“Food security, prices, and geopolitical risk: A dynamic panel threshold model”

AUTHORS	Samer Mehibel Reda Hamza Boudjana Manuel A. Zambrano-Monserrate Amel Bouzid Messaoud Lazereg

ARTICLE INFO	Samer Mehibel, Reda Hamza Boudjana, Manuel A. Zambrano-Monserrate, Amel Bouzid and Messaoud Lazereg (2025). Food security, prices, and geopolitical risk: A dynamic panel threshold model. *Geopolitics under Globalization*, *6*(1), 30-44. doi:https://doi.org/10.21511/gg.06(1).2025.04
DOI	https://doi.org/10.21511/gg.06(1).2025.04
RELEASED ON	Friday, 19 September 2025
RECEIVED ON	Wednesday, 25 June 2025
ACCEPTED ON	Friday, 05 September 2025
LICENSE	This work is licensed under a Creative Commons Attribution 4.0 International License
JOURNAL	"Geopolitics under Globalization"
ISSN PRINT	2543-5493
ISSN ONLINE	2543-9820
PUBLISHER	LLC “Consulting Publishing Company “Business Perspectives”
FOUNDER	Sp. z o.o. Kozmenko Science Publishing

NUMBER OF REFERENCES	NUMBER OF FIGURES	NUMBER OF TABLES
69	0	5

BUSINESS PERSPECTIVES

LLC "CPC "Business Perspectives"
Hryhorii Skovoroda lane, 10,
Sumy, 40022, Ukraine
www.businessperspectives.org

Samer Mehibel (Algeria), **Reda Hamza Boudjana** (Algeria),
Manuel A. Zambrano-Monserrate (Ecuador), **Amel Bouzid** (Algeria),
Messaoud Lazereg (Algeria)

FOOD SECURITY, PRICES, AND GEOPOLITICAL RISK: A DYNAMIC PANEL THRESHOLD MODEL

Abstract

Food security is a major worldwide concern that has received heightened focus due to the COVID-19 pandemic, which disrupted global food supply chains and agri-food value networks. This paper seeks to determine the threshold at which food security is considered vulnerable to geopolitical shifts. Thus, using a dynamic panel threshold model on a sample of 40 countries, covering both advanced and emerging economies, this paper explores the link between food security – measured by the Global Food Security Index (GFSI) and its four key pillars (affordability, availability, quality and safety, sustainability and adaptation) and geopolitical tensions, represented by the Geopolitical Risk Index (GPRI), over the period from 2012 to 2021. The analysis also accounts for key variables such as agricultural land use, the impact of COVID-19, shares of urban population, price levels, and GDP per capita. The main findings indicate that the inflationary impact of geopolitical risk is statistically significant. A point (threshold value) of 0.022 was identified for geopolitical risk, beyond which global food security is substantially weakened due to increased inflation. The findings reveal that geopolitical risks exacerbate price surges across key commodities, including fertilizers, food, and oil, thereby amplifying inflationary pressures arising from fiscal measures taken in response to geopolitical shocks. Moreover, elevated geopolitical risks heighten uncertainty regarding the inflation outlook, complicating trade-offs between monetary and fiscal policies.

Keywords food security, inflation, geopolitical risks, pandemic, dynamic panel threshold model

JEL Classification C23, E31, F40, Q17, Q18

Type of the article: Research Article

Received on: 25th of June, 2025
Accepted on: 5th of September, 2025
Published on: 19th of September, 2025

Samer Mehibel, Dr., Economic Policies and Macroeconomic Modeling Research Team, Macroeconomics and Economic Integration Research Division, Centre de Recherche en Economie Appliquée pour le Développement (CREAD) [Centre for Research in Applied Economics for Development (CREAD)], Algeria. (Corresponding author)

Reda Hamza Boudjana, Dr., Growth and Development Research Team, Macroeconomics and Economic Integration Research Division, Centre de Recherche en Economie Appliquée pour le Développement (CREAD) [Centre for Research in Applied Economics for Development (CREAD)], Algeria.

Manuel A. Zambrano-Monserrate, Dr., Professor, Faculty of Entrepreneurship, Business and Economics, Universidad Espíritu Santo [Espiritu Santo University], Ecuador.

Amel Bouzid, Dr., Diagnosis, Analysis and Agroeconomic Modeling Research Team, Agriculture, Territory and Environment Research Division, Centre de Recherche en Economie Appliquée pour le Développement (CREAD) [Centre for Research in Applied Economics for Development (CREAD)], Algeria.

Messaoud Lazereg, Research Associate, Dynamics of Agricultural Production Systems Research Team, Agriculture, Territory and Environment Research Division, Centre de Recherche en Economie Appliquée pour le Développement (CREAD) [Centre for Research in Applied Economics for Development (CREAD)], Algeria.

Conflict of interest statement:
Author(s) reported no conflict of interest

INTRODUCTION

Food security has become an increasingly critical issue for global stability, threatened by a complex interplay of geopolitical tensions, economic volatility, and environmental challenges. Worldwide, most countries depend heavily on imports of raw materials, fertilizers, and foodstuffs to sustain their populations, rendering them vulnerable to fluctuations in global markets, political conflicts, and climate-related disruptions (FAO et al., 2022; Headey & Fan, 2010). These vulnerabilities are amplified by the globalization and increasing complexity of food supply chains, which are sensitive to geopolitical events and economic shocks (Erokhin & Gao, 2020; Wellesley et al., 2017).

Recent geopolitical developments have had profound impacts on food systems at multiple levels. The war between Russia and Ukraine, two key global suppliers of grains and vegetable oils, has generated unprecedented destabilization in international agricultural markets, leading to sharp price increases and heightened food insecurity, particularly in low- and middle-income countries dependent on food imports via geopolitical hotspots (Behnassi & El Haiba, 2022; Magnan, 2017).

Concurrently, the COVID-19 pandemic triggered severe disruptions in logistics and production capabilities, exacerbating existing stresses on food access and affordability (Laborde et al., 2021; Ma et al., 2021).

The dynamics of food security are further complicated by macroeconomic factors, such as inflation and income inequality, which mediate the effects of external shocks on diverse dimensions of food availability, accessibility, quality, and sustainability (Espinoza et al., 2012; Ostry et al., 2014). Moreover, environmental pressures, including water scarcity, nutrient limitations, and climate volatility, pose additional risks to food system resilience and equity (Cordell & White, 2015; Foley et al., 2011; Springmann et al., 2018). At the global scale, geopolitical competition and economic interdependence are reshaping the governance and stability of food supply chains, as documented in recent assessments by the World Economic Forum and related studies (Ridder et al., 2013; WEF, 2023).

Given the multifaceted challenges confronting food security, understanding the critical intersections of geopolitical risk, economic conditions, and environmental factors is essential for shaping robust policy responses. This relevance is underscored by the increasing recognition of food security as a key domain of geopolitical strategy and international cooperation in the context of growing global uncertainties (Hopkins & Puchala, 1978; Yearley, 2013).

While existing studies have documented the direct impacts of supply shocks and macroeconomic instability on food access, less attention has been paid to the non-linear and regime-dependent nature of these effects. By capturing both short-term persistence and threshold effects, the analysis contributes a nuanced understanding of how shocks propagate through global food systems.

More precisely, three main additions are made in this paper. Firstly, we conduct an empirical analysis of the link between food security and geopolitical risk, utilizing the most recent data possible, focusing on the Global Food Security Index (GFSI) and the Geopolitical Risks Index (GPRI). Secondly, our results extend previous research by investigating the impact of geopolitical events on food security and the key macroeconomic indicators (Behnassi & El Haiba, 2022; Friedma & McMichael, 1989; Iacoviello et al., 2024; Saboori et al., 2022). Third, this work is to our knowledge the first effort to determine a point (threshold) for the Geopolitical Risks Index (GPRI) beyond which major economic metrics, particularly inflation and food security, are significantly affected. To achieve this, we use a Dynamic Panel Threshold model.

1. LITERATURE REVIEW

The nexus between geopolitical risk and food security has attracted scholarly attention across multiple disciplines, reflecting the multifaceted ways in which political instability and conflict reverberate through economic and social systems. Early research documented broad impacts of geopolitical tensions on financial markets (Hoque & Zaidi, 2020; Rupeika-Apoga & Wendt, 2022; Yang et al., 2021), banking sectors (Phan et al., 2022), and tourism (Balli et al., 2019), with emerging work identifying agriculture and commodity markets as particularly sensitive domains (Micallef et al., 2023; Saâdaoui et al., 2022). However, studies focused explicitly on the agricultural sector's response to geopolitical shocks remain limited (Tiwari et al., 2021), motivating more specialized examination of these complex interactions. Several investigations highlight how geopolitical tensions influence commodity price volatility, with Tiwari et al. (2021) employing a copula approach over nearly three decades to reveal significant co-movements between energy and key agricultural markets under varying risk conditions. This finding is corroborated by Cunado et al. (2020), who analyzed the time-varying effects of geopolitical risks on oil prices. These results underscore the systemic nature of shocks that transcend traditional sectoral boundaries.

Within the domain of food security, the concept itself has evolved significantly since the 1970s,

https://doi.org/10.21511/gg.06(1).2025.04

profoundly shaped by crises such as the 1974 global food shortage (FAO et al., 2022) and subsequent debates on demographic pressures (Ehrlich, 1968). The geopolitical instrumentalization of food resources is emphasized in seminal works such as Paarlberg (1978) and Hopkins and Puchala (1978), who positioned control over food production and distribution as crucial to national security (Clapp, 2017; Orme, 1997; Wallensteen, 1976). Contemporary challenges, including the global financial crises of 2007–2008 and 2011–2012, alongside rising geopolitical fault lines among major powers (Zhou et al., 2020), have further politicized food security, complicating governance and international cooperation.

More recently, the 2019 World Economic Forum's Global Risks Report highlighted the increasing frequency of "geopolitically motivated food-supply disruptions," warning of the obstacles posed by geopolitical competition to collaborative hunger alleviation efforts. These dynamics are particularly acute in regions vulnerable to water scarcity and critical input deficiencies such as phosphorus, with substantial reserves concentrated in geopolitically sensitive areas like Morocco and Western Sahara (Cordell & Neset, 2014; Nanda et al., 2019).

Armed conflicts directly degrade food security outcomes, as evidenced by enduring crises in conflict-affected zones where undernutrition remains high (Pettersson & Öberg, 2020). The use of food deprivation as a deliberate tactic in conflicts, as documented in UN Security Council resolutions, further disrupts accessibility and supply chain stability (Brück & d'Errico, 2019; Conley & de Waal, 2019). Melander et al. (2016) illuminate the increasingly internationalized character of such conflicts, linking geopolitical risk directly to food system vulnerabilities.

Nonetheless, much of the extant literature treats geopolitical risk either as a binary factor or assumes linear effects, neglecting the regime-dependent and nonlinear interactions that characterize real-world dynamics. This gap is notable given empirical observations in development economics that inflationary volatility and economic regimes fundamentally condition shock transmission (Headey & Fan, 2010).

In summary, while the literature robustly documents the multifaceted nature of geopolitical risk and its implications for food security, it remains dispersed across various domains and methodologies. Crucially, prior research lacks comprehensive models accommodating dynamic thresholds and non-linearities reflecting the empirical complexities of this nexus. This review highlights the need for dynamic, non-linear modelling approaches that capture such complexities, enabling nuanced policy insights.

Accordingly, this study aims to examine how geopolitical risk interacts with inflation-driven regime shifts to influence multiple dimensions of food security across diverse economies.

2. METHODS

We find it suitable to employ a panel data approach with a threshold effect. This approach permits to analyze a sample consisting of 40 nations (Argentina, Australia, Belgium, Brazil, Canada, Chile, China, Colombia, Denmark, Egypt, Finland, France, Germany, Hungary, India, Indonesia, Israel, Italy, Japan, Malaysia, Mexico, the Netherlands, Norway, Peru, the Philippines, Poland, Portugal, Russia, Saudi Arabia, South Africa, South Korea, Spain, Sweden, Switzerland, Thailand, Tunisia, Turkey, Ukraine, the United Kingdom, and the United States), including 17 advanced economies and 23 emerging market economies, for the period 2012–2021.

Two types of exogenous variables are considered in our model. The first category pertains to the variable representing the threshold (Geopolitical Risk Index (GPRI)). This aids in identifying whether an asymmetric threshold effect is present. Control variables are included in the second category: GDP (Gross Domestic Product) per capita, inflation, arable land, urban population, income inequality, purchasing power parity, total factor productivity, and CO_2 emissions per capita in metric tons (Table 1).

The sample selection was determined the availability of statistical data. We retrieved FSI from the Global Food Security Index database. GPRI by Caldara and Iacoviello (2022) measures detrimen-

 https://doi.org/10.21511/gg.06(1).2025.04

Table 1. Data description

Variable			Description
Dependent variables		fsi	The Index of Food Security
		fsi_aff	The Index of Food Security: Affordability
		fsi_ava	The Index of Food Security: Availability
		fsi_qsa	The Index of Food Security: Quality and Safety
		fsi_sus	The Index of Food Security: Sustainability and Adaptation
Independent Variables	Regime-dependent variable	inf	The inflation rate (annual %)
	Regime-independent variables	dcovid	This dummy variable takes on a value of 0 for the pre- and post-coronavirus periods (2012–2018) and after 2021, while for the coronavirus period (2019–2020), it takes on a value of 1
		arable_land	Arable land (% of land area)
		urb_pop	The rate of urbanization (% of total population)
		income inequality	Corresponds to the income of the top 10% income share divided by the total for the whole population
		ppp	Purchasing Power Parity
		tfp_index	Total Factor Productivity Index of the agricultural sector
		co2emissions	CO2 emissions per capita by metric tons
		lgdppc	Logarithm of the real GDP per capita
Threshold variable		gpri	The Geopolitical Risks Index

tal geopolitical developments and corresponding risks measured by analyzing the frequency of news articles about geopolitical tensions. Its evolution and economic impacts were monitored since 1900. Data on income inequality were gathered from the World Inequality Database, while data on CO2 emissions per capita, arable land, Purchasing Power Parity (PPP), GDP per capita, and urban population were sourced from the World Bank Database (WB). Total Factor Productivity (TFP) for the agricultural sector was sourced from the US Department of Agriculture.

Unlike the approach used by Mehibel et al. (2024), we propose the dynamic panel threshold regression method introduced by Kremer et al. (2013) to investigate the possible nonlinear relationship between food security and inflation across 40 countries. This method builds upon the estimation of the static panel threshold by Hansen (1999) and the cross-sectional instrumental variables (IV) threshold model by Caner and Hansen (2004), integrating estimators of the Generalized Method of Moments (GMM) to address endogeneity concerns. The model is structured as follows:

$$fsi_{it} = u_i + \beta_1 z_{it} + \beta_2 \inf_{it} I\left(GPRI_{it} \le \gamma\right) + \beta_2 \inf_{it} I\left(GPRI_{it} > \gamma\right) + \varepsilon_{it}. \quad (1)$$

In this model, i denotes the countries in the cross-sectional analysis ($i = 1, \ldots, 40$), whereas t is for the time series dimension for each country ($t = 2012, \ldots, 2021$). The dependent variable, fsi_{it}, is the index of food security. The term, u_i is the country-specific fixed effect, while $\varepsilon_{it} \approx (0, \sigma^2)$ represents the independently and identically distributed (idd) error term. The indicator function, $I(.)$ specifies the regime, with the Geopolitical Risk Index, $GPRI_{it}$ serving as the threshold variable and, as the value of the threshold. Additionally, z_{it} is an m-dimensional vector of regime-independent explanatory variables, which may contain the (lagged) dependent variable and other endogenous ones. The vector containing explanatory variables is divided into a subgroup of exogenous variables, which are uncorrelated with ε_{it}, and a subset of endogenous variables, which are correlated with ε_{it} by Kremer et al. (2013).

In the first step of estimating the model in equation (1), the individual effects (i) are removed using a transformation of fixed effects. To achieve this, we employ the (forward) orthogonal deviation method proposed by Arellano and Bover (1995), as follows:

$$\varepsilon_{it}^{*} = \sqrt{\frac{T-1}{T-t+1}}\left[\varepsilon_{it} - \frac{1}{T-1}\left(\varepsilon_{i(t-1)} + \ldots + \varepsilon_{iT}\right)\right]. \quad (2)$$

This approach offers the benefit of mitigating serial correlation among the adjusted error terms, thereby facilitating the application of estimation procedures originally designed for cross-sectional models to dynamic panel data models.

The subsequent step in the procedure of estimation employs two-stage least squares (2SLS) to determine the Geopolitical Risk Index (GPRI) threshold level. Initially, we estimate a reduced-form regression for the endogenous variables (z_{2it}) using the instruments (X_{it}). The predicted values ($\hat{z}_{2it}$) derived from this regression are subsequently substituted for the endogenous variables ($\hat{z}_{2it}$) in the structural equation. Finally, we estimate the model in equation (1) via least squares for a fixed threshold (γ). This process is repeated for various subsets of the threshold variable (GPRI). The threshold that results in the smallest sum of squared residuals (SSR(γ)) is identified as the most suitable threshold value ($\hat{\gamma}$) Equation (3) makes clear this process (Hansen, 2000).

$$\hat{\gamma} = \arg\min SSR(\gamma). \qquad (3)$$

Building on Hansen's (1999) earlier contribution, and then both Caner and Hansen (2004) and Kremer et al. (2013), a critical value is estimated under a 95% confidence interval for the geopolitical risk threshold value. These critical values are computed using equation (4):

$$\Gamma = \{\gamma : LR(\gamma) \le C(\alpha)\} \qquad (4)$$

where Γ represents the set of threshold values, $LR(\gamma)$ is the likelihood ratio for a specific (γ), and $C(\alpha)$ represents the critical value at the 95% confidence level.

In equation (4), $C(\alpha)$ represents the asymptotic distribution, and more precisely the 95th percentile of the likelihood ratio $LR(\gamma)$ Statistic. The last is adjusted to take into consideration the number of time periods for each cross section. Once the suitable ($\hat{\gamma}$) (threshold) value is identified in our dynamic panel model, the coefficients of the slope are found using the generalized method of moments (GMM) based on the previously determined instruments and estimated threshold.

In agreement with Arellano and Bover (1995) and Kremer et al. (2013), we use lagged values of the dependent variables (urb_pop, inf, CO2 emissions, and GDP per capita) as instruments. Choosing the number of delays (p) requires a trade-off between bias and efficiency for finite samples. Using all available IV lags ($p = t$) can improve efficiency, whereas reducing the number of lags to 1 ($p = 1$) can prevent overfitting of the instrumented variables and thereby potentially reduce bias in coefficient estimates.

3. RESULTS AND DISCUSSION

Before presenting the results of the estimation of our Dynamic Panel Threshold model, Table 2 shows the summary statistics of the main variables utilized in the analysis.

The information reported in Table 2 spans the years 2012–2021. For the countries in the sample, the geopolitical risk index (GPRI) has an average of 0.23, a maximum of 2.62, and a standard de-

Table 2. Descriptive statistics summary

Variables	Observations	Mean	Standard deviation	Minimum	Maximum
fsi	360	69.74	8.01	49.50	84.30
fsi_aff	360	82.42139	9.591702	51.4	94.2
fsi_ava	360	63.04278	8.164462	36	81.7
fsi_qsa	360	76.60306	9.797627	46.7	89.5
fsi_sus	360	55.74306	11.61226	28.2	87.4
inf	360	3.744304	6.501382	−2.093333	53.55
gpri	360	0.2338862	0.3949632	0.0056394	2.627627
urb_pop	360	74.90	14.59	31.63	98.08
tfp_index	360	100.77	8.52	74.27	179.67
Income inequality	360	0.43	0.10	0.29	0.66
ppp	360	182.84	721.58	0.54	4847.45
arable_land	360	18.44	15.60	1.28	60.80
co2emissions	360	6.50	4.04	0.88	17.41
lgdppc	360	9.70	1.05	7.20	11.38

 https://doi.org/10.21511/gg.06(1).2025.04

viation of 0.395, indicating small differences in GPRI among sample countries. Among all the FSIs (FSI and its pillars), FSI has the smallest standard deviation, while food security under 'sustainability and adaptation' aspects shows the highest. Additionally, most variables exhibit variances smaller than their means, suggesting relatively low dispersion and good stability in the sample. However, PPP stands out with a notably high standard deviation compared to its mean. Conversely, both GPRI and inflation show a slight increase in variance compared to their means.

It is essential as a first step to conduct a linearity test (Table 3) to ascertain the nonlinear nature of the food security-inflation relationship. The null hypothesis of the LM, LMF, and LRT tests across all estimated models is strongly rejected at the 1% significance level. This outcome suggests that inflation exerts nonlinear effects on the food security index and its sub-indices under varying levels of geopolitical risk. Consequently, it is appropriate to proceed with estimating the Dynamic Panel Threshold regression model to explore this relationship in greater detail.

Since we use the Dynamic Panel Threshold model, it is mandatory to identify the value of the threshold. In this regard, Table 4 displays the "single" threshold test findings together with bootstrap p-values. Using the global food security index (FSI), the test statistic is significant at 5%.

The levels of significance for food security for affordability, availability, quality and safety and sustainability and adaptation are always 5%. Therefore, it is possible to observe that there is only one threshold in the model's estimation; as a result, only one significant threshold is used due to the small number of observations (N = 400) in the analysis.

Following confirmation that there is just one threshold, we proceeded to estimate its value. Table 4 indicates that the threshold for FSI is estimated at 0.021, falling between the lower (0.01) and upper (0.91) confidence limits at a 5% significance level. The estimated thresholds for the pillars of the food security index are as follows: 0.28 (affordability), 0.015 (availability), 0.27 (quality and safety), and 0.032 (sustainability and adaptation), with respective significance levels of 5%, and respective confidence intervals (lower (L) and upper (U) bounds): 0.19 to 0.35, 0.01 to 0.91, 0.07 to 0.91, and 0.02 to 0.32.

Table 3. Linearity tests

Models	Tests	Statistics	P-values
FSI	Lagrange multiplier (LM_w)	44.013	0.001***
	Fisher Test (LM_F)	2.089	0.000***
	Likelihood-ratio test (LR)	46.945	0.000***
FSI_aff	Lagrange multiplier (LM_w)	48.949	0.000***
	Fisher Test (LM_F)	2.361	0.001***
	Likelihood-ratio test (LR)	52.613	0.000***
FSI_ava	Lagrange multiplier (LM_w)	42.137	0.005***
	Fisher Test (LM_F)	2.231	0.000***
	Likelihood-ratio test (LR)	51.768	0.000***
FSI_qsa	Lagrange multiplier (LM_w)	44.489	0.001***
	Fisher Test (LM_F)	2.115	0.004***
	Likelihood-ratio test (LR)	47.487	0.001***
FSI_sus	Lagrange multiplier (LM_w)	53.885	0.000***
	Fisher Test (LM_F)	2.640	0.000***
	Likelihood-ratio test (LR)	58.372	0.000***

Note: *** represents statistical significance at the 1%.

Table 4. Estimation of the threshold

Variables	fsi	fsi_aff	fsi_ava	fsi_qsa	fsi_sus
Threshold	0.022	0.28	0.015	0.27	0.032
95 %Confidence interval	[0.01;0.91]	[0.19; 0.35]	[0.01;0.91]	[0.07; 0.91]	[0.02;0.32]

In light of the estimated threshold value, the sample can now be divided into two groups based on two regimes. Accordingly, observations are classified as falling below and above the threshold. For the FSI, 11.11% of values fall below the threshold over a period of 10 years, while the other group comprises 88.89% of observations exceeding the threshold. The % for the FSI pillars are as follows:

- FSI_affordability: 0.56% under and 19.44% over;
- FSI _availability: 6.87% under and 93.13% over;
- FSI_quality and safety: 77.19% under and 22.81% over;
- FSI_sustainability and adaptation: 20% under and 80% over.

Table A1 (Appendix A) shows how important geopolitical risk is to inflation and how it changes over time. Our model results demonstrate the regime-dependent and independent variables' effects on food security, distinguishing those that contribute positively or negatively. Contrary to our expectations, we found that the coefficient of the lagged threshold variable (GPRI) was only significant in one regression (food security 'affordability'), where its impact was negative.

Including the lagged dependent variables (FSI and its four pillars) proved beneficial, with each showing significant positive contributions in their respective regressions, except for food security 'affordability', where the lagged variable was not significant. Across all regressions, GDP per capita coefficients positively contribute in a consistent manner to global food security and its pillars. Specifically, coefficients for 'affordability' and 'availability' were estimated at 10.70/11.39 and 12.43, respectively. These results were observed when the lagged threshold variable was included in the regressions. Notably, the smallest coefficient for the lagged threshold variable occurred in the 'quality and safety' regression, while the highest was in 'sustainability and adaptation'.

Excluding the lagged threshold variable (GPRI) resulted in different outcomes: coefficients for GDP per capita decreased in regressions for global food security, 'affordability', and 'sustainability and adaptation', but increased in 'availability' and 'quality and safety' regressions.

The findings for the threshold variable 'inflation' were mixed. Below the threshold (low geopolitical risk), 'inflation' was significant in all regressions except for global food security, with a negative impact observed only in 'affordability'. Conversely, under low geopolitical risk conditions, 'inflation' had a positive effect on food security 'availability', 'quality and safety', and 'sustainability and adaptation', although the interpretation remains complex. In the upper side of the threshold (high geopolitical risk), 'inflation' was significant in all regressions except for food security 'availability', with negative effects noted in the main index of food security, its 'affordability' dimension, 'quality and safety' dimension, and 'sustainability and adaptation' dimension, aligning with findings from previous literature (Caldara & Iacoviello, 2022; Saboori et al., 2022). Iacoviello et al. (2024) observed that high geopolitical tension increases economic uncertainty, suppresses economic activity, raises military spending, increases public debt, and reduces trade. However, a positive contribution was observed only in the regression for food security 'sustainability and adaptation'.

Income inequality had a negative impact on food security 'affordability' but positively influenced food security 'sustainability and adaptation' when the lagged threshold variable was excluded. Purchasing power parity positively affected global food security, the 'affordability' dimension, and the 'availability' dimension, while negatively influencing the dimension 'sustainability and adaptation'.

The 'arable land' variable (% of land area) positively and significantly influenced global food security (without the lagged threshold variable), food security 'affordability', and food security 'sustainability and adaptation' (with the lagged threshold variable), suggesting that a larger percentage of arable land enhances food security.

The 'urban population' variable (% of total population) was significant only in explaining 'availability', with a negative impact, indicating that urban

https://doi.org/10.21511/gg.06(1).2025.04

population growth deteriorates food security by 0.718 points. The 'TFP index' generally contributed positively across all regressions, except for food security 'quality and safety' and food security 'availability' when the lagged threshold variable was included. As expected, 'CO_2 emissions per capita/metric tons' had a negative impact on all regressions except for food security 'affordability'.

The COVID-19 dummy variable was significant and negative in most regressions, except for food security 'availability' and food security 'sustainability and adaptation' when the lagged threshold variable was not included.

Finally, the model constant reflects the initial food security situation, remaining significant in global food security, food security 'sustainability and adaptation', and food security 'affordability' when the lagged threshold variable was included.

The present study set out to examine the conditional effects of geopolitical risk on food security through the lens of inflation-dependent regime shifts, applying a dynamic panel threshold framework to a balanced panel of 40 countries over the period 2012–2021. The results provide strong empirical evidence that the relationship between geopolitical risk and food security is non-linear, with adverse effects magnifying once inflation surpasses a critical level. This finding not only corroborates selected strands of the existing literature but also challenges others, thereby contributing to a more nuanced understanding of the geopolitics-food nexus.

Early macro-food security literature tended to treat geopolitical uncertainties as either binary shocks or as linear covariates in cross-sectional or static panel settings (Barrett, 2010). For example, in their global cross-country analysis, Guliyev et al. (2024) identify economic growth, demographic structure, and institutional quality as principal determinants of food security stability, arguing that demographic shifts dominate policy outcomes in the medium term. However, their approach treats geopolitical risk as a secondary, largely linear control variable. Our findings diverge in critical respects: by incorporating a dynamic panel threshold model, we are able to show that geopolitical risk effects are contingent (almost dormant in low-inflation regimes, but significantly disruptive once inflation breaches the estimated threshold). This observation aligns with inflation–volatility interaction theories in development economics and supports the contention that macroeconomic context critically conditions the transmission of shocks from the geopolitical to the food system (Headey & Fan, 2010).

Hamulczuk et al. (2023), focusing on the Russia–Ukraine war, emphasize that heightened macroeconomic volatility amplifies agri-food supply chain vulnerability and increases consumer price pass-through. Their approach, while insightful, implicitly assumes a uniform transmission mechanism across time and countries. Our results both support and refine their conclusion: we confirm the amplification effect, but only above well-defined inflation thresholds. This implies that in relatively stable price environments, even significant geopolitical events may have a muted direct effect on aggregate food security indices, whereas in inflationary contexts, their effects can cascade through affordability, availability, and quality-and-safety dimensions at an accelerated pace.

Similarly, the analysis by Bellemare (2015), which applies a conventional linear modelling framework to assess the economic and social repercussions of food price shocks often associated with geopolitical disruptions, concludes that such shocks tend to have broadly uniform adverse effects on market performance. Our findings challenge this homogeneous risk portrayal by revealing that the influence of geopolitical pressures varies substantially across macroeconomic contexts, with certain regimes proving more resilient than others. This regime-specific response underscores the value of tailoring crisis-management strategies to prevailing economic conditions rather than relying on one-size-fits-all approaches.

Beyond this core result, the estimated models highlight the significant and positive coefficients on lagged food security indices, except in the affordability dimension, pointing to a high degree of persistence in both favorable and adverse food system conditions. Such path dependence reflects dynamics noted in the work of Headey and Ecker (2013), reinforcing the argument that timely and well-targeted interventions are critical to preventing temporary setbacks from evolving into longer-term structural problems.

The robust role of GDP per capita in improving all pillars of food security mirrors earlier findings (Deaton, 2013; Ravallion, 2012), but the scale of coefficients in our threshold model indicates that income effects are particularly important in high-risk, high-inflation contexts, serving as a buffer against shock propagation.

Examining inflation's role in greater detail underscores its asymmetric influence across the FSI dimensions. Affordability exhibits the largest negative marginal effects; an above-threshold increase in inflation reduces the affordability index by up to 0.204 points when past geopolitical risk is excluded, a magnitude greater than for any other pillar. This is fully in line with theoretical models where sustained inflation erodes real incomes, disproportionately harming lower-income households' access to adequate food (Espinoza et al., 2012). On the supply side, inflationary surges often reflect war-related disruptions to trade in grain, energy, and fertilizers (Glick & Taylor, 2010), while on the demand side, heightened price uncertainty dampens consumer confidence and constrains dietary diversity.

The negative and often significant impacts of income inequality on affordability, contrasted with their occasional positive correlation with sustainability and adaptation scores, add a novel twist to conventional equity narratives. This heterogeneity may reflect investment patterns in higher-inequality economies, where elite capital can underwrite certain adaptive infrastructure as suggested by Gradín (2016), even as broad-based food access deteriorates. This duality has received scant attention in prior empirical work and warrants deeper investigation. The persistent and statistically significant negative effect of income inequality on food affordability aligns directly with robust cross-country evidence showing that higher inequality erodes welfare and social cohesion (Ostry et al., 2014; Wilkinson & Pickett, 2013) and with behavioral economic theories such as the Easterlin Paradox. High inequality depresses aggregate welfare gains from growth, undermines social cohesion, and often translates into spatial disparities in market access (Bor et al., 2017). Notably, the inclusion of the inequality variable in our regressions frequently attenuates the coefficients of other socio-economic controls, indicating that inequality acts as a structural filter through which other macroeconomic variables affect food security outcomes.

Land endowment also emerges as a non-trivial determinant of food security. The positive associations between arable land share and the affordability and sustainability/adaptation pillars, coupled with its positive effect on overall FSI (in the static specification), confirm FAO analysis linking domestic production capacity to price stability and reduced import dependency (FAO, 2020). However, the absence of statistical significance for arable land in the availability regression is unexpected. One plausible explanation is that in certain high-income or heavily trade-integrated economies, availability is maintained through imports and stock management, breaking the direct correlation with domestic cultivated area.

Another notable empirical pattern is the environmental dimension: CO_2 emissions per capita are negatively associated with multiple food security pillars, consistent with causal pathways identified by Foley et al. (2011) and more recently by Springmann et al. (2018), where environmental degradation compromises both the productive resource base (arable land, water availability) and food distribution networks through increased climatic volatility. Incorporating CO_2 emissions within our panel threshold design illustrates that environmental and geopolitical pressures may operate simultaneously and interact with macroeconomic instability in shaping food outcomes.

Turning to environmental pressures, the consistently negative effect of CO_2 emissions per capita across most dimensions of food security underscores the complex nexus between environmental degradation and food system resilience (Bilgili et al., 2020; Sutton et al., 2013). Elevated emissions typically signal energy- and input-intensive agricultural practices, industrial pollution, and urban encroachment on fertile land, all of which can erode productivity and food safety over time (Godfray & Garnett, 2014). Combined with climate-induced yield volatility, these processes undermine both the physical availability and

https://doi.org/10.21511/gg.06(1).2025.04

the affordability of food, particularly in import-dependent developing states. Our model's capacity to estimate these effects alongside geopolitical and macroeconomic variables highlights the multi-dimensional risk architecture confronting policymakers.

The inclusion of agricultural total factor productivity (TFP) further enriches the analysis, tying into the literature on productivity-driven resilience (Fuglie, 2018). Our results show strong positive TFP effects on affordability and availability, with magnitudes that remain substantial across regimes, implying that productivity gains offer a relatively stable protection against the worst impacts of geopolitical shocks, even when inflation is high. This stability of effect across thresholds contrasts with the volatility of geopolitical risk coefficients and strengthens the argument for continuous productivity investments as a core element of national food security strategies.

The COVID-19 dummy variable results align with emerging post-pandemic literature (Laborde et al., 2020; Laborde et al., 2021), confirming the disruptive potential of global health crises for food systems. However, here again, our dynamic specification adds texture: in some cases, the direct COVID-19 impact is significant only in conjunction with elevated inflation and/or heightened geopolitical tensions, underscoring the compounding nature of simultaneous systemic risks.

The disaggregated pillar analysis further reveals that the COVID-19 shock exerted pronounced negative effects on the affordability and quality and safety dimensions of food security. The reduction in affordability during 2019–2020 reflects both diminished households' purchasing power and greater vulnerability to retail price fluctuations, conditions consistent with consumer behavior models under crisis pricing (Daoudi & Bouzid, 2020). For quality and safety, the disruption of supply chains limited access to diverse and nutritionally rich food options, while logistical bottlenecks reduced the availability of staple products meeting established safety standards. Interestingly, the sustainability and adaptation pillar responded positively to the pandemic shock, suggesting that in periods of acute disruption, both public and private actors intensified efforts to secure long-term resource resilience and accelerate climate adaptation measures. This adaptive shift corroborates evidence from crisis governance studies showing that emergencies can catalyze structural reforms in environmental and agricultural management (FAO, 2021).

From a methodological standpoint, this study directly addresses critiques levied at the food security–geopolitics literature for insufficient treatment of non-linearity's and dynamic effects (Baltagi, 2021). By implementing a dynamic panel threshold model, we extend static threshold approaches such as those used in growth convergence studies (Khan & Senhadji, 2001) and tailor them to the multi-dimensional, shock-sensitive domain of food security. This methodological adaptation allows for explicit regime delineation, enhancing both explanatory power and practical policy relevance.

The combination of these empirical and methodological contributions moves the literature forward in three main ways. First, it reframes the debate on geopolitical risk transmission by proving that the macroeconomic context (specifically the inflation regime) is a key conditioning variable. Second, it integrates environmental, socio-economic, and productivity metrics into a unified dynamic framework, enabling simultaneous estimation of their direct and interaction effects on multiple food security dimensions. Third, it shifts the empirical focus from average effects to conditional effects, which better reflect the lived policy environment in developing and developed economies alike.

In policy terms, these findings argue for differentiated crisis-management strategies. In low-inflation regimes, resilience measures might focus on targeted import diversification and strategic reserves; in high-inflation regimes, price stabilization mechanisms (through monetary, fiscal, or market interventions) become critical to preventing geopolitical shocks from triggering or intensifying food insecurity crises. Moreover, the identification of persistent lagged effects across most pillars suggests that early intervention yields dividends over multiple periods, reducing both the depth and duration of insecurity episodes.

CONCLUSION

Food security continues to be a significant worldwide concern, especially highlighted throughout the COVID-19 health crisis, which disrupted the global food supply network and the agricultural value chain. Alongside factors like climate change, any major geopolitical event exacerbates this challenge further.

This study aimed to investigate the nonlinear and regime-dependent relationships between geopolitical risk, inflation dynamics, and multi-dimensional food security across a diverse panel of 40 countries from 2012 to 2021. By applying a Dynamic Panel Threshold model, the analysis identified a critical geopolitical risk threshold beyond which inflationary pressures significantly undermine global food security, affecting its affordability, availability, quality, safety, and sustainability pillars.

The empirical evidence demonstrates that elevated geopolitical tensions intensify commodity price volatility, exacerbate inflationary pressures, and complicate monetary and fiscal policy trade-offs, thereby increasing vulnerability in global food systems. Notably, the mitigating role of per capita GDP highlights the importance of economic resilience in buffering adverse geopolitical and inflationary shocks. Furthermore, the study underscores the relevance of agricultural land endowment and productivity, which contribute positively to food security outcomes even amid heightened risks.

These findings have substantive implications for policymakers and international stakeholders, emphasizing the necessity of tailored crisis management strategies responsive to prevailing inflation regimes and geopolitical contexts. Proactive measures such as import diversification, strategic reserves, productivity enhancement, and climate adaptation emerge as critical components for strengthening food system resilience worldwide.

Looking ahead, future research should expand the temporal and geographical scope to capture longer-term trends and incorporate additional dimensions such as regional cooperation frameworks, climate change interactions, and alternative measures of geopolitical risk. Moreover, advancing methodological sophistication through structural modeling and machine learning could yield deeper insights into the complex interplay of shocks affecting food security. Such efforts will be indispensable in informing robust policies to safeguard global food systems amid an increasingly uncertain geopolitical landscape.

AUTHOR CONTRIBUTIONS

Conceptualization: Samer Mehibel, Reda Hamza Boudjana, Amel Bouzid.
Data curation: Samer Mehibel, Reda Hamza Boudjana.
Formal analysis: Samer Mehibel, Manuel A. Zambrano-Monserrate.
Investigation: Samer Mehibel, Reda Hamza Boudjana.
Methodology: Samer Mehibel, Reda Hamza Boudjana.
Project administration: Samer Mehibel.
Software: Reda Hamza Boudjana.
Supervision: Samer Mehibel, Amel Bouzid.
Validation: Samer Mehibel, Manuel A. Zambrano-Monserrate, Amel Bouzid, Messaoud Lazereg.
Visualization: Samer Mehibel, Manuel A. Zambrano-Monserrate, Messaoud Lazereg.
Writing – original draft: Samer Mehibel, Reda Hamza Boudjana, Manuel A. Zambrano-Monserrate, Amel Bouzid, Messaoud Lazereg.
Writing – review & editing: Samer Mehibel, Reda Hamza Boudjana, Manuel A. Zambrano-Monserrate, Amel Bouzid, Messaoud Lazereg.

https://doi.org/10.21511/gg.06(1).2025.04

ACKNOWLEDGMENT

This work was sponsored by the Economic Research Forum (ERF) and has benefited from both financial and intellectual support. The views expressed in this work are entirely those of the author(s) and should not be attributed to ERF, its Board of Trustees, or donors.

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APPENDIX A

Table A1. Estimation results of the Dynamic Panel Threshold model

Variables	(1) fsi	(2) fsi	(3) fsi_aff	(4) fsi_aff	(5) fsi_ava	(6) fsi_ava	(7) fsi_qsa	(8) fsi_qsa	(9) fsi_sus	(10) fsi_sus
L.fsi	0.347***	0.360***	–	–	–	–	–	–	–	–
	(0.0524)	(0.0258)								
L.fsi_aff	–	–	−0.00517	−0.0197	–	–	–	–	–	–
			(0.0216)	(0.0224)						
L.fsi_ava	–	–	–	–	0.188***	0.280***	–	–	–	–
					(0.0535)	(0.0498)				
L.fsi_qsa	–	–	–	–	–	–	0.478***	0.481***	–	–
							(0.0407)	(0.0381)		
L.fsi_sus	–	–	–	–	–	–	–	–	0.534***	0.532***
									(0.0671)	(0.0661)
inflation (below_thres)	0.00188	0.0288	−0.529***	−0.540***	0.378***	0.338***	0.217***	0.221***	0.157***	0.143***
	(0.0280)	(0.0268)	(0.0464)	(0.0466)	(0.0584)	(0.0617)	(0.0387)	(0.0394)	(0.0549)	(0.0547)
inflation (above_thres)	−0.0602***	−0.0431**	−0.181***	−0.204***	0.0402	0.0179	−0.0898***	−0.0658***	0.165***	0.145***
	(0.0154)	(0.0206)	(0.0460)	(0.0359)	(0.0391)	(0.0432)	(0.0222)	(0.0174)	(0.0456)	(0.0300)
dcovid	−0.536***	−0.517***	−1.010***	−0.782***	0.279	−0.149	−0.582***	−0.669***	125.2***	−0.399
	(0.112)	(0.103)	(0.196)	(0.163)	(0.375)	(0.399)	(0.147)	(0.147)	(28.59)	(0.276)
L.gpri	−0.473		−3.050*		−1.368		2.000		−0.344	
	(1.020)		(1.725)		(1.780)		(1.740)		(0.297)	
income inequality	−5.795	−2.949	−51.26**	−63.15***	−23.74	−6.260	3.252	−0.415	−2.047	95.11***
	(17.19)	(8.670)	(24.91)	(16.35)	(21.64)	(19.83)	(15.81)	(16.51)	(1.664)	(24.81)
urb_pop	0.0799	0.00710	0.138	0.0957	−0.267	−0.718***	−0.211	−0.0609	0.625	0.643
	(0.186)	(0.110)	(0.330)	(0.269)	(0.365)	(0.210)	(0.231)	(0.154)	(0.462)	(0.408)
arable_land	1.222	0.981***	2.071**	2.015***	−0.590	−0.128	−0.512	−0.336	0.0696**	0.773
	(0.952)	(0.292)	(0.842)	(0.620)	(0.816)	(0.667)	(0.646)	(0.632)	(0.0313)	(0.534)
ppp	0.0186**	0.0180***	0.0193	0.0277***	0.0233	0.0279***	0.00307	−9.66e−05	−0.0140**	−0.00886
	(0.00756)	(0.00487)	(0.0127)	(0.00992)	(0.0146)	(0.00931)	(0.00599)	(0.00561)	(0.00602)	(0.00602)
tfp_index	0.0798***	0.0791***	0.155***	0.142***	0.0117	0.0861***	−0.00219	−0.00456	1.027*	0.0962***
	(0.0240)	(0.0102)	(0.0219)	(0.0243)	(0.0405)	(0.0327)	(0.0206)	(0.0162)	(0.540)	(0.0233)
co2emissions	−0.991***	−0.905***	0.0305	0.313	−0.929**	−1.105***	−1.140***	−1.175***	−1.280***	−1.103***
	(0.191)	(0.167)	(0.350)	(0.273)	(0.386)	(0.423)	(0.255)	(0.244)	(0.421)	(0.416)
lgdppc	10.70***	9.990***	11.39***	6.470**	12.43***	12.79***	6.251***	7.078***	24.16***	20.05***
	(2.391)	(1.666)	(3.521)	(2.814)	(4.805)	(4.752)	(2.320)	(2.385)	(4.032)	(3.274)
Constant	−88.94***	−74.39***	−70.03*	−13.26	−28.67	−25.81	9.923	−9.798	−325.1***	−274.6***
	(25.07)	(18.05)	(37.85)	(23.87)	(46.99)	(43.88)	(22.54)	(16.64)	(58.80)	(47.45)
Observations	320	320	320	320	320	320	320	320	320	320
Number of id	40	40	40	40	40	40	40	40	40	40

Note: Standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

https://doi.org/10.21511/gg.06(1).2025.04