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Research article

Ensuring food sovereignty and nutritional sustainability in Egypt

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A R T I C L E I N F O

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A B S T R A C T

Understanding Egypt's dependence on wheat imports is crucial for enhancing food security and economic stability. This study aims to identify the extent of Egypt's wheat import dependency and recommend measures for increasing food self-sufficiency. We employed index analysis and an econometric model to analyze data sourced from the Food and Agriculture Organization (FAO), Observatory of Economic Complexity (OEC), Chicago Mercantile Exchange (CME), World Bank (WB), and Organisation for Economic Co-operation and Development (OECD). Quantitative and qualitative indicators of wheat production and consumption were examined. Key findings include that Egypt's food insecurity levels remain unchanged, and the country faces threats from rising global food prices, low-quality agricultural land, and climate change, which is expected to reduce cereal yields by 6–15 %. Econometric analysis revealed that a 1 % increase in population growth and protein intake results in a 1.09 % and 3.63 % increase in wheat imports, respectively, while a 1 % increase in wheat consumption leads to a 0.87 % decrease in wheat imports. These findings suggest the need for Egypt to diversify its agriculture by adopting less water-intensive crops and improving irrigation efficiency. Future research should explore non-linear models, recent data, and qualitative factors to build on these insights and further inform policy development.

1. Introduction

Food security is a concept that encompasses the availability, access, utilization, and stability of food for individuals and communities. The Food and Agriculture Organization (FAO) defines food security as the state where all individuals have physical, social, and economic access to sufficient, safe, and nutritious food that meets their dietary needs and preferences for an active and healthy life [1]. According to Jiang et al. [2], ensuring food security is essential, as it impacts countries worldwide and is crucial for maintaining peace, stability, and cooperation among nations. Ensuring food availability is also important in the event of various shocks and crises such as natural disasters, conflicts, and pandemics. A functioning food security system can help local communities and nations withstand and recover from unexpected challenges [3].

However, the ongoing threat of climate change significantly impacts global food production, affecting various aspects of agriculture

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and food security. Studies have shown that climate change, particularly global warming, influences food security through its effects on food availability, accessibility, utilization, and affordability [4]. Zhao et al. [5] point out that changes in climatic factors have a direct impact on agriculture, leading to noticeable impacts on crop yields and production. The sensitivity of most crops to temperature fluctuations and erratic rainfall is expected to make sustainable food production more difficult [6,7]. The negative impacts of climate change may disrupt food supply chains, affecting food availability and accessibility. Climate change-induced droughts and floods can also directly affect crop yields, which can lead to food shortages and price volatility [8].

Despite extensive research on food security and agricultural challenges, there is a notable gap in understanding the specific factors driving Egypt's heavy reliance on wheat imports. While numerous studies have addressed general agricultural vulnerabilities and the impacts of climate change on food security globally, few have provided a detailed econometric analysis of the interplay between domestic demand variables—such as population growth, protein intake, and food supply—and wheat importation in Egypt. This study fills this gap by using an ARDL bound test to quantify these relationships, offering a nuanced understanding that can inform targeted policy interventions.

Expert perspectives on Egypt's food self-sufficiency in the future are diametrically opposed. There are realities that Egypt can influence financial and non-financial incentives for farmers to produce, production of alternative commodities, or upgrading of the technical base. However, some phenomena constrain Egypt's food security. These are threats (climatic conditions, world food prices, availability of quality land) that are beyond the control of Egypt [9]. The impacts of these threats affect food security, malnutrition, and the percentage of hunger among the poorest part of the population. Countries dependent on imports of strategic agricultural commodities are often forced to accept significant volatility in world prices. Egypt is no exception [10]. When prices increase, it increases the financial burden on the importing country or reduces the quantity of imported food grain. There are few macroeconomic models capable of predicting Egypt's ability to cope with external negative conditions. This paper seeks to study this issue.

In 2021, agriculture contributed approximately 11.83 % to Egypt's GDP, with 30.79 % coming from industry and 52.23 % from the service sector [11]. Egypt has one of the largest agricultural economies in Africa [12] and agriculture has a significant impact on the Egyptian government budget revenues and expenditures. Egypt's state budget revenues from agriculture come mainly from taxes, fees, and import duties. Egypt currently applies considerable protection to its agricultural production and many agricultural products are burdened with high import duties to encourage local production and manufacturing (UNICEF, n.d.). Expenditures on agriculture are mainly focused on (a) supporting research and development of irrigation systems [13], (b) subsidies for fertilizer purchases [14], and (c) support for agricultural exports and other support measures [15]. Egypt invests in infrastructure such as roads, bridges, cargo ports, and warehouses for agricultural products, which contributes to the development of agriculture and the overall economic growth of the country [16].

2. Literature review

In 2009, the Egyptian Ministry of Agriculture and Land Reclamation (MALR) developed the "Sustainable Agricultural Development Strategy 2030" (SADS). The SADS prioritizes the production of strategic crops that contribute greatly to current food imports (wheat, corn, and sugar). The SADS aims to increase self-sufficiency rates and improve food security by increasing agricultural productivity per unit of land and water. SADS plans to increase agricultural productivity per unit of land and water through the development of drought, salinity, and pest-resistant varieties, cultivation of early maturing crop varieties, increasing productivity, and adoption of good agricultural and management practices [17].

Egypt has one of the oldest food subsidy systems in the world. Unfortunately, agricultural policies change frequently, and wheat producers have seen a massive decrease in government support between 2000 and 2020 [18]. Smallholder farmers often have no incentive to increase their production. This is due to lack of subsidized inputs, low wheat prices, climate change, diseases, and rising input prices. The attractiveness of wheat production, especially for the younger generation, declined between 2000 and 2020 [19].

Wheat is of great importance in Egypt for various reasons. It is the most important cereal in the country and plays a vital role in the economy as a strategic crop [20]. Egypt consumes about 20 million tonnes of wheat annually, with less than half of this amount covered by domestic production, highlighting the country's heavy reliance on imports to meet its wheat requirements [21]. Given this heavy reliance on imports and a growing population, Egypt's national goal is to increase wheat productivity to bridge the gap between local consumption and production [22].

Moreover, the impact of changes in world wheat prices on Egypt is significant given its position as the world's largest wheat importer. This heavy reliance on imports makes Egypt particularly vulnerable to fluctuations in world wheat prices [23].Various factors such as climatic conditions, past oil prices, and imports have been shown to have a significant relationship with changes in world wheat prices [24]. For example, during events such as the COVID-19 pandemic and the Russian-Ukrainian conflict, Egypt faced a significant increase in wheat prices, approximately 20 %, due to economic challenges and world market dynamics [23]. The government recognizes these vulnerabilities and considers wheat a critical strategic commodity necessary for political stability [25].

In addition to these events, climate change poses another major threat to wheat production. Studies show that rising temperatures and changing rainfall patterns can lead to declining wheat yields, especially in regions such as Upper Egypt that are characterized by warm climates [26]. Degradation of soil resources caused by factors such as urbanization, population growth, and unsustainable agricultural practices pose a significant constraint to the development of the agricultural sector in Egypt [27], further exacerbating the problems caused by climate change. Poverty plays a significant role in shaping the wheat production landscape in Egypt. Poverty can limit access to the resources and technologies necessary to increase wheat productivity, perpetuating food insecurity and hindering efforts to achieve self-sufficiency in wheat production [28]. Sustainable wheat production practices are necessary to address these challenges. Increasing production can lead to reduced imports, saving foreign exchange, and enhancing national food security [29].

Egypt has been one of the world's largest wheat importers for decades, and reducing its dependence on wheat imports is a priority for the country. Russia and Ukraine are the main exporters of wheat to Egypt. The ongoing conflict is exacerbating an already precarious food security situation in Egypt and many other import-dependent countries in Africa and Asia. Wheat imports over the last five years amounted to 62.6 million metric tonnes, with 59.7 % coming from Russia and 22.3 % from Ukraine. Egypt relies on Russian and Ukrainian wheat due to competitive prices, lower transportation costs, and shorter time to reach Egyptian ports compared to other origins [30]. It is important to reduce the large gap between wheat production and consumption in Egypt. Wheat production in Egypt has improved due to the development of breeding and cultivation techniques (e.g., raised beds) [31]. On the other hand, the importation of food and agricultural raw materials addresses water scarcity in the region. Food production is by far the largest form of societal water consumption, while only a minor portion of water is consumed for drinking, domestic, or industrial purposes [32]. Trade in water-intensive commodities brings water savings to importing regions and alleviates pressure on their own water resources [33]. Agricultural water consumption is on a noticeable upward trend globally, accounting for 90 % of global water consumption [34]. Water consumption is increasing due to rapid economic development, population explosion, improving living standards, expansion of the agricultural sector, and climate change [35]. The consequences of climate change therefore pose a major risk to food security. Global warming could disrupt the production of both rainfed and irrigated agriculture through higher water requirements in Egypt specifically. Switching to drought-tolerant crops may be a way to cope with climate change [26]. The Aqueduct project also helps to understand and identify current and future water risks to agriculture and food security. The project maps and analyses water risks in different locations around the world by 2030 and 2040 [36].

The potential reduction in the flow of the Nile into Egypt will have an adverse impact on agricultural production, especially in the summer season. This will lead to a reduction in cultivated areas and a decrease in crop yields. Egypt's import dependence will continue, and grain imports may increase as the population grows and land reclamation options remain limited [17]. Asseng et al. [19] have a similar view, suggesting that wheat demand will triple by the end of the century. Wheat yields will decline mainly due to climate change, despite some yield improvement due to new technologies. According to Silva et al. [37], energy and protein intake from wheat is highest in North Africa, corresponding to 1140 kcal capita-1year-1 (or 36 % of total energy intake) and 35 g capita-1year-1 (or 39 % of total protein intake). Econometric models have been used to shape economic policies by Tamea et al. [38] or Ye et al. [39]. These teams addressed the relationships of climate, socio-economic, and capital indicators (climate change, GDP, population, food demand, technology upgrading or the strength of virtual water imports and exports, arable land, water footprint of agricultural production, and geographical distances between countries). Another research team [40] investigated food system sustainability using a system dynamics approach. The variables were wheat exports and imports, employment, soil quality, and organic and chemical fertilizer use. The dynamic model indicates that agricultural development in general and wheat cultivation in particular increase environmental, economic, and social sustainability.

The main objective of this paper is to examine the impact of domestic demand for food, protein, and wheat on the importation of wheat into Egypt. The subsequent objective is to identify the extent of Egypt's dependence on wheat imports and to recommend measures to increase food self-sufficiency based on an econometric model. The objectives are decomposed into specific, measurable sub-objectives:

1. To quantify the effect of population size on wheat imports using the ARDL bound test.
2. To determine the relationship between domestic wheat production and wheat imports.
3. To assess the impact of protein supply on the volume of wheat imports.
4. To analyze the influence of overall food supply on wheat import levels.
5. To evaluate the current level of Egypt's dependence on wheat imports by measuring the proportion of total wheat consumption met through imports.
6. To develop policy recommendations aimed at reducing Egypt's wheat import dependency by at least 10 % within five years, based on the econometric model findings.
7. To identify specific strategies that can increase domestic wheat production by 15 % over the next decade.
8. To propose actionable measures to enhance protein supply from alternative sources, aiming for a 5 % reduction in wheat import dependency.

3. Materials and methods

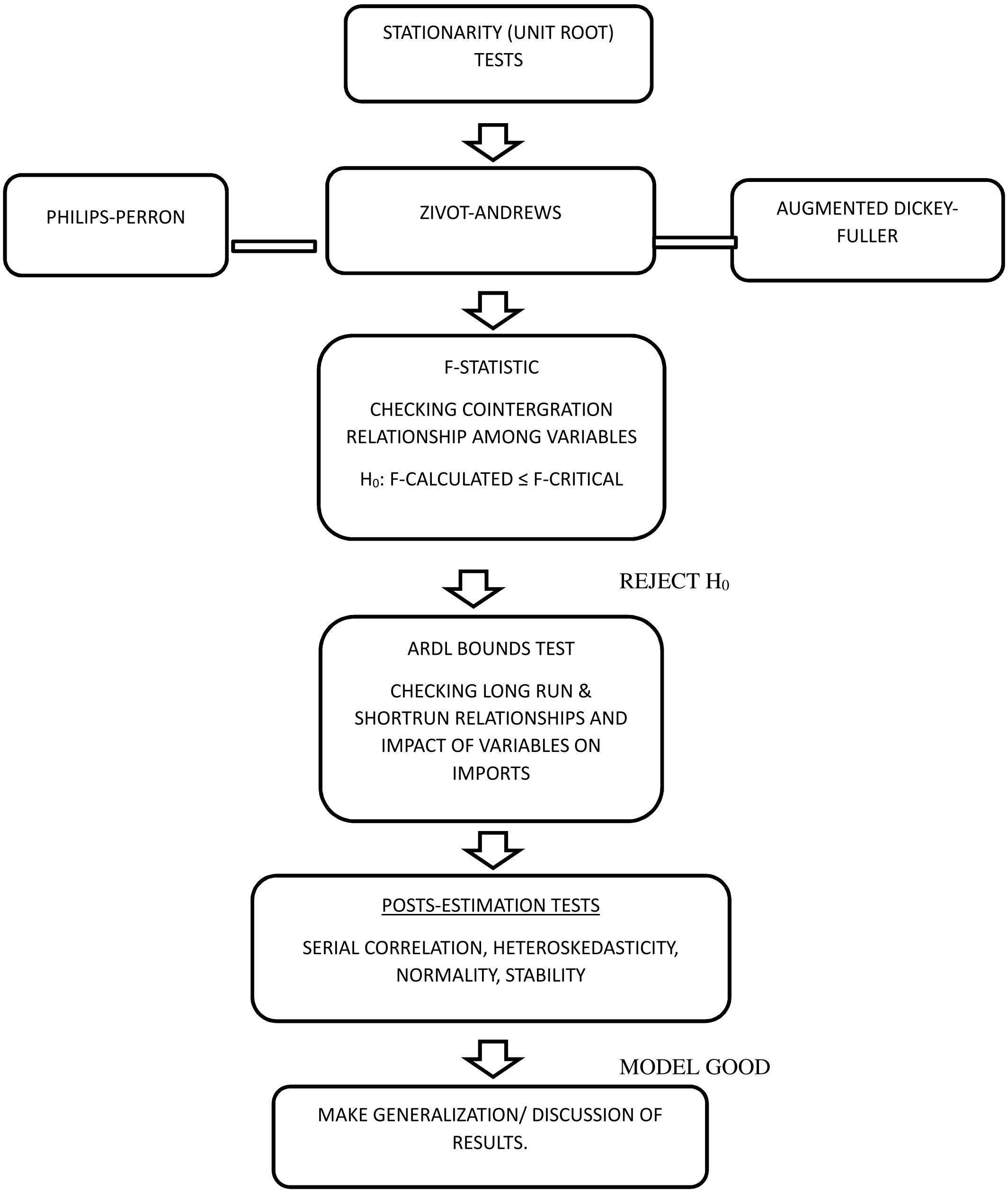
For the purposes of this research, we utilized data covering the time series from 1961 to 2023, with the starting year corresponding to the earliest available data from FAO and the latest year corresponding to the most recent year with comprehensive data across all variables of interest. The research employs a robust econometric model leveraging data sourced from the FAO, OEC, CME, WB, and OECD databases. The ARDL bound test methodology is particularly well-suited for this study as it allows for the examination of long-run relationships between variables with different integration orders, I(0) and I(1), which are common in time series data. Our sampling strategy ensures comprehensive coverage of relevant economic indicators, while the inclusion of structural break tests (Zivot-Andrews) enhances the reliability of our findings by accounting for potential shocks and policy changes. This methodological rigor enables us to draw precise and actionable conclusions regarding Egypt's wheat import dependency.

3.1. Data base

For the purposes of this research, we utilized data covering the time series from 1961 to 2023. The starting year of the FAO data presented is 1961. The latest year for the interval corresponds to the most recent year for which FAO provides data across all variables of interest simultaneously (at the time the data are provided for econometric processing).

The paper utilizes also descriptive statistics represented by world wheat price which is taken from the CME group's database (2021–2023). The daily wheat price is reported in units of cents per bushel. In addition, the world trade database of The Observatory of Economic Complexity (OEC, 2001–2021) is used. Quantitative indicators of agricultural production and information on the nutritional situation in Egypt are drawn from the FAO database (Faostat, 2001–2020). Other data are drawn from, for example, the World Bank database, the European Union, the US Department of Agriculture (USDA), the Development Bank of Egypt, Ecofin Agency [41]), and non-governmental sources (HRW, Human Rights Watch [42]).

Data for the model are drawn in the time series 1961–2019 from the FAOSTAT database for the state of EGYPT and are described in Appendix I.



Scheme 1. Summary of econometric procedure source: Own elaboration.

3.2. Methods and procedures

Two different approaches have been applied. The first approach, descriptive statistics, provides a better understanding of Egypt's nutrition and food situation. The second approach, econometric analysis, reveals the relationships between selected variables.

3.2.1. Descriptive statistics

Relative indicators: per capita wheat production and per capita consumption of wheat and wheat products.

Index analysis: on wheat production and consumption

$$Basic\ index = \frac{q_1}{q_0} \tag{1}$$

where q1 is the relevant individual value of the period measured against a base, e.g., the oldest value in the observation time series (q_0).

The measure of time series dynamics comparing the value of an indicator indicates the percentage change in value at time t_i compared to time t_{i-1}:

$$Growth\ rate = \frac{\Delta q_i}{q_{i-1}} * 100\% \tag{2}$$

3.2.2. Econometric procedure

The data used in the study was collected from the United Nations Food and Agriculture Organization (FAO) annual database with a specific focus on the period 1961 to 2019. Analysis and economic procedures were carried out with the EVIEWS 12 software. The variables of interest were wheat import quantities metric tonnes, total population, wheat production metric tonnes, food supply kg per capita, protein supply quantities in grams per day. Some variables wheat imports, population, and wheat produced quantities were transformed to logs (except for food and protein) making interpretations easier, scaling, and mitigating the effects of heteroscedasticity (Scheme 1).

3.2.2.1. Multivariate linear regression model. The model's general formula is as follows:

$$Import = f\ (Pop, Wheat, Food, Protein) \tag{3}$$

where: Import, Pop, Wheat, Food, and Protein are wheat import quantities metric tonnes, total population, wheat production metric tonnes, food supply of wheat in kg per capita and per year, protein supply quantities in grams per day respectively. Some variables (wheat imports, population, and wheat produced quantities) were transformed to logs (except for food and protein) making interpretations easier, scaling, and mitigating the effects of heteroscedasticity.

The model is represented in its stochastic form as:

$$Import = a_0 + a_1 Pop + a_2 Wheat + a_3 Food + a_4 Protein + U_t \tag{4}$$

where a_0 is Intercept; while a_1, a_2, a_3, and a_4 represent coefficients for the variables shown in the general formula and U_t is the unobserved Stochastic variable (term).

3.2.2.2. Unit root test. A unit root test, which determines if the variables in the sample data are stationary or not, is a crucial step before beginning any econometric operation. If any of the variables of interest are nonstationary, running a spurious regression is not avoided, which makes it difficult and unreliable to draw any conclusions when performing estimations [43–45]. The Augmented Dickey-Fuller (ADF) test and the Phillips-Peron (PP) test are the two most frequently utilized test techniques when attempting to determine whether stationarity exists in the variables of interest [46]. However, the Augmented Dickey-Fuller (ADF), which addresses any serial autocorrelation issues, is the favored method between the two [47]. The Zivot-Andrews (Z-A) test was superior to other tests at the PP and ADF tests because the latter are unable to account for any shock and structural breaks in the model by recording them as a unit-root, a premise that the Z-A test can account for. A test for the impact of structural breaks conducted on the variables of interest was required and also saved as a confirmatory test to the ADF and PP test using the Z-A test [48].

Concerning the ADF, it takes the general form as shown:

$$\Delta Y_t = + ++ \tag{5}$$

where: ΔY_t = related variable; β_1, β_2, δ, α = Parameters in the model; t = time trend; and E_t = Gaussians white noise with its mean = 0 and possible autocorrelation which is represented by time t.

3.2.2.3. ARDL bounds test. Bounds Test as previously mentioned, the ARDL Bounds test was first attributed to Pesaran et al. [45], who showed the flows of always estimating regression with levels (ordinary least squares), in a situation where some variables of interest (in a model) exhibit trending, and seemed to having level of integration either I(0), for example I(1) or a combination of all but I(2), ARDL Bounds test addresses these, a superiority to Engle and Granger [43] and Johansen and Juselius [49], which limit their combination to a specific level of integration as mentioned in section 4.2.2. All these attributes have made ARDL bounds test quite popular and used by scholars who had time series data with similar characteristics, in situation were models contained the long run dynamics, as well as the short error correction dynamics with respective error correction (cointegration) equations. The used of the ARDL with regards to data with characteristics mentioned by Pesaran et al. [45] has long been backed by several scholars including recent ones [50–57].

The Autoregressive Distributive Lag (ARDL) Bounds Test is used after performing the unit root test and determining the order of integration of the variables because it can run estimation for time series on variables with the order of integration such as I(0) and I(1) or even a mixture of both but strictly not of a higher order I(2 The ARDL Bounds Test can perform a regression with variables of order I (0), I(1), or a combination of both, making it preferable to Engle and Granger [43] and Johansen and Juselius [49] which limited the cointegration stages only to variables with the same order of integration. The Akaike Information Criterion (AIC), which can accommodate small sample sizes and reduce any chances of underestimating the lags in the sample as it improves chances of determining the correct lag length, was used to automatically calculate the optimal lag determination criteria adopted for each of the variables unlike the other methods such as the Sequential modified LR test statistic, Final prediction error, Schwarz information criterion, and Hannan-Quinn information criterion [58,59]. The ARDL model is represented as follows:

$$\Delta Import = \alpha + \sum_{i=1}^{p} \alpha \Delta Import_{t^{-}p} + \sum_{i=1}^{p} \alpha \Delta Pop_{t^{-}p} + \sum_{i=1}^{p} \alpha \Delta Wheat_{t^{-}p} + \sum_{i=1}^{p} \alpha \Delta Food_{t\text{-}p} + \sum_{i=1}^{p} \alpha \Delta Protein_{t\text{-}p} + \lambda Impor + \lambda Population_{t\text{-}p} + \lambda\ Wheat_{t\text{-}p} + \lambda \mathrm{Food}_{t\text{-}p} + \lambda\ \mathrm{Protein}_{t\text{-}p} + \mathrm{E} \tag{6}$$

where: Δ = the difference operator: p denotes optimal lag length α_0 is the constant term; α_{1i}, α_{2i}, α_{3i}, α_{4i}, α_{5i}, α_{6i} are coefficients of variables, Δ are error correction dynamics+ λ_1, λ_2, λ_3, λ_4, λ_5, λ_6 are long-term coefficients, E_t = White noise disturbance term.

Following the F-test, the cointegration test for the ARDL Bounds Test is conducted, and if the F-statistic is higher than the upper critical value or above the upper bound I(1) and lower bound I, the null hypothesis that cointegration is not present is rejected (0) cointegration produces inconclusive findings if the cointegration test requires that the F-statistic value is between the I(0) and I(1) bounds. And analysis fails to reject the null hypothesis if the F-statistic is smaller than the lower critical value or below the lower bound I(0) [45] [59].

3.2.2.4. Diagnostic tests. Heteroscedasticity, autocorrelation, model stability, and normality tests were among the post-estimation procedures examined in the study. According to Wooldridge [59], the preferred null hypothesis is the absence of autocorrelation, heteroskedasticity, with the acceptance having a lower F-statistic and a higher corresponding probability value, greater than 5 %. To test for model stability and stability without the impact of breaks, respectively, the CUSUM test and the CUSUM of squares tests were also carried out [59]. The results and discussion are included in the next section, which also includes the descriptive statistics for the relevant variables.

4. Results

The sub-sections focus on the nutrition of the population, important characteristics of foreign trade, Egypt's wheat production capacity, and the problems that lead to significant imports of agricultural commodities into Egypt.

4.1. Nutritional situation

Food crises must be anticipated in the future. Crises are accompanied by sharp increases in the prices of imported food commodities. According to Silva et al. [37] cereal consumption in Africa can be expected to shift in favour of local production over imported ones. However, this has not been observed in the case of major African wheat producing countries. In terms of qualitative indicators, it is appropriate to assess the situation in Egypt in terms of "Per capita consumption of wheat and wheat products". This has followed a steady trend in Egypt over the last twenty years (Fig. 1). Its value is 144.05 kg/capita/year and the average annual growth rate (formula 2) is 0.44 %. Wheat production per capita is slightly decreasing (−0.75 % p.a). It is problematic that there has been a

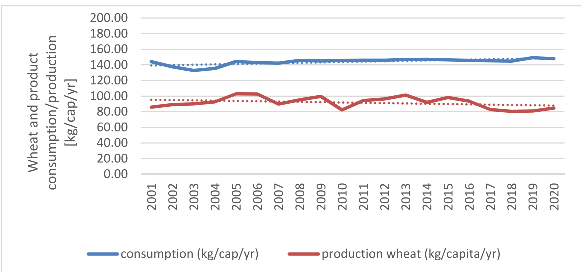


Fig. 1. Wheat production and consumption of wheat and products (kg/capita/year) in Egypt. **Source:** *FAO* [61]. **Note**: Base index of wheat consumption per capita = 1.02, base index of wheat production per capita = 91.74 (formula 1),

relatively low annual growth in wheat production over the period under review. This is mainly due to the occurrence of dry areas in Egypt [60].

The stabilized consumption of wheat and wheat products is also reflected in the stabilization of protein intake within the Egyptian population. In Egypt, the daily intake of plant-based protein is around 72 g/person/day (from wheat about 35 g). The total protein intake (animal and plant origin) is then approximately 97 g/person/day [61]. The recommended daily protein intake ranges from 0.8 to 1.5 g (g) per kilogram of ideal weight. The optimal ratio of plant to animal protein is 2:1.

Countries in North Africa (and East Asia) are largely dependent on imports of staple foods from Russia and Ukraine. Two years of coronavirus pandemics, persistent prolonged droughts, and extensive flooding have had an adverse impact on the rise in world food prices [60]. It can be assumed that the nutritional situation in Egypt may worsen for these reasons. The prevalence of severe food insecurity in the total population in Egypt ranges from 8.7 % (2016) to 7.1 % of the total population in 2020 [61]. Data on the prevalence of moderate food insecurity in the population are then available from the same period (2015–2020 data available). Here, the values range from 27.3 % (2020) to 33.2 % (2018). The undernourished are around 5 % in the Egyptian population.

4.2. Cereal production and imports

Egypt's response to global food trade problems is clear. Since 2017, there has been a gradual decline in imports, especially of wheat. In 2017, Egypt imported a record amount of wheat (12.9 million tonnes). In 2019, 81 % of 2017 wheat imports were imported and in 2021 only 45 % of 2017 imports were imported. However, 9 % more funds (USD) were spent on purchases in 2021 than in 2017. In the last 20 years, import expenditure on wheat is 50.42 % of the expenditure on vegetable imports and 66.07 % of the expenditure on cereal imports. Wheat imports alone account for an average of 5 % of all import expenditures ([62,63]).

Fig. 2 shows the three largest wheat importers (Egypt, Nigeria, Indonesia). The value of imports in 2021 was between USD 3 and 4.5 billion [62]. For each country, the map below shows the top three exporters.

Fig. 3 shows the calculated values of self-sufficiency in wheat production (%) and import values (USD) for 2020 [61]. The level of self-sufficiency depends on the level of wheat consumption and the size of wheat imports (kg/capita). Countries in Africa have low self-sufficiency (also with respect to low wheat consumption). In addition, Zimbabwe with a consumption of 19 kg/capita and Zambia (consumption of 10 kg/capita) are relatively self-sufficient in wheat production compared to other African countries. This highlights the varying levels of agricultural productivity and food security across the continent.

The extent of cereal imports and their total import value is influenced by the overall geopolitical situation, climatic conditions, and price changes in the world commodity market. The relationship between the quantity (tonnes) and the price of wheat (cent/bushel) is shown in Fig. 4.

The EU is also one of the world's leading exporters of wheat to developing countries such as Algeria, Morocco, Egypt, Pakistan, and Nigeria [68].

Fig. 4 shows the annual world wheat prices (up to early April 2023) based on daily "close price" tracking [64]. Prices after February 2022 have surpassed those of the 2007/2008 marketing period. Agricultural commodity prices rose at a record high in 2008. Low

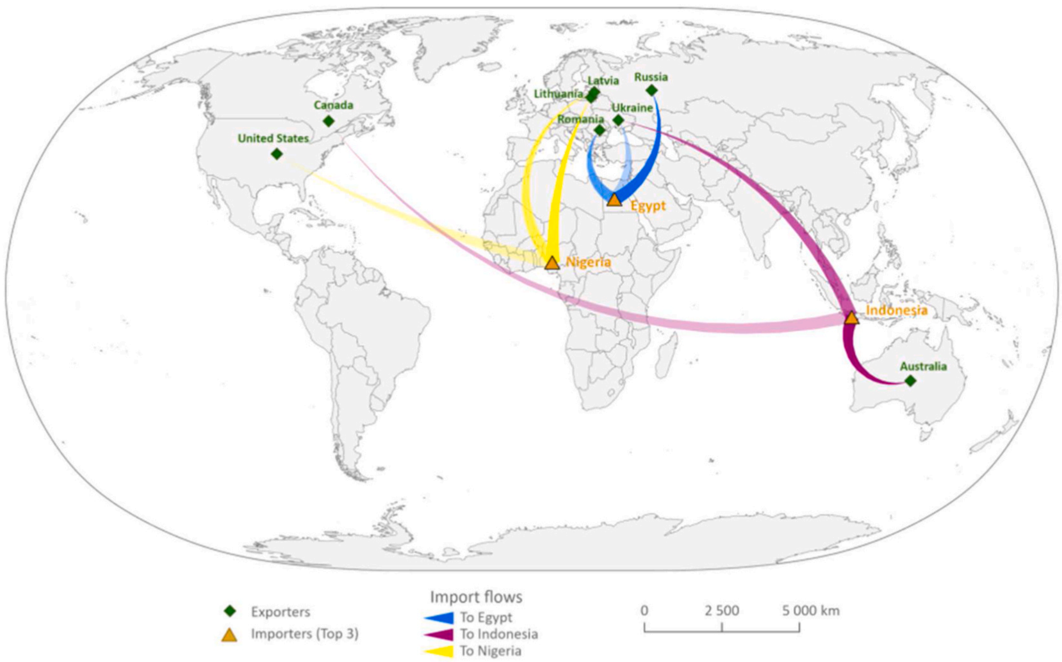


Fig. 2. Top three wheat importers in 2021 (USD). **Source:** Own processing according to OEC [61].

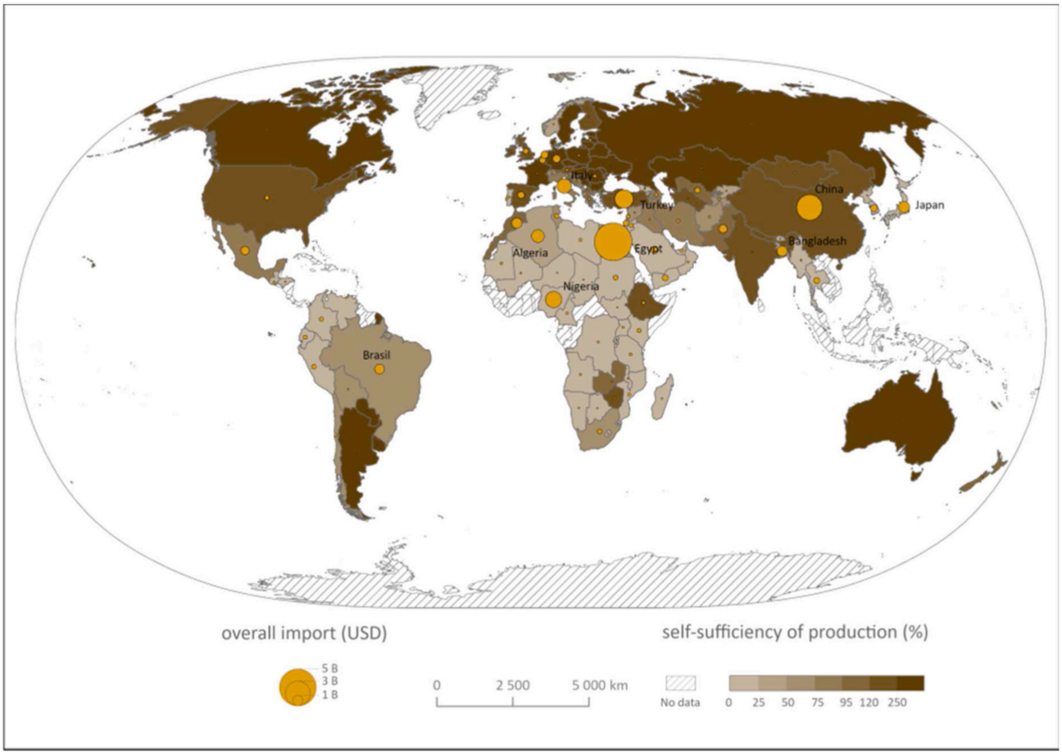


Fig. 3. Self-sufficiency in wheat production (%) and import value (USD) in 2020. **Source:** Own processing according to FAO [61]. **Note:** Available data is for 2020 [24], when China was the second largest importer. In 2021 (Fig. 2), China has reduced imports and its position has been replaced by Nigeria [61].

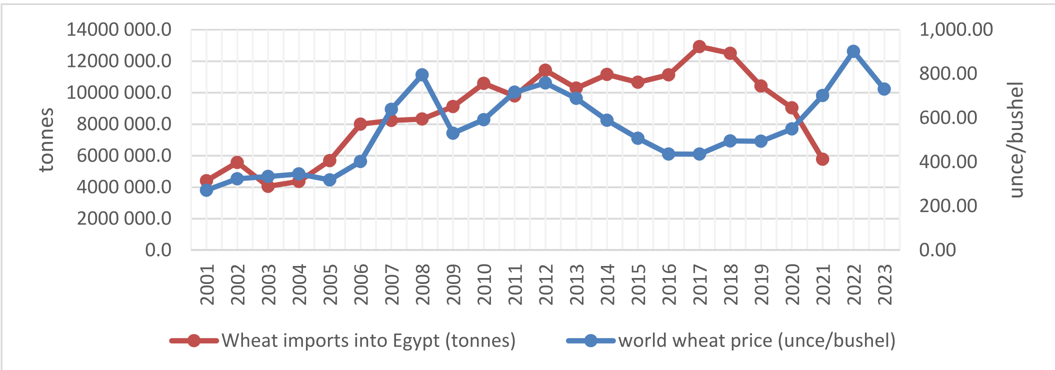


Fig. 4. Evolution of the world wheat price ands its impact on the quantity of wheat imported into Egypt. **Source:** own elaboration according to: FAO [63], CME [64] 1 bushel = 27,216 kg of wheat.

inventories and adverse weather (drought) around the world limited global wheat supplies in 2007 [65]. Sharply rising wheat prices are generally conducive to local food crises. Temporary price spikes are even linked to local uprisings in some countries (e.g., food riots in Egypt, Cameroon, Niger, Indonesia) [66]. Rising prices after 2021 have caused a significant drop in wheat imports into Egypt. The price rise triggered by the Ukrainian war in 2022 is even more pronounced. Ukrainian grain exports have been severely disrupted since the start of the Russian invasion of Ukraine in February 2022. Russian military vessels have blockaded Ukrainian ports in the Black Sea. Wheat (and corn) prices rose significantly and remained high until May 2022. On July 22, 2022, the UN and Turkey brokered an agreement to open a safe maritime humanitarian corridor in the Black Sea. In December 2022, the EU and the G7 agreed to cap the price of Russian oil (The Price of Urals). At the end of March 2023, wheat prices fell to the mid-2021 price. More than 65 % of wheat exported under the Black Sea Grain Initiative goes to developing countries. Along with the Russian invasion of Ukraine, the rise in wheat prices is also due to the increase in demand triggered by speculation of an impending food crisis [67].

Egypt's trade balance is increasingly burdened by food import expenditures. The value of expenditure on imports of all foodstuffs accounts for 47 % of import revenues. In the last 20 years alone, the indicator has deteriorated by 6 percentage points. According to our calculations based on FAOSTAT data the best ratio was reached in 2004–2006, when expenditure on crop imports was one of the lowest FAO [61].

4.3. Threads and opportunities for Egypt in terms of the possibility to increase food self-sufficiency

4.3.1. Soil characteristics and land use

Quantitatively, the expansion of cultivated land at the expense of forests and scrublands has significant economic implications. Increased agricultural activity can enhance food production and contribute to GDP growth. However, this shift also poses long-term risks to soil quality and sustainability. Qualitatively, the reduction in forest areas can exacerbate climate change effects, leading to higher temperatures and reduced rainfall, which in turn affects agricultural yields and water resources. These land use changes can also lead to increased soil erosion and loss of biodiversity, further impacting the agricultural productivity and ecological balance of the region. Therefore, sustainable land management practices are crucial to mitigate these adverse effects and ensure long-term economic and environmental stability.

According to the World Reference Base for Soils [18], soils in the Nile Valley include three main types: sandy silt, sandy clay, and sand. According to the ESA GlobCover project [69] bare land (31 %), scrub (29 %), cultivated land (23 %) forests (7 %) and pastures (6 %) are present in the basin. Forests and shrublands are dominant. Bare areas predominate in low-lying areas, especially in desert areas. Changes in land cover indicate a decrease in forest areas and an increase in cultivated land in almost all sub-basins [70]. According to FAO [61], Egypt's agricultural land accounts for only 3.9 % of its area and is 100 % irrigated. Of the agricultural land, arable land (about 85 %, i.e., 3.365 million ha) is the predominant cropland. The risk of cultivating agricultural land in Egypt in the future is illustrated in Fig. 5.

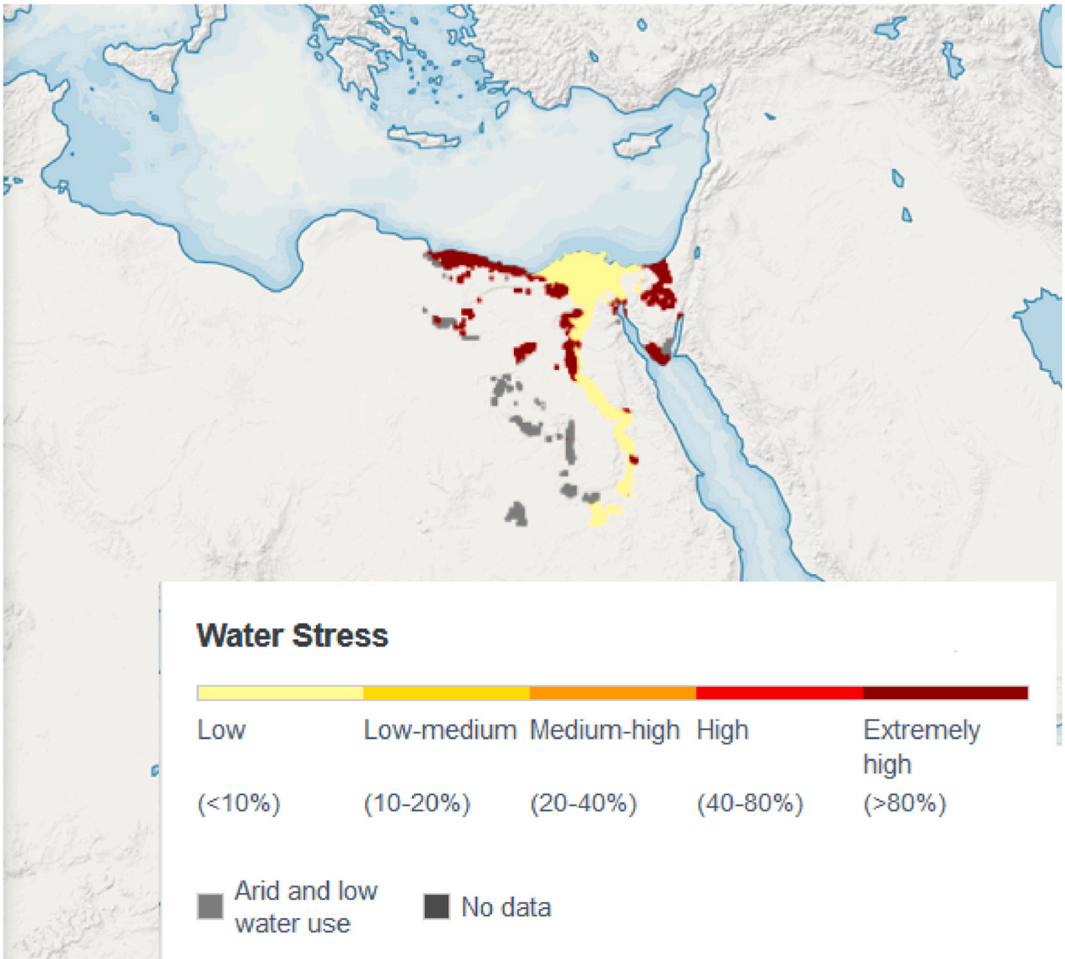


Fig. 5. Projected absolute risk of water scarity in 2040 in irrigated and rainfed areas in Egypt. **Source:** Own elaboration according to WRI [36]. **Note:** Water stress measures the ratio of total water withdrawals to available renewable surface and groundwater supplies. Water withdrawals include consumptive and non-consumptive uses for domestic, industrial, irrigation and livestock.

Quantitatively, the expansion of cultivated land at the expense of forests and scrublands has significant economic implications. Increased agricultural activity can enhance food production and contribute to GDP growth. However, this shift also poses long-term risks to soil quality and sustainability [71]. Qualitatively, the reduction in forest areas can exacerbate climate change effects, leading to higher temperatures and reduced rainfall, which in turn affects agricultural yields and water resources [72]. These land use changes can also lead to increased soil erosion and loss of biodiversity, further impacting the agricultural productivity and ecological balance of the region. Therefore, sustainable land management practices are crucial to mitigate these adverse effects and ensure long-term economic and environmental stability [73].

Natural and climatic conditions will clearly influence the outlook for the coming period. WRI projections [36] show that Egypt's agricultural area could decrease by 2.63 % by 2023 and 3.76 % by 2040 relative to today. The demand for food in the same period may increase by 33.62 % and 46.32 %, respectively. The production of agricultural commodities may increase by about 11 % and per hectare yields may increase by 15 % by the end of the forecast period.

However, the forecast yield parameters may be highly variable for individual commodities. According to the International Fund for Agricultural Development (IFAD), future wheat yields per hectare are highly problematic in their downward trend. By 2041, yields may fall by 14 % relative to 2020. The thermophilic crop sorghum is drought tolerant and has low nutrient requirements. The period 2029–2033 looks promising, when sorghum yields may increase by 7.5 % compared to 2020. Thereafter, a significant decline to −16 % basis points is expected in 2041. A positive development of per hectare yields is expected for sunflower. In the future, a 5 % increase in yields in kind can be achieved compared to 2020 ([74]; Fig. 6). The yield forecast until 2041 under full irrigation [74] projects a reduction of more than 6 % in hectare yields for maize, 5.5 % for wheat, about 4 % for sorghum and about 2.5 % for the others by 2041.

4.4. Model of Egypt's wheat production, consumption and import situation

The authors' contribution to the problem at hand is implemented on the basis of an econometric model that addresses Egypt's situation in wheat production, consumption and imports.

Descriptive statistics of the variables used in the empirical model, tests of the variables, and results are presented in Tables 1–3. Table 2 below shows the results for stationarity using the ADF, PP and Z-A tests.

The existence of unit-roots in the variables was checked before further econometric analysis in order to avoid spurious results. The Augmented Dickey Fuller (ADF) test which accounts for autocorrelation and Phillips-Perron (PP) test were used to test for stationarity with the Zivot-Andrew (Z-A) test being a confirmatory test. The ADF and PP tests do not account for structural breaks and shocks in time series data where they are frequently mistaken for unit roots, the Z-A test was therefore used as it takes into accounts for structural breaks and shocks and tests for the unit-root. The ADF, PP and Z-A tests are conducted on the null hypothesis that the data has a unit root and hence if the computed statistic value is greater than the critical value, the null hypothesis is rejected. The test results in Table 3 indicate that the null hypothesis was not rejected for all variables using the ADF and PP tests at level since the statistical values were less than the critical values at 5 % level of significance. At first difference, imports, population, wheat, food, and protein were found to be stationary as indicated by the computed absolute t-statistics calculated values of 10.27, 4.31, 9.77, 5.85, 6.06 respectively which were greater than their corresponding critical values at 5 % level of significance using the ADF test. Other than population, the PP test also indicated the other variables were stationary at first difference with computed absolute t-statistics calculated values of 10.86,

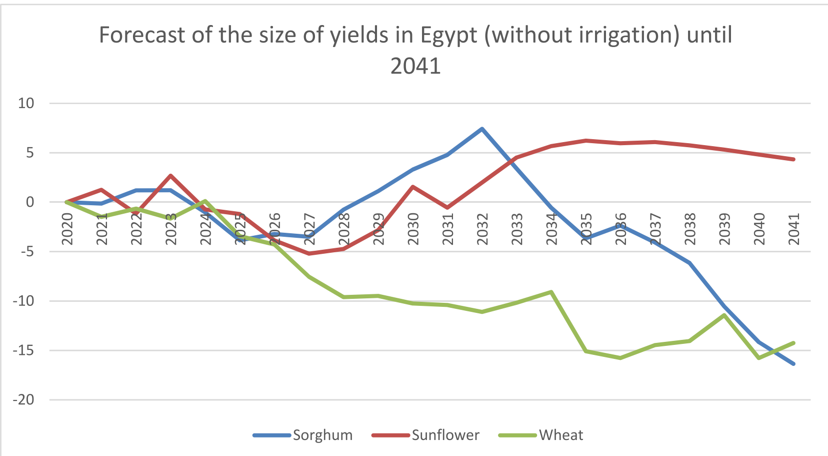


Fig. 6. Forecast of crop commodity yields in kind from 2020 to 2041 in Egypt. Source: Own elaboration according to **IFAD** [74]. **Note:** All CARD (Climate Adaptation Assessment Tool for Rural Development) data are based on the outputs of the Inter-Sectoral Impact Model Intercomparison Project (ISIMIP). Results of simulations of the baseline global crop grid models are currently included up to 2050. All underlying simulations use the RCP8.5 greenhouse gas emissions scenario, which leads to a global warming of approximately 4 °C by 2100. The authors chose the following scenario in the graph: Criterion 1: no irrigation. Criterion 2: risk level: median (This setting reflects a "best guess" of the uncertainties reflected in the models. The models are aggregated using the median.), 3. criterion: relative to base year (impact calculation, all crop yield impacts are calculated relative to the first year).

Table 1
Descriptive statistics of the variables used in this analysis. **Source:** Authors' calculations based on FAO data (1961–2019).

	IMPORT	POP	WHEAT	FOOD	PROTEIN
Mean	5250421.	58067295	4510872.	128.4766	31.18712
Median	4520000.	56134475	4268049.	143.1900	34.74000
Maximum	12930093	1.00E+08	9607736.	153.6500	37.28000
Minimum	661100.0	27366237	1272000.	82.73000	20.17000
Std. Dev.	3335523.	21416881	2912441.	24.71336	5.963254
Observations	59	59	59	59	59

Table 2
Unit root results. **Source:** Authors' calculations based on FAO data (1961–2019).

Variable	Test	Level		1st difference	
		Statistic	5 % critical	Statistic	5 % critical
Import	ADF	−2.524727	−4.127338	−10.27244*	−3.490662
	PP	−3.200281	−3.489228	−10.86045*	−3.490662
	Z-A	−5.326102* (1973)	−4.859812		
Pop	ADF	−0.440450	−3.495295	−4.305411*	−3.508508
	PP	−1.228112	−3.489228	−2.058706	−3.490662
	Z-A	−2.451255 (1777)	−4.859812	−5.173855* (2006)	−4.859812
Wheat	ADF	−2.118692	−3.489228	−9.775548*	−3.490662
	PP	−2.135723	−3.489228	−9.526923*	−3.490662
	Z-A	−5.072118 (1989)	−4.859812		
Food	ADF	−0.836186	−3.489228	−5.851042*	−3.490662
	PP	−1.143949	−3.489228	−5.811506*	−3.490662
	Z-A	−4.788041 (1977)	−4.859812	−6.43523* (1989)	−4.859812
Protein	ADF	−0.866038	−3.489228	−6.059918*	−3.490662
	PP	−1.085231	−3.489228	−6.054240*	−3.490662
	Z-A	−4.800754* (1977)	−4.859812	−6.718894* (1989)	−4.859212

Note: ADF is tested with constant and trend. * Indicates significance at 5 % level of significance respectively. The Year of structural break is indicated in brackets for the Z-A test.

9.52, 5.81 and 6.05 being greater than their respective critical values. Using the Z-A test, population, food and protein were stationary at first difference using with computed values of 5.17, 6.43 and 6.71 respectively being greater than their corresponding critical values. Import and wheat were stationary at level. The unit root results showed a combination of I(0) and I(1) orders of integration suggesting that there is a cointegration relationship and thus the model can be viably employed using the ARDL framework. Table 3 that follows displays the results of ARDL error correction regression.

The results in Table 3 indicates that the error correction term is negative (−0.65) and significant with a probability of less than 5 %. This indicates that 65 % of the previous year's disequilibrium in population, harvested wheat, consumption and protein supply is corrected every year and confirms the existence of a long-run relationship among the variables, with all variables adjusting to long run equilibrium in 1 and half years. This is confirmed by the F- statistic test which indicates that there is a cointegration relationship among the variables since the F-statistic of 7.67 was greater than the upper bound at I(0) at 10, 5, 2.5, and 1 significant levels having critical values of 2.45, 2.86, 3.25, and 3.74 respectively. and 3.52 respectively. F-statistic of 7.67 was also greater than the upper bound at I(1) at 10, 5, 2.5, and 1 significant levels having critical values of 3.52, 4.01, 4.49, and 5.06 respectively. Therefore, null hypothesis of no cointegration is therefore rejected. The model is also statistically significant based on the probability of the F-static being less than 5 %, for all F-calculated values. In the short-run, population and protein have a positive and significant effect on wheat imports while food has a positive and insignificant effect. Wheat harvest has a negative and insignificant effect on wheat imports. A 1 % increase in population will lead to an increase in imports by 49.47 % while a 1 % increase in wheat harvest will cause a decrease in imports by 0.26 %. A 1 kg increase in food per inhabitant will lead to a decrease in imports by 49 %, 12 % in the next year and an increase by 1 % in two years. A 1-g increase in protein per capital per day will lead to an increase in import by 4.75 % and a subsequent decrease in import by 67 % in the next year.

An important result of the model is the message resulting from Table 4.: In the long run (Table 4), it is clear that population growth and daily protein intake (from wheat) have a positive and significant effect on wheat imports into Egypt. On the other hand, wheat consumption (in kg/year) has a negative but significant effect on wheat imports. In other words, a 1 % increase in population growth will result in a 1.09 % increase in wheat imports and protein intake will result in a 3.626 % increase in wheat imports. In terms of food consumption, a 1 % increase will result in a 0.87 % decrease in wheat imports. This means that there is a negative relationship between the demand for wheat and its other substitutes. This is a very important finding. Egypt will not be able to continuously increase wheat imports and will therefore be forced to look for substitute commodities.

The population, harvested wheat, consumption, and protein supply variables show a significant long-term equilibrium, according to the results of the ARDL Bounds test for the Egypt research. With the error correction term being negative and significant, it is implied that yearly adjustments are made to 65 % of the disequilibrium from the preceding year, indicating a strong tendency towards

Table 3
ARDL cointegration equation. **Source:** Authors' calculations based on FAO data (1961–2019).

ARDL Error Correction Regression				
Dependent Variable: D(LIMPORT) Selected Model: ARDL(1, 1, 1, 3, 2) Case 3: Unrestricted Constant and No Trend Sample: 1961 2019 Included observations: 56 ECM Regression Case 3: Unrestricted Constant and No Trend				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	−9.285400	1.452666	−6.391971	0.0000
D(LPOP)	49.46939	11.38417	4.345456	0.0001
D(LWHEAT)	−0.263422	0.202321	−1.301998	0.1998
D(FOOD)	−0.400896	0.099170	−4.042530	0.0002
D(FOOD(-1))	−0.110761	0.045804	−2.418143	0.0199
D(FOOD(-2))	0.010876	0.006205	1.752699	0.0868
D(PROTEIN)	1.749478	0.410716	4.259583	0.0001
D(PROTEIN(-1))	0.508294	0.186458	2.726051	0.0092
CointEq(-1)[a]	−0.647550	0.100013	−6.474664	0.0000
R-squared	0.567256	Mean dependent var		0.042371
Adjusted R-squared	0.493597	S.D. dependent var		0.224900
S.E. of regression	0.160043	Akaike info criterion		−0.680520
Sum squared resid	1.203852	Schwarz criterion		−0.355017
Log likelihood	28.05455	Hannan-Quinn criter.		−0.554323
F-statistic	7.701149	Durbin-Watson stat		2.250605
Prob(F-statistic)	0.000002			
F-Bounds Test		Null Hypothesis: No levels relationship		
Test Statistic	Value	Signif.	I(0)	I(1)
F-statistic	7.670701	10 %	2.45	3.52
k	4	5 %	2.86	4.01
		2.5 %	3.25	4.49
		1 %	3.74	5.06
t-Bounds Test		Null Hypothesis: No levels relationship		
Test Statistic	Value	Signif.	I(0)	I(1)
t-statistic	−6.474664	10 %	−2.57	−3.66
		5 %	−2.86	−3.99
		2.5 %	−3.13	−4.26
		1 %	−3.43	−4.6

[a] p-value incompatible with t-Bounds distribution.

Table 4
Long run impact of variables on imports. Source: Authors' calculations based on FAO data [61].

Levels Equation				
Case 3: Unrestricted Constant and No Trend				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
LPOP	1.085346	0.639663	1.696745	0.0970
LWHEAT	0.527084	0.370836	1.421340	0.1624
FOOD	−0.874972	0.366813	−2.385336	0.0215
PROTEIN	3.626035	1.510973	2.399801	0.0208

equilibrium restoration in about 1.5 years. Cointegration between these variables is further supported by the significant F-statistic, which is important for developing policy. Egypt is heavily dependent on wheat imports to meet domestic demand, so the positive short-term effects of population growth and the availability of protein on wheat imports indicate that the country will become more dependent on wheat imports as its population grows and its dietary preferences change to include more protein. On the other hand, a little decrease in import dependency results with increased domestic wheat output, emphasizing the necessity of increasing local wheat production. Enhancing agricultural productivity and promoting sustainable farming techniques should be the primary priority of policymakers in order to preserve food sovereignty and nutritional sustainability while lowering vulnerability to changes in the global market. In order to ensure long-term food security in Egypt, the results highlight the significance of integrated plans that take into account dietary requirements, population increase, and agricultural development.

5. Discussion

The employed econometric model suggests that Egypt may be able to reduce its dependence on food imports in the future, which answers the main objective of the paper. The outcome of the modelled situation answers the main objective of the paper. The discussion presented here offers an argument to the result of the econometric model and fulfills the sub-objectives of the paper.

While this study focuses on Egypt, the findings have broader implications for other regions facing similar challenges with food security and import dependency. For instance, countries in Sub-Saharan Africa and South Asia, which also rely heavily on wheat imports and face climate-induced agricultural vulnerabilities [19,75], can benefit from the insights provided by this research. By applying the econometric model used in this study, policymakers in these regions can develop targeted strategies to enhance food self-sufficiency, optimize land use, and mitigate the impacts of climate change on agriculture. This research contributes to the global discourse on food security by offering a replicable model that can be adapted to different regional contexts, thereby broadening the relevance and impact of the study.

While poor global economic conditions are forcing many governments to cut spending, Egypt has been strategically increasing its budget for basic food price support in recent years. The subsidies will be mainly directed to basic commodities, fuel, export promotion, agricultural production support and development of the Upper Egypt region [30]**.** In recent years, a significant part of the budget has always been allocated to subsidies for staple foods (bread subsidies) [76]. Abdalla et al. [10] suggest continuing and increasing assistance (technical and financial) to millions of smallholder farmers. However, according to Siam [77]**,** a wheat policy aimed at self-sufficiency will allocate significant agricultural resources and thus may have high social costs. The literature offers a range of pathways and alternatives to respond to the food security problem. For example, according to Alwang et al. [29] mechanized wheat production on raised beds is an effective means of increasing productivity (25 % increase in productivity through higher yields, 50 % reduction in seed costs and water savings (25 %) as well as lower labor costs. This modern method of crop production is also advocated by Yigezu et al. [28]**.** El Shaer and Dakhee [78] suggest that instead of growing only wheat, farmers in Egypt could include other crops such as beans, peas, pulses, rape, soybean, or lentils in their crop mix. This would reduce the risk of depending on a single crop. It would also increase food production and improve soil quality. Preference should be given to high-yielding crops [79]. Wheat flour is unique in that it forms a viscoelastic dough that retains gas and solidifies during baking and therefore cannot be fully substituted, for example in bread making [80]. However, flour blends containing flour from other crops, often indigenous (cassava or legumes), have been developed for the production of several wheat-based products. Although this substitution usually changes the texture and taste of these products, it could significantly reduce wheat imports into the region. Another potential benefit is to improve the nutritional value of these products [81,82]. Soliman et al. [83], investigated the effect of replacing parts of wheat flour with quinoa, cassava, and guar flour with very positive results in sensory and quality tests. These studies were followed up by Omar et al. [84]**.** The proposed interventions address the change in crop rotation with rice and orchard seed fixation and promote the production of lentils, maize, onions, vegetables, milk, and meat.

The way to increase production is to use modern technologies that can help increase yield levels and reduce the cost of wheat cultivation in Egypt (precision agriculture, automation, or drones) [85]**.** Wheat productivity in Africa can be increased by reducing yield gaps (potential and actual) [12]**.** The potential to increase wheat yields depends on the size of the existing yield gap and the available interventions that can reduce it. In Egypt, the yield gap for irrigated wheat is approximately 30 % of the potential yield, which corresponds to a yield gap of approximately 1 t ha-1 [37]. Increasing input use combined with good agronomic practices and improved varieties is key to reducing the wheat yield gap in smallholder farming systems in East Africa [12]**.** Increasing input use combined with good agronomic practices and improved varieties is key to reducing the wheat yield gap in smallholder farming systems in East Africa [86]. According to Sayed et al. [87] agricultural production can achieve sustainability through the appropriate use of agricultural mechanization, where smallholder farmers should make more use of hired agricultural mechanization. Mahmoud et al. [88] suggest the cultivation of new wheat varieties with greater resistance to diseases and pests. Ali et al. [89] advocate better irrigation systems (e.g., drip irrigation systems). Kassim Y. et al. [90] support measures by which Egypt addresses self-sufficiency in developing new agricultural land on reclaimed “new lands”. Asseng et al. [19] addressed the food self-sufficiency situation through models for different climate change scenarios and for different crops with new technological trends. The ongoing program to double the irrigated area by 2035 in parallel with crop intensification could increase Egypt’s wheat production and self-sufficiency in the near future. After 2040, the program would no longer be sufficient even with moderate population growth. Forecasting studies suggest that per capita wheat consumption in the Middle East and North Africa countries should not increase further by 2050. The growth in wheat demand in these regions is expected to be driven solely by population growth [91]. According to Kheir et al. [92], it is the rapidly growing population (107.6 million people in April 2023) that will lead to increased wheat shortages in Egypt.

Economic support for Egypt is given significant attention in the discussion. Under the influence of disruptions in global supply chains, skyrocketing food prices, adverse demographic developments, and a long-standing unresolved combination of external and internal economic imbalances, Egypt has been placed in a critical situation [93]. Egypt receives economic assistance from both the African Union and, in particular, the European Union (EU). According to the European External Action Service (EEAS) [94] the EU has allocated support to Egypt in the form of grants and loans for economic development, job creation, and social inclusion. The EU provides economic assistance to Egypt through the New Partnership for Africa’s Development (NEPAD) programme, which aims to promote economic growth and development in African countries [95]. The European Neighbourhood Instrument (ENI) has been the EU’s key instrument for financing bilateral cooperation with the southern partner countries already in the period 2014–2020. It will continue with a new programme in 2021–2027). The World Bank has approved a new framework for partnership with Egypt for the financial years 2023–2027 [96]**.** Significant support to Egypt is from Official Development Assistance (ODA). ODA remains the main source of funding for development assistance [97]. In 2021, aid amounting to $8.2 billion was provided. This amounted to 2.1 % of

Egypt's GDP [98].

U.S. economic aid to Egypt has declined significantly over the past two decades as Egypt's basic economic indicators have steadily improved. The concept of "trade, not aid" has come to be emphasized in bilateral relations. By 2020, U.S. economic assistance to Egypt had gradually declined to $125 million, down from more than $800 million in 1998 [99].

Egypt is currently involved in an Extended Fund Facility program, which allows it to obtain a loan of US$3 billion for 46 months from the IMF. This program ends in 2025/2026. The loan agreement is intended to help the government meet its budget and balance of payments in the face of a rapidly deteriorating economic situation [42].

In relation to the outputs of this paper, the following simulations and models are available, for example: Tanaka [9] conducted stochastic and deterministic simulations to show the effects of a self-sufficiency policy for Egypt on food security using a multiregional stochastic computable general equilibrium (CGE) model. He addressed the extent to which an import tariff can achieve 100 % wheat self-sufficiency. It investigated the extent to which the self-sufficiency policy contributes to the stability of household welfare and consumer wheat prices as a function of wheat yield variability in Egypt. The simulations showed that Egypt can become self-sufficient in wheat with a 24 % increase in import tariff and household welfare reaches the optimal tariff at 10 %. The expected welfare volatility can be increased by changes in domestic productivity after the policy is implemented, which will increase dependence on domestic sources of supply while making the economy more resilient to external yield shocks. Tamea et al. [38] looked at the advantages and disadvantages of food imports and exports in terms of water resource use (based on virtual water). The authors identified important drivers of virtual water imports and exports for countries around the world and focused on changes in population, gross domestic product, arable land, WF (water footprint) of agricultural production and food demand, and geographical distance between countries. According to D'Odorico et al. [100] virtual water trading and transportation appears to be an excellent remedy for short-term local water scarcity. Indeed, it can prevent serious stress, famine, and even water wars. Li et al. [39] addressed the statistical significance of the influential factors, i.e., climate change, gross domestic product (GDP), population, food demand, and technology upgrading. The situation is solved by using a multivariate linear regression model (LRM) and a nonlinear regression model (NLRM). The results show that GDP and population were the dominant positive influential factors, while technology upgrading and food demand were the dominant negative influential factors affecting the changes in WFprod (water footprint of production) and WFcon (water footprint of consumption) in the net water import region. Silva et al. [37] outline a strategy to help reduce wheat import dependence in many African countries that should reconsider the value of wheat self-sufficiency as a strategic investment for national economies. (Promoting research and development, heat-tolerant varieties; improved seed quality and agronomy, adoption, agro-diverse production systems, growing alternative crops etc.).

6. Conclusion

This study highlights Egypt's significant dependence on wheat imports and the challenges associated with achieving food self-sufficiency. Our econometric model reveals that population growth and protein intake substantially increase wheat import demand, while increased food consumption could reduce it. The findings underscore the necessity for Egypt to diversify its agriculture by adopting less water-intensive crops and improving irrigation efficiency. Policy interventions such as subsidies and support for modern farming techniques are essential. Addressing these issues is critical not only for Egypt's food security but also for its economic stability in the face of global supply chain disruptions and climate change.

In summary, strategic agricultural development, effective land use management, and international cooperation are pivotal for mitigating Egypt's reliance on wheat imports and ensuring long-term food security.

7. Limits of study

While this study provides valuable insights into the factors affecting wheat import dependency in Egypt, several limitations should be acknowledged. First, the data used spans a long historical period, which may introduce inconsistencies due to changes in data collection methods and economic conditions over time. Second, the study focuses primarily on quantitative factors and does not fully account for qualitative aspects such as policy changes, farmer behavior, and technological advancements. Third, the econometric model assumes linear relationships between variables, which may oversimplify complex interactions. Finally, while the findings are specific to Egypt, the model may require adjustments for application to other regions with different socio-economic and environmental contexts.

Recognizing these limitations demonstrates a thorough and honest appraisal of the research, and future studies should aim to address these gaps by incorporating more recent data, exploring qualitative factors, and testing non-linear models. Despite these limitations, the study contributes to a deeper understanding of food security challenges and provides a foundation for future research and policy development.

CRediT authorship contribution statement

Zdeňka Gebeltová: Writing – review & editing, Writing – original draft, Methodology, Data curation, Conceptualization. **Joseph Phiri:** Writing – review & editing, Writing – original draft, Methodology, Data curation. **Klára Bartoňová:** Writing – review & editing, Writing – original draft, Resources, Formal analysis. **Michal Steininger:** Writing – original draft, Supervision, Conceptualization. **Karel Malec:** Writing – review & editing, Funding acquisition. **Vojtěch Blažek:** Visualization. **Jiří Mach:** Writing – review & editing, Investigation, Conceptualization. **Mansoor Maitah:** Supervision. **Jiří Marušiak:** Writing – original draft, Formal analysis,

Conceptualization. **Robert Koželský:** Conceptualization. **Emil Flegel:** Conceptualization.

Data availability statement

The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix 1. Definitions and measurability of variables for econometric model (period 1961–2019)

Database	Domain:	Variable (label)	Unit	Available:
FAO (Food and Agriculture Organization)	POPULATION AND EMPLOYMENT	Total Population - Both sexes (POP)	persons	https://www.fao.org/faostat/en/#data/OEA
FAO (Food and Agriculture Organization)	PRODUCTION (subdomain: Crops and livestock produkcts)	wheat production (WHEAT)	tones	https://www.fao.org/faostat/en/#data/QCL
FAO (Food and Agriculture Organization)	FOOT BALANCES (subdomain: Wheat and products)	Wheat consumption (FOOD)	kg/capita/yr	https://www.fao.org/faostat/en/#data
FAO (Food and Agriculture Organization)	FOOT BALANCES a (subdomain: Wheat and products) byla použita data pro proměnnou -	Protein supply quantity (PROTEIN)	g/capita/day	https://www.fao.org/faostat/en/#data
FAO (Food and Agriculture Organization)	TRADE (subdomain: Crops and livestock produkcts)	Import Quantity quantity (IMPORT)	tonnes	https://www.fao.org/faostat/en/#data/TCL
OEC (The Observatory of Economic Complexity)	Wheat imports		kg/capita/yr	https://oec.world/en/profile/country/egy

Appendix 2

Database	Domain:	Variable (label)	Unit	period	Available:	Note
FAO (Food and Agriculture Organization)	POPULATION AND EMPLOYMENT	Total Population - Both sexes (POP)	persons	1961–2019	https://www.fao.org/faostat/en/#data/OEA	Tables 1–4;
FAO (Food and Agriculture Organization)	PRODUCTION (subdomain: Crops and livestock produkcts)	wheat production (WHEAT)	tones kg/capita/yr	1961–2019 2001–2020 2001–2023	https://www.fao.org/faostat/en/#data/QCL	Tables 1–4; Fig. 4 Fig. 1 Fig. 3
FAO (Food and Agriculture Organization)	FOOT BALANCES (subdomain: Wheat and products)	Wheat consumption (FOOD)	kg/capita/yr	1961–2019	https://www.fao.org/faostat/en/#data	Tables 1–4; Fig. 1; 2
FAO (Food and Agriculture Organization)	FOOT BALANCES a (subdomain: Wheat and products) byla použita data pro proměnnou -	Protein supply quantity (PROTEIN)	g/capita/day	1961–2019	https://www.fao.org/faostat/en/#data	Tables 1-4
FAO (Food and Agriculture Organization)	TRADE (subdomain: Crops and livestock produkcts)	Import Quantity quantity (IMPORT)	tonnes	1961–2019	https://www.fao.org/faostat/en/#data/TCL	Tables 1-4
OEC (The Observatory of Economic Complexity)	Wheat imports		kg/capita/yr	2001–2020	https://oec.world/en/profile/country/egy	Fig. 2; 3

(continued on next page)

(*continued*)

Database	Domain:	Variable (label)	Unit	period	Available:	Note
CME Group (Chicago)	Daily price of wheat		Unce/ bushel	2001–2023	https://www.cmegroup.com/markets/agriculture/grains/wheat.html	Fig. 4
WRI (World Resources Institute)	Egypt's agricultural area (prognosis) The demand for food in Egypt (prognosis) Production of agricultural commodities in Egypt (prognosis)		%		https://www.wri.org/aqueduct	Fig. 5
IFAD (International Fund for Agricultural Development)	Forecasts of hectare yields until 2041 of crops: maize, wheat and sorghum.		%		https://www.ifad.org/en/web/knowledge/-/publication/climate-adaptation-in-rural-development-card-assessment-tool	Fig. 6

Appendix 3. Original ARDL estimation output

Dependent Variable: LIMPORT

Method: ARDL
Date: 10/11/22 Time: 07:57
Sample (adjusted): 1964 2019
Included observations: 56 after adjustments
Maximum dependent lags: 4 (Automatic selection)
Model selection method: Akaike info criterion (AIC)
Dynamic regressors (4 lags, automatic): LPOP LWHEAT FOOD PROTEIN
Fixed regressors: C
Number of models evaluated: 2500
Selected Model: ARDL(1, 1, 1, 3, 2)
Note: final equation sample is larger than selection sample

Variable	Coefficient	Std. Error	t-Statistic	Prob.*
LIMPORT(-1)	0.352450	0.123061	2.864022	0.0064
LPOP	49.46939	17.91475	2.761377	0.0084
LPOP(-1)	−48.76658	18.02278	−2.705830	0.0097
LWHEAT	−0.263422	0.237099	−1.111021	0.2727
LWHEAT(-1)	0.604735	0.254150	2.379436	0.0218
FOOD	−0.400896	0.146452	−2.737390	0.0090
FOOD(-1)	−0.276453	0.152839	−1.808779	0.0775
FOOD(-2)	0.121638	0.056033	2.170817	0.0355
FOOD(-3)	−0.010876	0.006651	−1.635215	0.1093
PROTEIN	1.749478	0.606763	2.883296	0.0061
PROTEIN(-1)	1.106853	0.628870	1.760067	0.0855
PROTEIN(-2)	−0.508294	0.224900	−2.260089	0.0289
C	−9.285400	4.858245	−1.911266	0.0627
R-squared	0.955631	Mean dependent var		15.31122
Adjusted R-squared	0.943249	S.D. dependent var		0.702370
S.E. of regression	0.167322	Akaike info criterion		−0.537663
Sum squared resid	1.203852	Schwarz criterion		−0.067492
Log likelihood	28.05455	Hannan-Quinn criter.		−0.355378
F-statistic	77.17900	Durbin-Watson stat		2.250605
Prob(F-statistic)	0.000000			

*Note: p-values and any subsequent tests do not account for model selection.
Source: Authors' computations (2023).

Wald test for short run causality from variables to wheat imports

Variable	F-stastistic	Prob
LPOP	6.024098	0.0049
LWHEAT	2.908554	0.0654
FOOD	4.199293	0.0059
PROTEIN	5.639239	0.0024

Source: Authors' computations (2023).

We used the Wald test to determine the causality of the variables towards import of wheat. Population, food, and protein indicated a statistically strong and significant connection to wheat importation with probabilities of 0.0049, 0.0059 and 0.0024 respectively which were less than 5 % level of significance, having respective F-statistic values of 6.024098, 2.908554, 4.199293, and 5.639239.

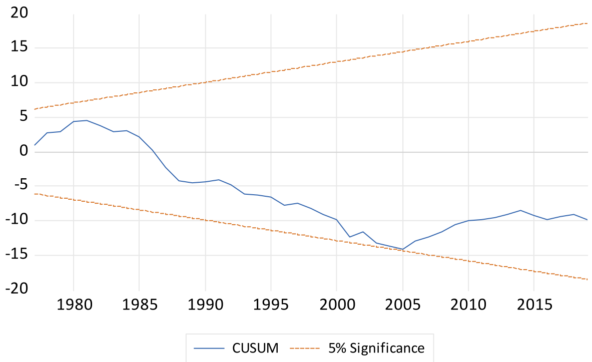
Diagnostic tests

Problem	Test	F-statistic	p-value
Autocorrelation	Breusch-Godfrey LM	1.103660	0.3413
Heteroskedasticity	Breusch-Pagan-Godfrey	1.183160	0.0731

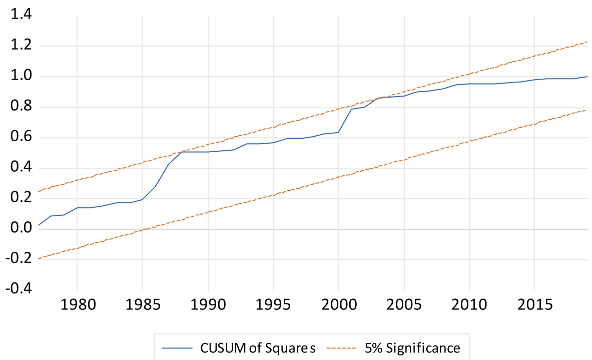
Source: Authors' computations (2023).

Post-estimation tests of autocorrelation and heteroscedasticity conducted under the null hypothesis that autocorrelation and heteroscedasticity is not present in the data is rejected with p-values of 0.34 and 0.07 respectively. Stability of the model was also tested using the cusum test and cusum squares test, Figs. 1 and 2 respectively. Figs. 1 and 2 indicates that the model is stable as the plot remains lie within 2 standard deviations.

Cusum test



Cusum squares test



Source: Authors' computations (2023).

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