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# New evidence in the relationship between trade openness and food security in Sub-Saharan Africa

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## Abstract

**Background** Since 2015, food insecurity has been a more serious threat than the previous years with a record high observed from the year 2020 onwards, especially in developing countries. This record could be due to response measures, notably the closure of borders due to the COVID-19 pandemic. This implies that trade openness have played an important role in achieving food security in the world. However, the debate on the effect of trade openness on food security remains no consensus in the economic literature. It is in this context that this paper aims to re-examine the effect of trade openness on food security in sub-Saharan African countries.

**Methods** Panel data covering 37 Sub-Saharan African countries over the period from 2004 to 2018 were mobilized. We use a dynamic empirical model based on the system Generalized Method of Moment (GMM) to control the unobserved heterogeneity and potential endogeneity of the explanatory variables. As food security is a multidimensional concept, we used four indicators ("average dietary energy supply adequacy", "average protein supply", "per capita food supply variability", and "share of dietary energy supply") to capture food security. To improve the robustness of the empirical effect of openness on food security, we also used globalization as an alternative factor to trade openness.

**Results** The empirical results show that trade openness significantly improves food security in 37 Sub-Saharan African countries. However, in the presence of political instability, a deterioration of the food security situation is observed. The results reveal also that the quality of institutions, economic growth, remittances, human capital, and the importance of the agricultural sector are also factors favouring the level of food security in sub-Saharan Africa countries.

**Conclusion** Any policy aimed at trade openness must consider the quality of institutions to achieve the expected results.

**Keywords** Dynamic panel, Food security, Quality of institutions, Sub-Saharan Africa, Trade openness

**JEL Classification** C33, F14, Q18

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## Introduction

The problem of food security continues to receive particular attention in both developing and developed countries [1]. This situation has been further exacerbated, especially in developing countries with the advent of the COVID-19 pandemic [2–4]. Globally, between 702 and 828 million people had suffered from hunger in 2021, or 103 million more between 2019 and 2020 [3]. In Africa, the situation aggravated to 248 million people in 2021. In addition, more than half (57.9%) of the population in 2021 were in food insecure [4]. This compares to just 30% worldwide at the same year [4].

Between 2020 and 2022, a drastic increase in food prices (more than 31%) due to trade and circulation restrictions has also been observed [5]. As a result, 46 countries in the world required external food assistance, of which about 75% are African countries [7]. Thus, in the context of climate change and other natural shocks with additional demographic pressure and ever-increasing conflicts, the eradication of hunger remains a major global challenge [6]. Moreover, food insecurity and malnutrition have direct consequences on human health and development [8]. This in turn contributes to low individual productivity and therefore a delay in economic development [9]. As a result, reaching the goal of zero hunger by 2030 remains an illusion, especially in sub-Saharan African countries [10].

Food security exists when people, at all times, have physical and economic access to sufficient, safe, and nutritious food to meet their dietary needs and food preferences for an active and healthy life [11, 12]. This definition emphasizes that food availability is a necessary but not sufficient condition for food security [13]. Indeed, food availability, which focuses on whether food is actually materially present, does not necessarily explain how households have access to food (accessibility dimension), including on a physical, financial and social level. Moreover, accessibility also neglects how the households used the food they have access (utilization dimension). Finally, the whole food system must be stable or permanent (stability dimension) for sustainable food security [14]. Apparently, to understand the problem of food security, it is important to consider the four dimensions mentioned above [15]. Furthermore, the analysis of the food supply and demand situation in Sub-Saharan Africa shows that the majority of these countries have import needs in 2022 [16]. This indicates that the problem of food insecurity remains a structural phenomenon in developing countries.

The survival of the population of Sub-Saharan Africa remains largely dependent on agriculture [17, 18]. Hence, to assert their sovereignty, at the continental level and within regional groups, food security issues are the underpinning of policy lines such as the Comprehensive Africa Agriculture Development Program, Agenda 2063, and common trade and agricultural policies. However, the incitement of Egbendewe et al. [19] have shown that under the influence of climate change, many countries in West Africa, for instance, will continue to import food as demand increases more than the area's production coverage. As a result, the problem of food security remains a threat.

In this dynamic, trade openness should be a major factor in achieving food security, at least in the short term. Economic theory suggests that countries facing a food supply constraint will tend to import more food from the rest of the world to meet their food needs. Supply constraints can arise from several factors including climate change, technology shock, and population growth [20]. In this context, trade openness allows nations to import from economies with food supply surpluses to countries with deficits. These imports or exports reinforce food availability, which is a necessary condition for food security at the national level.

Trade openness can allow consumers not only to access new markets, but also a greater variety of quality products at lower costs [21]. Their level of satisfaction increases and leads to an increase in the elasticity of demand for consumer goods. This competitive shock resulting from the opening up of trade requires companies to reduce their trade margins, in particular by lowering prices [22]. In addition, firms are forced to supply high-quality food and non-food goods to international markets [17]. Consequently, trade openness thus has a positive influence on food security by promoting food diversity and quality [17].

In an open economy, producers have greater flexibility in the supply of intermediate consumption goods and other inputs or factors of production needed for their activities [18]. This greater variety of inputs guarantees a more efficient production mix [26]. The differentiated production can be used as a final consumption good or as an intermediate consumption good, which constitutes a cage for food security. This is the quality effect of trade openness [19].

Trade openness can also be an important factor for agricultural technology transfer in an economy [21]. This transfer will improve agricultural productivity [28]. Accordingly, through better productivity, income is likely to improve. The income effect also allows better access to other products [29]. In addition, productivity can have a downward effect on product prices and consequently on food security.

However, it is not surprising that the role of trade openness is contested. Pessimists argue that trade openness threatens food security for several reasons. First,

trade openness can hinder diversification and lead to unsustainable development [24]. It can also increase the vulnerability of countries due to their dependence on international trade, while weakening the situation of agricultural producers in some developing countries [25]. Secondly, trade openness reshapes the global food supply chain by favouring multinational companies while depriving states of their resources [26]. Third, trade openness can have economic impacts. For example, international trade in agricultural products can have profound effects on the environment, nutrition, and population health [27, 28]

Empirically, the lack of consensus is equally noticed in developed and developing countries. Some authors such as Abdullateef & Ijaiy [32] and Bezuneh & Yiheyi [33] have found negative effects of trade openness on food security. Fusco et al. [34] and Dithmer & Abdulai [35] have found positive effects of trade openness on food security. The lack of theoretical and empirical consensus in the economic literature reopens the debate in the context of the pandemic, with natural disasters increasingly abundant with wars mostly in countries providing food and agricultural inputs. Thus, this paper aims to re-examine the effect of trade openness on food security in Sub-Saharan African countries.

This study contributes to the literature for two main reasons. First, the context and coverage area of the analysis. Indeed, in the Sub-Saharan Africa area to our knowledge, very few studies have been conducted in this sense [36]. However, these studies have not considered the role of the quality of institutions, the geographical location of countries, and natural disasters. Finally, most studies have used poverty indicators instead of direct food security indicators [34]. This study considers all these shortcomings and remains an emerging study using a dynamic panel approach with the generalized method of moments to understand the overall level of food security in Sub-Saharan Africa.

The rest of the paper is organized as follows: Sect. "Presentation of variables and empirical model" presents the theoretical and empirical framework, Sect. "Results and discussion" presents the empirical model, the estimation strategy, and the data. Section 4 presents the results and discussion. Conclusions are presented in Sect. 5.

## Trade openness and food security: theoretical and empirical relationship

Since the work of Smith [37] and Ricardo [38], the problem of the effect of trade openness on various aspects of the economy, in this case, food security, has attracted several researchers who have made it a privileged field of investigation. However, a reading of the theoretical and empirical work on this link reveals contradictions.

### Positive effect of trade openness on food security

The heterodox think that trade openness would positively affect food security through availability [20]; availability, diversity, and quality of products [17]; quality of products, an increased supply of inputs, technology [26], and technology transfer [28]. Some empirical studies have confirmed this positive relationship. These are the case of the work of Dithmer & Abdulai [35] and Fusco et al. [34].

### Negative impact of trade openness on food security

In contrast to the previous first thesis, the orthodox argue that trade openness has a negative or mixed effect on food security. Thus, trade openness leads to unsustainable development, reshaping the global food supply chain, and impacts the environment, nutrition, and population health. This poses a threat to food security. Advocates of this thesis include Bush [24] and Wittman et al. [27]. Some empirical studies have confirmed the negative relation between trade openness and food security [39, 69].

The review shows the contradiction between the expected effect of trade openness on food security and the importance of an appropriate model to analyse the relationship trade openness and food security. This study uses a dynamic panel with several indicators of food security and trade openness in the context of Sub-Saharan African countries.

## Presentation of variables and empirical model

### Sources and description of variables

#### *Area, period and sources of variables*

The study area covers 37 countries in Sub-Saharan Africa (Table 1) over the period from 2005 to 2018. The choice of countries and periods is justified by data constraints. Data used in the study are taken mainly from the World Development Indicators (WDI), Worldwide Governance Indicators (WGI), FAO's FAOSTAT, KOF Swiss Economic Institute, International Disasters Database (EM-DAT), and Research and Expertise on the World Economy (CEPII).

#### *Dependent variables*

To capture food security, which is a multidimensional concept, we used two main indicators:

(i) Average Dietary Energy Supply Adequacy (ADESA) is calculated in three-year averages, from 2000–02 to 2019–21, to reduce the impact of possible errors in estimated dietary energy supply adequacy, due to the difficulties in properly accounting for stock variations in a major food. It therefore provides an indicator of structural food supply adequacy.

**Table 1** List of countries in the study

| Countries | | | | |
|---|---|---|---|---|
| **Angola** | **Benin** | **Botswana** | **Burkina Faso** | **Cabo Verde** |
| Cameroon | Central African Republic | Chad | Comoros | Congo. Dem. Rep |
| Cote d'Ivoire | Eswatini | Ethiopia | Gabon | Gambia. The |
| Ghana | Guinea-Bissau | Kenya | Lesotho | Liberia |
| Madagascar | Malawi | Mali | Mauritania | Mauritius |
| Namibia | Niger | Nigeria | Rwanda | Sao Tome and Principe |
| Senegal | Sierra Leone | South Africa | Sudan | Tanzania |
| Togo | Zambia | | | |

Source: Authors based on data, 2022

(ii) Average protein supply (APS) is calculated as the sum of the elements of supply (production quantity, import quantity, and stock variation i.e., net increase or decrease) minus the elements of utilization (export quantity, food manufacturing, feed, seed, waste, and other uses).

These variables are more suitable and used in the recent literature to capture food security [34, 35]. In addition, the data are comparable across countries and are available for broad temporal and spatial coverage [48]. Finally, these two indicators are integral parts of the FAO food security indicators [35]. Nevertheless, we used other additional food security indicators (Share of dietary energy supply and Per capita food supply variability) to test the robustness of the first two indicators.

#### *Independent variables*

In this study, the variable of interest is trade openness. It is computed as the volume of trade (real exports plus imports) over real GDP [41]. This revealed openness measure is the measure usually employed in impact studies of trade liberalization and is arguably better than de jure measures (e.g. tariffs) to the extent that the latter is difficult to summarize in a single indicator [42–45]. The index of globalization is used as the robustness of trade openness [64]. Apart from the variable of interest, five groups of control variables are identified.

The first group concerns the context and characteristics of the country. Two variables are retained. The total amount of economic resources is captured by the gross domestic product in purchasing power parity, which is expected to have a positive impact on food security, given that it will allow the country to have strong purchasing power. The importance of agriculture is captured by agricultural value added as a percentage of GDP. This variable should have a positive effect on food security.

The second group concerns variables that capture the economic and demographic development of the country. In this group, we have also introduced two variables. The agricultural productivity captured by the cereal yield is assumed to positively affect food security. Finally, we introduced the population growth rate to capture the demographic pressure on food security as emphasized by the Malthusians.

The third group concerns non-economic events. These are natural disasters captured by the intensity of natural disasters of geophysical, meteorological, hydrological, climatological, biological, and extraterrestrial origin [46]. This could generate losses of agricultural and non-agricultural income, but also food availability. Finally, in this group, we considered whether or not the countries were landlocked (Annex Fig. 3). Indeed, maritime trade represents an important part of the volume of international trade in goods [47]. In this sense, landlocked countries would be food insecure since they may face persistent problems in accessing international markets [60]

The fourth group considers the macroeconomic stability of the country. For macroeconomic stability, we used the inflation rate (consumer price index). Indeed, domestic stabilization policies that create an economically stable environment tend to have welfare-enhancing effects, while macroeconomic instability would increase poverty and food insecurity [58].

Finally the study considers other variables such as education and receipt of remittances of migrants, which form the fifth group. Finally, robustness and interaction tests of the institutional variables were conducted. Table 2 provides a summary of the variables on their measures, units, recent authors, and sources of origin.

### Empirical framework and estimation technique

Following Dithmer & Abdulai [35] and Fusco et al. [34], this study adopts a dynamic panel approach to analyse the effects of trade openness on food security in Sub-Saharan Africa. The advantage of a dynamic model is that it allows for some dynamic aspects of trade

**Table 2** Details of model variables

| Variables | Definition of variables | Unity | Recent usage in extant Studies | Sources |
|---|---|---|---|---|
| ADESA | Average dietary energy supply adequacy | % | Fusco et al. [34] | FAOSTAT |
| APS | Average protein supply | g/cap/day | FAO, [60] | FAOSTAT |
| PCFSV | Per capita food supply variability | Kcal/cap/day | Remans et al.[61] | FAOSTAT |
| SDES | Share of dietary energy supply derived from cereals. roots and tubers | Kcal/cap/day | Bai and al., [62] | FAOSTAT |
| Openness | Trade openness in % of GDP [a] | % | Yanikkaya, [49] | WDI |
| Globalization | KOF index of globalization (0–100); composite index measuring three dimensions (economic, social, political) | N° | Gygli et al. [64] | KOF Swiss Economic Institute |
| Corruption | Control of corruption score [b] | N° | Kar & Saha, [65] | WGI |
| Governance | Government Effectiveness score | N° | Olofin et al.[66] | WGI |
| Political | Political Stability score | N° | Golo [36] | WGI |
| Remittances | Personal Remittances received | % of GDP | Mabrouk & Mekni, [67] | WDI |
| EDUC | Secondary school enrollment proxy of human capital | % Gross | Okah et al. [59] | WDI |
| Log (GDP) | GDP per capita. PPP Constant 2017 | international $ | Bezuneh & yiheyis [60] | WDI |
| SADGP | Agriculture, forestry, and fishing, value added | % GDP | *Ogunniyi* et al. [61] | WDI |
| POP growth | Population growth | (Annual %), | Yunusa et al. [62] | WDI |
| IND | The intensity of natural disasters is measured as the number of affected divided by the total population | % | Tirivangasi [63] | EM-DAT |
| Inflation | Consumer prices inflation | N° | Ames et al. [50] | WDI |
| Agri. product | Cereal yield | kg/per/hectare | Muzari [64] | FAOSTAT |
| Landlocked | Indicator variable takes the value of 1 for landlocked countries and 0 otherwise | N° | Rahim [65] | CEPII |

[a] Trade openness is the sum of exports and imports of goods and services measured as a share of gross domestic product (source: World Development Indicators, 2023)

[b] According to Worldwide Governance Indicators (WGI), the six aggregate indicators as institutional variables are reported in two ways: (1) in their standard normal units, ranging from approximately -2.5 to 2.5, and (2) in percentile rank terms from 0 to 100, with higher values corresponding to better outcomes. In this study, ranging from approximately − 2.5 to 2.5 is used following Ogunniyi et al. [61]

Source: Authors, 2022

reforms and efficiently addresses the potential endogeneity problem that is likely to arise from such a specification. Given the persistence of reforms over time, the majority of empirical studies have abandoned statistical models in favour of a dynamic model [35]. Thus, modelling current levels of food security as a function of past levels and other variables (Eq. 1) allows for the effects of trade reforms in Sub-Saharan African countries.

$$FS_{i,t} = \alpha + \beta FS_{i,t-1} + \gamma TO_{i,t} + \theta CV_{i,t} + \delta_i + \varphi_t + \varepsilon_{i,t} i = 1, 2, \ldots., 37; t = 1, \ldots, 15 \quad (1)$$

$FS_{i,t}$ is the dependent variable signifying food security, and $FS_{i,t}$-$_1$ is its lagged value. $TO_{i,t}$ denotes trade openness and $CV_{i,t}$ represents the other control variables that may influence food security, $\delta_i$ denotes country-specific effects, for example, geographic characteristics or unobserved cultural and institutional factors that are rather stable over time, $\phi t$ is the time-specific effect, capturing changes in world prices and controlling for shocks that are common to all countries such as global demand shocks and $\varepsilon_{i,t}$ is the error term.

The estimation of Eq. (1) by Ordinary Least Squares (OLS) or Two-Stage least squares (2SLS) regression generates inconsistent coefficients, even in the fixed or random effects settings, due to the presence of the lagged variable in the model, is often correlated with the error term [66]. One way to solve this inconsistency is to use the GMM [67]. There are two types of estimators: the Arellano and Bond [68] or difference GMM estimator and the system GMM estimators [68]. To eliminate a possible omitted variable bias related to specific effects in the Arellano and Bond [68] estimator, we take the first difference of Eq. (1).

$$\Delta FS_{i,t} = \phi + \vartheta \Delta FS_{i,t-1} + \omega \Delta TO_{i,t} + \sigma \Delta CV_{i,t} + \mathcal{S}_i + \xi_t + \tau_{i,t} i = 1, 2, ., 37, t = 1, , 15 \quad (2)$$

where ϕ, ϑ, ω, and σ are parameters to be estimated. $FS_{i,t}$; $_{FSi,t\text{-}1}$; $TO_{i,t}$ and $CV_{i,t}$ remain the same as in Eq. (1)

The lagged level of food security and the explanatory variables may be weak instruments [67]. In this case, the

GMM first difference estimator potentially suffers from a bias at the base with a high correlation between food security's indicators and their lagged values (see Appendix Table 7). To overcome, this problem and also eliminate reverse causality, this paper uses the system GMM estimators [69]. These estimators are derived from two simultaneous equations, one in level and the other in first difference. To ensure the validity of the instruments, we will use Sagan's tests for overidentifying restrictions and Arellano and Bond's tests for serial correlation.

## Results and discussion

### Descriptive analysis

Descriptive statistics are provided in Table 3. This table shows that Per capita food supply variability is 40.54 kcal/cap/day on average, with a Standard Deviation of 25.63, compared with 60.76 kcal/cap/day for Share of dietary energy supply derive, which has a Standard Deviation of 9.23 kcal/cap/day. Average Cereal yield is 1451.80 kg / per/ hectare with a minimum value of 34.3 kg /per/ hectare. Figures 1 and 2 show respectively the evolution of the indicators of food security (ADESA, APS, PCFSV, and SDES) and trade openness variables (Openness and Globalization) and the correlation between the indicators of food security and trade openness. Figure 1 shows that the indicators of food security and globalization have shown an upward trend over the period from 2004 to 2018, although slight decreases have been observed since 2015. The decline could be explained by the worsening of food insecurity in the world, particularly in Sub-Saharan Africa, since 2015 [1]. Thus, the prevalence of food insecurity increases from 44.4% in Africa in 2014 to 51.3% in 2018 [4]. The indicators of trade openness show an increasing trend.

Figure 2 shows that the slopes are relatively more significant, especially concerning globalization (Fig. 2b). This means that a high degree of trade openness would increase the level of food security in Sub-Saharan African countries. According to FAO [76], trade and related policies can play a major role in promoting and supporting the shift beyond aid, as they can create and enable conditions for facilitating structural transformation and mobilizing different sources of finance. Trade policies are expected to become increasingly important in supporting the implementation and finance of agricultural strategies and investment plans. In this case, trade openness could help strengthen food security. These findings are consistent with the econometric analysis in the next section.

### Econometric analysis

#### *Correlation matrix between independent variables*

The matrix correlation of the independent variables used in the estimations is presented in Appendix Table 8. We note that the coefficients of all variables are less than 0.50. This low correlation of the coefficients means that the problem of multi-collinearity will not arise as such in our estimations.

**Table 3** Descriptive Statistics of the variables

| Variable | Mean | Standard Deviation | Minimum | Maximum |
|---|---|---|---|---|
| ADESA | 164.936 | 332.8705 | 74 | 2322 |
| APS | 61.40372 | 12.39167 | 18.1 | 86.7 |
| PCFSV | 40.54372 | 25.63688 | 4 | 172 |
| SDES | 60,75772 | 9.238633 | 18 | 81 |
| Openness | 65.13726 | 28.59369 | 0.7846308 | 175.798 |
| Globalization | 44.895 | 13.183 | 28.29897 | 72.11279 |
| Corruption | − 0.5429532 | 0.5994993 | − 1.558522 | 1.216737 |
| Governance | − 0.662 | 0.61 | − 1.849 | 1.057 |
| Political | − 0.41 | 0.828 | − 2.7 | 1.2 |
| Remittances | 4.042124 | 6.279392 | 0.0001832 | 50.102 |
| EDUC | 45.1879 | 23.52161 | 6.487 | 109.444 |
| Log (DGP) | 22.86113 | 0.848 | 6.076 | 10.079 |
| SADGP | 22.614 | 14.30082 | 1.798135 | 79.042 |
| POP growth | 2.419 | 0.859 | -0.616 | 4.63 |
| IND | 2.44 | 8.101 | 0.0000413 | 95.698 |
| IPC | 7.729 | 17.396 | -9.616 | 359.937 |
| Agri. productivity | 1451.808 | 1055.928 | 34.3 | 9453.7 |
| Landlocked | 0.324 | 0.468 | 0 | 1 |

Source: Authors based on data, 2022

### *Econometric evidence of the link between trade openness and food security*

The econometric results of the effect of trade openness on food security in Sub-Saharan Africa are reported in Table 4. The first three columns present the effect of trade openness on the first indicator (Dietary energy supply adequacy: ADESA) while the last three present the effect on the second indicator (Average protein supply: APS). Columns 1, 2, 4, and 5 present results without and with the Control of corruption score on

**Table 4** Two-step system GMM model, effects of trade openness on food security

| Variables | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| | Dietary energy supply adequacy (ADESA) | | | Average protein supply (APS) | | |
| ADESA (– 1) | 0.973*** | 0.947*** | 0.912*** | | | |
| | (0.003) | (0.008) | (0.010) | | | |
| APS (– 1) | | | | 0.218*** | 0.176*** | 0.239** |
| | | | | (0.078) | (0.050) | (0.100) |
| Openness | 0.018*** | 0.061*** | | 0.045** | 0.061** | |
| | (0.006) | (0.012) | | (0.023) | (0.023) | |
| Globalization | | | 0.022*** | | | 0.123*** |
| | | | (0.007) | | | (0.004) |
| Corruption | | 0.732*** | 0.507*** | | 0.187 | 0.030 |
| | | (0.145) | (0.115) | | (0.113) | (0.047) |
| Remittances | 0.204*** | 0.076 | 0.021 | 0.447*** | 0.360*** | – 0.028 |
| | (0.054) | (0.069) | (0.199) | (0.107) | (0.125) | (0.029) |
| Education | 0.001*** | 0.286*** | 0.294* | 0.006*** | 0.005*** | 0.001* |
| | (0.000) | (0.067) | (0.173) | (0.001) | (0.001) | (0.000) |
| Log (GDP) | 0.248*** | 0.245*** | 0.730*** | 0.286 | 0.248 | – 0.012 |
| | (0.048) | (0.082) | (0.132) | (0.176) | (0.167) | (0.032) |
| SAGDP | 0.016*** | 0.018*** | 0.094*** | – 0.008 | 0.009 | 0.002 |
| | (0.001) | (0.001) | (0.005) | (0.015) | (0.011) | (0.003) |
| Population growth | – 0.252*** | -0.027 | – 0.002 | – 0.917*** | – 0.765*** | – 0.011 |
| | (0.042) | (0.050) | (0.137) | (0.131) | (0.161) | (0.040) |
| Natural disasters | 0.009 | – 0.771*** | -0.175 | – 0.269*** | -0.225*** | – 0.003 |
| | (0.052) | (0.090) | (0.174) | (0.059) | (0.056) | (0.008) |
| Inflation | – 0.106*** | – 0.115*** | -0.111*** | – 0.185*** | – 0.103*** | – 0.022* |
| | (0.006) | (0.011) | (0.010) | (0.052) | (0.038) | (0.012) |
| Agri. productivity | 0.003*** | 0.003*** | 0.006*** | 0.010*** | 0.011*** | 0.000 |
| | (0.000) | (0.001) | (0.001) | (0.002) | (0.002) | (0.001) |
| Landlocked | – 0.022*** | – 0.045*** | -0.028 | -0.034** | 0.025 | – 0.014*** |
| | (0.005) | (0.013) | (0.019) | (0.015) | (0.017) | (0.004) |
| Constant | – 311.597*** | – 332.356*** | – 740.930*** | – 422.154** | – 395.994** | 17.318 |
| | (45.320) | (76.852) | (127.943) | (178.156) | (171.505) | (35.317) |
| Observations | 555 | 555 | 555 | 555 | 555 | 555 |
| Number of countries | 37 | 37 | 37 | 37 | 37 | 37 |
| Number of instruments [c] | 24 | 24 | 24 | 24 | 24 | 24 |
| AR1 test | 0.000 | 0.002 | 0.012 | 0.000 | 0.003 | 0.010 |
| AR2 test | 0.324 | 0.157 | 0.978 | 0.723 | 0.998 | 426 |
| Hansen test | 0.909 | 0.667 | 0.508 | 0.099 | 0.126 | 0.153 |
| Diff-Hansen | 0.374 | 0.768 | 0.331 | 0.979 | 0.212 | 0.889 |

[a] For each regression, at most five instrumented variables with at most two lags are included. The number of instruments reported is based on the number of "collapsed" instruments, using the xtabond2 specification of Roodman [71]. The other specifications are explained in the text

[b] Diff-Hansen test reports the p-values based on the null hypothesis that the instruments in the levels equation are exogenous

[c] Standard errors are reported in parentheses

*** Significant at 1%, ** significant at 5%, * significant at 10%

Source: Authors based on data, 2022

**Table 5** Two-step system GMM model, the interaction of trade openness and institutional quality on food security

| VARIABLES | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
|---|---|---|---|---|---|---|---|---|
| | | ADESA | | | | | APS | |
| ADESA (– 1), | 0.634*** | 0.948*** | 0.879*** | 0.835*** | | | | |
| | (0.027) | (0.007) | (0.012) | (0.015) | | | | |
| APS (– 1) | | | | | 0.632** | 0.839*** | 0.421*** | 0.625*** |
| | | | | | (0.298) | (0.289) | (0.123) | (0.118) |
| Openness*governance | 0.284** | | | | 0.253** | | | |
| | (0.124) | | | | (0.123) | | | |
| Openness*political | | – 0.126*** | | | | – 0.193*** | | |
| | | (0.049) | | | | (0.057) | | |
| Openness*corruption | | | 0.023*** | | | | 0.117* | |
| | | | (0.003) | | | | (0.061) | |
| Openness*Landlocked | | | | 0.280*** | | | | 0.047*** |
| | | | | (0.028) | | | | (0.014) |
| Corruption | | | | – 1.052*** | | | | – 0.102* |
| | | | | (0.222) | | | | (0.061) |
| Remittances | 0.293 | 0.140 | 0.336** | 0.273* | 0.600*** | 0.514*** | 0.036 | – 0.077 |
| | (0.312) | (0.088) | (0.136) | (0.161) | (0.189) | (0.159) | (0.038) | (0.055) |
| Education | 0.002 | 0.001 | 0.003* | 0.003* | 0.007*** | 0.007*** | -0.000 | 0.002*** |
| | (0.002) | (0.001) | (0.002) | (0.002) | (0.001) | (0.001) | (0.000) | (0.001) |
| Log (GDP) | 0.562*** | 0.518*** | 0.899*** | 1.450*** | 0.098 | – 0.022 | 0.092** | – 0.429*** |
| | (0.112) | (0.062) | (0.225) | (0.181) | (0.129) | (0.138) | (0.042) | (0.068) |
| SAGDP | 0.037*** | 0.044*** | 0.035*** | 0.054*** | – 0.025*** | – 0.041*** | 0.004** | – 0.024*** |
| | (0.007) | (0.004) | (0.005) | (0.006) | (0.005) | (0.006) | (0.002) | (0.003) |
| Population growth | -0.317 | 0.095 | -0.261 | 0.398*** | 1.056*** | 1.056*** | – 0.060 | 0.210*** |
| | (0.198) | (0.095) | (0.227) | (0.149) | (0.201) | (0.217) | (0.057) | (0.051) |
| Natural disasters | – 0.198*** | – 0.142*** | – 0.072*** | (0.222) | – 0.088*** | – 0.068*** | – 0.051*** | 0.287*** |
| | (0.016) | (0.017) | (0.016) | 0.355* | (0.016) | (0.016) | (0.008) | (0.080) |
| Inflation | -0.163*** | -0.153*** | -0.098*** | – 0.087*** | – 0.129*** | – 0.121*** | – 0.173*** | – 0.135*** |
| | (0.015) | (0.011) | (0.015) | (0.020) | (0.019) | (0.018) | (0.013) | (0.014) |
| Agri. productivity | 0.006** | 0.003*** | 0.002 | – 0.003 | 0.011*** | 0.012*** | 0.022*** | 0.018*** |
| | (0.003) | (0.001) | (0.001) | (0.002) | (0.002) | (0.002) | (0.002) | (0.002) |
| Landlocked | – 1.043*** | 0.002 | – 0.084*** | | – 0.043*** | – 0.038** | – 0.018*** | |
| | (0.130) | (0.013) | (0.021) | | (0.017) | (0.016) | (0.005) | |
| Constant | – 680.47*** | – 528.72*** | – 820.90*** | – 467.29*** | – 304.69** | – 194.61 | -59.58* | 332.97*** |
| | (130.079) | (70.530) | (212.507) | (166.525) | (128.790) | (132.270) | (35.322) | (60.268) |
| Observations | 458 | 357 | 404 | 404 | 458 | 458 | 404 | 404 |
| Number of countries | 37 | 37 | 37 | 37 | 37 | 37 | 37 | 37 |
| Number of instruments [f] | 21 | 21 | 21 | 21 | 21 | 21 | 21 | 21 |
| AR1 test | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| AR2 test | 0.984 | 0.946 | 0.172 | 0.895 | 0.568 | 0.301 | 0.099 | 0.193 |
| Hansen test | 0.570 | 0.270 | 0.719 | 0.744 | 0.844 | 0.893 | 0.742 | 0.413 |
| Diff-Hansen [g] | 0.490 | 0.830 | 0.641 | 0.167 | 0.897 | 0.859 | 0.262 | 0.299 |

[a] For each regression, at most three instrumented variables with at most two lags are included. The number of instruments reported is based on the number of "collapsed" instruments, using the xtabond2 specification of Roodman [71]

[b] Diff-Hansen test reports the p-values based on the null hypothesis that the instruments in the levels equation are exogenous. [c] Standard errors are reported in parentheses. *** Significant at 1%, ** significant at 5%, * significant at 10%

Source: Authors based on data, 2022

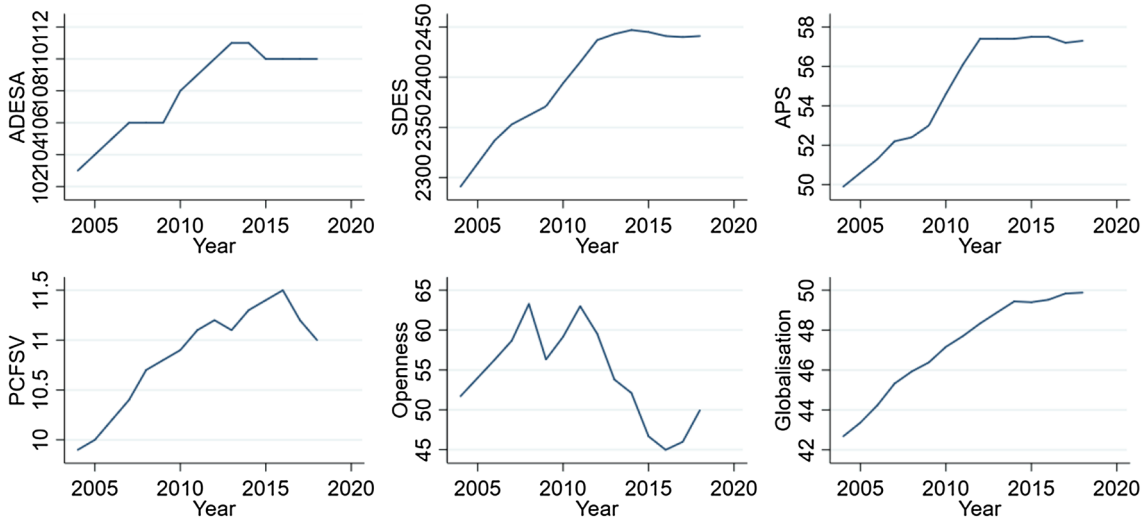


**Fig. 1** Evolution of food security indicators from 2004 to 2018 in Sub-Saharan Africa. Source: Authors based on data, 2022

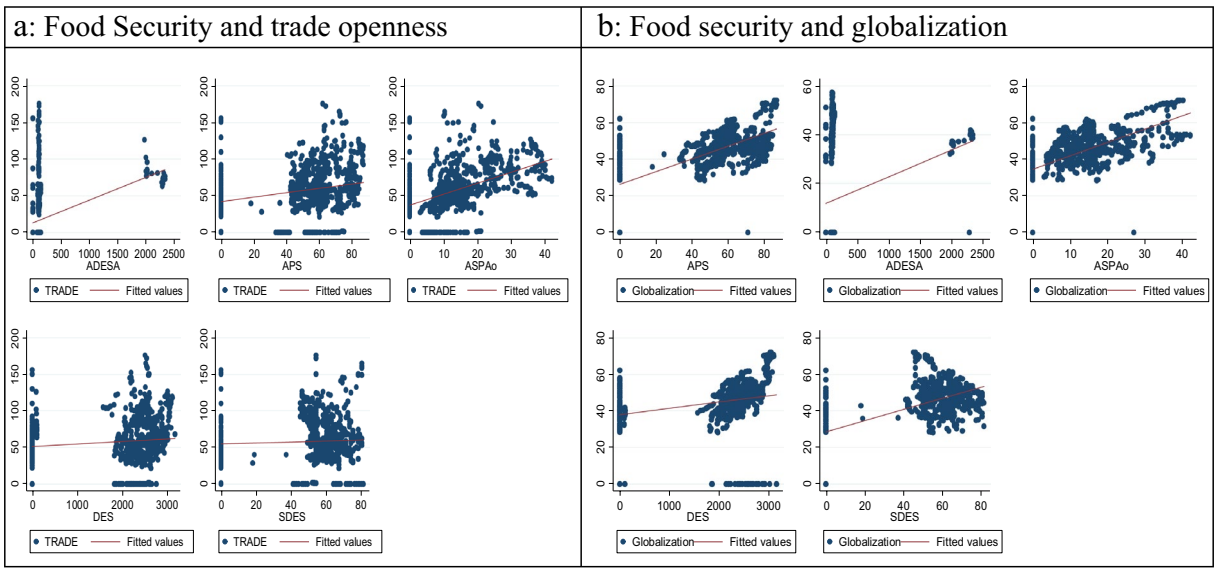


**Fig. 2** Correlation between food security and trade openness; TRADE = Openness here. Source: Authors based on data, 2022

each of the food security indicators, respectively. This highlights the importance of institutional quality in the presence of trade openness. Columns 3 and 6 present the results of the effect of trade openness on food security, using the variable Globalization as an alternative to the variable Openness.

Sargan's instrument validity tests for overidentification of restrictions and Arellano and Bond's test for serial correlation are provided at the bottom of Table 4. These tests show that Autocorrelation of first-order, AR(1), is present in the data, as it has been expected. Autocorrelation of second order, AR(2), is absent from the data, which

**Table 6** Two-step system GMM model, alternative food security indicators

| | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| VARIABLES | SDES | SDES | SDES | PCFSV | PCFSV | PCFSV |
| SDES (-1) | -0.218 | 0.124** | 0.510*** | | | |
| | (0.168) | (0.052) | (0.033) | | | |
| PCFSV (-1) | | | | 0.239*** | 0.083** | 0.569*** |
| | | | | (0.058) | (0.041) | (0.049) |
| Openness | 0.052*** | 0.077*** | | 0.121*** | 0.094*** | |
| | (0.014) | (0.020) | | (0.036) | (0.030) | |
| Globalization | | | 0.125***(0.004) | | | 0.034*** (0.009) |
| Corruption | | 0.244* | | | -1.225*** | |
| | | (0.128) | | | (0.349) | |
| Remittances | 0.204** | 0.388** | 0.039** | 0.082 | 0.161 | -0.020 |
| | (0.079) | (0.157) | (0.017) | (0.236) | (0.225) | (0.180) |
| Education | 0.004*** | 0.004*** | 0.001** | -0.001 | 0.001 | 0.002 |
| | (0.001) | (0.001) | (0.000) | (0.002) | (0.002) | (0.002) |
| Log (DGP) | -0.126 | 0.340* | 0.169*** | 1.387*** | 0.900*** | 0.664*** |
| | (0.121) | (0.177) | (0.021) | (0.243) | (0.286) | (0.228) |
| SAGDP | -0.013 | 0.021*** | -0.001 | 0.027** | 0.032*** | 0.009 |
| | (0.009) | (0.008) | (0.001) | (0.012) | (0.011) | (0.010) |
| Population growth | -0.562*** | -0.822*** | -0.046** | -0.561*** | -0.837*** | -0.932** |
| | (0.110) | (0.169) | (0.020) | (0.201) | (0.185) | (0.453) |
| Natural disasters | -0.321*** | -0.394*** | 0.013 | -0.218*** | -0.166*** | 0.023 |
| | (0.070) | (0.067) | (0.015) | (0.058) | (0.049) | (0.026) |
| Inflation | -0.175*** | -0.100*** | -0.010*** | -0.156** | -0.017 | 0.003 |
| | (0.038) | (0.030) | (0.003) | (0.064) | (0.052) | (0.027) |
| Agri. Productivity | 0.007*** | 0.009*** | 0.001*** | 0.005** | 0.002 | 0.011*** |
| | (0.001) | (0.002) | (0.000) | (0.002) | (0.003) | (0.002) |
| Landlocked | 0.016 | 0.025 | -0.001 | -0.121*** | -0.033 | -0.037 |
| | (0.010) | (0.016) | (0.002) | (0.043) | (0.054) | (0.056) |
| Constant | 19.653 | -517.651*** | 121.639*** | 306.152*** | 916.750*** | 753.158*** |
| | (133.662) | (185.779) | (22.002) | (221.044) | (257.355) | (262.206) |
| Observations | 442 | 414 | 442 | 414 | 414 | 414 |
| Number of countries | 37 | 37 | 37 | 37 | 37 | 37 |
| Number of instruments | 21 | 21 | 21 | 21 | 21 | 21 |
| AR1 test | 0.001 | 0.001 | 0.000 | 0.013 | 0.003 | 0.000 |
| AR2 test | 0.724 | 0.930 | 0.347 | 0.240 | 0.754 | 0.151 |
| Hansen test | 0.515 | 0.260 | 0.412 | 0.241 | 0.099 | 0.607 |
| Diff-Hansen | 0.841 | 0.292 | 0.656 | 0.092 | 0.173 | 0.169 |

[a] For each regression, at most three instrumented variables with at most two lags are included. The number of instruments reported is based on the number of "collapsed" instruments, using the xtabond2 specification of Roodman [71]

[b] Diff-Hansen test reports the p-values based on the null hypothesis that the instruments in the levels equation are exogenous. [c] Standard errors are reported in parentheses

*** Significant at 1%, ** significant at 5%, * significant at 10%

Source: Authors based on data, 2022

must be the case for the GMM estimator to be consistent. The Hansen test does not reject the over-identifying restrictions (exogeneity of instruments) at conventional levels of significance, indicating that the instruments are valid. The Difference-in-Hansen test suggests that the (additional) assumption of System-GMM is not violated and the additionally introduced instruments are valid, lending further support to the statistical properties of the results. Furthermore, the lagged of dependent variables [ADESA (-1) and APS (-1)] are significant and their magnitudes reveal that food security levels change only slowly over time and depend on past levels. This justifies the relevance of the estimation by a dynamic panel.

The estimates reported in Table 4 show that trade openness and globalization have a significant positive influence on food security in Sub-Saharan Africa. This effect is amplified when we introduce the control for corruption into the model. In this respect, improved trade openness improves food security in Sub-Saharan Africa. Column 1 of Table 4 shows, for example, that improving trade openness by one percent (1%) would increase the adequacy of average dietary energy intake by 0.018. In the long run, this increase would be estimated at 0.67 [0.018/(1–0.973)]. Therefore, a one standard deviation increase in trade openness leads to an improvement in intake adequacy of 27.45 kcal in Sub-Saharan Africa. A similar result is also observed for average protein supply, but relatively lower.

The positive effect of trade openness on food security in Sub-Saharan Africa can be explained by the availability of food products. Indeed, the majority of Sub-Saharan African countries have a food deficit [16]. Trade openness will allow these countries to import food and thus improve their food security through food availability. Trade openness can also be a source of food diversity and quality. Indeed, trade openness will allow consumers to access new markets and have a greater variety of quality products at lower costs [21]. In addition, firms are forced to provide high-quality ranges of food and non-food goods to sell on international markets [17]. It can also be a source of increased supply of inputs and externalities in Sub-Saharan Africa [19]. Finally, the accessibility and transfer of technology will also be improved by trade openness, which will enhance food security. The importance of technology trade in improving food security in Sub-Saharan Africa has been revealed by Gordon [72] and Hertel et al. [73]

Gillson & Fouad [74] and Clapp [75] have confirmed the positive relationship between trade openness and food security. Through the system-GMM estimation method, Dithmer & Abdulai [35] also showed that trade openness positively and significantly affects food consumption with a relatively small effect for Sub-Saharan African countries. A similar result is also obtained by Hoddinott & Yohannes [76] for 10 developing and middle-income countries in the world. Taking the example of the European Union countries, Fusco et al. [34] using a dynamic panel over the period from 2000 to 2017, showed that trade openness has a net positive effect on food security regardless of the robustness test.

However, the positive effect of trade openness on food security in our study is in contradiction with some previous studies. Indeed, no significant effect of trade openness on food availability is found in some African countries [33]. Some authors such as Bezuneh & Yiheyi [33] and Mary [77] found a negative effect between food security and trade openness. In a comparative study of Economic and Monetary Community of Central Africa (CEMAC) and West African Economic and Monetary Union (WAEMU) countries over the period 1987 to 2014, Assoumou-Ella & Eba-Nguema [39] found that trade openness harms the food security overall. However, considering only availability, there is a visible effect of trade openness. Finally, Rahman et al. [78] found mixed results for South Asian countries. For these authors, trade openness can hinder diversification, increase the vulnerability of countries due to their dependence on international trade, or have profound repercussions on the environment, nutrition, and health of the population, which will undermine the food security of countries. Moreover, trade openness implies the specialization of economies, considering their comparative advantage. However, small-scale producers in developing countries are not in a position to specialize in this way. As a consequence, trade liberalization can undermine local production, making these producers less competitive [79, 80].

Table 4 highlights the importance of the control variables. The quality of institutions is a crucial element for food security in Sub-Saharan Africa [81]. Indeed, the estimates show that the Corruption variable has a positive effect on food security. This means that an improvement in the problem of corruption in SSA could contribute to an improvement in the level of food security. This result corroborates the work of Ogunniyi et al. [61] who

showed that controlling corruption improves food security in Sub-Saharan Africa. Indeed, poor governance is a source of inequalities in access to natural resources and services. This ultimately reduces the performance of institutions and actors in marginalized sectors, as well as the expected results of economic policies [82].

The food security of a country depend on whether the country is landlocked or not. Our estimates show that being landlocked has a significant negative impact on food security. This result shows the importance of maritime trade in food security. Indeed, maritime trade represents more than 80% of the volume of international merchandise trade for some developing countries [47]. In this sense, landlocked countries are likely to be food insecure, as they may face persistent problems in accessing international markets [48]. However, this result must be put into perspective, as high agricultural productivity in these countries can strengthen their food security. Indeed, our results reveal that agricultural productivity positively affects food security. This means that all other things being equal, an increase in agricultural productivity can favour food security in Sub-Saharan Africa.

However, a commendable effort must be made to combat natural disasters, which in turn hurt food security. Indeed, the intensity of natural disasters affects populations and their livelihoods by causing huge losses in human lives and the destruction of agricultural or non-agricultural infrastructure necessary for their survival [89]. The impacts of these disasters are expected to be greater in potentially agricultural countries [83]. The results of our estimates are consistent with those of Haen & Hemrich [46] who showed that natural disasters can affect all four dimensions (availability, accessibility, stability, and utilization) of food security. Inflation also erodes people's purchasing power by preventing them from accessing food goods even if they are available in the market [84]. In doing so, price instability will increase the level of food insecurity in countries [85].

The fact that population growth will have an undesirable impact on food availability remains true for the level of food security in Sub-Saharan African countries. Obviously, population growth will create an additional demand to be satisfied, which will affect food availability. The lack of satisfaction with this demand may even lead to conflicts over natural resources, affecting all dimensions of food security [86]. This result corroborates the thesis defended by Malthusians that population growth affect food availability [87]. Molotoks et al.[88] also found that population growth remains the main driver of changes in the prevalence of undernourishment, and that countries with rapid population growth tend to experience the worst impacts on their food security. However, in the presence of technology, productivity improvements can counteract the negative impact of population growth on food availability [89].

According to our results (Table 4), if countries focus on investment in human capital, good management of migrant remittances, and more investment in the agricultural sector, they can improve their level of food security. Indeed, if remittances increase by about 1 percent of GDP, food security can improve by 0.76 percent (column 2) when referring to dietary energy supply adequacy (ADESA) and by 0.36 g/cap/day (column 5) for average protein supply (APS). Indeed, remittances constitute an additional source of income for the households that receive them. Similar findings were also reported for Sub-Saharan Africa by Sulemana et al. [90] who identified that receiving international remittances is positively associated with more household food security, and the frequency of receiving remittances matters more for this relationship. However, a negative link for the availability dimension of food security was also identified in African Countries [91]. A high level of education significantly reduces food insecurity [97, 98]. Education improves productivity and income, as well as access to other essential factors needed to promote food security [93].

In developing countries in general and in Sub-Saharan Africa in particular, the quality of institutions is a critical element for food security. This is revealed by the results of the interaction between the variables of institutional quality and trade openness on food security in Sub-Saharan African countries (Table 5). Indeed, when governance is effective and the country participates in international trade (openness*governance), there is a more effective improvement in its level of food security. Similar findings are also noted when corruption is

controlled, and the country is open to the rest of the world (openness*corruption). However, in the presence of political instability, even if the country is open to the rest of the world, there is a decline in the level of food security in the country. Previous studies have also emphasized the importance of the quality of institutions for good food and nutrition security in countries of Sub-Saharan Africa [61, 94].

Finally, the estimates in Table 5 show that landlocked countries that are open to the rest of the world have seen their food security improve. Indeed, a landlocked but open country (openness*Landlocked) can benefit from the advantages of trade through imports of products to fill the gap in food availability, which could easily increase its food security level [95]. Thus, regional and continental initiatives such as the African Continental Free Trade Area should enable landlocked countries to proactively and effectively address the food security and nutrition challenges they face [95].

#### *Robust testing of food security indicators*

To ensure the effectiveness of our results, we used two different indicators than those used in Tables 4 and 5. These are Per Capita Food Supply Variability (PCFSV) and Share of Dietary Energy Supply (SDES). The effect of trade openness and globalization remains the same. Indeed, Table 6 shows that trade openness and globalization have a positive effect on food security when both indicators are considered. In contrast, the effect of controlling corruption remains mixed. The effects of the other variables remain unchanged. Thus, education, remittances, economic growth, and agricultural productivity have a positive effect on food security. Variables like population growth, being a landlocked country, natural disasters, and inflation contribute negatively to food security in Sub-Saharan Africa. Population growth may affect food availability and other dimensions of food security because of the additional unmet demand created by this growth [96]. Landlocked countries, will face difficulties in closing their food gap; this could affect their food security [97]. However, natural disasters can affect all dimensions of food security by affecting production, income, and vital infrastructure in countries [98]. These results confirm the robustness of the food security indicators previously employed.

## Conclusion and policy implications

In the context of higher food insecurity in the world, this paper re-examines the effect of trade openness on food security in Sub-Saharan Africa. A cylindrical panel of 37 countries from 2004 to 2018 was mobilized. The effect of trade openness on food security was estimated using the two-step System-GMM approach.

The results have revealed that trade openness has a positive effect on food security in Sub-Saharan Africa, regardless of the food security indicator considered. This effect remains invariant with the use of the globalization index as the robustness of trade openness on food security. The results in the presence of institutional quality variables show that the effect of trade openness on food security is more robust. The interactions of trade openness and institutional quality show that the effect of trade openness can be canceled out and even become negative in the presence of political instability.

The results suggest that an improvement in the level of food security in Sub-Saharan African countries can be achieved through trade openness, with a particular emphasis on the quality of institutions. However, trade openness can have a perverse adverse effect because it exposes the country to external shocks. For this reason, trade openness should not be seen as a substitute for agricultural measures to address food insecurity at the national and regional levels, as agricultural added value and agricultural productivity are other factors that enhance food security in Sub-Saharan African countries.

## Appendix

See Tables 7 and 8

**Table 7** Correlation between food security variables and their lag

| | ADESA (-1) | APS (-1) | SDES (− 1) | PCFSV (− 1) |
|---|---|---|---|---|
| ADESA | 0.9724*** | | | |
| APS | | 0.6433*** | | |
| SDES | | | 0.7229*** | |
| PCFSV | | | | 0.8066*** |

Source: Authors based on data, 2022

**Table 8** Correlation of explanatory variables in the models

| | Openness | Corruption | Remittances | EDUC | Log (DGP) | SADGP | POP growth | IND | IPC | Agri. product | Landlocked |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Openness | 1 | | | | | | | | | | |
| Corruption | 0.2931* | 1 | | | | | | | | | |
| Remittances | 0.0477 | 0.1339 | 1 | | | | | | | | |
| EDUC | 0.2272 | 0.4123 | 0.0921 | 1 | | | | | | | |
| Log (DGP) | 0.4673** | 0.4014 | − 0.1140 | 0.3719 | 1 | | | | | | |
| SADGP | − 0.4296* | − 0.4548 | − 0.0663* | − 0.313 | −0.6829 | 1 | | | | | |
| POP growth | − 0.3280 | − 0.4680** | − 0.3441 | − 0.445 | − 0.4207 | 0.4204 | 1 | | | | |
| IND | 0.1008 | 0.0233 | 0.0836 | − 0.024* | − 0.0098* | − 0.0019 | − 0.0410 | 1 | | | |
| IPC | − 0.0681 | − 0.0496 | − 0.0717 | − 0.044 | − 0.0607 | 0.0075 ** | 0.0584 | − 0.0103* | 1 | | |
| Agri. product | 0.0421* | 0.1309 | -0.1837 * | 0.3361 | 0.1930** | − 0.1558 | − 0.1917** | − 0.0992 | − 0.0215* | 1 | |
| Landlocked | − 0.0478*** | 0.1319 | 0.0218 | − 0.0521 | − 0.2813 | 0.1168 | − 0.0571 | 0.1422 | − 0.0707 | − 0.1764*** | 1 |

Source: Authors based on data, 2022

## Appendix

See Fig. 3


**Fig. 3** Map of landlocked countries in the study. Source: authors from https://unctad.org/topic/landlocked-developing-countries/map-of-LLDCs

### Abbreviations

| | |
|---|---|
| ADESA | Average dietary energy supply adequacy |
| APS | Average protein supply |
| CEMAC | Economic and Monetary Community of Central Africa |
| CEPII | Research and Expertise on the World Economy |
| EM-DAT | International Disasters Database |
| FAO | Food and Agriculture Organization of the United Nations |
| GDP | Gross domestic product |
| GMM | Generalized Method of Moments |
| PCFSV | Per capita food supply variability |
| SDES | Share of dietary energy supply |
| WAEMU | West African Economic and Monetary Union |
| WDI | World Development Indicators |
| WGI | Worldwide Governance Indicators |

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### Author contributions

Kodjo Théodore GNEDEKA had the original idea for the paper, he collected and analysed the data and wrote the first draft. Kwami Ossadzifo WONYRA contributed to improving the methodology, and subsequent drafts and both authors read, approved, and revised integrally the final manuscript.

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### Availability of data and materials

The dataset was found on the websites of the following organizations/institutions: FAO: https://www.fao.org/faostat/en/#data/FS World Bank: https://databank.worldbank.org/source/world-development-indicators EM-DAT: https://public.emdat.be KOF Swiss Economic Institute: https://kof.ethz.ch/en/forecasts-and-indicators/indicators/kof-globalisation-index.html.

## Declarations

### Ethics approval and consent to participate

Not applicable.

### Consent for publication

Not applicable.

### Competing interests

The authors declare that they have no competing interests.

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