



Why Does Agricultural Productivity Fail to Drive Regional Growth? Agricultural Downstreaming, Export Orientation, and Climate Adaptation in North Sumatra

Utari Evy Cahyani^{1*} , Rizal Ma'ruf Amidy Siregar² , Farawi Ghannili³ 

¹Universitas Islam Negeri Syekh Ali Hasan Ahmad Addary Padangsidempuan, Padangsidempuan, Indonesia

²Universitas Islam Negeri Syekh Ali Hasan Ahmad Addary Padangsidempuan, Padangsidempuan, Indonesia

³Universitas Padjadjaran, Bandung, Indonesia

*utari@uinsyahada.ac.id

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Abstract

In many resource-rich regions, the abundance of agricultural production often grows more rapidly than the welfare it successfully creates. This study examines the role of agricultural downstreaming, export orientation, and climate adaptation in driving regional economic performance across 33 regencies and municipalities in North Sumatra during the 2019–2022 period. The analysis uses secondary panel data obtained from Statistics Indonesia (BPS) and Meteorology, Climatology, and Geophysical Agency (BMKG), covering six strategic commodities, as well as variables of agricultural wages, export values, and climate indicators. The empirical approach applies the Random Effect Model (REM) and Error Correction Model (ECM) to capture both short-term and long-term dynamics. The results show that increases in physical productivity are not always able to proportionally drive regional economic growth, particularly in commodities that still face limitations in downstream processing capacity and unequal market access. In contrast, agricultural wages and export orientation consistently show positive and significant effects across most commodities, confirming the importance of labor incentives and trade openness in strengthening regional agricultural economic performance. The interaction between productivity and climate adaptation shows mixed results, with positive effects on several commodities, but insignificant effects on others, thereby confirming the need for adaptation strategies based on local agroecological characteristics. The findings of this study contribute by demonstrating that improvements in agricultural productivity do not automatically drive regional economic growth and provide empirical evidence that agricultural transformation is more strongly determined by the integration of downstream development, labor incentives, trade openness, and ecological resilience. Finally, these findings imply the need for downstreaming policies that are agroecologically adaptive and spatially inclusive, as well as—within the perspective of Islamic economics—the strengthening of *maqāṣid*-based agricultural development that integrates productivity, welfare, adaptation, and equity.

Keywords: agricultural downstreaming; regional economic growth; export orientation; climate adaptation; *maqāṣid*; agricultural productivity.

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Introduction

In late 2025, catastrophic floods and landslides across Sumatra claimed hundreds of lives, displaced more than one million residents, and severely damaged roads, bridges, irrigation networks, and productive agricultural landscapes across several strategic regions, including North Sumatra.¹ Beyond the immediate humanitarian losses, the disaster exposed a deeper structural vulnerability within agrarian economies: regional economic growth remains highly susceptible to climate-induced disruptions that can abruptly interrupt production continuity, weaken supply chain connectivity, and reduce the feasibility of long-term agro-industrial investment. As argued by Jamie S. Davidson, governments in agricultural societies have long struggled to secure sustainable food systems while balancing competing priorities between domestic production, market efficiency, and long-term economic stability. In resource-rich regions facing intensifying environmental uncertainty, however, this dilemma extends beyond the traditional question of producing more or relying on external markets, toward a more fundamental challenge of how agricultural abundance can be transformed into resilient and sustainable regional value creation.² In regions where agriculture serves as both a livelihood foundation and a strategic economic sector, strengthening resilience is therefore no longer limited to increasing production capacity alone, but also requires the creation of more adaptive and value-oriented production systems.

Agricultural downstreaming—the process of extending the value chain from primary production into processing, packaging, and market integration—has been recognized as a key strategy in regional economic transformation, particularly in regions with high agrarian resource potential.³ In North Sumatra, which possesses diverse agroecosystems and a production base of strategic commodities such as corn, cassava, sweet potato, soybean, peanut, and mung bean, downstreaming has increasingly been prioritized to address structural inefficiencies in the agricultural sector.⁴ Although the physical output of several of these commodities has shown an increasing trend, its contribution to regional value-added growth remains fluctuating.⁵ This indicates that increases in production quantity have not yet been aligned with improvements in value creation without support from post-harvest handling, strengthening of processing capacity, and expansion of market access.⁶ At the same time, downstreaming policies

¹ Hans Nicholas Jong, “Indonesia Closes 2025 with Rising Disasters and Stalled Environmental Reform,” Mongabay, 2025.

² Jamie S. Davidson, *Rice Politics in Southeast Asia: Legacies of the Green Revolution*, 1st ed. (Cambridge University Press, 2026).

³ Gary Gereffi and Karina Fernandez-Stark, *Global Value Chain Analysis: A Primer*, 2nd ed. (Duke University Press, 2016); Raphael Kaplinsky and Mike Morris, *A Handbook for Value Chain Research* (Institute for Development Studies, 2016); Rajkumar Sharma and Satyendra Kumar Sharma, “Optimizing Agricultural Downstream Supply Chain: Addressing Information Asymmetry and Losses,” *Business Process Management Journal* 31, no. 7 (2025): 2801–24.

⁴ Budiman Achmad et al., “Traditional Subsistence Farming of Smallholder Agroforestry Systems in Indonesia: A Review,” *Sustainability* 14, no. 14 (2022): 8631; Bugi Biruloma Lagaida et al., “Indonesian Agricultural Sector Regional Value Chain in Regional Comprehensive Economic Partnership (RCEP),” *Business Review and Case Studies*, ahead of print, April 30, 2024; Kodrad Winarno et al., “Unlocking Agricultural Mechanisation Potential in Indonesia: Barriers, Drivers, and Pathways for Sustainable Agri-Food Systems,” *Agricultural Systems* 226 (May 2025): 104305.

⁵ FAO, *The State of Food and Agriculture 2023* (Food and Agriculture Organization of the United Nations, 2023).

⁶ Ana Bottega and João P. Romero, “Innovation, Export Performance and Trade Elasticities across Different Sectors,” *Structural Change and Economic Dynamics* 58 (September 2021): 174–84; Marhaendo Purno, “Economic Problems In Indonesia And Efforts To Solve Them,” *Return : Study of*

aligned with the national development agenda emphasize the establishment of integrated agro-industrial clusters, investment in processing facilities, and the optimization of export supply chains.⁷ However, their implementation in North Sumatra continues to face structural challenges, including limited rural infrastructure,⁸ fragmented supply chains,⁹ low adoption of adaptive agricultural technologies,¹⁰ and the unequal distribution of economic benefits across regions.¹¹

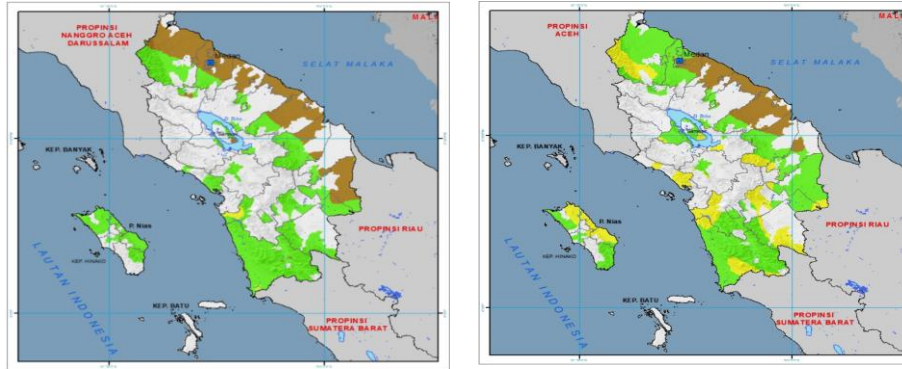


Figure 1. Flood-Prone Areas in North Sumatra During the Ten-Day Observation Periods of December 2021–January 2022 (Left) and December 2022–January 2023 (Right)

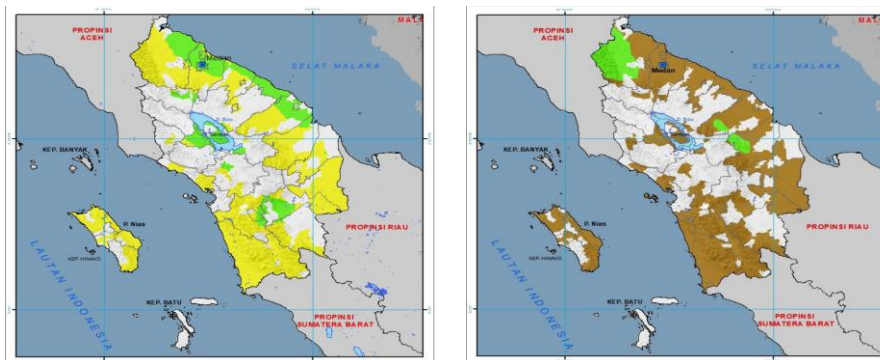


Figure 2. Flood-Prone Areas in North Sumatra During the Ten-Day Observation Periods of December 2023–January 2024 (Left) and December 2024–January 2025 (Right)

Management, Economic and Bussines 2, no. 2 (2023): 194–201; Fadi N. Sibai et al., “Forecasting The Consumer Price Index: A Comparative Study of Machine Learning Methods,” *International Journal of Computing and Digital Systems* 15, no. 1 (2024): 487–97.

- 7 Mukhlis et al., “Agglomeration of Manufacturing Industrial, Economic Growth, And Interregional Inequality in South Sumatra, Indonesia,” *International Journal of Economics and Financial Issues* 7, no. 4 (2017): 214–24; Salim Yilmaz and Ahmet Murat Günel, “Food Insecurity Indicators of 14 OECD Countries in a Health Economics Aspect: A Comparative Analysis,” *Frontiers in Public Health* 11 (April 2023): 1122331.
- 8 Cesar Blanco and Xavier Raurich, “Agricultural Composition and Labor Productivity,” *Journal of Development Economics* 158 (September 2022): 102934; Futoshi Yamauchi, “Wage Growth, Landholding and Mechanization in Agriculture Evidence from Indonesia,” paper presented at International Association of Agricultural Economists (IAAE) > 2015 Conference, 2015.
- 9 Thomas Reardon et al., “Rapid Transformation of Food Systems in Developing Regions: Highlighting the Role of Agricultural Research & Innovations,” *Agricultural Systems* 172 (June 2019): 47–59.
- 10 Tanja Cegnar et al., “Toward Effective Communication of Agrometeorological Services,” *Advances in Science and Research* 20 (May 2023): 9–16; Shambhu Katel et al., “Climate Smart Agriculture for Food Security, Adaptation, and Migration: A Review,” *Turkish Journal of Agriculture - Food Science and Technology* 10, no. 8 (2022): 1558–64.
- 11 Jamie Peck et al., “A Dialogue on Uneven Development: A Distinctly Regional Problem,” *Regional Studies* 57, no. 7 (2023): 1392–403.

Figures 1 and 2 in this study illustrate the spatial distribution of flood-prone areas in North Sumatra for the 2021–2022 and 2023–2025 periods. The maps indicate shifts and intensification of flood risk across several productive regencies, such as Serdang Bedagai, Langkat, and Deli Serdang, which may potentially disrupt production stability and downstream investment.¹² High-risk zones (red areas) may interrupt supply chain continuity and reduce the feasibility of processing projects, while low-risk or flood-free zones (green and white areas) represent strategic locations for the development of processing facilities that are more resilient to climate-related disruptions.¹³ Empirical evidence shows that labor incentives (efficiency wages) and trade openness play significant roles in increasing value added in the agricultural sector.¹⁴ However, for certain commodities, downstream transformation remains limited due to low processing intensity and dependence on primary markets that are vulnerable to fluctuations in global prices.¹⁵ Therefore, this study quantitatively examines the effects of productivity, wages, export orientation, and climate technology on the growth of value added across six major commodities in North Sumatra, while considering the implications of spatial climate risks as illustrated in Figures 1 and 2.

In the development of the literature, agricultural downstreaming has been positioned as a sustainable development strategy. As explained by Kaplinsky and Morris, this strategy serves as a key mechanism for strengthening the competitiveness of the agricultural sector in global markets.¹⁶ On the other hand, value chain upgrading through downstreaming has been proven to improve market efficiency, reduce post-harvest losses, and expand export opportunities.¹⁷ In the context of Indonesia, various downstreaming initiatives have encouraged the establishment of integrated agro-industrial clusters in regions with high-potential leading commodities.¹⁸ However, their effectiveness is highly influenced by infrastructure readiness, capital availability, and the quality of human resources.¹⁹ This momentum is certainly supported by the paradigm of

¹² Teny Handhayani and Irvan Lewenusa, “An Analysis of Meteorological Data in Sumatra and Nearby Using Agglomerative Clustering,” *Jurnal RESTI (Rekayasa Sistem Dan Teknologi Informasi)* 8, no. 2 (2024): 234–41; Sujata Manandhar et al., *Climate Vulnerability & Adaptive Capacity of Mountain Societies in Central Asia*, 2018.

¹³ Thomas Peprah Agyekum et al., “The Contribution of Weather Forecast Information to Agriculture, Water, and Energy Sectors in East and West Africa: A Systematic Review,” *Frontiers in Environmental Science* 10 (August 2022): 935696; Richard K. Crump et al., *A Simple Diagnostic for Time-Series and Panel-Data Regressions*, Staff Reports (Federal Reserve Bank of New York), Staff Reports (Federal Reserve Bank of New York) (Federal Reserve Bank of New York, 2024).

¹⁴ Blanco and Raurich, “Agricultural Composition and Labor Productivity”; Issah Sugri et al., “Postharvest Losses and Mitigating Technologies: Evidence from Upper East Region of Ghana,” *Sustainable Futures* 3 (2021): 100048; Yamauchi, “Wage Growth, Landholding and Mechanization in Agriculture Evidence from Indonesia.”

¹⁵ Weihua Liu et al., “Problem Identification Model of Agricultural Precision Management Based on Smart Supply Chains: An Exploratory Study from China,” *Journal of Cleaner Production* 352 (June 2022): 131622; Piya Wongpit et al., “Enhancing the Cassava Value Chain: Policy Recommendations and Strategies for Sustainable Development,” *Research on World Agricultural Economy*, September 20, 2024, 37–48.

¹⁶ Kaplinsky and Morris, *A Handbook for Value Chain Research*.

¹⁷ Gereffi and Fernandez-Stark, *Global Value Chain Analysis: A Primer*; Lagaida et al., “Indonesian Agricultural Sector Regional Value Chain in Regional Comprehensive Economic Partnership (RCEP).”

¹⁸ World Bank, “The World Bank Supports Indonesia’s Agriculture Sector to Become More Resilient and Inclusive,” World Bank Group, 2022.

¹⁹ Winarno et al., “Unlocking Agricultural Mechanisation Potential in Indonesia.”

post-productivism,²⁰ which shifts the orientation of agricultural development from a focus on increasing production volume toward an emphasis on quality, sustainability, and product differentiation.²¹ This transformation is essential in responding to the challenges of modern markets, which increasingly prioritize quality standards and environmental sustainability. In North Sumatra, several commodities such as coffee, cocoa, and processed corn products have begun to be directed toward export markets with premium segmentation, while staple food commodities such as cassava and sweet potato are still predominantly sold in raw form, resulting in relatively low contributions to value added.²² Interestingly, the emergence of the concept of climate-smart agriculture (CSA) emphasizes the integration of productivity goals with climate adaptation and risk mitigation. The utilization of weather forecasting technologies, such as data and indices provided by Meteorology, Climatology, and Geophysical Agency (BMKG), has been shown to reduce losses caused by hydrometeorological disasters and support decision-making at the farmer level.²³ Unfortunately, the level of CSA adoption in North Sumatra remains limited. The main constraints include low technological literacy, limited extension services, and insufficient financial support for investment in adaptive technologies.²⁴ The study by Manandhar et al. demonstrates that regions exposed to recurrent flooding require different technological interventions compared with regions facing drought risk or other extreme weather conditions.²⁵

On the other hand, as suggested by several studies, a potential solution for the context of North Sumatra lies in the efficiency wage hypothesis, which argues that increasing labor incentives, whether in the form of wages or workplace facilities, can enhance workers' marginal productivity, including in the agricultural sector.²⁶ In many cases, wage increases are positively associated with production efficiency and output quality. In addition, trade openness plays an important role in connecting farmers to international markets, which, in turn, can expand the share of value added enjoyed by producing regions.²⁷ However, studies by Liu et al. and Wongpit et al. warn that, without adequate downstreaming, trade openness may instead suppress raw commodity prices and widen disparities in economic gains between regions with processing access and those without.²⁸ Although a number of previous studies have examined agricultural downstreaming at both the global level and within Indonesia, most have focused primarily on one or two aspects, such as supply chain efficiency or the role of post-harvest technology, without directly linking them to variations in spatial climate risk and their

²⁰ Brian Ilbery and Ian Bowler, "From Agricultural Productivism to Post-Productivism," in *The Geography of Rural Change*, 0 ed., ed. Brian Ilbery (1998; Routledge, 2014), 28.

²¹ Bottega and Romero, "Innovation, Export Performance and Trade Elasticities across Different Sectors."

²² N. Sibai et al., "Forecasting the Consumer Price Index."

²³ Cegnar et al., "Toward Effective Communication of Agrometeorological Services"; Md Saidul Islam and Edson Kieu, "Tackling Regional Climate Change Impacts and Food Security Issues: A Critical Analysis across ASEAN, PIF, and SAARC," *Sustainability* 12, no. 3 (2020): 883.

²⁴ Agyekum et al., "The Contribution of Weather Forecast Information to Agriculture, Water, and Energy Sectors in East and West Africa"; Katel et al., "Climate Smart Agriculture for Food Security, Adaptation, and Migration."

²⁵ Manandhar et al., *Climate Vulnerability & Adaptive Capacity of Mountain Societies in Central Asia*.

²⁶ Blanco and Raurich, "Agricultural Composition and Labor Productivity"; Yamauchi, "Wage Growth, Landholding and Mechanization in Agriculture Evidence from Indonesia."

²⁷ Leck et al., "A Dialogue on Uneven Development."

²⁸ Liu et al., "Problem Identification Model of Agricultural Precision Management Based on Smart Supply Chains"; Wongpit et al., "Enhancing the Cassava Value Chain."

implications for regional economic value added.²⁹ Likewise, quantitative analyses that integrate productivity indicators, agricultural wages, export orientation, and climate technology within a single econometric model that distinguishes between short-term and long-term effects remain limited, particularly in the context of provinces with regional heterogeneity as high as that of North Sumatra. Existing studies also generally employ descriptive approaches or limited case studies and therefore have not been able to provide a comprehensive understanding of the simultaneous relationships among variables at the regency and municipal levels. In addition, previous studies often overlook the interaction between productivity and climate technology, even though, in the context of tropical agriculture that is vulnerable to hydrometeorological disasters, this interaction may become a determining factor in the sustainability of production and value creation.³⁰ The novelty of this study lies in the integration of four key dimensions—commodity productivity, labor incentives, trade openness, and climate technology adaptation—into an analytical framework based on panel data using the Random Effect Model and Error Correction Model. This study also utilizes flood risk maps (Figures 1 and 2) as a spatial approach to link the distribution of climate risk with downstream potential, an approach that has not been fully optimized in previous studies. Therefore, the findings of this study not only provide new empirical evidence regarding the determinants of agricultural value added in North Sumatra but also offer evidence-based policy recommendations that integrate spatial, economic, and environmental considerations in a comprehensive manner.

To provide a systematic and coherent analysis, this article is organized into several main sections. Following the introduction, the second section presents the research method, including the research design, data sources, variable construction, and the econometric approach employed in this study. The third section presents the empirical results, beginning with descriptive statistics, followed by panel estimation using the panel EGLS (Cross-section Random Effects) approach, as well as an examination of the role of productivity in the downstream development stage. The fourth section provides a more in-depth discussion by linking the empirical findings to broader theoretical reflections through From Empirical Evidence to Theoretical Reflection, interpreting the findings through the Computable General Equilibrium (CGE) and Partial Equilibrium Models (PEM) approaches, as well as offering normative reflections within the framework of *maslahah* and the perspective of Islamic economics through a *maqāṣid-based* interpretation, and finally, the last section presents the conclusion.

Research Method

This study employs a quantitative approach through two analytical models, namely the Computable General Equilibrium (CGE), an economic model that simulates the impact of policy interventions or other changes on the overall economy by capturing interactions among various sectors, and the Partial Equilibrium Models (PEM), an economic model that analyzes the equilibrium of a single market independently, which is useful for

²⁹ Bottega and Romero, “Innovation, Export Performance and Trade Elasticities across Different Sectors”; Gereffi and Fernandez-Stark, *Global Value Chain Analysis: A Primer*; Kaplinsky and Morris, *A Handbook for Value Chain Research*.

³⁰ Agyekum et al., “The Contribution of Weather Forecast Information to Agriculture, Water, and Energy Sectors in East and West Africa”; Cegnar et al., “Toward Effective Communication of Agrometeorological Services.”

understanding the direct impact of changes within specific markets,³¹ such as export conditions within intra-industry trade access. This study applies panel data regression to analyze the effects of agricultural productivity across six major commodities, namely corn, cassava, sweet potato, soybean, peanut, and mung bean, as well as agricultural minimum wages, sector-based exports, weather technology provided by the Meteorology, Climatology, and Geophysical Agency, and employment in the agricultural sector based on age classification (15–60+) on productivity value added (NPR) in gross regional domestic product at constant prices across 33 regencies and municipalities in North Sumatra during the 2019–2022 period. The data used in this study are secondary data obtained from Statistics Indonesia of North Sumatra. Furthermore, the data analysis technique employed in this study is static panel data regression using the Random Effect Model (REM), in which the model applies the Generalized Least Squares (GLS) estimation procedure by considering error components across cross-sectional and time-series dimensions.³² The econometric model specifications³³ are presented as follows (see Tables 5–10):

Equation (i) presents the Random Effect (RE) model estimation:

$$NPR_{it} = \beta_0 + \beta_1 P(t)_{nit} + \beta_2 UPr_{it} + \beta_3 EHP_{it} + \beta_4 P(t) * T_{(it)} + (\beta_5 15 - 19_{it} + \beta_6 20 - 24_{it} + \beta_7 25 - 29_{it} + \beta_8 30 - 34_{it} + \beta_9 35 - 39_{it} + \beta_{10} 40 - 44_{it} + \beta_{11} 45 - 49_{it} + \beta_{12} 50 - 54_{it} + \beta_{13} 55 - 59_{it} + \beta_{14} 60 +_{it}) + v_{it} \quad (i)$$

In this model, the dependent variable, NPR, represents productivity value added, measured by gross regional domestic product at constant prices. $P(t)$ represents agricultural productivity, covering corn, cassava, sweet potato, soybean, mung bean, and peanut, measured in agricultural output (tons). UPr represents formal labor wages, measured by the average monthly net wages or salaries of formal workers based on regency/municipality and main employment sector (Indonesian rupiah). EHP represents agricultural export productivity, measured by sector-based export volumes (tons). T represents technology or digitalization in agricultural productivity management, measured using indices provided by the Meteorology, Climatology, and Geophysical Agency (BMKG), including landslides, floods, droughts, forest and land

³¹ See: Ziad Ghaith et al., “Regional Computable General Equilibrium Models: A Review,” *Journal of Policy Modeling* 43, no. 3 (2021): 710–24; Yongxi Ma et al., “Impacts of Energy Price on Agricultural Production, Energy Consumption, and Carbon Emission in China: A Price Endogenous Partial Equilibrium Model Analysis,” *Sustainability* 14, no. 5 (2022): 3002; Osamu Nishiura et al., “Integration of Energy System and Computable General Equilibrium Models: An Approach Complementing Energy and Economic Representations for Mitigation Analysis,” *Energy* 296 (June 2024): 131039; Mark D. Partridge and Dan S. Rickman, “Computable General Equilibrium (CGE) Modelling for Regional Economic Development Analysis,” *Regional Studies* 44, no. 10 (2010): 1311–28; Achmad Rifa’i, “The Impact of Import Tariff Protectionism on Indonesia Textile Industry: GTAP Model,” *The Journal of The Textile Institute* 116, no. 12 (2025): 3207–19; Sahara et al., “Economic Impacts of Biodiesel Policy in Indonesia: A Computable General Equilibrium Approach,” *Journal of Economic Structures* 11, no. 1 (2022): 22; Haruna Suleiman Umar et al., “Welfare Implication of Paddy Price Support Withdrawal from Malaysian Rice Sector: Partial Equilibrium Method Approach,” *Agricultura Tropica et Subtropica* 48, nos. 3–4 (2015): 45–52.

³² Agus Widarjono, *Ekonometrika Pengantar Dan Aplikasinya Disertai Panduan Eviews*, 5th ed. (UPP-STIM YKPN, 2018).

fires, extreme weather, and volcanic eruptions (average shocks per regency/municipality).

The variables 15–60+ represent the average monthly net wages or salaries of agricultural workers based on age classification. β denotes the intercept, i denotes the sample units (regencies/municipalities), t denotes time or period, and v denotes the disturbance term, in which individual sample effects differ across units but remain constant over time. The next stage of analysis involves the *Error Correction Model (ECM)*. According to Domowitz and Elbadawi, the ECM is a model used when disequilibrium exists between each independent variable and the dependent variable. In addition, the ECM is considered valid when the coefficient of the *Error Correction Term (ECT)* is positive and statistically significant at $p < 0.05$ (see Tables 11 and 12).³³ The econometric specification of the ECT is expressed as follows:

$$EC_t = Y_t^* - \alpha_0 - \alpha_1 Y_t \tag{ii}$$

Equation (ii) presents the modified Random Effect–Error Correction Model (RE–ECM) estimation:

$$\Delta NPR_t = \beta_0 + \beta_1 \Delta P(t)_{n_t} + \beta_2 \Delta UPr_t + \beta_3 \Delta EHP_t + \beta_4 \Delta (P(t) * T)_{(t)} + (\beta_5 \Delta Int. 1_t + \beta_6 \Delta Int. 5_t + \beta_7 \Delta Int. 10_t) + \beta_{15} ECT_t + \varepsilon_t \tag{iii}$$

In this model, the notation Δ represents the asymptotic distribution, indicating changes or differences in the relationships among random variables. $\Delta(Int1, 5, \text{ and } 10)$ represents the interval percentages of agricultural exports (tons). ε denotes the error term, representing individual disturbance variables, while ECT , or the *Error Correction Term* in the ECM framework, explains how these variables correct errors or deviations from the predetermined long-run equilibrium. The data used in this study are presented in Table 1 as follows.

Table 1. Measurement and Descriptive Statistics of Variables

Dependent Variable	Symbol	Unit of Measurement	Source
Gross Regional Domestic Product at Constant Prices	NPR	Gross Regional Domestic Product at 2010 Constant Prices by Regency/Municipality	Statistika (2025)
Independent Variables			
Agricultural Productivity	$P(t)$	Harvested Area, Production, and Average Productivity by Regency/Municipality	BPS (2025)
Agricultural Wages	UPR	Average Monthly Net Wages/Salaries of Formal Workers by Regency/Municipality and Main Employment Sector	
Sector-Based Exports × Productivity	EHP	Exports of North Sumatra by Sector	
BMKG Technology (Meteorology, Climatology, and Geophysical Agency)	T	BMKG Climate and Disaster Indicators	BMKG (2025)
Control Variable			
Main Employment by Age Classification	15-60+	Average Monthly Net Wages/Salaries of Agricultural Workers	BPS (2025)

Source: Authors compilation

³³ Ian Domowitz and Ibrahim Elbadawi, “An Error-Correction Approach to Money Demand,” *Journal of Development Economics* 26, no. 2 (1987): 257–75.

Results

Descriptive Statistics

This study presents descriptive statistics as reported in Tables 2, 3, and 4. These tables display the descriptive statistics of the variables across the full sample of regency and municipal sub-samples in North Sumatra. Based on Tables 2, 3, and 4, the descriptive results illustrate the characteristics of the variables, including agricultural commodities with lower average production levels (soybean, peanut, and mung bean) and those with higher average production levels (corn, cassava, and sweet potato), as well as the technology index measured using data provided by the Meteorology, Climatology, and Geophysical Agency. The descriptive indicators include the mean, median, maximum, minimum, standard deviation, probability, and the number of observations.

Table 2. Agricultural Commodities with the Highest Downstreaming Potential

Low-Productivity Commodities	Soybean			Mung Bean			Peanut		
	Average Productivity (Kw/Ha)	Production (Tons)	Harvested Area (Ha)	Average Productivity (Kw/Ha)	Production (Tons)	Harvested Area (Ha)	Average Productivity (Kw/Ha)	Production (Tons)	Harvested Area (Ha)
Mean	7.01951	224.1069	205.4531	6.209138	70.08762	63.23473	9.050070	243.8796	196.3762
Median	8.43	4.6	3	10	5	5	10.38	63	56
Maximum	30	7215	6343	19.16	1078	922	19.16	5051	4358
Minimum	0	0	0	0	0	0	0	0	0
Std. Dev.	6.537578	658.1460	642.1107	5.310773	153.6122	134.5552	4.902051	4.902051	432.4174
Probbability	0.000007	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Observation	429	429	429	429	429	429	429	429	429

Table 2 represents the characteristics of agricultural commodities with the lowest productivity levels in North Sumatra. The average yield per hectare for the three commodities is relatively low, namely soybean (7.01 Kw/Ha), mung bean (6.21 Kw/Ha), and peanut (9.05 Kw/Ha), with high production variability across regions (for example, the standard deviation of peanut harvested area reaches 432 hectares). The disparity between the maximum and median values indicates an uneven distribution of production across regencies and municipalities, highlighting challenges in agricultural extension systems and the distribution of production inputs.³⁴ All minimum values are recorded at zero, reflecting the existence of regions that have not yet been actively engaged in cultivation, thereby indicating the need for intensification strategies in underdeveloped areas.

Table 3. Agricultural Commodities with the Lowest Downstreaming Potential

High-Productivity Commodities	Corn (Maize)			Sweet Potato			Cassava		
	Average Productivity (Kw/Ha)	Production (Tons)	Harvested Area (Ha)	Average Productivity (Kw/Ha)	Production (Tons)	Harvested Area (Ha)	Average Productivity (Kw/Ha)	Production (Tons)	Harvested Area (Ha)
Mean	48.25372	56330.61	8071.99	125.9374	3619.915	256.3254	273.7303	35496.72	1036.519
Median	49.91	4599.2	943	125.77	874.22	69	281.07	4998	193
Maximum	73.73	424221	109277	900.1	50736	4189	605.42	802208.4	20247
Minimum	0	0	0	0	0	0	0	0	0
Std. Dev.	13.93692	232603.7	18343.24	71.69957	7177.896	538.6556	102.1676	103225.5	2714.708
Probbability	0.000007	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Observation	429	429	429	429	429	429	429	429	429

³⁴ Ngadi Ngadi et al., “Challenge of Agriculture Development in Indonesia: Rural Youth Mobility and Aging Workers in Agriculture Sector,” *Sustainability* 15, no. 2 (2023): 922; Qiki Qilang Syachbudy et al., “Factors Determining the Performance of the Indonesian Agricultural Sector in the Era of Climate Change,” *Jurnal Ilmu Pertanian Indonesia* 30, no. 3 (2025): 490–99.

Table 3 shows that maize, sweet potato, and cassava exhibit significantly higher productivity levels than the commodities presented in Table 2. The average cassava yield reaches 273.7 Kw/Ha, substantially higher than that of the other commodities, and is accompanied by an exceptionally high maximum production output (802,208 tons). Nevertheless, the high standard deviations in both production and harvested area across all commodities (for example, maize = ±232,603 tons) indicate substantial spatial disparities, which are generally influenced by access to infrastructure, technology, and markets in productive regencies such as Deli Serdang and Serdang Bedagai.³⁵ The minimum values remain at zero, indicating that there is still considerable potential for the expansion of cultivated areas in other less productive regencies.

Table 4. BMKG Climate Technology Index (C1 = 100)

	Landslides	Floods	Droughts	Forest and Land Fires	Extreme Weather	Volcanic Eruptions
Mean	0.123543	0.599068	0.009324	0.053613	0.386946	0.044289
Median	0	0	0	0	0	0
Maximum	5	16	3	3	13	16
Minimum	0	0	0	0	0	0

Note: Author’s Calculation

Table 4 presents the natural disaster index based on categories developed by the Meteorology, Climatology, and Geophysical Agency. The average values for the extreme weather (0.38), flood (0.59), and landslide (0.12) variables indicate that regencies across North Sumatra face fluctuating and uneven climate risks. Although the median values are recorded at zero across all indicators, the maximum values reveal a considerable potential for extreme events, with extreme weather reaching up to 13 occurrences and floods reaching up to 16 occurrences during the observation period. This index is important for formulating climate-resilient agricultural strategies, particularly in regions vulnerable to hydrometeorological and volcanic disasters, such as Karo Regency and North Tapanuli Regency.³⁶

Panel EGLS (Cross-section Random Effects)

Based on the data presented in Table 5, the findings illustrate the development of maize downstreaming, intra-industry trade (exports), productivity-based wages, and maize agricultural productivity within the BMKG technology index in addressing natural disaster shocks toward regional economic growth in North Sumatra. In addition, the empirical results presented in Table 5 also explain the increase in regional economic growth, which is indirectly influenced by agricultural production wages (*formal-1*) across

³⁵ Ledy Festaria, “Analisis Produksi Jagung Dengan Penyertaan Dana Penguatan Modal Lembaga Usaha Ekonomi Pedesaan (Dpm-Luep) Di Provinsi Sumatera Utara” (Tesis, Universitas Medan Area, 2017); Suhartini et al., “The Role of Root and Tuber Crops on Food Diversification Facing the Climate Change in East Java Indonesia,” *IOP Conference Series: Earth and Environmental Science* 1323, no. 1 (2024): 012013; Barbara J. Craig et al., “International Productivity Patterns: Accounting for Input Quality, Infrastructure, and Research,” *American Journal of Agricultural Economics* 79, no. 4 (1997): 1064–76; Gonzalo Rizzo et al., “A Farmer Data-Driven Approach for Prioritization of Agricultural Research and Development: A Case Study for Intensive Crop Systems in the Humid Tropics,” *Field Crops Research* 297 (June 2023): 108942.

³⁶ Handhayani and Lewenusa, “An Analysis of Meteorological Data in Sumatra and Nearby Using Agglomerative Clustering”; Manandhar et al., *Climate Vulnerability & Adaptive Capacity of Mountain Societies in Central Asia*.

the working-age group of 15 to 60 years and above. These findings indicate that increases in production quantity have not yet been aligned with increases in value added. This condition can be explained through two main aspects: (1) limitations in post-harvest facilities and maize processing capacity, and (2) local oversupply conditions that suppress market prices.³⁷ In contrast, the *UPr* variable (average agricultural wages) and the *EHP* variable (agricultural export performance) consistently show positive and significant effects, as reflected, for example, in the *EHP* coefficient of 10755.23 (*PJ1*). This suggests that economic incentives and trade openness serve as the main drivers of value-added growth in maize downstreaming. This evidence is further supported by the findings of the Food and Agriculture Organization,³⁸ which confirm that market access and farmer wage incentives have a direct impact on the efficiency of maize agribusiness in developing countries.

Table 5. NPR Regression – Part I

Variables	Productivity Value Added from Maize Production									
	PJ1	PJ2	PJ3	PJ4	PJ5	PJ6	PJ7	PJ8	PJ9	PJ10
Constant	0.0002 (-)	0.0079 (-31514.42) ^a	0.0004 (-)	0.0155 (-)	0.0018 (-)	0.0034 (-)	0.0555 (-)	0.0003 (-)	0.0767 (-)	0.3396 (-18420.53)
Coeff.	43822.71) ^a	(-31514.42) ^a	41930.65) ^a	29315.28) ^b	36779.66) ^a	34976.88) ^a	24246.60) ^c	43829.54) ^a	23766.69) ^c	(-18420.53)
P(t)	0.0437 (-1.071559) ^b	0.0322 (-1.153188) ^b	0.0351 (-1.118370) ^b	0.0368 (-1.137762) ^b	0.0459 (-)	0.0791 (-)	0.0285 (-)	0.0644 (-)	0.0303 (-)	0.0357 (-1.198394) ^b
UPR	0.0000 (0.000365) ^a	0.0000 (0.000359) ^a	0.0000 (0.000363) ^a	0.0000 (0.000349) ^a	0.0000 (0.000366) ^a	0.0000 (0.000353) ^a	0.0000 (0.000343) ^a	0.0000 (0.000360) ^a	0.0000 (0.000321) ^a	0.0000 (0.000307) ^a
EHP	0.0000 (10755.23) ^a	0.0001 (8562.894) ^a	0.0000 (10420.34) ^a	0.0002 (8197.411) ^a	0.0000 (9485.581) ^a	0.0000 (9196.313) ^a	0.0013 (7309.560) ^a	0.0000 (10764.43) ^a	0.0026 (7288.457) ^a	0.0695 (6370.462) ^c
P(t)*t	0.5570 (0.115632)	0.4753 (0.142507)	0.4602 (0.145219)	0.4919 (0.138949)	0.5434 (0.120343)	0.6868 (0.081788)	0.4537 (0.152850)	0.5835 (0.108602)	0.4518 (0.156563)	0.5399 (0.130636)
15-19	0.0001 (1140.474) ^a									
20-24		0.0004 (730.1008) ^a								
25-29			0.0001 (657.0926) ^a							
30-34				0.0013 (468.1190) ^a						
35-39					0.0002 (576.5420) ^a					
40-44						0.0011 (497.5544) ^a				
45-49							0.0034 (388.9420) ^a			
50-54								0.0002 (532.0069) ^a		
55-59									0.0240 (297.8088) ^b	
60+										0.2185 (161.2016)
Symbol	++ <i>Accepted</i>	+ <i>Accepted</i>	+ <i>Accepted</i>	+/- <i>Accepted</i>	+ <i>Accepted</i>	+/- <i>Accepted</i>	+/- <i>Accepted</i>	+ <i>Accepted</i>	+/- <i>Accepted</i>	- <i>Rejected</i>
R-squared	0.469629	0.458836	0.470295	0.449301	0.465264	0.450139	0.442220	0.465590	0.427048	0.411084
F-statistic	22.13683	21.19672	22.19613	20.39685	21.76077	20.46606	19.82054	21.78060	18.63368	17.45089
Prob	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Obs	131	131	131	131	131	131	131	131	131	131

Note: ^{a,b,c} indicate significance levels at 1%, 5%, and 10%, respectively. The symbols (++) or ≥1,000 indicate highly significant, (+ or 500–999) indicate significant, (+/- or 200–499) indicate weakly significant, and (- or ≤199) indicate not significant.

The interaction term $P(t)*T$ (productivity × climate technology) does not demonstrate strong statistical significance, but it shows a positive direction, indicating

³⁷ Dagmawe Menelek Asfaw et al., “Analysis of Constraints and Opportunities in Maize Production and Marketing in Ethiopia,” *Heliyon* 10, no. 20 (2024): e39606; Sang Thanh Le et al., “Innovation in Two Contrasting Value Chains: Constraints and Opportunities for Adopting Alternative Crop Production in the Vietnamese Mekong River Delta,” *Regional Sustainability* 6, no. 1 (2025): 100198.

³⁸ FAO, *The State of Food and Agriculture 2023*.

the potential of predictive technologies, such as those provided by the Meteorology, Climatology, and Geophysical Agency, to support climate resilience in agriculture,³⁹ although their implementation still needs to be adapted to local conditions and needs. These findings suggest that maize production faces a productivity paradox: output continues to increase while value added declines, unless it is supported by export expansion and labor incentives.

Table 6. NPR Regression Results – Part II

Variables	Productivity Value Added from Cassava Production									
	PUK1	PUK2	PUK3	PUK4	PUK5	PUK6	PUK7	PUK8	PUK9	PUK10
Constant	0.0000 (-)	0.0013 (-)	0.0000 (-)	0.0041 (-)	0.0000 (-)	0.0002 (-)	0.0191 (-)	0.0000 (-)	0.0133 (-)	0.0305 (-)
Coeff.	69280.78) ^a	45742.55) ^a	66001.50) ^a	42370.66) ^a	55213.67) ^a	50897.42) ^a	38073.69) ^b	(-71561.53) ^a	42796.18) ^b	64114.12) ^b
P(T)	0.5874 (-0.261218)	0.7822 (-0.135358)	0.7586 (-0.146539)	0.8358 (-0.103127)	0.7782 (-0.133247)	0.7895 (-0.129435)	0.8107 (-0.121573)	0.8251 (-0.103566)	0.8039 (-0.128431)	0.7149 (-0.190623)
UPR	0.0000 (4855.879) ^a	0.0000 (4773.082) ^a	0.0000 (5099.082) ^a	0.0000 (4289.866) ^a	0.0000 (5795.909) ^a	0.0000 (5230.311) ^a	0.0001 (3600.802) ^a	0.0000 (5658.460) ^a	0.0006 (2715.689) ^a	0.8290 (1600.990)
EHP	0.0002 (9795.803) ^a	0.0605 (5656.058) ^c	0.0006 (8897.219) ^a	0.0746 (5661.527) ^c	0.0261 (6088.341) ^b	0.0359 (6043.488) ^b	0.1052 (5747.360)	0.0003 (9219.801) ^a	0.0351 (7713.250) ^b	0.0383 (12955.78) ^b
P(T)*T	0.9157 (0.017567)	0.8692 (0.027865)	0.8714 (0.026632)	0.9302 (0.015044)	0.8574 (0.029321)	0.9831 (-0.003527)	0.9462 (0.011835)	0.9592 (0.008248)	0.9728 (0.006090)	0.8644 (0.030876)
15-19	0.0001 (2190.873) ^a									
20-24		0.0004 (1447.534) ^a								
25-29			0.0000 (1357.962) ^a							
30-34				0.0019 (873.0378) ^a						
35-39					0.0000 (1409.331) ^a					
40-44						0.0001 (1198.297) ^a				
45-49							0.0170 (584.2753) ^b			
50-54								0.0000 (1298.025) ^a		
55-59									0.1308 (327.0849)	
60+										0.7844 (-) 62.87761)
Symbol	++ <i>Accepted</i>	++ <i>Accepted</i>	++ <i>Accepted</i>	+ <i>Accepted</i>	++ <i>Accepted</i>	++ <i>Accepted</i>	+ <i>Accepted</i>	++ <i>Accepted</i>	+/- <i>Rejected</i>	- <i>Rejected</i>
R-Squared	0.331770	0.310408	0.338215	0.294894	0.346144	0.325724	0.271714	0.358089	0.250454	0.237080
F-Statistic	12.41227	11.25334	12.77660	10.45566	13.23470	12.07678	9.327192	13.94620	8.353524	7.768853
Prob	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000002
OBS	131	131	131	131	131	131	131	131	131	131

Note: ^{a,b,c} indicate significance levels at 1%, 5%, and 10%, respectively. The symbols (++) or ≥1,000) indicate highly significant, (+ or 500–999) indicate significant, (+/- or 200–499) indicate weakly significant, and (- or ≤199) indicate not significant.

Table 6 presents the productivity value added generated from cassava production. The results show that cassava productivity, represented by $P(t)$, has a negative and statistically insignificant effect on cassava value added across all model specifications, while being controlled by wage categories based on age classification. In addition, intra-industry trade through exports (EHP) shows a positive effect on productivity value added, with a coefficient of 12955.78. Cassava production, which is indirectly influenced by the Meteorology, Climatology, and Geophysical Agency technology index, exhibits negative effects within the age groups of 40–44, 55–59, and 60 years and above, but shows positive effects across other age categories. The symbols indicate increases in

³⁹ Agyekum et al., “The Contribution of Weather Forecast Information to Agriculture, Water, and Energy Sectors in East and West Africa.”

productivity value added ranging from ($> 5 \times 10^2$ to $> 1 \times 10^3$), or (+ and ++), reflecting positive and significant effects within wage classifications across the 15–54 age groups. Labor wages show positive effects across all model specifications; however, they are statistically insignificant in *PUK10*, which is controlled by workers predominantly aged 60 years and above. Like maize, the *P(t)* variable for cassava remains consistently negative and statistically insignificant across all *PUK1–PUK10* models. The large negative coefficients (for example, -69280.78 in *PUK1*) reflect structural limitations in local pricing mechanisms and market access for this commodity. Mass-produced cassava often generates low profit margins due to limited downstream industrialization, as highlighted by Wongpit et al.⁴⁰ and Sugri et al.⁴¹ Nevertheless, *EHP* and *UPr* continue to demonstrate positive and significant effects in most model specifications, indicating that export orientation and wage improvement policies can strengthen the value structure of cassava production, consistent with the findings of the World Bank regarding the importance of supply chain integration and labor competitiveness in the primary food sector.⁴² Unlike maize, the interaction term *P(t)T* for cassava tends to be statistically insignificant and relatively weak, and in several models even shows a negative direction, such as -0.0035 in *PUK6*. This suggests that climate technology provided by the Meteorology, Climatology, and Geophysical Agency has not yet made a meaningful contribution to cassava productivity, either due to differences in planting seasons or the limited adoption of technology among farmers. Therefore, it can be concluded that the value added of cassava production depends strongly on labor incentives and export markets, while increases in output alone remain insufficient unless accompanied by industrialization and downstream transformation.

Table 7. NPR Regression Results – Part III

Variables	Productivity Value Added from Sweet Potato Production									
	PUJ1	PUJ2	PUJ3	PUJ4	PUJ5	PUJ6	PUJ7	PUJ8	PUJ9	PUJ10
Constant	0.0000	0.0014	0.0000	0.0047 ^a	0.0001	0.0005	0.0204	0.0000	0.0139	0.0424
Coeff.	(-)	(-)	(-)	(-41253.15)	(-)	(-)	(-)	(-)	(-)	(-)
P(T)	0.0393	0.1091	0.0986	0.1625	0.1038	0.1600	0.1487	0.1675	0.1699	0.1434
	(-)	(-)	(-)	(-)	(-7.815386)	(-)	(-7.472271)	(-6.578669)	(-7.259397)	(-7.811910)
UPR	10.10433 ^b	7.980092	8.000661 ^c	7.082782	(-7.815386)	6.916440	(-7.472271)	(-6.578669)	(-7.259397)	(-7.811910)
	(4957.512) ^a	(4757.741) ^a	(5092.011) ^a	(4229.642) ^a	(5769.298) ^a	(5259.879) ^a	(3556.485) ^a	(5606.283) ^a	(2651.055) ^a	(1668.428) ^c
EHP	0.0002	0.0617	0.0006	0.0747	0.0282	0.0546	0.1042	0.0004	0.0333	0.0511
	(9460.208) ^a	(5510.135) ^b	(8773.751) ^a	(5561.386) ^c	(5907.734) ^b	(5503.379) ^c	(5640.586)	(8941.311) ^a	(7652.734) ^b	(12055.16) ^c
P(T)*T	0.8760	0.9978	0.9144	0.8949	0.8858	0.4597	0.9231	0.7359	0.8355	0.7689
	(-0.979231)	(0.017964)	(0.675703)	(-)	(-)	(-)	(-)	(-)	(-)	(-)
15-19	0.0000									
	(2268.139) ^a									
20-24		0.0004								
		(1442.993) ^a								
25-29			0.0000							
			(1358.317) ^a							
30-34				0.0022						
				(852.5878) ^a						
35-39					0.0000					
					(1401.152) ^a					
40-44						0.0001				
						(1205.462) ^a				
45-49							0.0185			
							(570.8522) ^b			
50-54								0.0000		
								(1279.831) ^a		
55-59									0.1574	
									(303.8675)	

⁴⁰ Wongpit et al., “Enhancing the Cassava Value Chain.”

⁴¹ Sugri et al., “Postharvest Losses and Mitigating Technologies.”

⁴² World Bank, *Indonesia Economic Prospects, December 2023: Climate Action for Development* (World Bank, Washington, DC, 2023).

60+										0.8494 (-43.11467)
Symbol	++ Accepted	++ Accepted	++ Accepted	+ Accepted	++ Accepted	++ Accepted	+ Accepted	++ Accepted	+/- Rejected	- Rejected
R-Squared	0.0350441	0.322437	0.350584	0.304656	0.358107	0.338042	0.282328	0.367495	0.260581	0.248422
F-Statistic	13.48765	11.89696	13.49613	10.95344	13.94728	12.76675	9.834852	14.52536	8.810330	8.263327
Prob	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000001
OBS	131	131	131	131	131	131	131	131	131	131

Note: ^{a,b,c} indicate significance levels at 1%, 5%, and 10%, respectively. The symbols (++ or ≥1,000) indicate highly significant, (+ or 500–999) indicate significant, (+/- or 200–499) indicate weakly significant, and (- or ≤199) indicate not significant.

Meanwhile, Table 7 presents the productivity value added generated from sweet potato production. In general, the regression results show that the $P(t)$ variable has a negative and significant effect on sweet potato productivity across almost all model specifications ($PUJ1$ – $PUJ10$), with statistically significant coefficients observed in $PUJ1$, $PUJ3$, and $PUJ7$. This indicates that increases in output $P(t)$ do not automatically lead to higher value added, which may be attributed to post-harvest inefficiencies, limited access to local markets, or fluctuations in domestic prices.⁴³ Meanwhile, UPr and EHP remain variables that significantly drive productivity value added, further reinforcing the findings of the previous models. The $P(t)T$ interaction term in several models even shows a negative but statistically insignificant direction, and in $PUJ6$ reaches -4.73 , indicating a mismatch between predictive technology inputs and the agroecological realities of sweet potato cultivation.⁴⁴ Therefore, these findings suggest that the sweet potato model presents a duality: although exports and labor wages contribute positively to value added, there remains a contradiction in which increases in output volume may reduce value-added efficiency.

Table 8. NPR Regression Results – Part IV

Variables	Productivity Value Added from Soybean Production									
	PK1	PK2	PK3	PK4	PK5	PK6	PK7	PK8	PK9	PK10
Constant	0.0000 (-)	0.0009 (-)	0.0000 (-)	0.0033 (-)	0.0000 (-)	0.0002 (-)	0.0158 (-)	0.0000 (-)	0.0128 (-)	0.0301 (-)
Coeff.	69327.04 ^a	46449.65 ^a	66233.01 ^a	42632.62 ^a	55778.54 ^a	50952.07 ^a	38492.35 ^b	71874.66 ^a	42292.28 ^b	63074.94 ^b
P(T)	0.4350 (10.13708)	0.3014 (13.53349)	0.3358 (12.28167)	0.2231 (16.13659)	0.2799 (13.63938)	0.1484 (18.59778)	0.2438 (15.78547)	0.1872 (16.39786)	0.2119 (17.21258)	0.2314 (16.72150)
UPR	0.0000 (4724.889) ^a	0.0000 (4696.154) ^a	0.0000 (5021.790) ^a	0.0000 (4279.411) ^a	0.0000 (5724.836) ^a	0.0000 (5301.798) ^a	0.0001 (3577.871) ^a	0.0000 (5666.802) ^a	0.0005 (2747.351) ^a	0.0747 (1630.718) ^c
EHP	0.0001 (9951.705) ^a	0.0477 (5870.261) ^b	0.0004 (9025.506) ^a	0.0669 (5712.130) ^b	0.0200 (6268.414) ^b	0.0350 (5948.909) ^b	0.0936 (5841.422) ^c	0.0002 (9253.643) ^a	0.0354 (7570.826) ^b	0.0385 (12714.53) ^b
P(T)*T	0.9143 (-11.25251)	0.9239 (-10.12530)	0.9429 (7.403320)	0.9771 (3.078922)	0.9845 (1.994064)	0.8150 (24.46014)	0.9235 (-10.54612)	0.8480 (19.34925)	0.9445 (7.788308)	0.9449 (7.827891)
15-19	0.0001 (2095.660) ^a									
20-24		0.0005 (1407.313) ^a								
25-29			0.0000 (1324.539) ^a							
30-34				0.0019 (867.1838) ^a						
35-39					0.0000 (1383.566) ^a					
40-44						0.0001 (1223.443) ^a				
45-49							0.0178 (574.1316) ^b			
50-54								0.0000 (1300.853) ^a		

⁴³ Cicero Z. De Lima et al., “Heat Stress on Agricultural Workers Exacerbates Crop Impacts of Climate Change,” *Environmental Research Letters* 16, no. 4 (2021): 044020; Reardon et al., “Rapid Transformation of Food Systems in Developing Regions.”

⁴⁴ Mohd Idris Nor Diana et al., “Farmers’ Adaptation Strategies to Climate Change in Southeast Asia: A Systematic Literature Review,” *Sustainability* 14, no. 6 (2022): 3639.

55-59										0.1176 (335.1850)
60+										0.8027 (-56.74857)
Symbol	++	++	++	+	++	++	+	++	+/-	-
	Accepted	Accepted	Accepted	Accepted	Accepted	Accepted	Accepted	Accepted	Rejected	Rejected
R-Squared	0.329423	0.311799	0.338745	0.299244	0.347968	0.334147	0.275183	0.364161	0.255003	0.240627
F-Statistic	12.28133	11.32660	12.80689	10.67578	13.34169	12.54583	9.491473	14.31812	8.557191	7.921888
Prob	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000001	0.000002
Obs	131	131	131	131	131	131	131	131	131	131

Note: ^{a,b,c} indicate significance levels at 1%, 5%, and 10%, respectively. The symbols (++ or ≥1,000) indicate highly significant, (+ or 500–999) indicate significant, (+/- or 200–499) indicate weakly significant, and (- or ≤199) indicate not significant.

Table 8 presents the productivity value added generated from soybean production. In soybean production, the $P(t)$ variable shows a positive but statistically insignificant coefficient, while the constant term remains significantly negative across almost all model specifications, such as $PK1$ (-69327.04) and $PK2$ (-46449.65). This indicates the presence of structural pressures or high fixed costs that reduce productivity margins.⁴⁵ The $P(t)T$ interaction term shows a positive but statistically insignificant effect in most model specifications, and even reaches a relatively high value in certain models (for example, $PK6 = 24.46$), which may indicate a mismatch between the application of climate technology and soybean planting seasons—an important finding within the climate–agriculture literature (Nendel, 2023). Meanwhile, labor wages and exports (UPr and EHP) remain positive and statistically significant, reflecting the elasticity of output in response to labor inputs and market openness. Therefore, the findings presented in Table 8 reveal that soybean production remains highly dependent on labor inputs and export performance yet has not responded effectively to increases in quantitative output or climate technology interventions.

Table 9. NPR Regression Results – Part V

Variables	Productivity Value Added from Peanut Production									
	PKT1	PKT2	PKT3	PKT4	PKT5	PKT6	PKT7	PKT8	PKT9	PKT10
Constant	0.0000	0.0009	0.0000	0.0032	0.0000	0.0002	0.0170	0.0000	0.0136	0.0244
Coeff.	(-69661.58) ^a	(-46470.14) ^a	(-66671.55) ^a	(-42682.72) ^a	(-56022.48) ^a	(-51344.11) ^a	(-38069.34) ^a	(-72159.72) ^a	(-42009.52) ^a	(-65825.40) ^b
P(T)	0.6787	0.3828	0.3708	0.3316	0.4157	0.4968	0.3519	0.3546	0.3558	0.4429
	(-29.39271)	(-62.51987)	(-62.37313)	(-70.70378)	(-56.33346)	(-48.22289)	(-69.25536)	(-63.34605)	(-70.23255)	(-58.89982)
UPR	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0004	0.0874
	(4773.187) ^a	(4780.788) ^a	(5108.566) ^a	(4337.540) ^a	(5768.917) ^a	(5246.298) ^a	(3662.847) ^a	(5678.404) ^a	(2799.156) ^a	(1568.401) ^c
EHP	0.0001	0.0505	0.0004	0.0691	0.0199	0.0320	0.1030	0.0002	0.0382	0.0313
	(9961.03) ⁵ ^a	(5787.851) ^c	(9015.585) ^a	(5672.247) ^b	(6276.858) ^b	(6109.970) ^b	(5681.153)	(9314.758) ^a	(7478.489) ^b	(13308.27) ^b
P(T)*T	0.5769	0.4385	0.4190	0.4767	0.5906	0.9574	0.4204	0.7221	0.4379	0.4552
	(31.6499) ⁹	(44.48538)	(45.14194)	(41.45914)	(29.87622)	(3.082620)	(47.97613)	(19.55725)	(47.08682)	(46.15347)
15-19	0.0001									
	(2123.85) ⁹ ^a									
20-24		0.0004								
		(1442.602) ^a								
25-29			0.0000							
			(1354.496) ^a							
30-34				0.0016						
				(883.9352) ^a						

⁴⁵ Ramon Felipe Bicudo Da Silva et al., “The Soybean Trap: Challenges and Risks for Brazilian Producers,” *Frontiers in Sustainable Food Systems* 4 (February 2020): 12.

35-39	0.0000 (1396.525) ^a									
40-44	0.0001 (1205.472) ^a									
45-49	0.0140 (597.7405) ^b									
50-54	0.0000 (1303.393) ^a									
55-59	0.1057 (349.5886)									
60+	0.7297 (-79.12071)									
Symbol	++	++	++	+	++	++	+	++	+/-	-
R-Squared	Accepted	Accepted	Accepted	Accepted	Accepted	Accepted	Accepted	Accepted	Rejected	Rejected
F-Statistic	0.328276	0.311858	0.339738	0.297605	0.345989	0.325589	0.274476	0.359499	0.253130	0.238020
Prob	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000001	0.000002
Obs	131	131	131	131	131	131	131	131	131	131

Note: ^{a,b,c} indicate significance levels at 1%, 5%, and 10%, respectively. The symbols (++ or ≥1,000) indicate highly significant, (+ or 500–999) indicate significant, (+/- or 200–499) indicate weakly significant, and (- or ≤199) indicate not significant.

Meanwhile, Table 9 presents the productivity value added generated from peanut production. The constant term and $P(t)$ consistently show large and statistically significant negative coefficients across all model specifications, such as $PKT1$ (-69661.58) and $PKT3$ (-66671.55), while the $P(t)T$ interaction term shows positive but statistically insignificant values, such as $PKT1$ (31.65) and $PKT6$ (3.08), indicating that the climate technology applied has not yet contributed to the optimization of peanut production. The consistent negative effect and statistical significance of $P(t)$ suggest that overproduction, or the disconnect between production output and value systems—such as downstream industrialization, distribution, and processing—remains a persistent structural challenge.⁴⁶ On the other hand, UPr and EHP continue to demonstrate positive and statistically significant effects across almost all model specifications. However, labor variables associated with workers aged 60 years and above generate substantially lower or even negative productivity effects. Therefore, the findings reveal that peanut productivity exhibits signs of structural stagnation, primarily because increases in output quantity are not accompanied by corresponding increases in value added. Export support, therefore, remains a key factor in improving the economic value efficiency of this agricultural commodity.

Table 10. NPR Regression Results – Part VI

Variables	Productivity Value Added from Mung Bean Production									
	PKH1	PKH2	PKH3	PKH4	PKH5	PKH6	PKH7	PKH8	PKH9	PKH10
Constant	0.0000	0.0022	0.0000	0.0073	0.0001	0.0005	0.0309	0.0000	0.0239	0.0407
Coeff.	(-)	(-)	(-)	(-)	(-)	(-)	(-3544.87) ^b	(-)	(-)	(-)
P(T)	68364.08) ^a	43859.31) ^a	64421.18) ^a	39967.11) ^a	53490.35) ^a	49031.62) ^a	(-196.3153)	69874.63) ^a	39619.54) ^b	61279.14) ^b
	0.9326	0.4781	0.5094	0.3876	0.5021	0.5185	0.4267	0.4201	0.4394	0.6152
	(-)	(-)	(-152.0514)	(-)	(-153.3878)	(-151.2697)	(-182.3593)	(-)	(-)	(-)
	19.83086)	168.0788)	(-152.0514)	208.6524)	(-153.3878)	(-151.2697)	(-196.3153)	(-182.3593)	196.0508)	127.8072)
UPR	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000	0.0004	0.0751
	(4885.515) ^a	(4815.490) ^a	(5122.796) ^a	(4376.516) ^a	(5830.719) ^a	(5270.786) ^a	(3682.589) ^a	(5708.451) ^a	(2811.338) ^a	(1651.009) ^c
EHP	0.0003	0.0835	0.0010	0.1102	0.0380	0.0519	0.1490	0.0005	0.0589	0.0501
	(9572.460) ^a	(5258.893) ^c	(8576.814) ^a	(5119.649)	(5728.942) ^b	(5651.559) ^c	(5168.903)	(8851.964) ^a	(7018.610) ^c	(12372.45) ^c
P(T)*T	0.5381	0.4038	0.4217	0.4115	0.3975	0.4827	0.4348	0.4382	0.4907	0.6309
	(130.1868)	(180.0082)	(168.3676)	(179.7968)	(175.8590)	(149.3327)	(175.0064)	(159.0967)	(157.4660)	(111.5604)
15-19	0.0001									
	(2211.137) ^a									
20-24		0.0003								
		(1461.463) ^a								
25-29			0.0000							

⁴⁶ Liu et al., “Problem Identification Model of Agricultural Precision Management Based on Smart Supply Chains.”

			(1362.701) ^a							
30-34				0.0014						
				(897.3967) ^a						
35-39				0.0000						
				(1417.093) ^a						
40-44				0.0001						
				(1207.819) ^a						
45-49							0.0133			
							(605.6269) ^b			
50-54								0.0000		
								(1309.730) ^a		
55-59									0.1028	
									(355.7613)	
60+										0.8246
										(-51.11110)
Symbol	++	++	++	+	++	++	+	++	+/-	-
	Accepted	Accepted	Accepted	Accepted	Accepted	Accepted	Accepted	Accepted	Rejected	Rejected
R-Squared	0.330635	0.311365	0.338555	0.297207	0.346862	0.326463	0.273454	0.359651	0.251988	0.236392
F-Statistic	12.34881	11.30369	12.79606	10.57234	13.27676	12.11750	9.409369	14.04121	8.421928	7.739302
Prob	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000001	0.000002
Obs	131	131	131	131	131	131	131	131	131	131

Note: ^{a,b,c} indicate significance levels at 1%, 5%, and 10%, respectively. The symbols (++ or ≥1,000) indicate highly significant, (+ or 500–999) indicate significant, (+/- or 200–499) indicate weakly significant, and (- or ≤199) indicate not significant.

Meanwhile, Table 10 presents the development of productivity value added generated from mung bean production. The regression results show that $P(t)$ remains negative and statistically insignificant, with very large and negative constant terms across all model specifications (for example, $PKH1 = -68364.08$ and $PKH2 = -43859.31$), further reinforcing the findings presented in Tables 7–9 that quantity-based productivity does not automatically lead to higher value added, particularly for commodities with high perishability characteristics, such as mung beans.⁴⁷ The $P(t)T$ interaction term also remains statistically insignificant and even shows relatively large but directionally inconsistent values (positive in $PKH1 = 130.18$ versus negative in $PKH10 = 111.56$), reflecting the limited effectiveness of generalized technology-based policies. The younger working-age group (15–54 years) continues to show positive and statistically significant effects (++) , while older workers (60 years and above) demonstrate significantly negative contributions, consistent with the theory of optimal working-age efficiency.⁴⁸ Based on these findings, it can be concluded that the PKH model indicates that increases in value added depend heavily on wage incentives and export market access, while remaining vulnerable to mismatches in technology strategies that are not adequately adapted to local capacities and conditions.

Advanced Productivity Dynamics

To obtain a deeper understanding of the dynamic role of agricultural downstream productivity in regional economic growth, this section extends the previous static panel analysis by applying the *Random Effect–Error Correction Model (RE–ECM)*. This approach enables the identification of both long-run equilibrium relationships and short-run adjustment mechanisms among agricultural productivity, labor incentives, export-oriented trade, and climate-adaptive technology across 33 regencies and

⁴⁷ Guancheng Guo et al., “The Impact of Aging Agricultural Labor Population on Farmland Output: From the Perspective of Farmer Preferences,” *Mathematical Problems in Engineering* 2015 (2015): 1–7.

⁴⁸ Stads, Gert-Jan et al., *Agricultural Research in Southeast Asia: A Cross-Country Analysis of Resource Allocation, Performance, and Impact on Productivity*, ASTI synthesis reports no. 134063 (International Food Policy Research Institute (IFPRI), n.d.); Yamauchi, “Wage Growth, Landholding and Mechanization in Agriculture Evidence from Indonesia.”

municipalities in North Sumatra. Furthermore, this analysis distinguishes between high-productivity and low-productivity agricultural commodities in order to examine whether the determinants of productivity value added exhibit different adjustment patterns under varying commodity structures, market conditions, and agroecological risks. The empirical results of this advanced-stage productivity analysis are presented in Tables 11 and 12.

Table 11. Highest Agricultural Productivity across 33 Regencies and Municipalities in North Sumatra

Variables	NPR. MAIZE		NPR. CASSAVA		NPR. SWEET POTATO	
	Long term	Short term	Long term	Short term	Long term	Short term
Constant	0.9516	0.8834	0.9859	0.1081	0.6645	0.0044
Coeff.	(-26251.23)	(-169.0095)	(7409.096)	(-2365.514)	(175924.4)	(-1882.516) ^a
NPR(-1)		0.7092		0.9515		0.6836
		(-0.019757)		(-0.001033)		(-0.006018)
P(T)	0.1836	0.0239	0.9001	0.0256	0.2103	0.0000
	(-4.056211)	(-3.958434) ^b	(-0.399558)	(0.990930) ^b	(-205.9899)	(-43.05131) ^a
UPR	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	(61605.16) ^a	(48484.68) ^a	(60849.89) ^a	(62211.11) ^a	(60159.60) ^a	(60983.66) ^a
EHP	0.4466	0.9173	0.3931	0.0000	0.2071	0.0000
	(-61492.67)	(-3504.875)	(-66918.30)	(-102708) ^a	(-96061.46)	(-107743.2) ^a
P(T)*T	0.2471	0.0000	0.9367	0.1920	0.8156	0.6031
	(7.159879)	(11.42259) ^a	(0.272839)	(0.696440)	(36.74746)	(9.556491)
INT.1 - EXPORT	0.7806	0.0288	0.1798	0.0213	0.0672	0.0019
	(10909.02)	(15553.64) ^b	(12403.39)	(3715.652) ^b	(10299.71) ^c	(2491.574) ^a
INT.5 - EXPORT	0.7806	0.5175	0.6726	0.8005	0.2234	0.0381
	(3172.712)	(4514.491)	(3863.771)	(396.2903)	(15854.20)	(2069.433) ^b
INT.10 - EXPORT	0.3300	0.0127	0.1652	0.0110	0.2291	0.0484
	(11047.97)	(18255.25) ^b	(14994.15)	(4605.308) ^b	(44891.88)	(3907.192) ^b
ECT		0.0000		0.0000		0.0000
		(0.817741) ^a		(0.987552) ^a		(0.977763) ^a
		Accepted		Accepted		Accepted
R-Squared	0.265219	0.670527	0.271406	0.966772	0.270673	0.974473
F-Statistic	6.342410	26.68303	6.545466	381.4665	6.521231	500.5133
Prob.	0.000002	0.000000	0.000001	0.000000	0.000002	0.000000
Obs	131	128	131	128	131	128

Note: ^{a,b,c} indicate significance levels at 1%, 5%, and 10%, respectively.

Based on Table 11, the findings present an advanced assessment of high-productivity agricultural commodities across 33 regencies and municipalities in North Sumatra in enhancing production value added as a driver of regional economic growth. Table 11 illustrates the growth of gross regional domestic product (NPR), which is influenced by the downstream industrialization of maize, cassava, and sweet potato production, represented by $P(t)$, production wages (UPr), intra-industry export trade (EHP), export interval scales of 1%, 5%, and 10%, as well as agricultural productivity indirectly influenced by natural disaster shocks (T) through the climate index provided by the Meteorology, Climatology, and Geophysical Agency. The empirical results show that maize and sweet potato productivity have negative and statistically significant effects on production value added, whereas cassava productivity demonstrates a positive and statistically significant effect on production value added. In addition, intra-industry trade (*exports*) in cassava and sweet potato exhibits negative and statistically significant effects on production value added in the short run, with coefficients of $UK = -102708$ and $UJ = -107743.2$, respectively. However, for other productivity variables, the effects remain negative but statistically insignificant in both the short run and the long run. Meanwhile, at the industrial export percentage level, sweet potato production can

significantly increase economic value added across all export intervals (1%, 5%, and 10%) in the short run, with coefficients of 2491.574, 2069.433, and 3907.192, respectively. Furthermore, disaster mitigation supported by the Meteorology, Climatology, and Geophysical Agency contributes significantly to increasing maize productivity in the short run, with a coefficient of 11.42259, although this effect is not observed in the long run. In contrast, cassava and sweet potato production also show positive effects, although these effects remain statistically insignificant in contributing to agricultural productivity value added.

Overall, the findings indicate that agricultural downstream productivity and intra-industry trade (*exports*) in maize, cassava, and sweet potato production contribute positively to regional economic growth in North Sumatra, with short-run diagnostic residual values of 0.670527, 0.966772, and 0.974473, respectively. However, in the long run, the diagnostic residual values have not yet been able to consistently capture all explanatory variables, as reflected by values below 0.5. In addition, the overall results consistently demonstrate that sweet potato production provides the strongest contribution to production value added, as reflected in the *Error Correction Term (ECT)* coefficient of 0.977763 in the short run, based on a total of 128 observational samples. Furthermore, all variables exhibit probability values of $p < 0.01$, $p < 0.05$, and $p < 0.10$, indicating that the overall model is statistically significant simultaneously, thereby rejecting the null hypothesis.

Table 12. Lowest Agricultural Productivity across 33 Regencies and Municipalities in North Sumatra

Variables	NPR – SOYBEAN		NPR – PEANUT		NPR – MUNG BEAN	
	Long term	Short term	Long term	Short term	Long term	Short term
Constant	0.3365	0.0138	0.6304	0.0000	0.4023	0.0011
COEFF.	(422969.5)	(784.5061) ^b	(193772.3)	(-2133.415) ^a	(350150.6)	(231.8502) ^a
NPR(-1)		0.4263		0.8360		0.0692
		(-0.007855)		(-0.001884)		(-0.004526) ^c
P(T)	0.8103	0.0362	0.3073	0.0000	0.5832	0.0000
	(-161.7157)	(57.10455) ^b	(-751.6943)	(-566.7275) ^a	(-3401.479)	(-3702.683) ^a
UPR	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	(62270.21) ^a	(61983.34) ^a	(61817.98) ^a	(60427.14) ^a	(62316.19) ^a	(62412.00) ^a
EHP	0.8410	0.0000	0.1809	0.0000	0.1000	0.0000
	(-142007)	(-119986.4) ^a	(-101045.5)	(-108052.2) ^a	(-129014.6)	(-125566.8) ^a
P(T)*T	0.4764	0.0000	0.3827	0.0000	0.3691	0.0000
	(1846.805)	(1245.818) ^a	(1309.345)	(1280.366) ^a	(5908.183)	(5971.005) ^a
INT.1 - EXPORT	0.4545	0.0002	0.2151	0.0000	0.7545	0.0000
	(-3905.28)	(-1892.238) ^a	(6751.972)	(2727.542) ^a	(-1657.963)	(-554.3615) ^a
INT.5 - EXPORT	0.6477	0.0000	-	-	-	-
	(25285.37)	(12847.58) ^a	-	-	-	-
INT.10 - EXPORT	-	-	-	-	-	-
	-	-	-	-	-	-
ECT		0.0000		0.0000		0.0000
		(0.883537) ^a		(0.985340) ^a		(0.999587) ^a
		Accepted		Accepted		Accepted
R-Squared	0.249651	0.988586	0.257106	0.990190	0.249705	0.999271
F-Statistic	6.876062	1288.320	8.652191	1730.271	8.320231	23493.86
Prob.	0.000003	0.000000	0.000000	0.000000	0.000001	0.000000
Obs	131	128	131	128	131	128

Note: ^{a,b,c} indicate significance levels at 1%, 5%, and 10%, respectively.

Meanwhile, as presented in Table 12, the analysis examines low-productivity agricultural commodities across 33 regencies and municipalities in North Sumatra in contributing to production value added as a driver of regional economic growth. Table

12 illustrates the growth of gross regional domestic product (*NPR*), which is influenced by the downstream industrialization of agricultural production, represented by $P(t)$, production wages (UPr), intra-industry export trade (EHP), export interval scales of 1%, 5%, and 10%, as well as agricultural productivity indirectly influenced by natural disaster shocks (T) through the climate index provided by the Meteorology, Climatology, and Geophysical Agency in North Sumatra. The results show that, overall, the explanatory variables consistently influence regional value-added growth in the short run, although this relationship is not consistently observed in the long run. The findings in Table 12 also demonstrate that average agricultural wages (UPr) exert a positive and statistically significant effect on regional value-added growth across all model specifications. In addition, intra-industry trade exhibits fluctuating short-run effects. For example, the export interaction variables at the 1% and 5% intervals in soybean productivity show different economic impacts, with coefficients of -1892.238 at the 1% interval and 12847.58 at the 5% interval, indicating heterogeneous responses to export intensity.

On the other hand, productivity adjusted by the Meteorology, Climatology, and Geophysical Agency climate index demonstrates positive effects in supporting regional economic growth across all agricultural production models, both in the short run and the long run. Furthermore, soybean productivity shows a positive and statistically significant effect on regional economic growth in the short run, with a coefficient of 57.10455 , although this effect is not sustained in the long run. In contrast, the productivity of peanut and mung bean production exhibits negative but statistically insignificant effects. Overall, the findings indicate that agricultural downstream productivity and intra-industry trade (*exports*) in soybean, peanut, and mung bean production contribute to regional economic growth in North Sumatra, with short-run diagnostic residual values of 0.988586 , 0.990190 , and 0.999271 , respectively. However, in the long run, the diagnostic residual values have not yet consistently captured all explanatory variables, as reflected by values below 0.5 . These findings suggest that soybean, peanut, and mung bean production generate statistically significant but fluctuating effects on regional economic growth in the short run, while their long-run effects remain less stable. In addition, the *Error Correction Term (ECT)* values for peanut and mung bean production exceed 0.9 , indicating that the relationships between the independent and dependent variables maintain long-run equilibrium across the time series.

Discussion

From Empirical Evidence to Theoretical Reflection

The findings presented in Tables 11 and 12 consistently demonstrate that although physical productivity $P(t)$ increases, value added does not always grow linearly—particularly in commodities such as maize, sweet potato, mung bean, and peanut. This evidence reinforces the post-productivism theory in rural development, which emphasizes that the transition from quantity-oriented production toward quality, sustainability, and value differentiation has become a critical determinant of agricultural value added.⁴⁹ In addition, the positive and statistically significant effects observed in

⁴⁹ Bottega and Romero, “Innovation, Export Performance and Trade Elasticities across Different Sectors”; Tri Haryanto et al., “Impact of Credit Access on Farm Performance: Does Source of Credit Matter?,” *Heliyon* 9, no. 9 (2023): e19720; Tianxiang Li et al., “Rural Demographic Change, Rising Wages and the Restructuring of Chinese Agriculture,” *China Agricultural Economic Review* 9, no. 4 (2017): 478–503;

the $P(t)T$ interaction term—such as in maize and peanut production—indicate that weather forecasting and early warning systems can enhance farmers' adaptive responses to climate uncertainty. This finding is highly relevant to the concept of *Climate-Smart Agriculture (CSA)*, which emphasizes the integration of climate information technology with productivity improvement and food system resilience.⁵⁰ Meanwhile, the UPr variable (production wages) consistently demonstrates positive and statistically significant effects across all commodities. This finding further strengthens the *efficiency wage hypothesis* within the informal agricultural sector, particularly within family-based farming structures in North Sumatra. This theory suggests that higher labor incentives can increase workers' marginal productivity, even in labor-intensive sectors.⁵¹

On the other hand, the significantly negative effect of *exports (EHP)* on value added in commodities such as cassava and mung bean indicates structural inequality in the distribution of trade gains. This finding is relevant to the *New Economic Geography* proposed by Paul Krugman,⁵² which argues that regions located farther from major ports—such as Belawan and Sibolga—or lacking efficient trade infrastructure tend to capture lower benefits from economic openness.⁵³ Furthermore, the exceptionally large constant coefficients observed in several models (for example, soybean = 422,969) indicate the presence of baseline productivity gaps across regions. Regencies with structurally low productivity baselines, such as North Nias and South Labuhanbatu, remain unable to generate significant value added despite increases in production factors. This finding highlights the need for *place-based policies* to improve regional development equity.⁵⁴ The results of the *CUSUM* and *CUSUM-Q* graphical analyses for maize, cassava, and sweet potato productivity across 33 regencies and municipalities in North Sumatra further reveal the temporal stability of the *ARDL* regression models. The *CUSUM* graph for maize indicates parameter instability, as it exceeds the 5% significance boundary, reflecting significant structural shocks, potentially driven by price fluctuations and climatic disturbances during the pandemic period. In contrast, the *CUSUM-Q* graph remains within the confidence boundaries, indicating that although parameter changes occurred, the regression error variance remained controlled. For cassava, both graphs remain within the confidence limits, demonstrating coefficient stability and variance consistency, thereby reinforcing the robustness of this model in explaining cassava value-added growth. This finding is consistent with the report of the Food and Agriculture Organization, which highlights regional resilience to production volatility in root-crop sectors.⁵⁵

N. Sibai et al., "Forecasting The Consumer Price Index"; Winarno et al., "Unlocking Agricultural Mechanisation Potential in Indonesia."

⁵⁰ Cegnar et al., "Toward Effective Communication of Agrometeorological Services"; Katel et al., "Climate Smart Agriculture for Food Security, Adaptation, and Migration."

⁵¹ Blanco and Raurich, "Agricultural Composition and Labor Productivity"; Yamauchi, "Wage Growth, Landholding and Mechanization in Agriculture Evidence from Indonesia."

⁵² Paul Krugman, "Increasing Returns and Economic Geography," *Journal of Political Economy* 99, no. 3 (1991): 483–99.

⁵³ Peck et al., "A Dialogue on Uneven Development."

⁵⁴ OECD, *OECD Regional Outlook 2021: Resilience in the COVID-19 Crisis and Transition to Net Zero Greenhouse Gas Emissions*, OECD Regional Outlook (OECD Publishing, 2021); Jens Suedekum, "Place-Based Policies – How to Do Them and Why," *Global Challenges & Regional Science* 1 (March 2025): 100003.

⁵⁵ FAO, *The State of Food and Agriculture 2023*.

Meanwhile, sweet potato productivity shows a *CUSUM* graph approaching the stability threshold, with the *CUSUM-Q* graph fluctuating but remaining within acceptable tolerance limits. These findings indicate the sensitivity of sweet potato productivity to external factors, such as agroclimatic conditions and market access, particularly in highland regions such as Karo and Humbang Hasundutan. Although the model does not structurally indicate extreme instability, seasonal variability continues to affect short-run model reliability. Therefore, spatially differentiated policies and the adoption of adaptive climate technologies remain essential to maintaining productivity stability and value-added growth in the regional agricultural sector.⁵⁶ Overall, the *CUSUM* analysis provides important validation for the need for evidence-based policy interventions in managing regional agricultural productivity in North Sumatra.

1. Highest Agricultural Productivity across 33 Regencies in North Sumatra

Understanding regional disparities in agricultural productivity provides the empirical basis for assessing downstream development in North Sumatra. This section maps the highest productivity patterns across 33 regencies and municipalities and tests their stability using *CUSUM* and *CUSUM-Q* diagnostics for maize, cassava, and sweet potato.

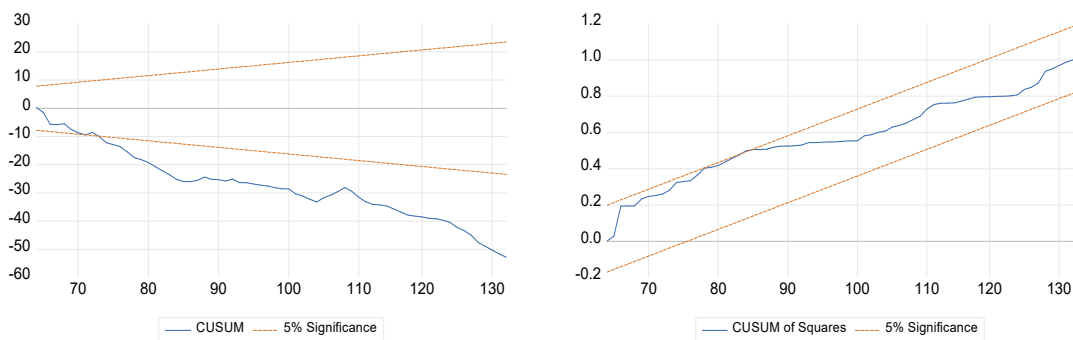


Figure 3. CUSUM and CUSUM-Q for the Stability of Maize Productivity

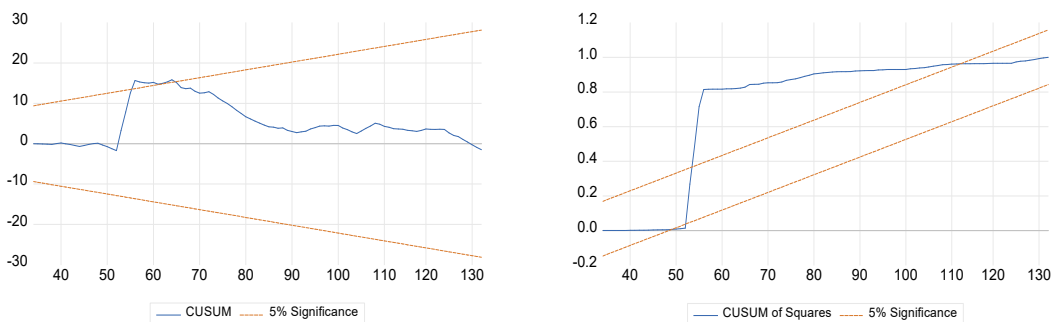


Figure 4. CUSUM and CUSUM-Q for the Stability of Cassava Productivity

⁵⁶ Crump et al., *A Simple Diagnostic for Time-Series and Panel-Data Regressions*.

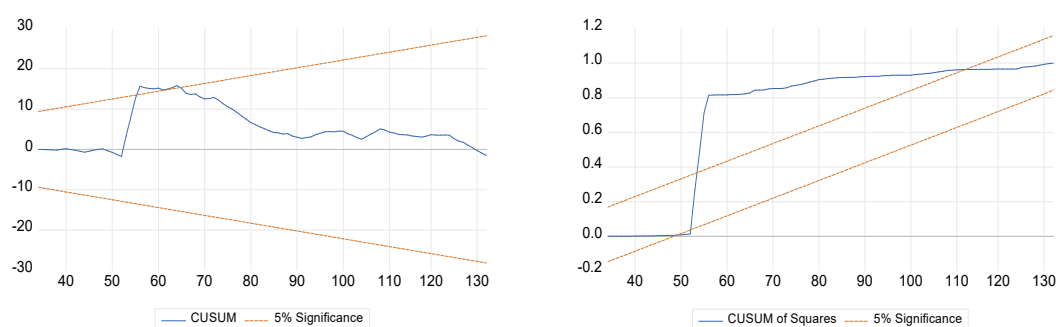


Figure 5. CUSUM and CUSUM-Q for the Stability of Sweet Potato Productivity

The *CUSUM* and *CUSUM-Q* graphical analyses presented in Figures 6, 7, and 8, which illustrate the productivity of soybean, peanut, and mung bean in North Sumatra, reveal a relatively strong pattern of model stability, particularly in the short run. In Figure 6 (soybean), the *CUSUM* graph remains within the 5% significance boundaries, indicating that the regression coefficients do not experience substantial structural shifts throughout the observation period. Meanwhile, the *CUSUM-Q* graph also demonstrates a stable residual variance pattern, further strengthening the reliability of the short-run predictive model, particularly in regencies such as Toba, Dairi, and Pakpak Bharat. These findings are consistent with the *time-variant stability analysis* approach in econometric literature, in which the structural resilience of a model reflects the consistency of relationships among variables within the context of spatial constraints and protein-crop production systems.⁵⁷ This stability may also reflect the presence of local institutional support and semi-modern agricultural practices that have gradually been adopted in these supporting regencies.⁵⁸

In contrast to soybean, the *CUSUM* and *CUSUM-Q* graphs presented in Figures 7 and 8 for peanut and mung bean exhibit more fluctuating patterns, although they remain within the significance boundaries, indicating potential parameter instability in the medium term. This condition may be associated with the limited intensity of technological adoption and inadequate agribusiness infrastructure in peripheral regions such as Nias, South Labuhanbatu, and Central Tapanuli. The predominantly negative regression coefficients and fluctuating model variance reflect market uncertainty and weaknesses in consistent climate risk management.⁵⁹ As explained by Stads et al., parameter stability in agricultural models is strongly influenced by institutional support, access to production inputs, and farmers' adaptive capacity in responding to extreme weather conditions.⁶⁰ In addition, geographically isolated regions tend to experience

⁵⁷ Crump et al., *A Simple Diagnostic for Time-Series and Panel-Data Regressions*; Wooldridge J.M, "Introductory Econometrics a Modern Approach," in *Tolerance Analysis of Electronic Circuits Using MATHCAD*, 0 ed. (CRC Press, 2018).

⁵⁸ FAO, *The State of Food and Agriculture 2023*.

⁵⁹ Islam and Kieu, "Tackling Regional Climate Change Impacts and Food Security Issues"; Julia Jouan et al., "Economic Drivers of Legume Production: Approached via Opportunity Costs and Transaction Costs," *Sustainability* 11, no. 3 (2019): 705.

⁶⁰ Stads, Gert-Jan et al., *Agricultural Research in Southeast Asia: A Cross-Country Analysis of Resource Allocation, Performance, and Impact on Productivity*.

uneven production cycles, which reduces the reliability of long-run model predictions.⁶¹ Therefore, policies aimed at strengthening local capacity, developing agricultural logistics infrastructure, and integrating farmers into export-oriented value chains are essential for improving the sustainability of legume productivity across North Sumatra.⁶² Overall, the CUSUM and CUSUM-Q results confirm that the models are statistically stable, with soybean showing the strongest consistency, while peanut and mung bean exhibit greater fluctuations. These findings highlight the importance of institutional support, infrastructure, and climate adaptation in sustaining legume productivity in North Sumatra.

2. Lowest Agricultural Productivity across 33 Regencies in North Sumatra

To complement the analysis of high-performing regions, this section examines the lowest agricultural productivity across 33 regencies and municipalities in North Sumatra and evaluates the model stability of soybean, peanut, and mung bean productivity using CUSUM and CUSUM-Q diagnostics.

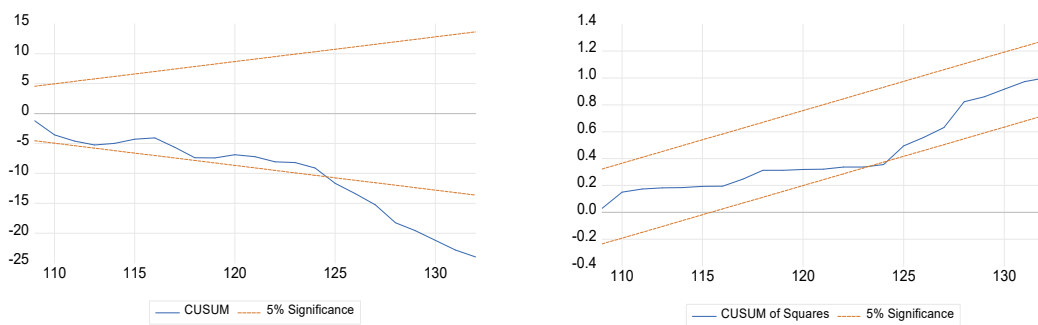


Figure 6. CUSUM and CUSUM-Q for the Stability of Soybean Productivity

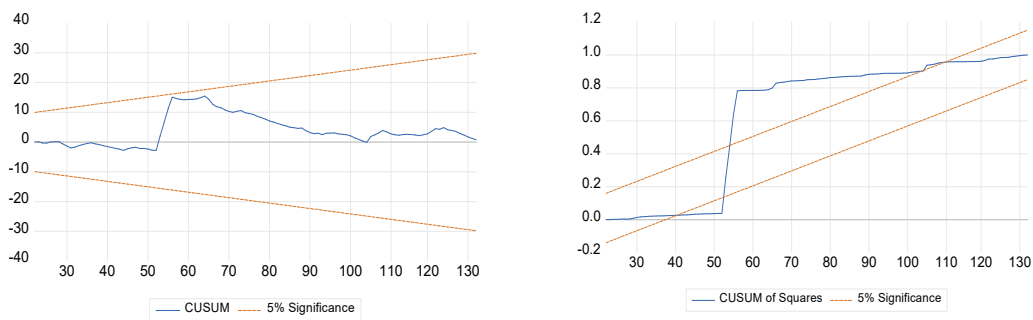


Figure 7. CUSUM and CUSUM-Q for the Stability of Peanut Productivity

⁶¹ Peck et al., “A Dialogue on Uneven Development”; World Bank, *Indonesia Economic Prospects, December 2023*.

⁶² OECD, *OECD Regional Outlook 2021*; Suedekum, “Place-Based Policies – How to Do Them and Why.”

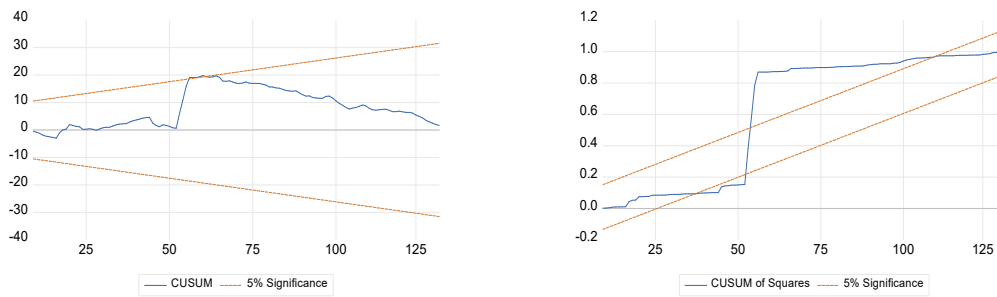


Figure 8. CUSUM and CUSUM-Q for the Stability of Mung Bean Productivity

Interpreting the Findings through CGE and PEM Approaches

The *Computable General Equilibrium (CGE)* approach is employed to understand the impact of policy interventions on the economy by modeling interactions among sectors, households, energy systems, and factor markets.⁶³ The CGE framework is comprehensive, as it can capture cross-sectoral effects arising from downstream industrialization policies, wage increases, and climate technology adaptation.⁶⁴ In the context of North Sumatra, this model is particularly relevant for assessing how investments in maize or cassava processing not only increase value added in the agricultural sector, but also generate multiplier effects in manufacturing industries, distribution services, and employment creation. The empirical findings of this study, which demonstrate the significant effects of wage variables (*UPr*) and exports (*EHP*) across most commodities, are consistent with CGE predictions that trade openness and labor incentives can improve overall economic efficiency, as also highlighted by Festaria.⁶⁵

Meanwhile, Partial Equilibrium Models (PEM) focus on the analysis of individual markets, making them particularly suitable for identifying the direct effects of changes in prices, quantities, and value added within specific commodities without considering full intersectoral interactions.⁶⁶ In this study, the relevance of PEM is reflected in the significantly positive market responses to export expansion in maize, cassava, and peanut production, even though physical productivity $P(t)$ in several commodities shows negative or statistically insignificant effects on value added. This finding suggests that downstreaming and trade strategies should integrate the macroeconomic perspective of CGE in designing cross-sectoral policies, while simultaneously incorporating the microeconomic insights of PEM to ensure the competitiveness of leading commodities in both domestic and international markets.⁶⁷

⁶³ Ziad Ghaith et al., “Regional Computable General Equilibrium Models: A Review,” *Journal of Policy Modeling* 43, no. 3 (2021): 710–24; Sahara et al., “Economic Impacts of Biodiesel Policy in Indonesia: A Computable General Equilibrium Approach,” *Journal of Economic Structures* 11, no. 1 (2022): 22.

⁶⁴ Angel Aguiar et al., “The GTAP Data Base: Version 10,” *Journal of Global Economic Analysis* 4, no. 1 (2019): 1–27.

⁶⁵ Festaria, “Analisis Produksi Jagung Dengan Penyertaan Dana Penguatan Modal Lembaga Usaha Ekonomi Pedesaan (Dpm-Luep) Di Provinsi Sumatera Utara.”

⁶⁶ Eddy Bekkers and Hugo Rojas-Romagosa, “Applied General Equilibrium Modelling on Trade Policy and Development,” paper presented at Summer Academy 2021 Applied General Equilibrium Modelling, 2021; Niven Winchester and Dominic White, “The Climate Policy Analysis (C-PLAN) Model, Version 1.0,” *Energy Economics* 108 (April 2022): 105896.

⁶⁷ Ziad Ghaith et al., “Regional Computable General Equilibrium Models: A Review,” *Journal of Policy Modeling* 43, no. 3 (2021): 710–24; Yongxi Ma et al., “Impacts of Energy Price on Agricultural

Maslahah Framework and Islamic Economics Perspective: A Maqāṣid-Based Interpretation

The empirical findings of this study demonstrate that increases in agricultural productivity do not automatically generate proportional improvements in regional economic value added. In several commodities, such as maize, sweet potato, peanut, and mung bean, the physical productivity variable $P(t)$ even shows negative or statistically insignificant effects on value-added growth, while labor wage (UPr) and export trade (EHP) variables consistently demonstrate positive and statistically significant effects. From the perspective of Islamic Economics, this phenomenon cannot be sufficiently understood through the logic of production efficiency alone, but rather requires analysis through the framework of *maqāṣid al-sharī'ah*, which is oriented toward the creation of systemic social welfare (*maslahah*).

Referring to the systems approach developed by Jasser Auda, *maqāṣid* is no longer understood as a purely normative and static concept, but as a multidimensional framework that emphasizes interrelatedness, openness, purposefulness, and human development as the core of economic activity.⁶⁸ In this context, the findings indicate that agricultural productivity in North Sumatra has not yet fully reflected the realization of *maslahah*, as increases in quantitative output have not consistently generated equitable economic benefits across regions or among production actors. According to Auda, the success of an economic system should not be measured solely by the accumulation of production, but by the extent to which the system generates sustainable human well-being.⁶⁹ Therefore, the finding that the production wage variable (UPr) exerts a positive and statistically significant effect across all commodity models demonstrates that improvements in labor welfare occupy a central position in realizing *maqāṣid*-based development, particularly within the dimensions of *ḥifẓ al-māl* (economic protection), *ḥifẓ al-naḥs* (protection of life), and *ḥifẓ al-nasl* (intergenerational social sustainability).⁷⁰ Within this perspective, agricultural labor is positioned not merely as a factor of production, but as a central subject of economic development. Furthermore, the positive effect of the interaction between

Production, Energy Consumption, and Carbon Emission in China: A Price Endogenous Partial Equilibrium Model Analysis," *Sustainability* 14, no. 5 (2022): 3002; Haruna Suleiman Umar et al., "Welfare Implication of Paddy Price Support Withdrawal from Malaysian Rice Sector: Partial Equilibrium Method Approach," *Agricultura Tropica et Subtropica* 48, nos. 3–4 (2015): 45–52.

⁶⁸ Auda fundamentally reconceptualizes *maqāṣid al-sharī'ah* beyond its classical treatment as a fixed hierarchy of legal objectives concerned merely with the protection of religion, life, intellect, lineage, and property. Through a systems approach, he argues that *maqāṣid* should be understood as a dynamic and multidimensional framework characterized by six interrelated features: cognitive nature (*al-idrākiyyah*), wholeness (*al-kulliyyah*), openness (*al-infitāh*), interrelated hierarchy (*al-harakiyyah al-tarātubiyyah*), multidimensionality (*ta'addud al-ab'ād*), and purposefulness (*al-maqṣidiyyah*). Within this framework, economic activity is evaluated not solely through output maximization or allocative efficiency, but through its capacity to generate human development, institutional resilience, distributive justice, and long-term social wellbeing (*maslahah 'āmmah*) within an interconnected socio-economic system. See: Jasser Auda, *Maqasid Al-Shariah as Philosophy of Islamic Law: A Systems Approach* (International Institute of Islamic Thought, 2008), 1–25, 45–67.

⁶⁹ Auda argues that the ultimate purpose of social and economic institutions lies not in procedural compliance or material accumulation, but in achieving comprehensive human development and sustainable wellbeing. See: Jasser Auda, *Maqasid al-Shariah as Philosophy of Islamic Law: A Systems Approach* (London: The International Institute of Islamic Thought, 2008), 21–25.

⁷⁰ Auda expands the classical *maqāṣid* framework from legal preservation toward developmental objectives centered on human dignity, social protection, family sustainability, and economic justice. See: Jasser Auda, *Maqasid al-Shariah as Philosophy of Islamic Law: A Systems Approach*, 2–5, 240–45.

climate technology and productivity in several models—particularly in maize production in the short run—indicates that the integration of predictive technologies has strong relevance to Auda’s principles of *openness* and *adaptive systems*.⁷¹ Agricultural systems that are capable of anticipating climate change, adjusting planting patterns, and responding rapidly to disaster risks reflect economic systems that are adaptive and resilient. Conversely, the statistical insignificance of technological variables in several other commodities indicates that technology transfer has not yet been fully integrated with local conditions, and therefore its benefits have not yet generated *collective maslahah*. Auda emphasizes that systems that fail to adapt to environmental complexity will gradually lose their capacity to sustain long-term development.⁷²

On the other hand, the export variable (*EHP*), which demonstrates significant effects across almost all model specifications, indicates that trade openness is capable of increasing regional value added. However, when the benefits of trade remain concentrated in specific regions or commodities, such conditions do not fully satisfy the principle of *wholeness* within Auda’s systems approach.⁷³ The findings regarding productivity disparities between high-productivity and low-productivity regencies suggest that agricultural downstreaming in North Sumatra continues to face challenges related to spatial inequality and the uneven distribution of economic benefits. From the *maqāṣid* perspective, economic development can only be considered successful when growth, distribution, environmental resilience, and social welfare operate simultaneously as an interconnected system. Therefore, the findings of this study confirm that agricultural downstreaming should not be directed solely toward increasing output, exports, or market efficiency, but must be transformed toward *maqāṣid*-based agricultural development that positions productivity, farmers’ welfare, climate adaptation, and regional equity as an integrated developmental objective. The systems perspective developed by Jasser Auda provides a strong theoretical foundation for understanding that regional economic growth will generate sustainable *maslahah* only when all elements of production, technology, markets, labor, and the environment function in an integrative, adaptive, and human-centered manner.⁷⁴

Conclusion

This study confirms that agricultural downstreaming in North Sumatra requires an integrated development approach that extends beyond increasing production volume toward strengthening processing capacity, expanding market access, and adopting climate-adaptive technologies. The empirical findings demonstrate that physical

⁷¹ In discussing openness (*openness of systems*), Auda explains that sustainable systems must remain responsive to changing external realities, technological developments, and environmental uncertainties. See: Jasser Auda, *Maqasid al-Shariah as Philosophy of Islamic Law: A Systems Approach*, 46–50.

⁷² Auda maintains that closed systems unable to absorb complexity, feedback, and contextual change will gradually lose their developmental effectiveness. See: Jasser Auda, *Maqasid al-Shariah as Philosophy of Islamic Law: A Systems Approach*, 51–56.

⁷³ The principle of wholeness (*wholeness of systems*) requires economic outcomes to be evaluated through the interdependence of growth, equity, social welfare, and institutional sustainability rather than isolated sectoral gains. See: Jasser Auda, *Maqasid al-Shariah as Philosophy of Islamic Law: A Systems Approach*, 39–45.

⁷⁴ Auda’s multidimensional systems approach emphasizes that long-term *maslahah* emerges only when human, institutional, environmental, and economic elements operate as an integrated and purpose-oriented system. See: Jasser Auda, *Maqasid al-Shariah as Philosophy of Islamic Law: A Systems Approach*, 57–65.

agricultural productivity does not automatically generate proportional increases in regional economic value added. In several commodities, such as maize, sweet potato, peanut, and mung bean, the productivity variable $P(t)$ exhibits negative or statistically insignificant effects on value-added growth, indicating that output expansion alone remains insufficient without downstream industrial transformation. In contrast, labor incentives (UPr) and export-oriented trade (EHP) consistently show positive and statistically significant effects across most commodity models, highlighting the strategic role of wage improvements and market openness in strengthening agricultural value creation. In addition, the interaction between productivity and climate technology produces mixed results, suggesting that the effectiveness of adaptive technologies is highly dependent on agroecological suitability and farmers' adaptive capacity. Furthermore, the flood-risk mapping presented in Figures 1 and 2 emphasizes the importance of incorporating spatial climate risks into downstream investment strategies, where low-risk regions offer stronger potential for sustainable agro-industrial development, while high-risk regions require more intensive mitigation and adaptation measures.

This study contributes theoretically by integrating *Computable General Equilibrium (CGE)*, *Partial Equilibrium Models (PEM)*, and a *maqāṣid*-based perspective from Islamic Economics to explain the multidimensional relationship between productivity, trade, labor incentives, climate resilience, and regional value-added growth. Empirically, it contributes new evidence by combining panel econometric analysis with spatial flood-risk mapping to examine agricultural downstreaming across 33 regencies and municipalities in North Sumatra. Nevertheless, this study has several limitations, including the relatively short observation period, the exclusion of institutional and logistics variables, and the limited incorporation of spatial spillover effects among regions. Therefore, future research should expand the analytical framework by incorporating institutional quality, supply chain governance, and longer time-series observations, while applying spatial econometric approaches to better capture interregional interactions and the long-term sustainability of agricultural downstream transformation. Through these extensions, future studies are expected to generate more inclusive, climate-resilient, and globally competitive downstream development strategies.

Appendix

Table 13. Classification of Productivity Levels Eligible for Export Trade across 33 Regencies and Municipalities in North Sumatra

NO.	REGENCY/MUNICIPALITY	HIGHEST PRODUCTIVITY			LOWEST PRODUCTIVITY		
		Maize Production	Cassava Production	Sweet Potato Production	Soybean Production	Peanut Production	Mung Bean Production
1	Nias	EK>ES	EK	EK	EK=TTP	EK	EK<TTP
2	Mandailing Natal	ES,EK<EB	EK>ES	EK	EK<TTP	EK	EK<TTP
3	Tapanuli Selatan	EB	EK<ES	EK	EK	EK	EK
4	Tapanuli Tengah	EK	EK	TTP	TTP	TTP	TTP
5	Tapanuli Utara	EB	EB=ES	ES	EK<TTP	EK	TTP
6	Toba	EB	EB=ES	EK	EK=TTP	EK	TTP
7	Labuhan Batu	EK=ES	EK>ES	EK=TTP	EK=TTP	EK	EK<TTP
8	Asahan	ES	ES	EK	EK	EK	EK
9	Simalungun	EB	EB	EB<ES	ES<EK	EK	EK=TTP
10	Dairi	EB	EB=ES	EB	EK<TTP	EK	TTP

11	Karo	EB	EK<TTP	ES	EK<TTP	EK>TTP	TTP
12	Deli Serdang	EB	EB	EK>ES	EK<	EK	EK
13	Langkat	EB	ES	EK>ES	EK	EK	EK>TTP
14	Nias Selatan	EK,EB<ES	EB	EK<ES	EK<TTP	EK	EK
15	Humbang Hasundutan	EB	ES	ES	EK<TTP	EK	TTP
16	Pakpak Bharat	EB=ES	EK	EK	EK=	EK	TTP
17	Samosir	EB	EK=ES	ES	EK=	EK	TTP
18	Serdang Bedagai	EB>ES	EB	TTP	EK	EK	EK
19	Batu Bara	EK<ES	EB,EK<ES	EK	EK<	EK	EK>TTP
20	Padang Lawas Utara	EK=ES	EK	EK	EK	EK	EK>TTP
21	Padang Lawas	EK=ES	ES	EK	EK	EK	EK
22	Labuhanbatu Selatan	EK	EK<ES	EK	EK<TTP	EK	TTP
23	Labuhanbatu Utara	EK>ES	EK	TTP	EK<TTP	TTP	TTP
24	Nias Utara	EK>ES	EK<ES	EK=TTP	EK=TTP	EK>TTP	EK<TTP
25	Nias Barat	EK=TTP	EK=TTP	EK<TTP	TTP	TTP	TTP
26	Sibolga	TTP	TTP	TTP	TTP	TTP	TTP
27	Tanjungbalai	EK	EK	TTP	EK>TTP	EK<TTP	EK<TTP
28	Pematangsiantar	ES	ES	TTP	TTP	EK=TTP	TTP
29	Tebing Tinggi	EK	ES	EK=TTP	TTP	EK<TTP	TTP
30	Medan	EK	EK	EK=TTP	TTP	EK>TTP	TTP
31	Binjai	ES	EK	EK	EK<TTP	EK	EK
32	Padangsidempuan	EK	ES	EK	EK	EK	EK<TTP
33	Gunungsitoli	EK	EK	EK	EK<TTP	TTP	EK<TTP

Notes:

1. Observations are arranged alphabetically from A to Z as follows: Asahan (1–4), Batu Bara (5–8), Binjai (9–12), Dairi (13–16), Deli Serdang (17–20), Gunungsitoli (21–24), Humbang Hasundutan (25–28), Karo (29–32), Labuhanbatu Utara (33–36), Labuhan Batu (37–40), Labuhanbatu Selatan (41–43), Langkat (44–47), Mandailing Natal (48–51), Medan (52–55), Nias (56–59), Nias Barat (60–63), Nias Selatan (64–67), Nias Utara (68–71), Padang Lawas (72–75), Padang Lawas Utara (76–79), Padangsidempuan (80–83), Pakpak Bharat (84–87), Pematangsiantar (88–91), Samosir (92–95), Serdang Bedagai (96–99), Sibolga (100–103), Simalungun (104–107), Tanjungbalai (108–111), Tapanuli Selatan (112–115), Tapanuli Tengah (116–119), Tapanuli Utara (120–123), Tebing Tinggi (124–127), and Toba (128–131).
2. The symbols represent the following export classifications: EB = Large Exports (10% of total exports), ES = Medium Exports (5% of total exports), EK = Small Exports (1% of total exports), and TTP = No Trade Occurrence (0 productivity at the export percentage measured in tons).
3. The Random Effect Model was selected because the number of cross-sectional samples exceeds the number of time-series observations. According to Widarjono (2018), this method is used to overcome the limitations of the Pooled Ordinary Least Squares (OLS) model, while also controlling for constant individual effects across entities or groups within panel data.
4. The population selection in this study includes all available samples (observations) using an unbalanced panel dataset obtained from Statistics Indonesia of North Sumatra.
5. The color classification used in Figures 1 and 2 is defined as follows: Red = High Risk, Yellow = Moderate Risk, Green = Low Risk, Brown = Safe, and White = Non-Flood Area.

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