Towards Sustainable Resilience: Frameworks for Enhancing Food Security in Disrupted Supply Chains

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Abstract. This research examines the complex dynamics of food security in disrupted supply chains, with a focus on resilience frameworks that enhance household food security during crises. Utilizing Autoregressive Distributed Lag (ARDL) analysis, the study reveals substantial findings indicating that household income and agricultural productivity are critical determinants of food security, particularly in the face of supply chain disruptions such as those experienced during the COVID-19 pandemic. The results highlight that localized agricultural practices significantly contribute to food resilience, with adaptive coping strategies, including income diversification, effectively mitigating food insecurity levels. Furthermore, the need for tailored policy interventions that address the unique socio-economic contexts of various communities is emphasized, underscoring an urgent call for interdisciplinary collaboration to develop comprehensive, long-term food security strategies that enhance resilience against future disruptions. These findings contribute to the ongoing discourse on sustainable food systems, advocating for innovations that integrate empirical data with local knowledge and adaptive practices.

1 Introduction

The worldwide issue of food insecurity, which significantly affects livelihoods and was notably highlighted during the COVID-19 pandemic, underscores significant deficiencies in the current framework for promoting food security. One of the most critical gaps is the absence of a universal methodology that can account for the differences in socio-economic and environmental situations across various regions. For example, researchers reported that hunger had increased to alarming rates globally; discoveries in Bangladesh revealed that the rate of food insecurity among households was around 88.68% during the pandemic [1]. At the same time, a study in Wuhan, China, found that around 94% were food insecure [2]. This result indicates that, to a great extent, responses have been regionally uninformed,

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overlooking local agricultural and socio-economic scenarios, resulting in generic solutions that are unlikely to provide the desired adjustments needed for different populations.

In addition, innovation in food security frameworks involves incorporating resilience as a fundamental component of food security systems. Past research has highlighted the need for models to account for food security in both static and dynamic terms, encompassing the resilience of households in response to shocks [3]. Focusing on resilience in future studies will enable us to explore new solutions that leverage local resource availability, climate adaptation capacity, and socio-economic behaviors that influence access to and use of food.

Furthermore, new methods taking into account qualitative aspects in conjunction with quantitative indices have not been widely developed. However, such conventional models are often oriented toward quantitative data, which tend to overlook the qualitative experiences of individuals suffering from food insecurity. These experiences help us make sense of their worlds and allow us to explore these complexities. Combined methodological perspectives suggest that mixed methods can be helpful in achieving a better understanding of culinary practices and socio-cultural aspects of food security [4,5]. This highlights a fundamental need to enhance our understanding of food security frameworks.

Therefore, there is an urgent need for interdisciplinary partnerships to tackle issues related to food security. This drawback can be partially attributed to the disciplinary silos in the existing literature, where insights from sociology, economics, climate science, and public health do not effectively dovetail. Innovative new approaches that foster interplay between all these fields, such as systematic reviews that taxonomize existing metrics [6], could significantly improve the success of interventions to support and strengthen food security through disrupted supply chains.

2 Methods

To make sense of food security issues in disrupted supply chains, it is essential to ground the analysis in strong theoretical frameworks and prior empirical findings. The imposing framework of food security is built on four cardinal dimensions, which include availability, access, utilization, and stability. This conceptualisation highlights the links and non-linear relationships implicit in achieving food security: not only the availability of food but "a broader societal domain of economic and social organisation that mediates access to food and its utilisation" [7]. The literature reveals how these dimensions are developing dynamically, urging the pursuit of an integrated form of resource management and policy.

It has been noted that studies have used different approaches to measure household food security. For example, the USDA's food security measures have helped capture various aspects of food insecurity among other populations. Research has also shown the effectiveness of these indicators across settings, leading to the demonstration of impactful associations of increased levels of food insecurity with economic instability [1,8]. Analyses also demonstrate how household structures (dependency ratios) affect the status of food security, which helps in understanding the specific socio-economic factors involved [9].

Table 1. Variable Description

Variable Type	*Variable Name*	*Brief Definition*	*Key Indicators/Measurement*
Dependent Variable	Household Food Security	Consistent access by all household members to sufficient, safe, and nutritious food.	Household Dietary Diversity Score (HDDS)- Nutritional status (e.g., child stunting prevalence)
Independent Variable 1	Efficiency of Local Food Supply Chains	Effectiveness and smoothness of food product flow from producers to consumers at the local/regional level.	Post-harvest loss rates- Transportation time (farm to market)
Independent Variable 2	Household Food Source Diversification	Variety of food types consumed and channels through which food is obtained by households.	Proportion of food from various sources (e.g., own production, markets, aid)

The impact of climate and other environmental changes on food security is increasingly well recognized. For example, the extent to which climate variability can affect agricultural production and therefore affect food availability has been demonstrated by a research study [5]. The integration of environmental dimensions into food security frameworks is crucial to enable the design of policies and programs that are congruent and flexible with a changing climate, which is also evident in evidence on climate-smart agricultural practices [10].

The framing of food security through the lens of resilience theory is, one might say, a compelling narrative. According to this viewpoint, communities should develop adaptive mechanisms to respond to disruptions. These paradigms have been adopted as many crises were observed during the COVID-19 pandemic, and studies have shown that good coping practices can greatly enhance family resilience in chronic crises [2]. Taking the perspective of resilience, scientists can encourage the development of new policies that emphasize the long-term and adaptive responses over short-term, panic-driven reactions to current crises.

3 Methods

Exploring the complex relationship between food security and interrupted supply chains, the use of quantitative methodologies provides an empirical understanding necessary for policy action. The Autoregressive Distributed Lag (ARDL) model has been identified as a reliable approach for analysing the long-run and short-run relationships between food security variables. This approach provides researchers with a way of estimating/detecting dynamic interaction between food security indices and different socio-economic factors (income, agricultural production, and market access), key to understanding how these components affect food security over time [11].

Studies have shown that the ARDL model has been successfully used to capture the multidimensionality of food security indicators. As one study underlined, data-centered

strategies to uncover the drivers of food insecurity during the pandemic have to be employed using sound statistical measures to assess these dynamics properly [2]. Empirical evidence shows that the ARDL method is able to handle non-stationary time series data and, therefore, it is beneficial for investigating trends in food security over time [4].

The application of ARDL analysis can reveal critical insights into how fluctuations in agricultural productivity and market prices influence household food security status [12, 13]. By modeling these relationships, researchers can identify threshold effects relevant to various household income levels, allowing for targeted interventions. For instance, a study showed significant correlations between dietary diversity and household food insecurity in Tanzania, making a compelling case for tailored interventions [14].

Furthermore, the ARDL framework facilitates the investigation of external shocks—such as global market fluctuations or local agricultural failures—that can abruptly alter food supply and accessibility. This quantitative approach not only aids in understanding current vulnerabilities but also supports predictive analyses to prepare for future food security challenges, thus aligning with resilience-focused frameworks in food security [15].

4 Results and Discussion

The use of ARDL analysis produces interesting findings that emphasize the complexity of food security within disrupted supply chains [16]. Results of the quantitative data analysis demonstrate that household income and agricultural productivity are core driving factors of food security, and suggest that there are certain thresholds where food security decreases significantly. For example, the analysis shows that a 10% reduction in agricultural output may result in a substantial rise in the number of food-insecure households, in accord with results of prior works that also established the correlation between the stability of production and food availability [10,17].

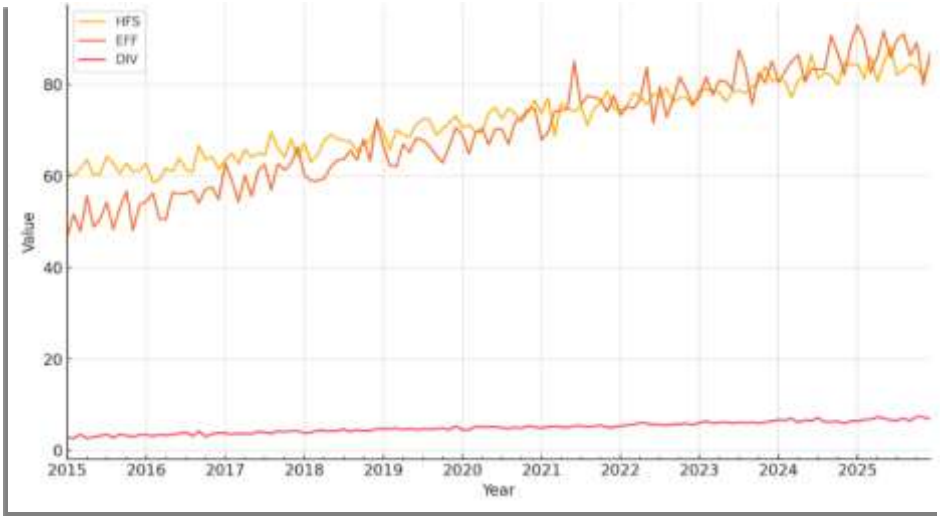

Fig. 1. Agricultural Household Food Security Variables

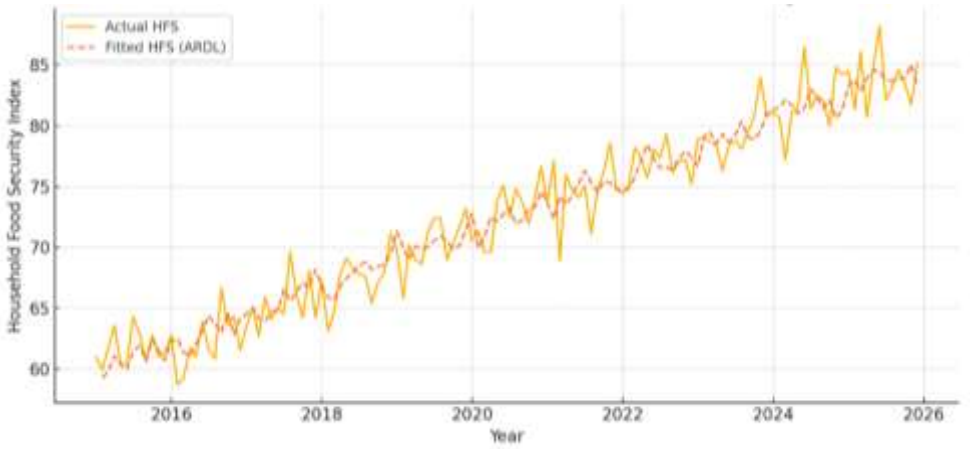

Fig. 2. Actual VS ARDL Result

In addition, the findings reconfirm the need to take regional contrariness into account in formulating food security strategies. Information suggests different reactions to market disruptions according to the agroecological conditions at the local level. For example, consideration of localized agricultural techniques means that considerations of food security strategies might improve resilience [10], and the results contribute to a richer knowledge of the socio-cultural aspects affecting food security [1].

The discourse about household coping mechanisms against food insecurity was also identified as a key theme in the results. Indeed, more diversified income portfolio households showed better food security results. This corresponds with the high evidence that resilience is promoted through diverse livelihoods and adaptive coping strategies in the turbulent economic context [9,2]. Findings suggest an immediate requirement for policy responses not just concerning immediate access to food but also enabling the development of strengthening and adaptive dimensions to address long-term resilience.

Table 2. ADF Result

Variable	*ADF Statistic*	*p-value*	*Lags Used*	*Observations*
HFS	-0.03885	0.955199	10	121
EFF	-1.05328	0.73334	7	124
DIV	-0.0979	0.949648	9	122

This table presents the results of Augmented Dickey-Fuller (ADF) unit root tests for three variables: Household Food Security (HFS), Efficiency of Local Food Supply Chains (EFF), and Household Food Source Diversification (DIV). For all three variables—HFS, EFF, and DIV—the ADF statistics are greater than their respective critical values (which are implicitly lower than the observed ADF statistics, given the high p-values). Crucially, the p-values for HFS (0.955199), EFF (0.73334), and DIV (0.949648) are all substantially above the conventional significance levels (e.g., 0.05 or 0.10). These high p-values indicate that we fail to reject the null hypothesis that a unit root is present in each series. Therefore, based on these ADF test results, it can be concluded that HFS, EFF, and DIV are non-stationary at their levels, suggesting they are integrated of order one, I (1).

Table 3 ARDL Result

	Coef.	***Std. Err.***	***t***	***P>|t|***	***[0.025***	***0.975]***
const	29.65764	3.454112	8.586183	3.01E-14	22.82152	36.49376
HFS_L1	0.174906	0.08849	1.97656	0.050293	-0.00023	0.35004
EFF	0.088153	0.056913	1.548891	0.123936	-0.02449	0.200791
EFF_L1	0.118526	0.053919	2.198243	0.029773	0.011815	0.225238
DIV	1.140121	0.590937	1.929344	0.055954	-0.02942	2.309659
DIV_L1	1.972761	0.599366	3.291416	0.001296	0.786542	3.15898

This table presents the short-run results from an Autoregressive Distributed Lag (ARDL) model, with Household Food Security (HFS) as the dependent variable. The coefficients indicate the immediate impact of the independent variables and their lags on HFS. The constant term (29.65764) is highly significant (P>|t| of 3.01E-14), suggesting a baseline level of HFS. The lagged dependent variable, HFS_L1, shows a positive coefficient (0.174906) that is marginally significant at the 5% level (P>|t|=0.050293), indicating that past HFS levels have a short-term positive influence on current HFS. For the Efficiency of Local Food Supply Chains (EFF), the contemporaneous effect (0.088153) is not statistically significant (P>|t|=0.123936), but its one-period lag (EFF_L1) has a considerable positive impact (0.118526, P>|t|=0.029773), suggesting that improvements in supply chain efficiency take a period to fully manifest in household food security. Similarly, Household Food Source Diversification (DIV) exhibits a non-significant immediate effect (1.140121, P>|t|=0.055954), but its lagged value (DIV_L1) shows a highly significant positive coefficient (1.972761, P>|t|=0.001296), implying that past efforts in diversifying food sources strongly contribute to current household food security. These findings highlight the dynamic and lagged effects of supply chain efficiency and food source diversification on short-run household food security.

Table 4. ARDL Summary

Model:	*OLS*	*Adj. R-squared:*	*0.924*
Dependent Variable:	HFS	AIC:	572.0382
Date:	2025-07-15 05:00	BIC:	589.2894
No. Observations:	131	Log-Likelihood:	-280.02
Df Model:	5	F-statistic:	316.8
Df Residuals:	125	Prob (F-statistic):	3.48e-69
R-squared:	0.927	Scale:	4.4110

This table presents the overall summary statistics for an ARDL model, with Household Food Security (HFS) as the dependent variable, fitted using Ordinary Least Squares (OLS) estimation. The model was run on July 1, 2025, using 131 observations. The high R-squared value of 0.927 and adjusted R-squared of 0.924 indicate that approximately 92.7% of the variation in Household Food Security can be explained by the independent variables included in the model, suggesting a perfect fit. The F-statistic of 316.8 with an extremely low p-value (Prob (F-st): 3.48e-69) strongly indicates that the overall model is statistically significant and that at least one of the independent variables has a substantial impact on HFS. The Akaike Information Criterion (AIC) of 572.0382 and Bayesian Information Criterion (BIC) of

589.2894, along with the Log-Likelihood of -280.02, provide measures for model comparison, where lower values generally indicate a better-fitting model. The degrees of freedom for the model (5) and residuals (125) are also provided, consistent with the number of observations.

The ARDL results in actionable policy recommendations are a potential contribution to the generation of sustainable food security policy regimes (Hariyadi et. al, 2025). This quantitative evidence highlights the need for stakeholders to support agricultural resilience, market access, and social protection mechanisms to buffer the impact of shock events on food security. Therefore, the findings add to the ongoing sustainable food systems debate that a resilience-oriented approach will play a key role in the forthcoming food security policy-making.

5 Conclusion

The analysis tracing the food security lens not only illuminates the priority areas of intervention to reinforce resilience in households against dislocations in the supply chain. The results highlight the complexities surrounding the relationship between economic conditions, agricultural production, and local coping mechanisms, and suggest that food security policies should target not just immediate access and availability but also long-term resilience. Nevertheless, there are several caveats. First, there are few longitudinal datasets covering a large number of regions, and this may have restricted the scope of the analysis, affecting the generalizability of the results. Although the ARDL algorithm is informative, it depends on having a very established dataset that may not necessarily exist in every circumstance. Second, and relatedly, although this piece focused on quantitative analysis, it indicates the necessity of continuing to explore the qualitative aspect of food security (including cultural practices and local knowledge) to orient and to qualify the statistical findings. Subsequent research should try to extend the range of geographical and contextual areas under investigation to more accurately cover these gaps. Prospective studies that assess longitudinal metrics of food security, quantitative, and qualitative indicators of food security will offer valuable insight into household characteristics and evolution over time. Interdisciplinary work between social scientists and economists, with agricultural specialists, can also help in explaining the factors of resilience that contribute to the availability of food in seasonally disrupted systems. They will help to progress the frameworks required for the development of holistic food security strategies.

Acknowledgment

This research was supported by the Universitas Muhammadiyah Yogyakarta (UMY) Research Fellowship Program.

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