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The impact of climate change on inflation in Tunisia:
Evidence from the asymmetric NARDL model

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Abstract: In recent years, several studies have demonstrated that climate change is responsible for short- and medium-term disturbances in agricultural production, economic growth, and national or international price mechanisms. This paper aims to examine the relationship between climate shocks, represented by extreme weather phenomena such as drought and heat waves on one hand and agri food and overall inflation on the other hand by applying a Nonlinear Autoregressive Distributed Lag (NARDL) model to the Tunisian case for the period 1985-2020. The paper employs econometrics based on Pesaran's cointegration tests, which recognize the existence of asymmetric effects of climate shocks on agri-food inflation in both the short and long run. The study considers various climate shocks representative of climate change, such as extreme temperatures and rainfall episodes. In the case of Tunisia, the estimation results of the NARDL model indicate that, in the long term, there is a positive and significant effect of rainfall on grain production. On one hand, a prolonged shortage in rainfall leads to an increase in both agri-food inflation and the general Consumer Price Index. On the other hand, an increase in average temperature causes an increase in both overall inflation and food prices.

Keywords: Climate change, Agriculture, climate inflation, NARDL, Tunisia.

JEL codes: Q50, Q54, Q10, P24, C15.

1. INTRODUCTION

Climate change poses a potential threat to humanity with long-term global consequences, including rising sea levels, biodiversity loss, deforestation, freshwater contamination, water scarcity, heatwaves, and recurring periods of drought. In recent years, numerous studies have highlighted that climate change is accountable for short- and medium-term disturbances in agricultural production, economic growth, and national or international price mechanisms.

According to the World Bank, climate change could force more than 130 million people into poverty by 2030 and result in a 200 million people migration by 2050 (World Bank, 2021). The impacts of climate change could be devastating for many countries, due to their geographical attributes and the limited diversification of their economies. Low income countries meet much higher challenges in implementing specific economic and social processes to adapt to climate change.

In recent years, the direct effects of climate change on agricultural production and economic development have been extensively documented. The analysis of the economic climate change consequences has been introduced in recent theoretical works and empirical reports from international organizations, including the World Bank. They all admit that climate change can be identified by the increased frequency of extreme weather events (such as rising temperatures, reduced rainfall, and floods) which lead to agricultural supply shocks (Dafermos et al., 2018; Batten et al., 2020). Climate change shocks result in productivity losses, infrastructure damage, destruction of available capital stock, and inevitably lead to a net decline in agricultural production in some countries. Climate change exacerbates the occurrence of food shortages, given the high sensitivity of agricultural outputs to weather conditions. Droughts and floods reduce the availability of arable land, subsequently decreasing harvests. Reduced production levels and increased production costs contribute to an overall rise in the price level of agricultural goods, significantly impacting the general consumer price index. This underscores the crucial role of the agricultural sector in addressing both current and future climate challenges (World Bank, 2021).

This paper builds upon these previous studies. It aims to study the relationship between climate change and inflation by employing a NARDL model in the context of Tunisia. The paper uses a Pesaran cointegration test, which admits possible asymmetric effects of positive and negative climate change shocks on general and agri-food inflation in both the short and long run. The paper is structured as follows: Section 2 offers a recent literature review on climate change and inflation. Section 3 provides a descriptive analysis of Tunisia's agricultural production system and agri-food market trends. Section 4 introduces the model, discusses methodological issues, and outlines data specifications. Section 5 presents the results from the econometric model. The concluding section summarizes findings and discusses economic policy implications.

2. A BRIEF LITERATURE REVIEW

This paper specifically delves into recent literature that explores the repercussions of climate change on agricultural production and food markets. In recent years, a series of works focus on the link between climate change, agricultural production, and climate inflation. All these studies consider that climate change, discerned through climate variability and the growing frequency and intensity of

extreme weather events, affects the stability of food availability, and amplify the risks associated with food supply (FAO, 2016).

Nelson (2009) studies the impact of climate change on crop production and prices in Europe. Climate change has a negative impact on agricultural yields and food consumption, resulting in inflationary pressures in key final markets for major crops, such as rice, wheat, corn, and soybeans. Djukic et al. (2009) show that a 10% rise in the price of agricultural products corresponds to a 3% increase in the price of their industrial derivatives.

Stoica and Damian (2013) investigate the relationship between agri-food inflation and overall inflation in Europe. They assess the impact of the Common Agricultural Policy on inflation rates in countries that joined the European Union in 2004. Their study first compares consumer food prices in ten member States before and after joining the European Union. Second, it employs a multifactor regression model for the period 2003-2010 for six new member states (Czech Republic, Hungary, Latvia, Lithuania, Slovakia, and Slovenia) to examine the impact of agri-food price shocks on general inflation. The results reveal a net positive influence of agricultural product prices on the consumer price index. Lloyd et al. (2015) deliver a comparative analysis of agri-food inflation in the European Union, focusing on its effects on general inflation trends. They demonstrate that this relationship is stronger in low-income countries.

Several empirical studies examine the relationship between climate shocks and food prices as well as agricultural production in Asian countries. Misra (2013) investigates the impact of climate change on agricultural and water resources in India. His findings indicate that long-term climate changes influence both the quantity and quality of crops, leading to a decrease in agricultural production and an increase in both food inflation and overall inflation rates.

Similarly focusing on the Indian context, Kar and Das (2015) employ a Ricardian approach to explore the effects of climate change on the value of agricultural land. They use a counterfactual measure of agricultural income on rural consumption expenditure and provide evidence that the impacts of climate change on food production and prices can negatively affect household consumption, thereby contributing to increase inflation. In another study concerning the Indian peninsula, Bhattacharya and Gupta (2018) utilize a multiple regression model to test the relationship between agri-food inflation and agricultural production during the period 2006-2018. Their findings confirm the results of previous studies and highlight a robust correlation between agricultural production and the general inflation rate.

Using a computable general equilibrium model, Xin et al. (2008) undertake a study to evaluate the repercussions of declining agricultural production on agricultural prices and overall inflation in China. Their findings suggest that a 5% reduction in agricultural production, stemming from unpredictable and extreme weather events, leads to a 50% change in agricultural prices and a 40% increase in the general consumer price index. Using panel data from the Philippines, Arcenas (2018) estimates the effects of short-term climate shocks such as El Niño and La Niña, on inflation in the Philippines. The results indicate a significant impact of climate shocks on the general price index in the country, as well as on the unemployment rate and the Philippine currency exchange rate. Conversely, long-term climate change effects, specifically changes in average temperature or annual rainfall, do not appear to have a significant impact on the general price index.

Solaymani (2018) builds a computable general equilibrium model that incorporates historical rainfall and temperature data, as well as agricultural productivity data, to examine the impact of climate change on Malaysian food security and inflation. The study's findings indicate that climate shocks lead to a reduction in consumption and welfare across all household groups, with particularly pronounced effects in rural areas due to the diminished agricultural supply and increasing prices for agricultural products.

Finally, numerous studies investigate the relationship between climate change, agri-food inflation, and food security in Africa. Zougmoré et al. (2018) demonstrate that without appropriate interventions, climate change and variability adversely affect agricultural yields, food security, and poverty in most sub-Saharan African countries. Africa appears particularly vulnerable to climate change and climate variability, contributing to biodiversity loss, food insecurity, water scarcity, and an increase in drought frequency. Several studies indicate that climate change is likely to reduce yields and production of key staple crops such as rice (Akinbile et al., 2015; Van Oort and Zwart, 2018), wheat (Trnka et al., 2019), and maize (Davenport et al., 2018; Freduah et al., 2019; Murray-Tortarolo et al., 2018).

Some studies aim to establish a connection between climate change and food market security by examining the impact on prices in Africa. Hagos (2018) uses time series data to assess the influence of climate change on food inflation in Ethiopia. The regression results reveal that a 1°C temperature increase corresponds to a significant price increase for all agricultural products. The effects depend on the type of product, with prices increasing by 186% for barley and 60% for wheat.

In a similar study, the World Bank cautions that climate change could diminish agricultural production, particularly in regions already grappling with food insecurity. Tamako and Thamaga-Chitja (2017) show that a deficit in food supply, resulting from the adverse impacts of climate change on yields and production, leads to an increase in food prices, affecting millions of low-income individuals in areas already afflicted by high rates of hunger and poverty, such as the Sub-Saharan Africa. The situation is alarming for populations reliant on agriculture for their livelihoods and income, especially for small-scale farmers (Descheemaeker et al., 2016; García de Jalón et al., 2018; Williams et al., 2018).

The present paper builds on previous studies examining the relationship between climate change, food inflation, and general inflation. Its objective is to enhance the estimations of this relationship from an econometric perspective, with a specific focus on the case of Tunisia.

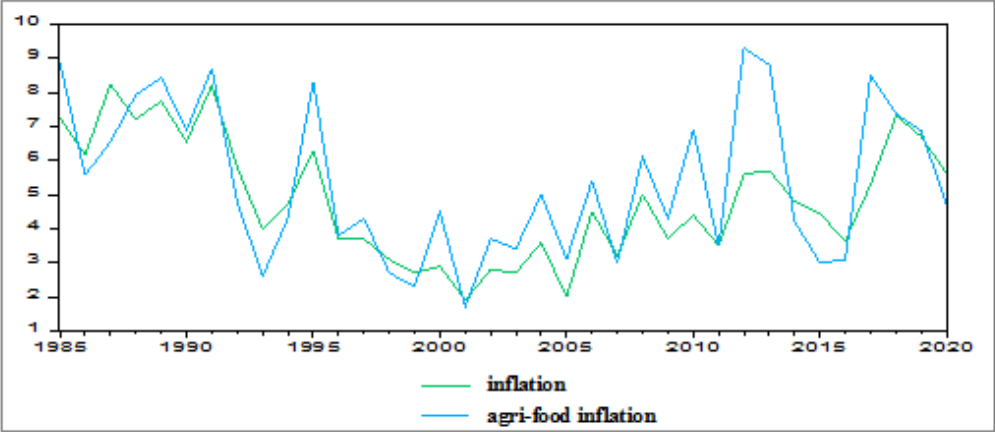
3. A DESCRIPTIVE ANALYSIS FOR AGRI-FOOD INFLATION IN TUNISIA

In Tunisia, the average consumption basket comprises one thousand products, categorized into different groups or categories, including food and beverages, housing, water, gas, electricity, and other fuels. When examining the structure of the Consumer Price Index (CPI), it is clear that the group of food products, sourced from the agricultural sector, carries substantial weight (accounting for almost 30%) compared to other final product groups.

Between 1985 and 2020, consumer prices for crops and leguminous products exhibited significant fluctuations, reflecting the variations observed in the consumer price index for all agri-food products.

Fruit prices feature a lower level of convergence with the general agri-food product price index. The CPI-based inflation experienced notable increases in 2002, 2013, and 2016, all three years marked by severe droughts in Tunisia. Figure 1 illustrates a robust positive relationship between the overall Consumer Price Index and the Consumer Price Index of agri-food products in Tunisia, suggesting that the latter may be considered as the primary source of inflation.

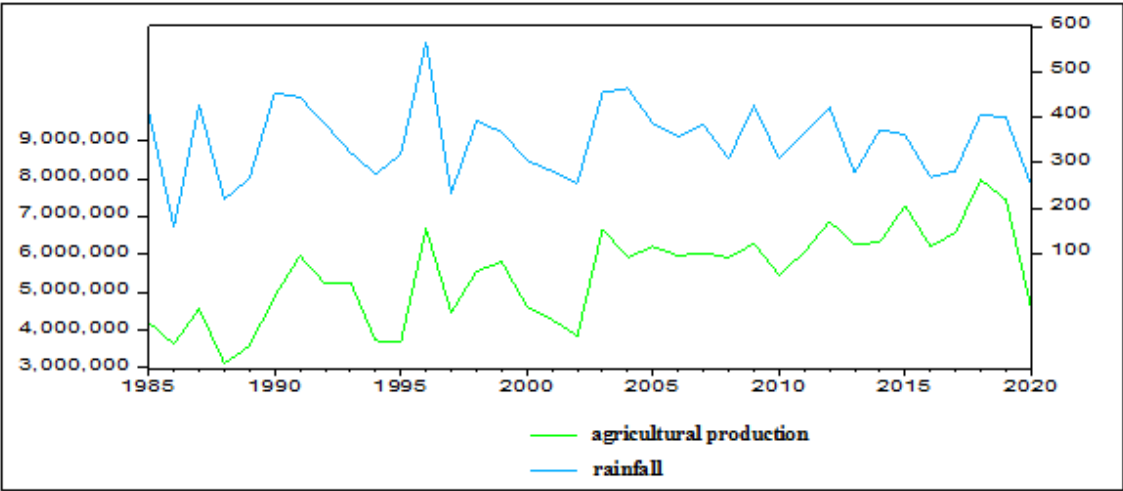
Figure 1: Relationship between inflation and agri-food inflation



Data provided by INS 2022

Figure 2a and 2b depict the relationship between agricultural production, annual rainfall (2a), and annual average temperature (2b).

Figure 2a: Relationship between rainfall and overall agricultural production



Data provided by INS 2022

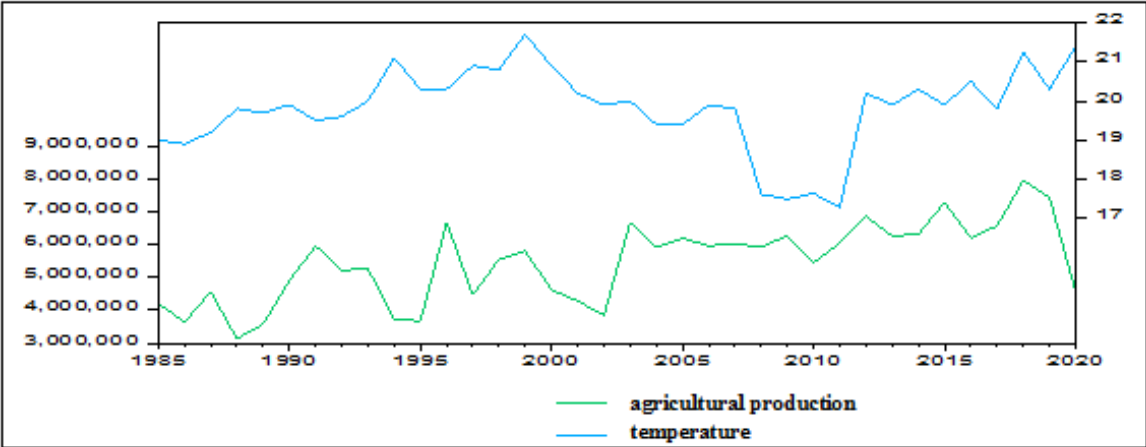
Figure 2a features a relatively strong correlation between changes in rainfall levels and agricultural production. For instance, in 1987, abundant and well-distributed rainfall (426.7mm) coincided with important agricultural production, reaching 4,575.737 million tons of products, compared to the 3,630.306 million tons in the previous year. This led to a gradual decrease in the inflation rate during the last semester of 1987 and 1988, with the average annual inflation rate standing at 7.2%, compared to 8.23% in the previous year. Similarly, in 1996 and 1997, higher rainfall (564.8 mm in 1996 compared to 318.6 mm in 1995) resulted in higher agricultural production, which reached

6,690.740 million tons of products, compared to 3,676.087 million tons in the previous year. Inflation levels once again decreased by 21.7% and 41.26% in 1996 and 1997, respectively, compared to 1994 and 1995.

In 2016 and 2017, Tunisia experienced a decline in average rainfall to 268.6 mm and 282.46 mm, respectively (compared to 361 mm in 2015). Consequently, agricultural production decreased to 6,222,799 and 6,587,380 million tons of products, and prices increased at a rate of 5.3% compared to 2015. Food market inflation reached 8.5% in 2017; this is a significant increase compared to the rate of 3% observed in 2015. In 2018, the average annual rainfall increased once again to 406.52 mm. The harvest was notably good, particularly for crops, which reached an exceptional production of 21,322 thousand quintals (compared to 1,603.9 thousand quintals the previous year!) and olive oil production, which reached a production of 1,600,000 tons (compared to 500,000 tons in 2017). Both food inflation and overall inflation decreased starting from July 2018.

Figure 2b illustrates the relationship between temperature and overall agricultural production. In contrast to the previous case, it does not reveal any significant association between the two factors.

Figure 2b: Relationship between temperature and overall agricultural production

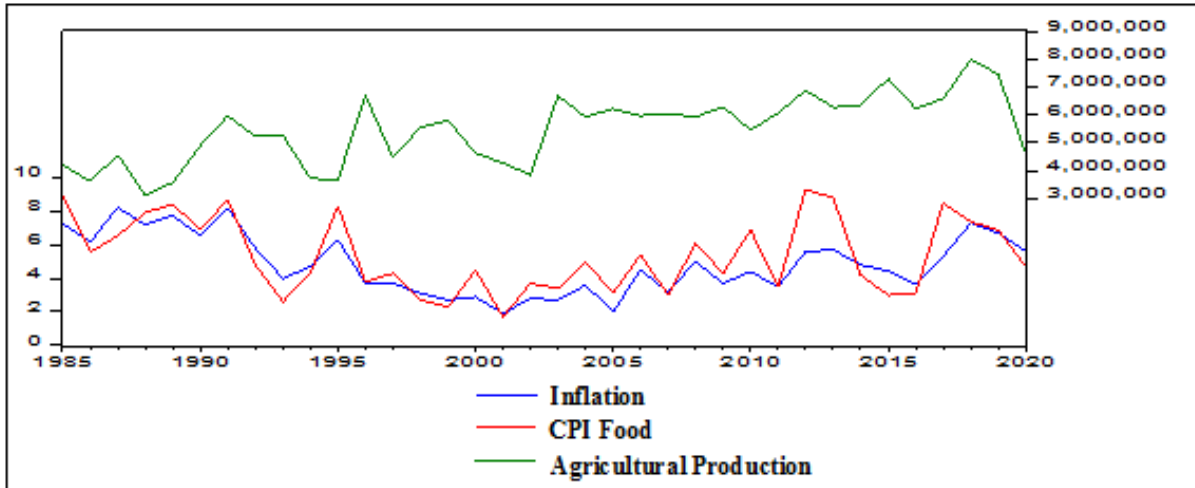


Data provided by INS 2022

When examining the relationship between agricultural production and inflation, it becomes evident that the variability of agricultural supply influences the trends of both agri-food and overall inflation. This is particularly pronounced in developing countries where the agricultural sector plays a significant role in the economy and serves as a source of inputs for other industries. In some countries undergoing structural changes and industrialization, the significance of the agricultural sector diminishes. Agricultural products gradually transit into food industry products, making them less vulnerable to direct climatic shocks.

Figure 3 illustrates the relationship between the evolution of overall inflation, the inflation rate of agri-food products, and the evolution of agricultural production. The prices of agricultural products exert a significant influence on inflation. However, certain agricultural commodities like wheat, barley, and maize do not directly contribute to the general consumer price index basket; instead, these products are sold in their raw form or processed into various manufactured goods. As a result, they indirectly impact the prices of related industrial products such as bread, pasta, pastries, hotel catering services, leather, and their by-products.

Figure 3: Inflation, CPI Food and Agricultural Production



Source: Data provided by INS 2022

Any change in agricultural production has a significant impact on the Consumer Price Index (CPI). A decrease in agricultural production usually leads to inflation in the food sector market. This, in turn, influences general inflation, as food prices typically have a substantial weight in the overall CPI basket. The interconnectedness between agricultural production, food prices, and overall inflation highlights the vulnerability of economies, particularly in regions where the agricultural sector plays a crucial role.

4. MODEL SELECTION AND DATA SPECIFICATION

Our database spans a 35-year period, from 1985 to 2020, focusing on Tunisia. The data is sourced from national institutions' databases, including the National Institute of Statistics (INS), the Institute of Quantitative Economics (IEQ), various editions of the monthly statistical bulletins, Tunisia's statistical yearbooks, the National Observatory of Agriculture (ONAGRI), and the National Institute of Meteorology, covering the 24 governorates in Tunisia.

From a methodological point of view, incorporating nonlinearity is crucial for achieving accurate forecasts. The regime-switch models are employed to deal with nonlinearity, even though they may not acknowledge the potential presence of a nonlinear long-run relationship. Shin et al. (2009) use an asymmetric ARDL model with bond tests to investigate the existence of nonlinear cointegration. Cointegration between series implies the presence of one or more long-run equilibrium relationships among these series; these relationships can be integrated with the short-run dynamics in an error correction model (VECM). Unlike the ARDL model, the NARDL model allows for asymmetric effects of positive and negative changes in exogenous variables on the endogenous variable in both the short and long run.

In the present study, we construct five distinct models, each defining a specific endogenous variable. The first two models use global and agri-food inflation, while the following three focus, respectively, on changes in the prices of crops, vegetables, and fruits. The exogenous variables are consistent across all models and include average temperature, annual precipitation, agricultural production, imports of agricultural products, real exchange rate, and household consumption. We adopt the methodology developed by Shin et al. (2014) and implement the NARDL model as follows:

$$\begin{aligned} \Delta \ln inf_t Y = & \alpha_0 + \rho \Delta Y_{i,t-1} + \beta_1^+ \ln Y_{t-1}^+ + \beta_2^- \ln Y_{t-1}^- + \beta_3^+ \ln T_{t-1}^+ + \beta_4^- \ln T_{t-1}^- + \beta_5^+ \ln P_{t-1}^+ + \beta_6^- \ln P_{t-1}^- + \beta_7^+ \ln M_{t-1}^+ \\ & + \beta_8^- \ln M_{t-1}^- + \beta_9^+ \ln MM_{t-1}^+ + \beta_{10}^- \ln MM_{t-1}^- + \beta_{11}^+ \ln TCR_{t-1}^+ + \beta_{12}^- \ln TCR_{t-1}^- + \beta_{13}^+ \ln C_{t-1}^+ + \beta_{14}^- \ln C_{t-1}^- + \\ & \sum_{j=0}^m \Delta \ln inf_{t-j} + \sum_{j=0}^m (\varphi_j^+ \Delta \ln Y_{t-j}^+ + \varphi_j^- \Delta \ln Y_{t-j}^-) + \sum_{j=0}^m (\varphi_j^+ \Delta \ln T_{t-j}^+ + \varphi_j^- \Delta \ln T_{t-j}^-) + \\ & \sum_{j=0}^m (\varphi_j^+ \Delta \ln P_{t-j}^+ + \varphi_j^- \Delta \ln P_{t-j}^-) + \sum_{j=0}^m (\varphi_j^+ \Delta \ln M_{t-j}^+ + \varphi_j^- \Delta \ln M_{t-j}^-) + \sum_{j=0}^m (\varphi_j^+ \Delta \ln MM_{t-j}^+ + \varphi_j^- \Delta \ln MM_{t-j}^-) + \\ & \sum_{j=0}^m (\varphi_j^+ \Delta \ln TCR_{t-j}^+ + \varphi_j^- \Delta \ln TCR_{t-j}^-) + \sum_{j=0}^m (\varphi_j^+ \Delta \ln C_{t-j}^+ + \varphi_j^- \Delta \ln C_{t-j}^-) + \varepsilon_t \end{aligned} \quad (1)$$

In the first model, Y corresponds to the general inflation rate (Y1). In the second model, it represents the agri-food inflation rate (Y2). The last three models focus on changes in the prices of crops (Y3), vegetables (Y4), and fruits (Y5). Unlike the optimal ARDL model, where Δ represents the first difference operator and α_i denotes the short-term effect, the selection of an optimal lag number for each variable in the NARDL model is based on information criteria such as AIC, SBC, FPE, or HQ. Once these lag numbers are determined, the coefficients of the long-term relationships can be estimated. Subsequently, the error correction model (ECM) can be estimated, with prior verification of stationarity and cointegration.

In the NARDL model, the coefficients β_i^+ and β_i^- represent the positive and negative long-run effects of climate change on inflation and more specifically on agri-food inflation. $\sum_{j=0}^m \varphi_j^+$ and $\sum_{j=0}^m \varphi_j^-$ denote the positive and negative short-run effects, respectively. The positive (+) and negative (-) signs for the different exogenous variables indicate the partial sum of positive and negative changes.

Shin et al. (2014) introduced a first generation test to identify symmetric or alternatively asymmetric long-term cointegration processes. The standard procedure involves testing the null hypothesis ($H_0 = \beta_1^+ = \beta_1^- = \beta_2^+ = \beta_2^- = \dots = \beta_{20}^+ = \beta_{20}^- = 0$), which admits a symmetric effect in the long run, against the alternative hypothesis ($H_1 \neq \beta_1^+ \neq \beta_1^- \neq \beta_2^+ \neq \beta_2^- \neq \dots \neq \beta_{20}^+ \neq \beta_{20}^- \neq 0$), using the F-statistic.

5. RESULTS AND DISCUSSION

Unit root tests are crucial in time series modeling to address potential spurious regression issues. These tests help identify deterministic or stochastic trends, providing insights into the (non)stationarity of the series. The Augmented Dickey-Fuller (ADF) test and the Phillips-Perron test are employed to ascertain whether the variable of interest is a first-order integrated time series, denoted as I(1).

The results in Table 1 clearly reject the null hypothesis for fruit production and temperature. In first difference, these series exhibit stationarity. Global agricultural production, vegetable, and cereal production, as well as precipitation, also reject H1. This implies a potential cointegration relationship among the different variables. The results also indicate that capital, export, inflation, and money supply are stationary at the level, as the calculated statistics are below the critical values of 1% and 5%. On the other hand, labor, consumption, import, and exchange rate only become stationary in the

first difference and are integrated of order 1. The results from the Phillips-Perron tests are consistent like those obtained from the ADF test, supporting the presence of cointegrating relationships between the variables. The NARDL bounds test verifies these cointegration relationships.

To examine the existence of a cointegrating relation between series, we apply the test of Pesaran et al. (2001). The results in Table 2 show that the calculated Fischer value exceeds the upper bound at the critical limits of 1% and 10%. Therefore, we reject the null hypothesis and accept the alternative, which asserts the presence of a cointegration relation between the variables. In other words, there is a long-term equilibrium relation between the variables for all five estimated models.

Table 1: Unit root tests

Variable	ADF			PP		
	In level	In 1 st diff	Order of integration	In Level	In f 1 st diff	Order of integration
Inflation	-6.262 (0.000)	–	I(0)	-6.279 (0.002)	–	I(0)
Cereal inflation	-3.160 (0.031)	–	I(0)	-3.202 (0.028)	–	I(0)
Vegetable inflation	-6.750 (0.000)	–	I(0)	-7.184 (0.000)	–	I(0)
Fruit Inflation	-5.681 (0.000)	–	I(0)	-5.714 (0.000)	–	I(0)
Agri-food inflation	-4.452 (0.001)	–	I(0)	-4.477 (0.001)	–	I(0)
Agricultural production	-3.288 (0.023)	–	I(0)	-3.219 (0.027)	–	I(0)
Cereal production	-6.262 (0.000)	–	I(0)	-6.279 (0.000)	–	I(0)
Vegetable production	-2.713 (0.081)	–	I(0)	-2.935 (0.051)	–	I(0)
Fruit production	-1.958 (0.302)	-6.040 (0.000)	I(1)	-1.773 (0.387)	-13.499 (0.000)	I(1)
Consumption	-2.410 (0.146)	-5.133 (0.000)	I(1)	-2.551 (0.112)	-5.133 (0.000)	I(1)
Importation	-1.884 (0.335)	-6.741 (0.000)	I(1)	-1.824 (0.362)	-6.756 (0.000)	I(1)
Exchange rates	-0.383 (0.900)	-6.579 (0.000)	I(1)	-2.897 (0.055)	–	I(0)
Money supply	0.429 (0.981)	-7.686 (0.000)	I(0)	0.254 (0.972)	-7.442 (0.000)	I(1)
Temperature	-2.358 (0.160)	-7.271 (0.000)	I(1)	-2.259 (0.190)	-7.277 (0.000)	I(1)
Rainfall	-7.175 (0.000)	–	I(0)	-7.150 (0.000)	–	I(0)

Table 2: Co-integration tests

F-stat	4.397		4.140		4.364		6.82		5.48	
	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)
10%	1.76	2.77	1.62	1.42	1.76	2.77	2.23	4.12	1.76	2.77
5%	1.98	3.04	1.95	1.76	1.98	3.04	2.54	4.23	1.98	3.04

1%	2.41	3.61	2.58	2.44	2.41	3.61	3.58	5.87	2.41	3.61
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The results of the diagnostic tests for the NARDL model are presented in Table 3. Empirical tests for the normality of residuals and the Ramsey functional form test (RESET) confirm the absence of heteroscedasticity and reject the presence of autocorrelation in the errors.

Table 3: Diagnostic test of the NARDL model

	Tests	Model (1)	Model (2)	Model (3)	Model (4)	Model (5)
Autocorrelation	Breusch-Godfrey	4.823 (0.350)	1.627 (0.236)	4.727 (0.330)	1.423 (0.273)	4.725 (0.350)
Heteroskedasticity	Breusch-Pagan-Godfrey	1.015 (0.511)	0.534 (0.902)	2.361 (0.569)	0.520 (0.911)	0.981 (0.522)
	Arch-test	0.486 (0.490)	1.077 (0.307)	0.558 (0.460)	1.986 (0.192)	0.389 (0.537)
Normality	Jarque-Bera	0.624 (0.731)	0.687 (0.709)	0.470 (0.790)	1.119 (0.571)	0.424 (0.808)
CUSUM		Stable	Stable	Stable	Stable	Stable
CUSUM-SQ		Stable	Stable	Stable	Stable	Stable

Table 4 presents the results from the model on the long term, and Table 5 the results for the short term. In the long run, in Tunisia, a 1% decrease in agricultural production leads to a 0.42% increase in the country's inflation rate, as shown in Table 4. When examining specific products, the study reveals that a 1% decrease in crop production results in a significant 0.28% increase in the general Consumer Price Index.

Table 4: NARDL model long-run results

Variables	Model 1 inflation	Model 2 inflation agro	Model 3 inflation vegetabl	Model 4 inflation crop	Model 5 inflation fruit
T ⁺	4.659** (0.017)	7.712** (0.032)	14.415** (0.022)	17.438*** (0.008)	11.726** (0.038)
T ⁻	-4.697** (0.085)	-11.146** (0.034)	-3.114 (0.713)	-8.821 (0.272)	-23.431 (0.175)
P ⁺	0.363 (0.380)	-1.583** (0.091)	-3.196** (0.005)	-7.296*** (0.001)	-4.579** (0.051)
P ⁻	0.033 (0.933)	0.668 (0.376)	0.681 (0.476)	-0.026 (0.982)	1.763 (0.293)
C ⁺	1.015 (0.277)	0.243 (0.891)	0.107 (0.970)	0.285 (0.915)	-5.331 (0.293)
C ⁻	0.573 (0.806)	5.453 (0.218)	6.722 (0.406)	8.879 (0.304)	14.597 (0.378)
M ⁺	0.473** (0.380)	0.124 (0.935)	2.813 (0.306)	3.340* (0.108)	9.783** (0.079)
M ⁻	1.164 (0.933)	-1.23 (0.023)	-1.208 (0.363)	-0.168 (0.855)	-2.048 (0.273)
Y ⁺	-0.368 (0.277)	1.400 (0.124)	-0.270 (0.379)	-2.010 (0.031)	-7.631 (0.104)
Y ⁻	0.419*** (0.806)	1.376 (0.283)	5.187** (0.073)	0.352** (0.043)	0.020 (0.997)
MM ⁺	4.582** (0.080)	1.743 (0.648)	15.784** (0.026)	-7.067 (0.296)	-24.705 (0.113)
MM ⁻	-9.932* (0.176)	-1.547 (0.888)	-30.195* (0.133)	16.337 (0.376)	46.879 (0.263)
TCR ⁺	1.772 (0.474)	-2.951 (0.832)	28.494 (0.259)	22.538 (0.373)	3.030 (0.950)
TCR ⁻	-2.482** (0.005)	-3.438* (0.123)	-8.329** (0.046)	-1.945 (0.697)	-10.786* (0.111)

When examining climate and environmental variables, our findings reveal that a 1% increase in rainfall corresponds to a 1.58% decrease in prices in the agri-food market. The impact of increased

rainfall is even more pronounced in specific markets: the model estimates a 3.19% decrease in vegetable prices, a 7.29% decrease in crop prices, and a 4.58% decrease in fruit prices. These results confirm the assumption of a strong correlation between changes in rainfall and agricultural production in Tunisia from September to June. A reduction in agricultural production following a season of limited rainfall leads to a negative agricultural supply, contributing to inflationary trends.

The positive shock in the partial sum of temperature (T^+) is also significantly positive, indicating that an increase in average temperature results in higher inflation in the long run. Conversely, the negative shock in the partial sum of temperature (T^-) is significantly negative, signifying that a decrease in temperature leads to a reduction in aggregate inflation and food inflation in the short run.

Table 5: NARDL model short-run results

Variables	Model 1 inflation	Model 2 inflation agro	Model 3 inflation vegetabl	Model 4 inflation crop	Model 5 inflation fruit
T^+	2.998** (0.020)	5.349** (0.036)	11.005** (0.031°)	12.505*** (0.006)	9.557 (0.388)
T^-	-3.022** (0.088)	-7.731** (0.040)	-2.377 (0.717)	-6.325 (0.292)	-19.098** (0.084)
P^+	0.233 (0.369)	-1.360** (0.109)	-2.440** (0.014)	-5.232*** (0.001)	-3.732** (0.040)
P^-	0.021 (0.933)	0.463 (0.401)	0.520 (0.491)	-0.018 (0.982)	1.437 (0.248)
C^+	0.653 (0.255)	0.168 (0.890)	0.082 (0.970)	0.204 (0.915)	-4.345 (0.317)
C^-	0.369 (0.808)	3.782 (0.240)	5.132 (0.401)	6.367 (0.311)	11.897 (0.361)
M^+	0.749** (0.175)	0.086 (0.087°)	-2.147 (0.567)	-2.395* (0.108)	-7.973** (0.064°)
M^-	-0.304** (0.087)	-0.856** (0.022)	-0.922 (0.378)	0.120 (0.855)	1.669 (0.311)
Y^+	0.237 (0.472)	0.971** (0.015)	0.206 (0.350)	1.441 (0.226)	6.220 (0.415)
Y^-	0.270 (0.544)	-0.954 (0.308)	3.960** (0.101)	0.252** (0.226)	0.017 (0.415)
MM^+	2.948** (0.039)	1.209 (0.649)	12.050** (0.027)	-5.068 (0.305)	-20.137 (0.116)
MM^-	-6.390* (0.106)	-1.073 (0.887)	-23.053 (0.122)	11.715 (0.044)	38.210 (0.997)
TCR^+	1.140 (0.811)	-2.047 (0.832)	21.755 (0.243)	16.162 (0.370)	2.469 (0.950)
TCR^-	-1.596** (0.047)	-2.385** (0.104)	-6.359** (0.064)	-1.395 (0.699)	-8.791* (0.109)

The NARDL models incorporate control variables such as money supply or the currency exchange rate, influencing the Consumer Price Index and specific market prices like vegetables, crops, and fruits in the short or long run. The results are consistent with the fundamental theoretical assumptions in modern international economics. For instance, a positive and statistically significant relationship is observed between an increase in imports (M^+) and inflation: a 1% increase in imports corresponds to a 0.47% rise in the general consumer prices index, a 3.34% increase in crop prices, and a 9.78% increase in fruit prices.

This scenario is frequently observed due to climate change: as domestic agricultural production fails to meet the population's needs the supply shortfall must be addressed through imports. This exacerbates the country's trade balance deficit, causing a significant devaluation of the local currency and leading to inflation. Consequently, climate change can impact domestic food prices in various indirect ways, such as inducing a higher demand for imports of agricultural goods, which, in turn, contributes to inflation.

6. CONCLUSION

In this paper, we investigate the impact of climate change on agri-food inflation in Tunisia, examining both short and long-term effects. The paper applies an original NARDL price model on a detailed database for Tunisia spanning from 1985 to 2020. We explore various climate change shocks, such as extreme temperatures and limited rainfall episodes. Our key findings for Tunisia indicate a positive and significant effect of rainfall on grain production. This implies that a long-term shortage in rainfall leads to an increase in both agri-food inflation and overall inflation, as reflected in the Consumer Price Index.

This result underscores the crucial role played by the supply of agricultural products in shaping agri-food and general inflation trends in Tunisia. The agricultural sector retains significant importance in the country, with domestic agricultural products representing a substantial part of the final consumption basket. Climate shocks appear as agricultural supply shocks, leading to shortages and tensions in the food market, which result in inflation. Agri-food inflation, in turn, influences the general Consumer Price Index, that is the overall inflation rate of the country. This increases economic and social inequalities, since the rise of agri-food products prices particularly impacts low-budget households, which struggle to maintain a satisfactory level of food consumption.

Strengthening the resilience of the domestic agricultural system and adapting it to climate change shocks stands as the primary challenge for Tunisia for the next decade. Conventional monetary and fiscal policies prove to be inefficient instruments in addressing the rising prices resulting from declining supply and increasing production costs in domestic agriculture due to factors such as reduced rainfall, drought, soil degradation, and temperature rise. Consequently, there is an urgent need to consider more sustainable and targeted measures. These measures could involve promoting the development of agricultural products that are more resilient to climate change and less affected by decreasing rainfall. Potential policies might include providing farmers with specific seeds and seedlings, encouraging changes in consumption habits to favor locally produced goods, and assisting people in adopting climate-smart practices in agriculture and land use, such as soil fertility restoration and the production of nutrient-rich food.

Declarations:

Conflict of interest The author declares that he has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Ethics approval and consent to participate Not applicable.

Consent for publication Not applicable.

7. REFERENCES

- Akinbile C., Akinlade G., Abolude T. (2015). Trend analysis in climatic variables and impacts on rice yield in Nigeria. *Journal of Water and Climate Change*, 6(3), 534–543.
- Arcenas A. (2018). Determining the Inflationary Effects of El Niño and La Niña in the Philippines, *Econ Store Paper*, 2018-02.
- Batten S., Sowerbutts R., Tanaka, M. (2020). Climate change, macroeconomic impact and implications for monetary policy. *Ecological, Societal and Technological Risks and the financial sector*, 1243, 11-48.
- Bhattacharya R., Gupta S. (2018), Drivers and impact of food inflation in India, *Macroeconomics and Finance in Emerging Market Economies*, 11 (2), 146-168.
- Dafermos Y., Nikolaidou M., Galanis G., (2018) Climate change and monetary policy. *Ecological Economics*, 152, 219-234.
- Davenport F., Funk C., Galu G. (2018). How will East African maize yields respond to climate change and can agricultural development mitigate this response? *Climatic Change*, 147(3–4), 491–506.
- Descheemaeker K., Oosting S, Homann-Kee Tui S., Masikati P., Falconnier G., Giller, K. (2016). Climate change adaptation and mitigation in smallholder crop–livestock systems in sub-Saharan Africa: a call for integrated impact assessments. *Regional Environmental Change*, 16(8), 2331–2343.
- Djukić M., Pjescić V., Vilaret S. (2009). Prices of agriculture products and monetary policy reaction. *Economics of Agriculture*, 56(3), 469-479.
- FAO, (2016), *The State of Food and Agriculture: Climate Change, Agriculture and Food Security*. FAO, Rome.
- Freduah B., MacCarthy D., Adam M., Ly M., Ruane A., Timpong-Jones E. Adiku S. (2019). Sensitivity of Maize Yield in Smallholder Systems to Climate Scenarios in Semi-Arid Regions of West Africa: Accounting for Variability in Farm Management Practices. *Agronomy*, 9(10), 639.
- García de Jalón S., Iglesias A., Neumann M. (2018). Responses of sub-Saharan smallholders to climate change: Strategies and drivers of adaptation. *Environmental Science & Policy*, 90, 38–45.
- Hagos B (2018). L'inflation alimentaire due au changement climatique en Éthiopie ?. *Asian Journal of Empirical Research*, 8(1), 13-22.
- Kar S., Das N. (2015), Climate change, agricultural production, and poverty in India. In Heshmati A., Maasoumi A., Gang X. (2015) *Poverty Reduction Policies and Practices in Developing Asia*, Springer, 55-76.
- Lloyd T., McCorriston S., Morgan W., (2015) *Food inflation in th EU: contrasting experience and recent insights*, Oxford University Press, London.
- Misra A. (2013). Climate change impact, mitigation and adaptation strategies for agricultural and water resources, in Ganga Plain (India), *Mitigation and Adaptation Strategies for Global Change*, 18(5) , 673-689.
- Murray-Tortarolo G., Jaramillo V., Larsen J. (2018). Food security and climate change: the case of rainfed maize production in Mexico. *Agricultural and Forest Meteorology*, 253–254, 124–131.

- Nelson G. C., Rosegrant M., Koo J., Robertson R., Sulser T., Zhu T., Magalhaes M. (2009). Climate change: Impact on agriculture and costs of adaptation, *Intl Food Policy Res Inst*, 21, 76-98.
- Pesaran M.H., Shin Y. et Smith R.J. (2001), Bounds Testing Approaches to the Analysis of Level Relationships, *Journal of Applied Econometrics*, 16 (3), pp. 289-326.
- Shin Y., Yu B., Greenwood-Nimmo M. (2014). Modelling Asymmetric Co-integration and Dynamic Multipliers in a Nonlinear ARDL Framework. In W. Horrace, R. Sickles (Eds.), *Festschrift in Honor of Peter Schmidt: Econometric Methods and Applications*, 281-314.
- Solaymani S. (2018). Impacts of climate change on food security and agriculture sector in Malaysia. *Environment, Development and Sustainability*, 20(4), 1575–1596.
- Stoica O., Damian M., (2009), Evaluation of the Common Agricultural Policy's Impact upon Inflation Rate in Central, Eastern and Southern Europe Countries. *International Journal of Economics and Financial Issues*, 3(1), 229-236.
- Tamako N., Thamaga-Chitja J. M. (2017). Does social capital play a role in climate change adaptation among smallholder farmers for improving food security and livelihoods? *Food and Nutrition Challenges in Southern Africa*, 6(2), 16–27.
- Trnka M., Feng S., Semenov M. A., Olesen J. E., Kersebaum K. C., Rötter R., Büntgen U. (2019). Mitigation efforts will not fully alleviate the increase in water scarcity occurrence probability in wheat-producing areas. *Science Advances*, 5(9), 145-167.
- Van Oort A.J., Zwart J., (2018). Impacts of climate change on rice production in Africa and causes of simulated yield changes. *Global Change Biology*, 24(3), 1029–1045.
- Williams A., Crespo O., Abu M., Simpson N. P. (2018). A systematic review of how vulnerability of smallholder agricultural systems to changing climate is assessed in Africa. *Environmental Research Letters*, 13(10), 35-55.
- World Bank (2021), <https://www.worldbank.org/en/topic/climatechange>.
- Xin X., Wang X. (2008). Was China's inflation in 2004 led by an agricultural price rise? *Canadian Journal of Agricultural Economics/Revue canadienne d'agroéconomie*, 56(3), 353-364.
- Zougmore R. B., Partey S. T., Ouédraogo M., Torquebiau E., Campbell B. M. (2018). Facing climate variability in sub-Saharan Africa: analysis of climate-smart agriculture opportunities to manage climate-related risks. *Cahiers Agricultures*, 27(3) 340-361.