Macrothink Institute™

Business and Economic Research
ISSN 2162-4860
2024, Vol. 14, No. 4

Price Volatility and Cereal Food Security in Tunisia: Determining the Critical Threshold of Cereal Price Volatility Using the Threshold Model

Ibtissem Gannoun (Corresponding author)

Department of Economics and International Trade, Higher Institute of Business

University of Sousse, Sousse, Tunisia

E-mail: ibtissemgannoun@gmail.com

Naoufel Liouane

Department of Economics, Higher Institute of Finance and Taxation

University of Sousse, Sousse, Tunisia

E-mail: naoufel_liouane@yahoo.fr

Dorsaf Jammali

Department of Economics, Higher School of Economic and Commercial Sciences Tunis

University of Tunis, Tunis, Tunisia

E-mail: dorsafjammalim@yahoo.fr

Received: September 2, 2024 Accepted: October 16, 2024 Published: October 31, 2024

doi:10.5296/ber.v14i4.22210 URL: https://doi.org/10.5296/ber.v14i4.22210

Abstract

This study examines the substantial impact of grain price volatility on food security in Tunisia, a nation heavily reliant on cereal consumption. Employing Hansen's (1999) threshold model, we pinpoint the precise level of price volatility that poses a significant threat to cereal food security in Tunisia. A novel application of this methodology, our analysis, spanning 1991-2021, focuses on cereals, constituting over 50% of Tunisia's food imports. The threshold model identifies a critical volatility threshold of 4.65%. Beyond this point, food security is significantly compromised. This finding underscores the study's capacity to quantify the precise level of grain price volatility that exacerbates food security risks in Tunisia. To mitigate these risks, policymakers should prioritize price stabilization measures, enhance risk management and storage mechanisms, and develop targeted adaptation strategies for vulnerable populations. These actions will bolster the resilience of the Tunisian food system.

Keywords: Cereal food security, Price volatility, Threshold model

1. Introduction

The issue of food security is not a recent one, dating back several centuries. However, global awareness of the importance of food security and efforts to address it have intensified since the Second World War. Malthus' theory (1978) highlighted the problem of food scarcity and insecurity, positing that exponential population growth coupled with limited food resources would inevitably lead to food crises, poverty, and human suffering. Agriculture is a pivotal instrument in ensuring food security (Chebbi and Lachaal, 2004; Abdelhedi and Zouari, 2020; Ouessar et al., 2021; CARE, 2023).

The surge in agricultural commodity prices during 2006-2008 underscored the severity of food insecurity, placing it at the forefront of international concerns. Subsequent events, including the 2020 health crisis and the Russia-Ukraine conflict, have exacerbated this issue (Chebbi et al., 2023). Beyond conflicts, which are primary drivers of acute food crises, climate change poses a significant threat, directly impacting agricultural yields and prices, with particularly devastating consequences in the Global South (Jemmali et al., 2021).

While food insecurity is a global challenge, its prevalence and severity vary across countries. Tunisia, though facing its own unique set of challenges, has maintained a relatively stable food security situation compared to many others. As per the Global Food Security Index (GFSI) 2021, Tunisia ranked 54th out of 113 countries, achieving a score of 62.7%. The nation's strengths in food security are evident in its robust food safety measures, low poverty levels, adequate food supply, and well-established social safety nets.

Tunisia's food security remains precarious despite notable progress. The agricultural sector, which contributed 21.45% to GDP in 1972, has seen a significant decline to 10.14% in 2021, diminishing the nation's self-sufficiency in food production. Coupled with the volatility inherent in agriculture, this decline exposes Tunisia to substantial food security risks. External shocks, such as the COVID-19 pandemic and the Russia-Ukraine war, have exacerbated these vulnerabilities, (Jouili and Elloumi, 2022). These events have triggered inflationary pressures, devalued the Tunisian dinar, and widened the budget deficit, thereby increasing the cost of food imports and production. Tunisia's heavy reliance on cereal imports, with a dependency ratio of 65.4% in 2018-2020, further compounds these challenges. Approximately 50% of the country's wheat consumption is sourced from imports (ONAGRI, 2016-2021).

Domestically, Tunisia faces a confluence of challenges including low-productivity rain-fed agriculture, overexploitation of groundwater resources, and soil degradation. These environmental factors undermine agricultural productivity and resilience. Moreover, the increasing value of food imports as a percentage of total merchandise exports, from 10% (2001-2003) to 14% (2019-2020) as per FAO (2012, 2019) and GRFC (2023), highlights the nation's vulnerability to global market fluctuations.

Tunisia is grappling with severe water scarcity, a condition exacerbated by a rapidly increasing water stress index. The country's per capita renewable water resources have dwindled to a mere 410 cubic meters per year, falling significantly below the 500-cubic meter threshold often used to define water scarcity. This marked decline, as evidenced by the sharp increase in the water stress index from 66.02 in 2000 to 98.11 in 2020, underscores the critical nature of Tunisia's water insufficiency.

These water constraints have far-reaching implications for the nation's food security. The agricultural sector, a significant contributor to the economy, is particularly vulnerable to water scarcity. Moreover, the recurrence of global food price volatility, as exemplified by the 53% price increase in 2021, has further compounded Tunisia's food security challenges. The extreme vulnerability of North African countries to rising food prices, which can trigger social unrest, has been well-documented (Bellemare et al., 2011; Breisinger et al., 2011; Lagi et al., 2011).

While numerous studies have explored food security in Tunisia, the majority have relied on descriptive and qualitative analyses (Chebbi and Lachaal, 2004; Ben Kahla, 2019; Chebbi et al., 2023). Although econometric studies on food safety exist, none have employed the threshold model approach (Chebbi and Lachaal, VAR model, 2007; Jeder et al., VECM, 2020; Ben Abdallah et al., VECM, 2023; Habib and Jmaii, MLM, 2024).

This study aims to fill this gap by assessing Tunisia's cereal food security through a threshold model, a methodology first proposed by Hansen (1999). Given the central role of cereals in the Tunisian diet, our focus on grain food security is justified. By identifying the threshold at which regime changes occur in relation to cereal price volatility, we seek to develop early warning indicators for potential food security crises. These indicators can inform the development of proactive measures and strategies to mitigate food insecurity risks.

To address our research question, we will initially focus on determining the optimal volatility threshold of the price index. Once this threshold is established, we will proceed to estimate regime models based on the identified threshold. Before implementing the threshold regression (TR) model, however, we will conduct a series of diagnostic tests to validate its suitability for our data. Upon completion of the estimation, we will rigorously analyze the results to draw meaningful conclusions and formulate evidence-based recommendations.

2. Econometric Model and Methodology

2.1 Econometric Model and Data

To examine the intricate relationship between price volatility and food security in Tunisia, this study employs a threshold model, a sophisticated statistical technique capable of identifying regime shifts in the underlying dynamics. Utilizing annual time series data spanning from 1960 to 2021, the model effectively captures abrupt changes or asymmetries in macroeconomic conditions, providing valuable insights into the effects of economic, political, climatic, and geopolitical shocks.

Hansen's (1999) threshold model distinguishes itself by its data-driven approach, estimating the optimal threshold value rather than imposing it a priori. This flexibility allows for a more nuanced analysis of nonlinear relationships, such as the complex interplay between food security and cereal price volatility. The general form of our threshold model with a single transition function is as follows:

$$y_t = \mu_t + \alpha_0 \pi_t \, \Pi(q_t < k) + \alpha_1 \pi_t \, \Pi\,(q_t > k) + \beta_\gamma x_t + \varepsilon_t. \quad (1)$$

In this context, $y_t$represents the domestic demand as a proxy for food security, x_t is the vector of control variables, and $\varepsilon_t$is the error term. Annual time series covering the period 1990-2021 were used for this purpose and transformed into logarithmic differences in order to interpret the results in the form of elasticities.

Domestic demand serves as a pivotal indicator of a nation's or region's food security, quantifying overall food accessibility. The concept of food security is multifaceted, encompassing four fundamental dimensions: availability, access, utilization, and stability. These dimensions were first formally defined at the 1996 World Food Summit. While food availability is considered the most critical factor, the other dimensions are equally important for ensuring long-term food security.

The International Food Policy Research Institute (IFPRI, 2010a) has developed a composite index to comprehensively assess food security. This index integrates several key indicators: the ratio of food imports to total exports (reflecting the food trade balance), food production per capita (indicating agricultural potential), and the Global Hunger Index. The selection of these proxy measures often involves trade-offs, as the specific objectives of a study can influence the choice of indicators (Pinstrup, 2009; Barrett, 2010).

In this study, we propose to evaluate cumulative national food security by examining net domestic demand. This approach aligns with the definition put forward by Mhiri (2022). Net domestic demand represents the difference between domestic food production and food consumption, providing a measure of a country's self-sufficiency in food.

Food Security = Domestic Production - Exports + Imports.

We maintain this approach due to the rarity of a country achieving complete food self-sufficiency. Domestic production alone is insufficient to guarantee the availability dimension of food security. Consequently, we advocate for the inclusion of both food exports and imports in our analysis, recognizing the essential role of international trade in ensuring a stable food supply. As for the control variables, (See appendix, table A1), we specify that we have retained five control variables, namely, per capita GDP expressed in US dollars and in constant 2015 terms (GDPc), (Chebbi and Lachaal, 2007; Chianeh, 2021; Mashref, 2024), the ratio of the poor population based on the national poverty line (SP), (Padilla, 2008; Abdulai and Kuhlgatz, 2012; Kumar and Sharma, 2013; Moncada et al., 2022), the net barter terms of trade index (2000 = 100) (ITE), (Mary, 2019), the stock of external debt (expressed in current

US$) (DE), (Yerima and Tahir, 2020), the real effective exchange rate index (2010=100) (TCER), (Huchet et al., 2013; Applanaidu, 2014; PAM, 2024) and the inflation rate in Tunisia, approximated by the consumer price index (IPC), (Jeder et al., 2020), Yerima and Tahir (2020)). π_t is the threshold variable being the cereal price index (IP), (Verpoorten et al., 2013; Applanaidu, 2014; Arndt, 2016; Kalkuhl and Maximo, 2016; KoÃ et al., 2017; Shittu et al., 2018; Wossen et al., 2018; Mashref, 2024), $x_t$represent the control variables, and $\mu_t$the random-effect.

Furthermore, the transition function is represented by an indicator function Π which takes the value (1) if the constraint in parentheses is satisfied, (0) otherwise. Hansen (1999) imposes two restrictions on this specification: the explanatory variable and the transition variable must necessarily vary over time, and the residuals are assumed to be iid (independently and identically distributed) with a mean of zero and finite variance. The parameters are the coefficients α_0 if $q_t < k$ and $\alpha_1$if $q_t > k$. If we consider only two regimes, the threshold value must be searched among the values of the transition variable.

This model presents a time series with multiple distinct regimes, each characterized by a linear dynamic. The transition is abrupt, knowing that a country can switch from one regime to another in one period. The threshold model, in our case, takes the following form:

$$\Delta logSA_t = \alpha_0 + \alpha_1 \Delta log\,(IP)_t + \alpha_2 \Delta log\,(GDPc)_t + \alpha_3 \Delta log\,(IPC)_t + \alpha_4 \Delta log\,(SP)_t + \alpha_5 \Delta log\,(ITE)_t + \alpha_6 \Delta log\,(DE)_t + \alpha_7 \Delta log\,(TCER)_{t\_}\varepsilon_t,\ si\ \ (q_t < k) \quad (2)$$

$$\Delta logSA_t = \alpha_0 + \alpha_1 \Delta log\,(IP)_t + \alpha_2 \Delta log\,(GDPc)_t + \alpha_3 \Delta log\,(IPC)_t + \alpha_4 \Delta log\,(SP)_t + \alpha_5 \Delta log\,(ITE)_t + \alpha_6 \Delta log\,(DE)_t + \alpha_7 \Delta \log(TCER)_{t_{\varepsilon_t}},\ si\ \ (q_t > k)^* \quad (2')$$

Where t = 1991,…, 2021 determines the analysis period. the table below, and Δlog denotes the logarithmic variation.

To enhance the robustness of our findings, we have measured national production, cereal imports, and exports in physical quantities rather than monetary values. This approach mitigates the potential distortions caused by fluctuating prices, providing a more accurate reflection of underlying trends in cereal supply and demand. Table 1 presents a summary of the key variables employed in the analysis spanning the period from 1960 to 2021. These variables were selected based on their relevance to the study's objectives and the availability of data.

Table 1. Descriptive Statistics

Variables	N observation	Mean	Standard-deviation	Minimum	Maximum
Dependent variable					
SA	32	4055281	844763.2	2132229	5498952
Threshold variable					
IP	32	90.24709	21.09985	64.6575	133.9144
Control variables					
IPC	32	94.34172	34.06473	47.64585	173.4394
GDPc	32	3219,991	694,1657	2085,533	4094,878
SP	32	21,6625	4,05655	15,2	26
ITE	32	101,5297	8,292058	89,49716	117,9841
DE	32	2,03E+10	1,01E+10	7,69E+09	4,17E+10
TCER	32	110,8681	18,83362	78,38844	133,1146

Source: Authors.

2.2 Methodology

2.2.1 Stationarity Tests

Prior to estimating the model, we conducted a series of diagnostic tests to ensure the robustness of our analysis, (Kalai and Helali, 2021; Alimi and Ben Dhiab, 2023; Ben Abdallah et al., 2024). Specifically, we performed unit root tests, including the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests, to verify the stationarity of the time series data. Stationarity is crucial for time series analysis, as it ensures that the statistical properties of the data remain constant over time. The results of which are reproduced in the following Table 2:

Table 2. Stationary Test

	In level				In difference			
Tests	ADF		PP		ADF		PP	
Variable (in log)	ADF	prob	Z(t)	prob	ADF	prob	Z(t)	prob
l_SA	-3.437	0.0466**	-3.534	0.0359**	-8.222	0.0000***	-8.725	0.0000***
l_IP	-2.225	0.4759	-2.296	0.4363	-4.520	0.0014***	-4.386	0.0023***
l_PC	0.199	0.9958	-0.791	0.9664	-3.652	0.0257**	-3.764	0.0185**
l_GDPc	0.275	0.9962	0.714	1.0000	-5.852	0.0000***	-5.858	0.0000***
l_SP_	-1.471	0.8390	-1.864	0.6731	-5.386	0.000***	-5.394	0.000***
l_ITE	-0.951	0.9504	-1.256	0.8984	-4.307	0.0031***	-4.176	0.0049***
l_DE	-2.590	0.2845	-2.689	0.2405	-4.674	0.0010***	-4.605	0.0010***
l_TCER	-2.526	0.3152	-2.552	0.3026	-3.604	0.0295**	-3.442	0.0460**

Source: Authors.

To address potential multicollinearity among the independent variables, we conducted a variance inflation factor (VIF) test. The results, as shown in Appendix Table A3, indicate a mean VIF of approximately 1.24, suggesting no serious multicollinearity concerns. To assess heteroscedasticity, we performed a test, the results of which (see Appendix Table A2) do not reject the null hypothesis of homoscedasticity at the 5% significance level. Furthermore, to justify our choice of a threshold model, we employed both the Fisher linearity test and the

Business and Economic Research
ISSN 2162-4860
2024, Vol. 14, No. 4

Brock, Dechert, and Scheinkman (BDS) test. Both tests strongly reject the null hypothesis of linearity and normality at the 1% significance level, providing compelling evidence for a nonlinear and non-normal time series. To examine the stationarity of the data and detect potential structural breaks, we applied the Perron test (Perron, 1989 cited in Kalai and Helali, 2021; Ben Abdallah et al., 2024). The results indicate the presence of structural breaks, suggesting that the underlying data-generating process has changed over time due to exogenous shocks such as economic crises, policy changes, or other significant events. These structural breaks are often associated with changes in the mean or trend of the time series.

Table 3. Unit root test with break in level and first difference Perron (1997)

	1_SA	1_IP	1_IPC	1_ITE	1_GDPc	1_SP	1_TCER	1_DE
In level								
Breakdate	2001	2006	2002	2001	2003	2010	2016	2001
Statistics	-2.820833	-4.410520	0.401756	-1.509426	-2.584172	-2.701196	-1.559677	-1.607082
Probability	0.7776	0.0550	> 0.99	> 0.99	0.8746	0.8301	> 0.99	> 0.99
Conclusions	NS	NS	NS	NS	NS	NS	NS	NS
In difference								
Breakdate	2009	2007	2004	2008	2010	2008	2002	2002
Statistics	-9.519630	-5.068045	-5.896064	-5.527859	-6.367388	-5.850647	-5.086948	-5.099479
Probability	S	S	S	S	S	S	S	S
Conclusions	< 0.01							

Source: Authors.

Unit root tests indicate that all-time series become stationary after first differencing at the 1% significance level. This implies that the original series were non-stationary and required differencing to achieve stationarity. Furthermore, a structural break was detected in the differenced series. When examining the series in their level form, significant break dates were found only for variables directly related to food security (1_SA), the cereal price index (1_IP), GDP per capita (1_GDPc), and the poverty threshold (1_SP). These findings suggest that these variables experienced structural changes over the sample period.

2.2.2 Cointegration Test

Recognizing the potential impact of structural breaks on the cointegration relationship between food security and the cereal price index, we employed the Gregory-Hansen (1996), (cited in Kalai and Helali (2021), Ben Abdallah et al. (2024)), cointegration test. This test specifically allows for the identification of structural breaks within the cointegration vector. Prior to applying the Gregory-Hansen test, we conducted unit root tests using the Perron (1997), (cited in Kalai and Helali (2021), Ben Abdallah et al. (2024)), procedure to confirm that all variables were integrated of order one, I(1). These findings, along with evidence of non-linearity in the series, justified the use of the Gregory-Hansen test to explore the long-term relationship between food security and the cereal price index in the presence of potential regime shifts.

Table 4. Gregory and Hansen (1996) Cointegration Test with Regime Shift

Tests	Statistic	Break point	Break date	Probability at 1%	Probability at 5%	Probability at 10%
ADF	-8,81	12	2002	-5,13	-4,61	-4,34
Zt	-8,84	19	2009	-5,13	-4,61	-4,34
Za	-44,67	19	2009	-50,07	-40,48	-36,19

Source: Authors.

The Gregory-Hansen (1996) cointegration test, conducted at the 1%, 5%, and 10% significance levels, provides evidence of a long-run equilibrium relationship between the variables. However, the test also indicates the presence of a structural break in the cointegration relationship, particularly for variable 1_IP. Additionally, the cointegration test reveals a nonlinear deterministic time trend, suggesting that the relationship between the variables is not strictly linear. Despite this nonlinearity, the long-term cointegration relationship persists, implying a significant long-term association between the time series. The identified structural break in 2009 is consistent with the global financial crisis, which is known to have caused significant volatility in commodity prices and exacerbated food security issues (Lagi et al., 2011).

3. Results and Discussions

The linear model indicates no significant association between food security and the other variables included in the analysis. However, employing a threshold model revealed a non-linear relationship, with a critical threshold value of approximately q = 4.65%. This threshold divides the data into two distinct regimes: a low-volatility regime ($q \leq 4.65\%$) and a high-volatility regime ($q > 4.65\%$). Notably, all control variables in the high-volatility regime exhibit a significant relationship with the dependent variable at the 1% level, suggesting a heightened sensitivity to price volatility compared to the low-volatility regime. The results of the estimation of the threshold model as defined in equations (2) and (2') are reported in Table 5.

Table 5. Volatility of cereal prices and food security, estimation of the Threshold model

	OLS without Threshold		**Threshold Model**			
			Regime 1 : q ≤ 4,65%		**Regime 2 : q > 4,65%**	
Independents.V	Coefficient	T-student	Coefficient	T-student	Coefficient	T-student
Constant	0,06074511	0,77086105	0,37386367	3,45993821***	1,26960546	12,562892***
dl_IP	-0,12463588	-0,73287108	0,46302519	2,68993063***	0,84864454	5,44675795***
dl_GDPc	-0,58559894	-1,12529546	-4,72563968	-3,08586237***	-5,46075032	-9,98723289***
dl_SP_	0,3500617	0,505129	1,19627522	1,20387458	17,1386282	11,0920843***
dl_ITE	0,91922035	1,40520037	1,40283958	2,20661206**	0,6364433	4,10696773***
dl_DE	0,09741041	0,25290727	0,43199619	1,23951804	-2,58545164	-12,2454269***
dl_TCER	-0,02447041	-0,04465109	2,0931677	2,29036882**	-6,91127517	-10,1700634***
dl_IPC	-0,64037387	-0,33866505	-3,88913813	-2,77168214***	-25,5542523	-11,4996905***
Observations	31		20		11	
BDS Test Statistic (p=0,7; m=6)	0.3452		0.618625		0.8985	
R^2	0,54020541		0,56524445		0,96788837	

Source: Authors.

Our analysis reveals a nonlinear relationship between food security and cereal prices in Tunisia. A regime shift analysis identified a significant structural break at a 4.65% logarithmic differential of the cereal price index. When this threshold is exceeded, a stronger positive correlation between cereal prices and food security emerges. Specifically, a 1% increase in global cereal prices is associated with a 0.84% increase in food security in the high-volatility regime (where the logarithmic differential of the cereal price index is greater than 4.65%), compared to a 0.46% increase in the low-volatility regime. This heightened sensitivity to price fluctuations in the high-volatility regime can be attributed to two primary mechanisms: (1) Production incentives: Higher international cereal prices can stimulate domestic production, improving food security, albeit contingent on favorable climatic conditions; and (2) Policy responses: Governments often implement social safety nets, such as cereal subsidies, to mitigate the negative impacts of price volatility on food security, aligning with previous research (Diaz-Bonilla and Ron, 2010; Gouel, 2013, 2014).

When examining the effects of other control variables, such as GDP per capita, consumer price index, terms of trade, and poverty threshold, we found consistent impacts across both regimes. However, the effects of total debt and the real effective exchange rate varied significantly between the low- and high-volatility regimes

Contrary to the conventional wisdom of a positive correlation between GDP per capita and food security, our empirical analysis reveals a robust negative association in both regimes examined. In the Tunisian context, the negative relationship between GDP per capita and food security is particularly evident. This counterintuitive finding can be attributed to several factors. First, as incomes rise, there is a tendency for consumers to shift towards more expensive, often imported, food items, increasing reliance on food imports. In this regard, promoting the consumption of local food products through public awareness campaigns or fiscal policies could help reduce dependence on imports. Second, without equitable income distribution, economic growth can exacerbate inequalities, marginalizing vulnerable populations and hindering their access to adequate food. These results suggest that GDP per capita, while a useful measure of overall economic development, is an insufficient indicator of long-term food security. To effectively address food insecurity, policymakers must adopt targeted interventions that prioritize equitable access to food and reduce vulnerabilities, as highlighted in previous studies (Fan and Rosegrant, 2008; FAO, 2012).

The findings indicated that a markedly volatile exchange rate exerted a considerable negative influence, with an increase of 1% in the actual effective exchange rate resulting in a 6.91% deterioration in food security (FS) under regime 2. A depreciation in currency value will result in an increase in the cost of imported goods. Those in the lowest income brackets are particularly susceptible to the effects of currency fluctuations, given that they typically allocate a larger proportion of their budget to food. Furthermore, currency depreciation can have a detrimental impact on local farmers by reducing their competitiveness in international markets, which could result in a decline in domestic agricultural production and a reduction in the availability of food locally. However, in regime 1, where $q \leq 4.65\%$, the exchange rate has a significant positive impact on food security, which is likely attributable to the increased agricultural exports resulting from currency depreciation. In order to mitigate the negative effects of exchange rate fluctuations on food security, it is recommended that food supply sources be diversified, strategic food reserves be established and price stabilization policies be implemented.

Our analysis highlights the intricate link between poverty and food security, with poverty acting as a significant driver of food insecurity by limiting access to essential resources. Counterintuitively, we found a positive correlation between poverty and food security in Regime 2. This suggests that a simplistic view of poverty as a direct cause of food insecurity may be insufficient. Instead, it underscores the complex interplay between monetary poverty, food security, and broader socio-economic factors. The positive correlation in Regime 2 can be attributed to the effectiveness of Tunisia's food security policies and social interventions, which may be disproportionately benefiting poorer households. This highlights the importance of targeted interventions and social safety nets in mitigating the impacts of poverty on food security.

However, this relationship between poverty and food security is less pronounced in Regime 1, where grain price volatility is low, suggesting that the impact of poverty on food security may be exacerbated by periods of high food price volatility. Our findings emphasize the need for a nuanced understanding of the relationship between poverty and food security, and the importance of context-specific policies to address food insecurity.

Our analysis highlights the significant role of terms of trade in influencing food security. We find a robust positive correlation between terms of trade and food security in both regimes, with a more pronounced impact in Regime 1, characterized by lower price volatility. Improvements in terms of trade can boost national income, stimulating investments in agriculture, infrastructure, and agricultural technologies, thereby enhancing food production and strengthening food security resilience. Moreover, During periods of cereal price volatility, the local currency depreciates, making imports more expensive. This leads to higher consumer prices, disproportionately affecting the poorest households who allocate a larger share of their income to food, thus exacerbating food security challenges.

To mitigate the impact of exchange rate fluctuations, implementing hedging mechanisms against exchange rate risks, such as forward exchange contracts, could stabilize import costs. Strengthening foreign exchange reserves could also moderate the impacts of exchange rate fluctuations.

In contrast, external debt poses a significant threat to food security, particularly in Regime 2. A 1% increase in external debt is associated with a 2.58% decline in food security in this regime. The negative effects of external debt are manifested in reduced farmers' incomes, higher food import costs, and decreased access to adequate food, especially for vulnerable households (Dhaouadi and Bouzid, 2020). It is important to note that periods of high cereal price volatility exert pressure on debt service levels and generate crowding-out effects on public agricultural expenditures. While periods of high cereal price volatility are likely to exert pressure on debt repayment levels and crowd out public agricultural spending, the correlation coefficient between external debt stocks and the volume of investments directed towards the agricultural sector in Tunisia, at -0.24, indicates a rather weak link. Moreover, we observe an increase in external debt from 64% of GDP in 1993 to 92% in 202, while agricultural investments declined over the same period, from 5.6% to 2.5%. The weak negative correlation suggests that the low volume of agricultural investments is not solely the result of high external debt, but also of other factors intrinsic to the policies adopted, which hinder the agricultural sector and threaten food resilience, including: the stagnation, or even decline, of public investments, without significant recovery of private investments, the weak organization of value chains, a poorly performing institutional framework and a lack of organization of the profession, as well as agrarian structures that severely limit development efforts.

Therefore, the unsustainability of Tunisia's public debt exacerbates these challenges, underscoring the urgent need for prudent debt management and agricultural policies designed to bolster food security. Therefore, aligned with the goals of COP28, debt-for-green-investments initiatives could be explored as a means of debt relief.

Our findings reveal a robust negative correlation between inflation, as measured by the Consumer Price Index (CPI), and food security in Tunisia. This relationship holds across both regimes, with a significantly more pronounced impact in Regime 2. Specifically, a 1% increase in the CPI is associated with a 25.54% decline in food security in Regime 2, compared to a 3.89% decrease in Regime 1. These results corroborate the findings of Arndt et al. (2016), who highlighted the disproportionate impact of inflation on the food security of low-income households in developing countries.

To mitigate the adverse effects of inflation on food security, the Tunisian government should consider implementing supply-side policies aimed at enhancing agricultural productivity and resilience. Such policies could include incentivizing agricultural financing, exploring alternative water sources for cereal cultivation, and promoting the adoption of climate-smart agricultural practices. Additionally, the Tunisian state could enhance subsidies on essential food items during periods of crisis and/or refine the indexation of monetary transfers to inflation to safeguard the purchasing power of households, especially low-income ones, through a targeted distribution policy.

4. Conclusion

Our findings align with the unique characteristics of Tunisia's food and economic landscape. Cereals, a significant component of food imports, exhibit relatively inelastic domestic prices, independent of global market fluctuations. The Hansen (1999) model identified a critical threshold of 4.56%. While variables like GDP per capita, the consumer price index, terms of trade, and the poverty line exhibit consistent impacts across both regimes, total debt and the real effective exchange rate exhibit varying influences. Notably, Regime 2, characterized by high volatility, is more susceptible to the adverse effects of inflation, exchange rate fluctuations, and external debt on food security. Conversely, the positive correlation between poverty and grain food security is an unexpected finding. To mitigate these risks, Tunisia should implement risk management strategies such as food security stocks, social safety nets, and subsidy systems. Ultimately, stabilizing food prices and managing water resources are crucial for enhancing Tunisia's food resilience.

References

Abdelhedi, I. T., & Zouari, S. (2020). Agriculture and Food Security in North Africa: A Theoretical and Empirical Approach. *Journal of Knowledge Economy, 11*, 193-210. https://doi.org/10.1007/s13132-018-0528-y

Abdulai, A., & Kuhlgatz, C. (2012). *Food Security Policy in Developing Countries.* In The Oxford Handbook of the Economics of Food Consumption and Policy. https://doi.org/10.1093/oxfordhb/9780199569441.013.0014

Alimi, N., & Ben Dhiab, L. (2023). Governance and Economic Growth in Developing Countries: A Panel Threshold Regression Analysis. *Economic Horizons, 25*(2), 105-120. https://doi.org/10.5937/ekonhor2302117A

Applanaidu, S. D., Abu Bakar, N., & Baharudin, A. (2014). An Econometric Analysis of Food Security and Related Macroeconomic Variables in Malaysia: A Vector Autoregressive Approach (VAR). *UMK Procedia, 1*, 93-102. https://doi.org/10.1016/j.umkpro.2014.07.012

Arndt, C., Hussain, M., Salvucci, V., & Østerdal, L. B. (2016). Effects of food price shocks on child malnutrition: The Mozambican experience 2008/2009. *Economics & Human Biology, 22*, 1-13. https://doi.org/10.1016/j.ehb.2016.03.003

Barrett, C. B. (2010). Measuring food insecurity. *Science, 327*(5967), 825-828. https://doi.org/10.1126/science.1182768

Bellemare, M. F., Barrett, C. B., & Just, D. R. (2011). The Welfare Impacts of Commodity Price Volatility: Evidence from Rural Ethiopia. *American Journal of Agricultural Economics, 95*(4), 877-899. https://doi.org/10.1093/ajae/aat018

Ben Abdallah, A., Guidara, S., Aloulou, R., Kalai, M., & Helali, K. (2024). Enquête sur la relation entre l'inflation et la croissance économique en Mauritanie: une analyse empirique utilisant le modèle de changement de régime. *SN Business & Economics, 4*(1), 1-25.

Ben Abdallah, M., Farkas, M., Vasa, L., & Lakner, Z. (2023). Food Security of Tunisia: Comprehensive Analysis of a Composite Index. *Acta Polytechnica Hungarica, 20*(10), 199-216. https://doi.org/10.12700/APH.20.10.2023.10.12

Ben Kahla, K. (2019). *From food security to food sovereignty in Tunisia: Main challenges and obstacles.* Working Papers. HAL.

Breisinger, C., Ecker, O., & Al-Riffai, P. (2011). Économie du printemps arabe. De la révolution à la transformation et la sécurité alimentaire. *Politiques alimentaires en perspective, 18*, 2-4.

CARE. (2023). *Growth is not enough: Solving the global hunger crisis requires investments in gender equality.*

Chebbi, H. E., & Lachaal, L. (2004). L'agriculture et la sécurité alimentaire : une étude comparative des pays du Maghreb. *New Medit, 3*(3), 4-11.

Chebbi, H. E., & Lachaal, L. (2007). *Agricultural sector and economic growth in Tunisia: Evidence from co-integration and error correction mechanism.*

Chebbi, H., Amrani, M., & Bouallegui, F. (2023). *Le système agricole et agroalimentaire tunisien face aux crises: Focus sur la chaîne de valeur céréalière: Constats et réflexions pour la proposition d'un plan de relance à court et à moyen termes. Organisation des Nations Unies pour l'alimentation et l'agriculture.*

Chianeh, L. H., Mohammad, A., Zeraatkish, S. Y., & Moghaddasi, R. (2021). The mathematical Analysis of the Impact of Macroeconomic Variables on Various Dimensions of Food Security in Developing Countries. *Advances & Applications in Discrete Mathematics, 26*(1). https://doi.org/10.17654/DM026010063

De Schutter, O. (2009). *The role of development cooperation and food aid in realizing the right to adequate food: moving from charity to obligation*. Promotion and Protection of All Human Rights, Civil, Political, Economic, Social and Cultural Rights, Including the Right to Development.

Dhaouadi, A., & Bouzid, A. (2020). La sécurité alimentaire de l'Algérie à l'épreuve de pandémie COVID-19. *Les Cahiers du Cread, 36*(3).

Diaz-Bonilla, E., & Ron, J. F. (2010). *Food security, price volatility and trade: Some reflections for developing countries.* ICTSD Programme on Agricultural Trade and Sustainable Development, Issue Paper n°28. International Center for Trade and Sustainable Development, Geneva, Switzerland. https://doi.org/10.7215/AG_IP_20101129

Fan, S., & Rosegrant, M. (2008). *Investing in agriculture to overcome the world food crisis and reduce poverty and hunger*. Policy Brief 3. International Food Policy Research Institute, Washington, DC.

FAO, FIDA, OMS, PAM, & UNICEF. (2019). *L'État de la sécurité alimentaire et de la nutrition dans le monde: Se prémunir contre les ralentissements et les fléchissements économiques.* Rome.

FAO. (2012). *The state of food and agriculture: investing in agriculture for a better future.* FAO. Rome.

Global Report on Food Crises. (2023). *Food Security Information Network.*

Gouel, C. (2013). Optimal food price stabilization in a small open developing country. *European Economic Review, 57*, 118-134. https://doi.org/10.1016/j.euroecorev.2012.10.003

Gouel, C. (2014). *Food Price Volatility and Domestic Stabilization Policies in Developing Countries.* National Bureau of Economic Research, Inc., 261-306. https://doi.org/10.7208/chicago/9780226129082.003.0008

Habib, H., & Jmaii, A. (2024). Effect of income instability and social transfers on food security during COVID-19 in Tunisia. *International Journal of Social Economics.* Emerald; Emerald Group Publishing Limited; MCB University Press Ltd.

https://doi.org/10.1108/IJSE-11-2023-0867

Hansen, B. E. (1999). Threshold effects in non-dynamic panels: Estimation, testing, and inference. *Journal of Econometrics, 93*, 345-368.
https://doi.org/10.1016/S0304-4076(99)00025-1

Huchet, M., Laroche-Dupraz, C., & Senadin, A. L. (2013). *Impact du taux de change sur la sécurité alimentaire des pays en développement.* Working Paper SMART-LERECO N°13-10.

IFPRI. (2010a). *Food Security and Economic Development in the Middle East and North Africa: Current State and Future Perspectives*. IFPRI. Washington, DC.

Jeder, H., Hattab, S., & Frija, I. (2020). *An econometric analysis for food security in Tunisia.* New Medit. https://doi.org/10.30682/nm2004a

Jemmali, H., Morrar, R., & Ben Aissa, M. S. (2021). *Le lien dynamique entre les changements climatiques, la durabilité agricole et la pauvreté alimentaire et hydrique dans un panel de pays sélectionnés de la région MENA. Journal de l'Eau et du Changement Climatique*. https://doi.org/10.2166/wcc.2019.309

Jouili, M., & Elloumi, M. (2022). Extraversion versus développement agricole autocentré : Le cas des pays du Maghreb. *Canadian Journal of Development Studies / Revue Canadienne d'études Du Développement, 44*(3), 410-429.
https://doi.org/10.1080/02255189.2022.2092459

Kalai, M., & Helali, K. (2021). Threshold Effect of Foreign Direct Investment on Economic Growth: *New Evidence From a Panel Regime Switching Models.*
https://doi.org/10.21203/rs.3.rs-167596/v1

Kalkuhl, M., & Maximo, J. T. (2016). *Food Price Volatility and Its Implications for Food Security and Policy*. Library of Congress Control Number: 2016931306.
https://doi.org/10.1007/978-3-319-28201-5

KoÃ, A., Ozdamar, O., & Uysal, P. (2017). The Economic Determinants of Food Security in the MENA Region. *International Journal of Food and Beverage Manufacturing and Business Models (IJFBMBM), 2*(1), 1-19. https://doi.org/10.4018/IJFBMBM.2017010101

Kumar, A., & Sharma, P. (2013). *Impact of climate variation on agricultural productivity and food security in rural India. Economics Discussion Papers 2013-43*. Kiel Institute for the World Economy.

Lagi, M., Bertrand, K. Z., & Yaneer, B. Y. (2011). *The Food Crises and Political Instability in North Africa and the Middle East.* New England Complex Systems Institute. Cambridge, MA.
https://doi.org/10.2139/ssrn.1910031

Malthus, T. R. (1815/1970). *An inquiry into the nature and the progress of rent and the principles by which it is regulated.* In The pamphlets of Thomas Robert Malthus (Reprinted by A.M. Kelly, New York).

Market Watch. (2024). *Currency Exchange Rate and Food Security, Ethiopia*. PAM.

Mary, S. (2019). Hungry for free trade? Food trade openness and extreme hunger in developing countries. *Food Security, 11*, 461-477. https://doi.org/10.1007/s12571-019-00908-z

Mashref, M. (2024). Measuring the impact of public agricultural spending on food security by applying it to the MENA region. *Scientific Journal of Agricultural Sciences, 6*(1), 249-272. https://doi.org/10.21608/sjas.2024.255314.1372

Mhiri, A. (2022). *La Sécurité alimentaire en Tunisie et le défi de l'agriculture tunisienne à accroître durablement sa contribution à l'équilibre de la balance alimentaire du pays.* Communication présentée au Forum Ibn Khaldoun pour le Développement.

Moncada, L., De la O Campos, A. P., & Tornarolli, L. (2022). *Food insecurity and poverty: A cross-country analysis using national household survey data*. FAO Agricultural Development Economics Working Paper, No. 22-14. Rome, FAO.

ONAGRI. (2016-2020). *La Balance Commerciale Alimentaire.*

Ouessar, M., Sghaier, A., Frija, A., Sghaier, M., & Baig, M. B. (2021). Impacts of Climate Change on Agriculture and Food Security in Tunisia: Challenges, Existing Policies, and Way Forward. In M. Behnassi, M. B. Barjees Baig, M. El Haiba, & M. R. Reed (Eds.), *Emerging Challenges to Food Production and Security in Asia, Middle East, and Africa* (pp. 37-61). Springer, Cham. https://doi.org/10.1007/978-3-030-72987-5_3

Padilla, M. (2008). *Dietary patterns and trends in consumption*. In Mediterra: The future of agriculture and food in Mediterranean countries (pp. 149-170). International Centre for Advanced Mediterranean Agronomic Studies, Paris; Presses de Sciences Po.

Pinstrup, A. (2009). Food security: Definition and measurement. *Food Security, 1*, 5-7. https://doi.org/10.1007/s12571-008-0002-y

Shittu, A. M., Akerele, D., & Haile, M. (2018). *Effects of Food Price Spikes on Household Welfare in Nigeria.* ZEF-Discussion Papers on Development Policy No. 248. https://doi.org/10.2139/ssrn.3156939

Verpoorten, M., Arora, A., Stoop, N., & Swinnen, J. (2013). Self-reported food insecurity in Africa during the food price crisis. *Food Policy, 39*, 51-63. https://doi.org/10.1016/j.foodpol.2012.12.006

Wossen, T., Berger, T., Hailé, M. G., & Troost, C. (2018). Impacts de la variabilité climatique et de la volatilité des prix alimentaires sur les revenus des ménages et la sécurité alimentaire des ménages agricoles en Afrique de l'Est et de l'Ouest. *Agricultural Systems, 163*, 7-15. https://doi.org/10.1016/j.agsy.2017.02.006

Yerima, A. U., & Tahir, H. M. (2020). The impact of external debt on agricultural production in Nigeria (1980-2016): Autoregressive Distributed Lag Modelling. *Bullion, 44*(2).

Appendix

Table A1. Variables of the Model, Definitions and Sources

Variables	Définitions	Sources
SA	SA= P+M-X	FAO
IP	Cereal Products Price Index	FAO
GDPc	GDP per capita (constant 2015 US$)	WDI
IPC	Consumer Price Index in Tunisia. Proxy variable for inflation.	FAO
SP	Ratio of the poor population based on the national poverty line (% of population)	WDI
ITE	Net merchandise terms of trade index (2000=100)	WDI
DE	External debt stocks, total (Current US$)	WDI
TCER	Real effective exchange rate index (2010=100)	WDI

Table A2. HeteroscedasticityTest

Breusch-Pagan / Cook-Weisberg test for heteroskedasticity
Ho: Constant variance
chi2(1) = 0.88
Prob > chi2 = 0.3490

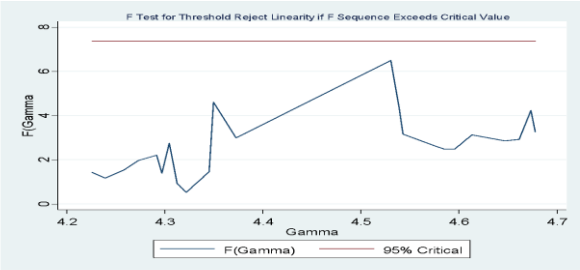
Table A3. Multicollinearity Test

Variables	VIF	1/VIF
dl_IPC	1.47	0.681286
dl_ITE	1.38	0.724705
dl_GDPc	1.24	0.804064
dl_TCER	1.24	0.807937
dl_DE	1.16	0.859636
dl_SP	1.11	0.897620
dl_IP	1.09	0.919253
Mean VIF	1.24	

Tableau A4. The BDS test results

BDS Test	l_SA	l_IP	l_IPC	l_ITE	l_GDPc	l_SP	l_TCER	l_DE
m	z-Statistic							
2	8.844013	13.61772	21.14395	13.20377	19.61360	17.2660	20.46355	23.06307
3	9.305438	14.12411	21.05194	15.94448	20.63423	17.0152	21.00902	23.59481
4	10.29547	15.25483	21.62109	16.18095	21.65240	16.7955	21.17111	25.03747
5	11.70771	15.52259	22.90567	16.18796	23.42619	16.774	21.81757	27.45085
6	13.04162	16.66506	24.87758	16.23296	26.09417	16.5655	23.31129	30.89147
Probability	0.0000							

The test verifies the nonlinearity of the different series in our study, with Prob<1%.



thresholdtest l_SA_ l_IP, q(l_IP)

Test of Null of No Threshold Against Alternative of Threshold

Allowing Heteroskedastic Errors (White Corrected)

Number of Bootstrap Replications:	2000
Trimming Percentage:	.15
Threshold Estimate:	4.53069019
LM-test for no threshold:	6.50160225
Bootstrap P-Value:	.102

Figure A1. Nonlinearity Test