(0.295)
Omega	0.0000(0.830)	0.011(0.098)	0.000(0.797)
Alpha	0.015(0.061)	0.313(0.037)	0.089(0.288)
Beta	0.983(0.000)	0.626(0.000)	0.894(0.000)
Alpha DCC		**0.000(0.977)**	**0.161(0.042)**
Beta DCC		**0.911(0.000)**	**0.009(0.994)**

Source: Author's own work based on R studio results

Tunisian lamb meat shows a significant sensitivity and persistence to its own previous value. As indicated in table 31, the sum of Alpha DCC and Beta DCC parameters are less than 1. It proves the model stability and suitability.

Table 17 illustrates the wheat price volatility. It indicates the volatility spillovers between international wheat price and retail price in Morocco. Two kind of wheat, durum and soft wheat, are considered in our analysis.

The international wheat price has a significant beta value, that means that it is persistent to its previous shock. Retail durum wheat price has a significant alpha and beta values, it proves that it is sensitive to its own past price shocks, and has a persistent own volatility transmission from its previous price.

Table 17. Volatility spillovers between the global wheat price and the domestic wheat prices in Morocco

Variables	International wheat price	Retail durum wheat price	Retail soft wheat price
Mu	-0.000(0.927)	0.002(0.661)	0.001(0.000)
Omega	0.0000(0.999)	0.0006(0.138)	0.000009 (0.0264)
Alpha	0.000(0.99)	0.127(0.05)	0.000(0.99)
Beta	0.996(0.000)	0.638(0.003)	0.99(0.000)
Alpha DCC		**0.000(0.99)**	**0.000(0.99)**
Beta DCC		**0.924(0.000)**	**0.913(0.000)**

Source: Author's own work based on R studio results

As indicated in table 17, the sum of Alpha DCC and Beta DCC parameters are less than 1. It proves the model stability and suitability. It signifies the existence of continuous linkage between the global wheat price and the retail durum and soft wheat prices. However, the beta coefficient of soft wheat price is higher than Beta DCC (0.99> 0.913). It indicates that the retail soft wheat price is highly affected by its own previous price. The magnitude of the conditional volatility in Morocco of both kind of wheat, Beta DCC, are high, that means the retail wheat price is persistent to international dairy price shocks.

Give a brief summary of your findings by country and product – maybe a summary table with: which product, what country, what relationship identified.

4.3. Food security index forecast

In this part, we describe the followed steps to estimate to unique food security index. The weight has been calculated based on DALYs values. DALYs values are retrieved from the Global Burden disease website. The coefficient indicates the rate of the DALY resulted from deficiency of the food. Table 18 illustrates these rates.

Table 18. The weight of the dietary composition

	Diet low in fruits	Diet low in vegetables	Diet low in whole grains	Diet low in nuts and seeds	Diet low in milk	Diet low in seafood omega-3 fatty acids	Diet low in legumes	Total
Tunisia	9%	2.5%	53.5%	4.1%	1.6%	7.2%	21.7%	100%
Algeria	8.5%	7.5%	42.7%	16.3%	1%	6%	18%	100%
Congo	24.4%	23%	25.6%	1%	3.4%	5 %	17.6%	100%
Morocco	6%	5.2%	59.6%	15.4%	1.3%	7.8%	4.7%	100%
Kenya	299%	19.2%	24.6%	9.8%1	2.2%	4.6%	9.7%	100%
Egypt	8%	0.7%	56.5%	16.1%	1.5%	11.1%	6.1%	100%
Uganda	11.4%	36.5%	34.8%	1.2%	5%	6.4%	4.7%	100%
Nigeria	25.2%	15.6%	32.3%	0.6%	2.8%	6.1%	17.4%	100%

Source: Author's own work based on Global Burden Disease database (https://www.healthdata.org/gbd/2019)

Table 18 shows the percentage of the diet low of the different food category (i.e. fruits, vegetables, whole grains, nuts, milk, seafood, and legumes). the weight of each item describes the importance of each food category.

$$FSI_{y,t}= \sum a_{x,t} \times \text{dietary supply deficit}_{(x,y,t)} \quad (32)$$

FSI designs the forecasted food security index for a country "y", at a "t" year. $a_{x,t}$ is the weight of each food subcategory "x" at the time "t". The coefficient "$a_{x,t}$" is retrieved from the global burden disease database. It presents the percentage of DALY caused by dietary insufficiency. It is the aggregated value of the weighted food subcategories.

We notice clearly that every country has a different weight of each food subcategory diet deficit. For Tunisia, the weight of cereal supply has the highest percentage, 53%, among other items. The diet low in cereal has the topmost percentage for all countries, except Kenya, where the fruit supply deficit has the highest percentage.

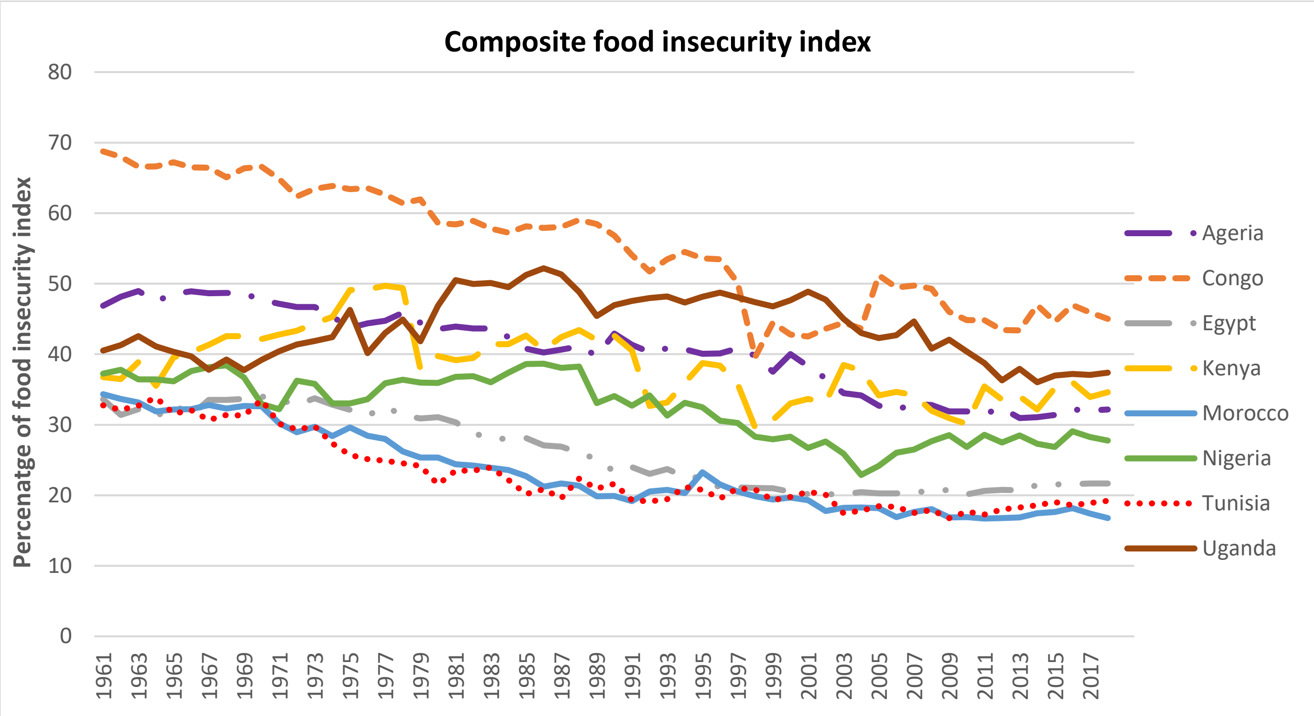

Figure 4: The forecasted food insecurity index

Source: Author's own calculation

We illustrate the forecasted food security index from 1961 till 2018 in figure 4. The highest percentage describes the highest food insecurity level, that means the decrease of the percentage signifies an improvement of the food security index value. A fluctuation has been registered in all countries; it is translated by the perturbation in the food supply. Congo has the highest food insecurity along the years that reflects the serious concern of food supply.

Tunisia and Morocco, has almost, the lowest food insecurity index, followed by Egypt. The northern African countries have an ameliorated food security index comparing the other African countries. Their location could be among the reasons that explains the easiness of the trade.

4.4. Empirical results of food security determinants

The link between the explanatory variables (i.e. macroeconomic variables and agricultural producer price) and the food security index was examined through the two-step system GMM method.

Two step GMM model has been selected instead of the one step GMM, because of its robustness to the autocorrelation and heteroscedasticity characteristics. Table 19 provides the two-step dynamic GMM model results.

Table 19. Two-step dynamic GMM model results

variables	Coefficients	Standard error	T-Stat	Probability
Lag (FSI)	1.27300	0.0109	116.7^{8}1	<2e-16 ***
APPI	-0.05748	0.0073490	-7.8^{2}1	<2e-16 ***
IR	1.093	0.002511	-435.329	<2e-16 ***
EXG	0.0006034	0.00007102	8.496	<2e-16 ***
TO	0.06148	0.002659	23.119	<2e-16 ***
Oil	0.01330	0.005794	2.296	0.0217 **
INF	0.31470	0.007264	43.3^{2}9	<2e-16 ***
EMP	0.10320	0.01508	-6.8^{4}5	<2e-16 ***

Significance level: *** 0.001 and ** 0.05

The F-statistic of the overall model is equal to 51156255 with a significance level <0.001. It justifies the suitability of the model to fit our data. The system GMM estimator’s statistical tests proved the model's stability using F-statistics, as the model is empirically stable at the 1% level of confidence range.

As indicated in the Table 34 all variables are significant at 1% except crude oil price which is significant at 5%. That means the independent variables explain well the dependent variables which is the food insecurity index.

To measure the impact of the agricultural producer price on food security, macroeconomic variables have been employed as well. All variables show a positive dependence with the food insecurity index, a negative effect on food security, except the APPI which has a negative connection with the food insecurity index, thus a positive correlation with the food security. The food Insecurity index is affected by its past value.

APPI has a negative impact on food insecurity index. An increase of APPI will decrease the level of food insecurity, thus improves the food security index. It means that an increase of APPI enhances the food security level. This positive correlation is explained by the fact of increasing the investment in the agriculture field. An upward shift in the APPI encourages farmers to produce more, therefore the food production increases and the supply gap could be ameliorated by the availability of domestic agricultural products.

The interest rate shows a positive coefficient, that explains an increase of interest rate will increase the food insecurity index, which means it aggravate the food security status. An amplification of the interest rate led to reinforce the credit restrictions. Small farmers are the most affected because they rely more on credit to insure their production. A growing interest rate will hamper the agricultural production, and as a consequence the food security level. The expanding of the interest rate will create an extra cost for the agricultural production, even for large scale farmers, which force them to reduce their production.

The exchange rate exhibits a positive effect on the forecasted food insecurity index. A higher exchange rate will amplify the food insecurity, deteriorate the food security level. An increase of the exchange rate will raise the cost of import, because of the depreciated local money. Thus, the imported food may get shortened, followed by a diminishing of food availability. Furthermore, it may affect the cost of production, where it increases the imported agricultural input.

Trade openness increases the insecurity index. A non-restricted trade policy implemented within a country, facilitate the trade activity and improve the logistical infrastructure to enhance the import activity. As a result, it decreases the self-sufficiency of the country and create a disequilibrium of the balance trade.

The used “employment” variable describes the number of employed people. The results suggest that an increase of employment depreciate the food security. This finding is explained by the fact that the employed people are in the industrial sector. That creates a lack of labor in agriculture field. It reflects as well the increasing urbanization. People prefer to move to urban area to get employed, which has a negative effect on farm activity, less workforce, and as a result, low productivity.

An increasing in the oil price promotes the increasing in the inflation rate. Both indicators create a disequilibrium of the food market price. They threaten the food security situation. An increase of the crude oil price leads to the increasing the agricultural inputs price from one side, and from the other side, farmers will allocate their land to produce biofuel products instead of others.

Accordingly, the agricultural products will decrease significantly, and the food security, too. Interest rate has the highest coefficient. This implies the importance of the agricultural investments, and financial depts needed by farmers to maintain and enhance the agricultural activities.

Table 20 summaries the hypothesis results.

Table 20. Summary of the hypothesis findings

Hypothesis	Results	Relevant table with supporting results
H1: Food prices are significantly impacted by its own past values: a past volatility is significantly transmitted to the present value in Africa	Accepted	
H2: Crude oil price is significantly impacted by its own past values: a past volatility is significantly transmitted to the present value in Africa	Accepted	
H3: Crude oil price has a significant volatility spillover on the global food price in Africa	Accepted	
H4: Highly perishable agricultural commodity price (meat price) has the highest own volatility among other commodities in Africa	Rejected	
H5: The global food price volatility is significantly transmitted the domestic food price in Africa	Accepted	
H6: The crude oil has a significant influence on the global and domestic food prices: energy and food price and highly interdependent in Africa	Accepted	
H7: The agricultural producer price has a significant negative effect on forecasted food insecurity index in Africa	Accepted	
H8: Trade openness, exchange rate, inflation rate, interest rate, employment rate, and crude oil price have significant positive effects on the forecasted food insecurity index in Africa	Accepted	

Source: Author’s own work

5. CONCLUSION AND RECOMMENDATIONS

5.1. Conclusion

Volatility is a directionless measure of the extent of the variability of a price or quantity. Exorbitant price volatility has an impact on farmers, consumers, processors, and traders, as well as the political system. It has the potential to skew farmer's' and intermediaries'' output and investment decisions, resulting in inefficient resource allocation. Poor customers may be compelled to cut back on their food and non-food spending. If this trend continues, it may induce to political disequilibrium.

This dissertation measures the degree of interdependence, at the global scale between food and crude oil price, and between domestic and international food prices.
Research results applied from univariate GARCH indicate the significance of past volatility on the present value. A previous shock in price is transmitted to the present price.

A bivariate DCC-GARCH model detects the spatial interdependence between global and domestic food prices. We tried to evaluate the price volatility transmission across international food price and domestic food price, as well across energy price and food price employing for that the DCC-GARCH model. DCC-GARCH shows the characteristics of the correlation between the used variables. A volatility spillover has been found across crude oil price to food price, different magnitude of volatility has been registered which reveals the strength of its persistence. From these findings we understand the conditional correlation transmission. Furthermore, the results highlight the strong persistence of the volatility transmitted from crude oil price to food price. However, increased biofuel demand may raise concerns of the agricultural commodity prices, potentially jeopardizing food security, particularly in vulnerable nations. The global cereal price showed the highest price volatility, this fact can be explained by the importance of the cereal sector in African countries to provide the basic food. Roman et al, 2020 found that there is a significant volatility transmission from the crude oil and international meat prices. As well, Koirala et al, in 2015, confirm the significance of the conditional correlation between energy price and agricultural commodity prices.

Because of the oil price inflation is destructive to food security, it is important to expand energy consumption in this sector, moving away from a reliance on fossil fuels and toward an optimal mix of renewable and nonrenewable energy resources that will benefit both energy and food security.

In most of most of research papers the food security index is presented by different proxies (e.g. food production, Average protein supply, average energy supply, etc…) (Henchion et al., 2017). Given the efforts to achieve the United Nations; Sustainable Development Goals (SDGs) for food security by 2030, this research examines the impact of the agricultural producer price on the food insecurity index in African countries from 1995 to 2018.

We investigated a dynamic panel data model based on the one-step system using multiple regression approaches. The System- GMM estimator, proposed by Arellano and Bover (1995) and subsequently refined by Blundell and Bond (1998), was chosen over other techniques because of its efficiency in removing simultaneous biases associated with regression model estimations. Because of the efficiency of its optimal weighting matrices, the one-step System-GMM was favored over the two-step System-GMM for our estimation. The results confirm the existence of positive relationship between agricultural producer price and food security, that indicates the importance to develop the domestic production.

Africa continent has the lowest rate of the share of the public expenditure in agriculture comparing other continents. In accordance with our results of the dynamic GMM approach, the negative relationship detected between the food security index and agricultural price reflects the importance of the domestic production. That means these countries should rely more on their national agricultural production by encouraging the agricultural investments.

African countries should focus on agricultural investments and encourage farmers to expand their agricultural activities instead of releasing trade barriers to facilitate the food import.

To conclude, implementing trade policy, by policy makers is not enough to strengthen the food security, but they need to build monetary policy that protect the country from macroeconomic fluctuation to prevent the economic crisis.

5.2. Recommendations and managerial implications

The significant linkage between the crude oil and food price, justifies that any crude oil price perturbation may disturb the food market price, thus policy makers should carefully diversify the energy portfolio as an agricultural input.

The level of interdependence between the international and domestic food price can provide an image about the domestic food market resistance strength against global price fluctuation. It helps policy makers to implement the efficient policy to protect the food market from unexpected price increase.

According to our results, considering that public investments in agriculture raise producer prices, which has a long-term positive influence on food security, African countries should consider policy reforms that enhance total agricultural investment responsibilities.

5.3. Limitation

As any research work, we faced some limitations to elaborate the dissertation. Lack of data is the main imitation faced. At the beginning, we tried to collect producer price of some agricultural commodities, but we could not find enough data to run the model correctly. The African continent is suffering from difficulties of data availability. Not all data was successfully found. There is especially, lack of data for developing countries. We tried to contact the national statistic offices but unfortunately no feedbacks. For the reliability of our data sources, we are limited to trusted websites such as FAO, and World Bank database.

Our dissertation is limited to the crude oil price as energy, three retail commodity prices (wheat, meat, and milk), and eight countries are considered. Future research can consider more retail commodity prices, and producer price. Other countries as well can be examined to have a wider picture about the different markets.

6. NEW SCINTIFIC RESULTS

This study offers new scientific findings based on the collected data, findings, and analysis.

These findings may serve a framework as for future research and to expand the model using the analytical technique utilized and new components in the model that were included in this study.

1- The research has proven the volatility spillovers between food and oil price. In this way the work gives an update that covers the Global Financial Disaster (GFC), European Sovereign Debt Crisis (ESDC), and the Covid-19 pandemic health and economic crisis which spans the years 2000-2021.

2- The research contributes to the current literature by using the generalized autoregressive heteroscedasticity model to measure the magnitude of the dynamic correlation, volatility spillovers, between crude oil and the food prices. The dynamic behavior of the spillover effect is critical since it provides point-in-time information on the effect. In other words, the dynamic approach shows how volatility spillover changes over time as a result of shocks absorbed by the market.

3- The work offers a synthetic overview on the movement of price volatility and the dynamic correlation between food price and global food price from one side, and from the other side, between retail commodity prices and global commodity prices.

4- My research work tackles the food security issue from the gap in the supply side in order to estimate a unique index. It is the first study research that suggested model assigns weights based on DALY indicators, avoiding the difficulties of subjective weighing, which is the novelty in our research. I was the first to develop a food insecurity index, based on the gap between the supplied and required of food sub-categories (i.e. milk, vegetables, fruits, cereals, legumes, nuts, and fish).

5- My dissertation is the first study that examines price volatility spillovers among international food- and local retail food prices in north African countries (Tunisia, Algeria, Morocco, and Egypt).

6- I have firstly proven a significant effect of macroeconomic variables on the unique forecasted food insecurity index in African countries through a panel approach.

7. SUMMARY

Our dissertation tackles three main parts. First of all, a bibliometric analysis was carried out. It highlights the importance of the link between food price and food security. It highlights the importance of the emerging studies that link the effect of agricultural price on the national food security status in African countries. From this point, we tried to focus on this gap to elaborate our research on examining the relationship between food security and agricultural price.

Prior, the investigation of the relation between agricultural price, food security index and macroeconomic indicators, an examination of price volatility spillovers among food and crude oil prices, and spatial volatility transmission between domestic food market and global food market prices has been carried out to get a clear idea how much the food domestic market is vulnerable to an international food price shocks. DCC-GARCH model has been employed to achieve the purpose, because of its suitability to catch the conditional variance. Price volatility, which is a common aspect of agricultural commodity prices presents a high uncertainty for the food market. Understanding the magnitude of volatility might assist in defining strategies to mitigate the negative effects of price instability. Our results justify the high conditional correlation between the crude oil and food price, the significance of this linkage explains the movement of food price followed by a crude oil price shock. The considered countries show a significant dynamic interdependence between the global food price and the domestic food price except Nigeria and Egypt, where an international food price shock is not persistent in these domestic food prices.

Crude oil price shows a significant linkage with the domestic food price, it highlights the degree of the connectedness of the agriculture sector to the energy price, crude oil price. It demonstrates the strong conditional dependence between the crude oil and the overall national food prices.

In contrast to one hypothesis that we have made (H3), the global cereal price shows the highest own price volatility magnitude, comparing meat and dairy products.

To tackle the food security challenges, we focused on food supply gap and food deficiency. To measure the food supply deficit, we introduced a novel weighting method to aggregate the food sub-categories (vegetables, fruits, nuts, cereals, milk, legumes, and seafood). The aggregated food insecurity index has been presented for 8 African countries; it shows the food supply deficit in these countries.

Dynamic two-step system GMM approach has been applied because of its robustness on the hidden heterogeneity and endogeneity potentiality of the key explanatory variables. The model is efficient to determine the effect of the explanatory variables. The GMM approach was found to gives significant results, it proves the model robustness. The agricultural producer price shows a negative effect on the forecasted food insecurity index, that means an increase of the agricultural price will improve the food security situation. The other macroeconomic indicators exhibit a positive and significant relation with the forecasted food insecurity index. Trade openness shows a positive significant effect on food insecurity, that could be explained by the inefficiency of the existed trade policies in supplying food.

The positive effect between agricultural producer price and food security, and the negative effect of interest rate and the food security raise the importance of the agricultural investment. In other words, the liberalization of the trade policy does not solve the issue of food insecurity. Policy makers should focus on the self-sufficiency and encourage farmers to expand their agricultural activities to enhance the domestic productivity. Trade liberalization may hamper national diversification and force nations into a non-sustainable development plan.

LIST OF PUBLICATION

Peer-reviewed Scientific Published Article

- Ben Abdallah, M., Farkas, M. F., & Lakner, Z. (2020). Analysis of meat price volatility and volatility spillovers in Finland. Agricultural Economics, 66(2), 84. [Scopus ranking: Q2]
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- Ben Abdallah, M., Farkas Fekete, M., Vasa, L., & Lakner, Z. (2023). Food Security of Tunisia: Comprehensive Analysis of a Composite Index. *Acta Polytechnica Hungarica*, *20*(10). *Acta* [Scopus ranking: Q2]

Conference & Presentation

- Ben abdallah M. Examining price volatility along the meat supply chain (2018); 25th Anniversary of the Doctoral School of Management and Business Administration, Szent István University.Book of abstracts.
- Ben Abdallah M et al. The effects of food price volatility on macroeconomic variables in Tunisia. (2019) Megjelent: V. International Winter Conference of Economics PhD Students and Researchers : Conference Proceedings pp. 5-12
- Ben abdallah M et al., Examining price volatility along the meat supply chain : case of Finland ; "Smart developments and sustainability" 5th VUA YOUTH Scientific Session, Gödöllő, Magyarország : Szent István Egyetem (2018) 246 p. pp. 160-166. , 7 p.

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