

Extended Abstract

From Pixel to Policy: Remote Sensing, Spatial Spillovers, and Multidimensional Food Security-Price Stability Nexus in Sumatra Island, Indonesia

Food security and price stability represent two critically interconnected economic indicators that have attracted growing attention for decades. In Indonesia, the world's fourth most populous nation, food security challenges persist despite agricultural potential, driven by rapid population growth, increasing food demand, climate change impacts, and price volatility. Sumatra Island, a major agricultural production centre contributing approximately 22% of Indonesia's national rice production in 2024, exemplifies this paradox: despite significant local agricultural output, the region experiences persistent food insecurity coupled with price instability. The existing Food Security Index produced by Indonesia's National Food Agency fails to capture resource security dimensions, a critical oversight given that provinces classified as "very secure" frequently experience inflation rates exceeding national averages. This research gap motivates the present study, which aims to develop a more comprehensive food security measurement framework integrating remote sensing data and to examine the spatial spillover effects of food security dimensions on price stability across Sumatra's districts.

Combining official data and remote sensing data from 2021 to 2024, this study attempts to investigate the spatial clustering, spatio-temporal pattern and the nexus between food security and price stability. *First*, we construct a multidimensional food security index incorporating four dimensions: economic security, quantity security, quality security, and resource security. Resource security is constructed by examining cropland areas from MODIS Land Cover, Normalized Difference Vegetation Index, Normalized Difference Water Index, rainfall average, and flood risk from Global Surface Water and Landsat derived from Google Earth Engine. *Second*, this study estimates inflation rate for non-Consumer Price Index (non-CPI) cities by applying "sister city" approach using hierarchical clustering, extending price stability assessment to all districts. *Third*, the study applies spatial econometric methods, specifically Dynamic Spatial Durbin Model, to calculate direct and indirect effects of food security dimensions on inflation levels across the 2021-2024 period across districts in Sumatra.

This study incorporates 15 indicators across four food security dimensions from multiple data sources. Official statistics from BPS-Statistics Indonesia provide socio economic to produce quantity, quality, and economic security. Quantity security consists of several indicators such as harvested area, paddy production, and paddy productivity. Economic security comprises subsidised food recipients and per capita food consumption, while quality security consists of per capita expenditure, prevalence of nourishment, and protein and vegetable consumption. Resource security from remote sensing data obtained from Google Earth Engine, consists of MODIS 500-meter resolution land cover classification identifying croplands, 16-day NDVI composites at 250-meter resolution from MODIS MOD13Q1, NDWI derived from Landsat 8, daily precipitation estimates from CHIRPS (0.05° resolution), and flood frequency data from the Global Surface Water dataset. Each indicator is normalised using coefficient variation weighting, allowing synthesis into a composite food security index. Principal Component Analysis validates the adequacy of selected indicators using Kaiser-Meyer-Olkin sampling measurements. The study compares multiple clustering methodologies, including Ward hierarchical clustering, average linkage clustering, Gaussian mixture models, and CLARA (Clustering Large Applications) to classify 154 districts in Sumatra into four robust food security clusters. Exploratory space-time data analysis uses Rose Diagrams and Directional LISA to examine spatio-temporal and spatial co-evolution between districts and provinces with their neighbouring regions. Spatial econometric analysis is conducted by preliminary testing cross-sectional dependence for panel data to confirm spatial dependence within the data. Further, five spatial panel econometric models are estimated and compared, with the dynamic Spatial Durbin Model emerging as the best-fit specification based on information criteria.

Four food security clusters are generated across Sumatra's districts. Cluster 1 represents the highest resource security with moderate quantity and quality security, while Cluster 4 demonstrates the highest quantity security with relatively high quality security. Cluster 3 exhibits the highest quality security, while Cluster 2 shows the second highest resource security. Spatio-temporal analysis through Rose Diagram depicts that three of four food security dimensions (quantity, economic, and resources) demonstrate noticeable vulnerability to external shocks from neighbouring regions. Central Sumatra exhibits the highest sensitivity to spatial spillover effects and the least persistence in maintaining food security dimensions compared to the Northern and Southern parts of Sumatra during the 2021-2024 period. Quality security solely shows consistent

spatial co-evolution, displaying positive spatial movement towards north-east direction. Furthermore, directional LISA analysis confirms apparent spatial heterogeneity in how provinces respond to neighbouring provinces' food security movements. Unlike other dimensions, directional LISA of quality security indicated that all provinces only share the static spatial movement, which were moving forward into same direction. It implies that the level of quality security (nutrition level and healthy consumption level) in each province positively associated with the increase level of nourishment prevalence and healthy food consumption level in other provinces.

The sister city clustering approach for inflation measurement represents a methodological contribution that addresses data limitations while maintaining analytical rigour. Classification of inflation level is generated from hierarchical clustering analysis and successfully shape groups of 24 cities (2021-2023) and 41 cities (2024), producing inflation estimates using "sister-city approach" for previously unmeasured districts with approximately 0.852 correlation coefficient, enabling comprehensive regional price stability evaluation.

The spatial econometric analysis establishes that the conventional OLS model significantly ignores the role of space in measuring the complexity of the food security-price stability nexus by failing to account for spatial dependencies. Using dynamic Spatial Durbin Model as the best fit, it reveals that significant spill-over effects exist, particularly for negative spatial lag of explanatory variables from quality security (higher level of nourished prevalence and nutritious food consumption) and resource security (vegetation index, water surface level, rainfall average, and minimum flood risk) which succeed to reduce the inflationary pressure in the neighbouring districts. Specifically, dynamic Spatial Durbin Model suggests that there are fundamental differences between direct and indirect effects. Although direct effect was only significant in economic security, indirect effects affect significantly in almost all dimensions, particularly in the long run. Quality security exhibits the most pronounced negative spillover (-11.955 in long-run indirect effect), indicating that improving nutritional prevalence in neighbouring regions significantly reduces inflation level. Likewise, resource security demonstrates significant negative spillover (-6.233), suggesting that the higher level of resource security would tend to decrease inflationary pressure. Most remarkably, economic security generates the largest positive spatial spill-over (34.842), indicating that increases in per capita expenditure in neighbouring districts generate significant inflationary pressures spilling-over across regions through demand hike and

interconnected supply chains. The substantial gap between indirect effects relative to direct effects fundamentally challenge policy approaches based on isolated local interventions. The magnitude of economic security's indirect effect in the long run, which is nearly 22 times larger than its direct effect, implies that economic well-being and security create broad-based inflationary influence across regional economies. This finding entails inter-regional policy coordination emphasising food security and price stability management. The pronounced negative spillovers from quality and resource security suggest that investments in nutritional programs and agricultural resource management produce significant advantages of regional stability through reduced inflation transmission.

This research brings forward understanding of the food security-price stability linkage by integrating geospatial analysis with spatial econometric methods, accommodating regional interdependencies that conventional regression modelling neglected. The methodological contribution provides practical tools for comprehensive regional economic evaluation. The predominance of long-run indirect effects substantially reshapes policy design toward regional coordination and collaboration channels. Six major policy directions emerge from this research's results: (1) Regional/local governments could consider to monitor the inflation level and tackling strategies based on the non-CPI estimates from sister city approach (2) Resource security demands integrated regional environmental and agricultural policies given vulnerability to climate change; (3) Economic security requires stable management to maintain purchasing power and ensure that social assistance is enjoyed by people falling into poverty; (4) Quality security emerges as significant contributor in managing inflationary pressure, thus the sufficiency of nutritious food consumption, such as high-protein and mineral foods (fish and vegetables), is needed and will impact price stability in the long run (5) Quantity security's statistical insignificance suggests production volumes matter less for price stability than effective policy on local value chains, including distributing products effectively, improving powerful trade linkage, and establishing proper connectivity hubs across neighbouring districts. (6) Inter-regional policy cooperation through integrated frameworks for neighbouring districts is essential for optimising supply chains.