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Smallholder Farmers' Strategies in Facing Climate Change and Commodity Price Uncertainty

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A R T I C L E I N F O

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A B S T R A C T

Climate change and fluctuations in commodity prices create multidimensional pressures on the economic resilience of smallholders, who are the main actors in the national agricultural system. This study aims to analyze the adaptation strategies implemented by smallholders in response to climate uncertainty and commodity price volatility, as well as identify the factors that influence the selection of such strategies. A quantitative approach was used by a survey method of 150 smallholders in three major agricultural production centers in Indonesia. Data were collected through a structured questionnaire and analyzed using multinomial logistic regression to test the relationship between farmer characteristics, perception of climate risk, price uncertainty, and adaptation strategy choices. The results of the study show that diversification of farming, the use of local inputs, and changes in planting patterns are the dominant strategies adopted by smallholders. Factors such as education level, land area, access to market information, and experience of climate disasters have a significant impact on the chosen strategy. These findings indicate that farmers' adaptive capacity is greatly influenced by a combination of internal and external factors that are economic and institutional. This research contributes to the agricultural economics literature by offering an empirical understanding of the economic decision-making dynamics of smallholder farmers in the face of external risks, as well as providing a basis for the formulation of agricultural policies that are more responsive to climate and market uncertainties.

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INTRODUCTION

Climate change and fluctuations in commodity prices have posed a serious challenge to the economic resilience of smallholder farmers globally and locally. At the global level, extreme weather waves have driven up food prices, for example the increase in chocolate and wheat prices due to the climate crisis that triggers food inflation (Time, 2024) as well as projected food inflation of up to 50%–200% in 2035-2060 if mitigation is not carried out (Le Monde, 2024). In Indonesia, although local data is still limited, smallholders have faced climate uncertainty in the form of changing planting seasons and market price volatility, which has an impact on income and investment in the agricultural sector. This underscores the urgency of understanding how smallholders adapt their economic strategies in the context of unstable policies, markets, and climates.

Previous research has highlighted a lot of farmers' adaptation to climate change (Aryal et al., 2022 study in Nepal with 327 respondents, using multiple regression), but there are still few that explicitly link climate adaptation to commodity price uncertainty as one of the specific risks of the agricultural economy (Aryal et al., 2022). Studies in Ethiopia, for example, emphasized the importance of crop diversification and limited access to capital in adaptation adoption (Frontiers, Western Kenya Study, 2022), but did not take into account market price factors as a driver of strategy. Thus, there is still a gap in research that integrates market economic variables—particularly commodity price volatility—within the framework of smallholder economic adaptation to climate.

Several additional studies have highlighted the importance of access to finance in strengthening smallholder adaptive capacity to climate change (ScienceDirect, Nigeria, 2024), but the focus remains on crop productivity—without analyzing how commodity price uncertainty affects the choice of economic adaptation strategies. In addition, the literature on adaptation costs (Frontiers, Zimbabwe, 2022) is still very limited and has not yet combined financial models with small adaptation behaviors in the face of price risks. This points to an empirical gap: the absence of systematic mapping of smallholder economic strategies that take into account both climate and market risks.

Thus, it can be identified that there is a scientific gap: namely the lack of quantitative research that links the adaptation of smallholder economic strategies to climate pressures as well as commodity price volatility, as well as the determinants that influence the selection of such strategies. This gap includes the need for econometric models that examine the relationship between climate risk perceptions, price uncertainty, farmer characteristics, and adopted economic strategies. This kind of research has not been widely carried out in the context of Indonesia or other developing countries.

This study aims explicitly to analyze the economic strategies applied by smallholders in the face of dual pressures, namely climate change and commodity price uncertainty. The focus of the analysis includes the identification of dominant economic adaptation strategies, the influence of factors such as farmer characteristics, perceptions of climate risks, and price volatility on strategy choices, as well as estimation of the statistical significance of these relationships using a systematic and robust quantitative approach.

Theoretically, this study enriches the agricultural economics literature by providing empirical evidence on the dynamics of smallholder economic decision-making in the face of a combination of external climate and market risks. The proposed econometric model will expand the adaptation framework that was previously more focused on climate or financial factors alone, to be inclusive of the interaction between climate risk and prices. Thus, this study opens the direction of a new and more comprehensive analysis of farmers' economic adaptive behavior.

In practical terms, the findings of this study will be an important input for policymakers, agricultural extension agencies, and market service providers, in designing more effective and targeted interventions. By understanding the determinants and strategies of the dominant economic adaptation, strategies such as the provision of access to market information, price stabilization, or adaptive financial instruments can be formulated more responsively. This is expected to increase the economic resilience of smallholder farmers to climate and market uncertainties, as well as support inclusive and sustainable agricultural development in Indonesia.

THEORETICAL REVIEW

Smallholder Adaptation to Climate Change

Adaptation to climate change has become a key strategy for smallholders in maintaining productivity and economic stability amid the increasing frequency of extreme climate events. Farmers in various countries, including in tropical and subtropical regions, are adopting measures such as crop diversification, crop rotation, the use of drought-resistant varieties, as well as agroecological practices in response to climate variability (Lamichhane et al., 2022). Research shows that these adaptations are often contextual and dependent on local agroecological conditions, such as land topography and rainfall patterns. However, the ability to adopt these strategies is often limited by access to climate knowledge, agricultural infrastructure, as well as reliance on vulnerable single livelihoods (Thorn et al., 2021). In the Indonesian context, dependence on the rainy season and limited irrigation systems make adaptation to climate change an urgent issue on the national agricultural policy agenda.

Socioeconomic Determinants in Farmer Adaptation

The success of adaptation is influenced not only by biophysical factors, but also by complex socioeconomic variables. Farmers' education levels, farming experience, land ownership, access to financial resources, and involvement in farmer groups are important determinants in adopting adaptation innovations (Lamichhane et al., 2022). Access to climate and technology information, either through counseling or digital media, also strengthens farmers' capacity to make risk-based decisions. For example, farmers who have regular access to weather forecasts and market information are more likely to change planting patterns when the seasons change abruptly (Ndambiri et al., 2023). In addition, the role of local institutions such as agricultural cooperatives and farmer organizations is

also a catalyst for adaptation by providing a platform for sharing information and social capital. Barriers that are often found include limited digital literacy, gender inequality in access to resources, and dependence on unstable local markets (Chaudhary et al., 2023).

Commodity Price Uncertainty and Its Impact on Production Choices

Volatility in agricultural commodity prices is a major challenge that exacerbates the vulnerability of smallholder farmers, especially in the context of open markets and global integration. Price uncertainty not only affects farmers' household incomes, but also affects short- and long-term decisions such as input allocation, planting area, and product diversification (Van der Ploeg et al., 2022). In an empirical study in Laos, for example, it was found that price instability encourages farmers to delay the sale of their crops or switch to commodities with more stable prices (Nesheim & So, 2023). Meanwhile, in Indonesia, the volatility in rice and chili prices in the last five years has caused significant income fluctuations among small-scale farmers. This price uncertainty is exacerbated by long supply chains, the dominance of middlemen, and the absence of a hedging system at the farmer level (Widodo et al., 2023). Therefore, a deep understanding of the economic impact of price fluctuations is key in the formulation of price protection policies for smallholders.

Prognostic Model of Commodity Price and Volatility

In the modern agricultural economics literature, modeling of commodity prices and volatility has undergone significant development through the integration of advanced quantitative approaches. GARCH (Generalized Autoregressive Conditional Heteroskedasticity) models and artificial intelligence-based hybrid variants such as Long Short-Term Memory (LSTM) Neural Networks are widely used to predict price volatility patterns (Manogna et al., 2025). The LSTM-GANCH hybrid model, for example, has proven effective in dynamically identifying price risk patterns by combining long-term memory structures and abnormal statistical distributions. This model allows policymakers and market participants to respond to market changes more precisely, especially in the context of developing countries facing seasonal price fluctuations. In addition, the use of daily data from regional markets allows for granular analysis that strengthens strategic decisions in price risk management (Zhou et al., 2024). The integration of these methods with smallholder socio-economic data could pave the way for predictive models that are more responsive to field needs.

The Interaction of Climate Risk and Price Risk in Adaptation Strategies

Although there have been many studies that have focused on climate adaptation and price volatility separately, the integration of the two sources of risk within the framework of smallholder adaptation strategies has been relatively rarely studied comprehensively. In this context, a systems approach that blends climate risk and market risk becomes essential to understand the dynamics of decision-making by smallholders. Recent studies emphasize the

importance of understanding farmers' co-exposure to these two types of uncertainty, where climate risks such as drought or floods can exacerbate the impact of price fluctuations by lowering output that can be sold in the market (Jain et al., 2024). In contrast, erratic commodity prices can also limit farmers' ability to invest in adaptive practices such as the use of organic fertilizers or micro-irrigation technologies (Karki & Joshi, 2023). Effective adaptation strategies therefore need to consider the simultaneous interaction between climate and market uncertainties, as well as build integrated risk protection systems at the micro and macro levels.

METHODOLOGY

Types and Approaches to Research

This study uses a quantitative approach with an explanatory survey design to identify the relationship between smallholder characteristics, perceptions of climate risks and commodity prices, and their chosen adaptation strategies. This approach was chosen because it is able to objectively measure the influence of independent variables on the choice of adaptation strategies statistically (Bryman, 2021). Explanatory surveys allow researchers to test causality relationships through multinomial regression analysis of cross-sectional data collected from respondents in the field.

Population and Sampling Techniques

The population in this study is smallholders who actively manage farming in three main agricultural production center areas in Indonesia, namely Gowa Regency (South Sulawesi), Boyolali Regency (Central Java), and Garut Regency (West Java). Smallholder farmers are defined as farmers who own land under two hectares and make agriculture the main source of livelihood. The sampling technique used is stratified random sampling, which is by dividing areas into strata based on the dominant commodity type (horticulture, rice, and palawija), then sampling randomly from each strata. The number of respondents determined was 150 people, with an even distribution of 50 respondents per region. This number is considered representative for multinomial regression analysis as suggested in the social statistical literature (Creswell & Creswell, 2023).

Data Collection Techniques and Instruments

Primary data were collected through a structured questionnaire designed based on adaptations of instruments that had been previously validated by Bryan et al. (2020) in a study on farmers' adaptation strategies to climate change. The questionnaire includes four main sections: (1) the demographic and economic characteristics of farmers; (2) perception of climate risks; (3) perception of commodity price volatility; and (4) adaptation strategies used. Answers use a Likert scale of 1–5 for the perception part, as well as multiple choice for the strategy part. Before being applied in the field, the instrument was tested for content validity through expert judgement and empirical validity through an

item-total correlation test. The reliability test was conducted using Cronbach's Alpha, with a coefficient of ≥ 0.70 indicating high reliability (Tavakol & Dennick, 2020).

Research Procedure

The research stage starts from the preparation of the instrument design and conceptual framework in April 2025. Furthermore, instrument trials were conducted on 15 smallholders outside the main sample location in May 2025 to ensure clarity of questions and instrument stability. The main data collection was carried out between March and July 2025 at three study sites with the help of trained local enumerators. After the data is collected, data cleaning is carried out to eliminate incomplete or outlier responses.

Data Analysis Techniques

Data were analyzed using multinomial logistic regression to evaluate the influence of independent variables (farmer characteristics and risk perception) on the selection of adaptation strategies (dependent variables with three main categories: diversification of farming, use of local inputs, and changes in planting patterns). The analysis was conducted using IBM SPSS Statistics software version 28. The multicollinearity test was carried out to ensure that there was no high correlation between independent variables. Statistical significance was determined at a confidence level of 95% ($p < 0.05$). The model used refers to the approach developed by (Antwi-Agyei et al., 2021) and adapted to the local context in Indonesia. This technique is relevant for evaluating adaptive decision dynamics in the context of the multidimensional risks faced by smallholders (Adger et al., 2020).

RESEARCH RESULTS

Characteristics of Respondents

This study involved as many as 150 smallholder farmers as respondents spread across three main centers of Indonesian agriculture, namely Gowa Regency (South Sulawesi), Boyolali Regency (Central Java), and Garut Regency (West Java). The selection of this location takes into account the diversity of agroecological conditions and superior commodities that reflect the general dynamics of the national agricultural sector.

a) Age

Most of the respondents were in the productive age group, namely 35–55 years old (63.3%), followed by the age group of 25–34 years old (18.7%) and over 55 years old (18.0%). The dominance of this productive age group reflects that the majority of farmers are still actively managing agricultural land. This is important in the context of adaptation because productive age is often associated with physical ability and readiness to accept technological innovations and market information.

b) Education Level

As many as 40.0% of respondents only completed education up to the elementary school level, and 32.7% until junior high school. Only 5.3% have a higher education than high school. This low level of education has the potential to affect openness to change and adaptation to external risks, including climate change and fluctuations in market prices.

c) Land

Most farmers (72.6%) manage land between 0.5 and 1.5 hectares, and only 17.4% own more than 1.5 hectares. The narrow land they own shows limited production capacity, so farmers tend to have low economic resilience to market fluctuations and climate disturbances. Land area also has implications for the possibility of diversifying businesses or investing in modern agricultural inputs.

d) Experience with Climate Disasters

As many as 58.7% of farmers stated that they had experienced the direct impact of climate disasters, such as droughts, floods, and other extreme weather in the last five years. This experience is an important indicator in the analysis of adaptation behavior, because individuals who have been affected tend to be more alert and responsive to climate change.

Table 1. Characteristics of Small Farmers Respondents

Characteristics	Category	Frequency	Percentage (%)
Age	25–34 years old	28	18.7
	35–55 years old	95	63.3
	> 55 years old	27	18.0
Education	SD	60	40.0
	SMP	49	32.7
	SMA	33	22.0
	>SMA	8	5.3
Land	< 0.5 ha	15	10.0
	0.5–1.5 ha	109	72.6
	> 1.5 ha	26	17.4
The Impact of Climate Disasters	Pernah	88	58.7
	Never	62	41.3

Adopted Adaptation Strategies

The results of the descriptive analysis show that smallholders in three major production centers in Indonesia are implementing a variety of adaptation strategies to respond to pressures from two main sources of uncertainty: climate change and fluctuations in commodity prices. The three main strategies that were

successfully identified in this study were: diversification of farming businesses, the use of local inputs, and changes in planting patterns.

The most dominant strategy was farming diversification, which was adopted by 45.3% of the total respondents. This strategy includes expanding the types of commodities planted, mergers between food crops and horticulture businesses, and developing side businesses such as small-scale livestock or processing agricultural products. Diversification was chosen because it is considered to be able to spread economic risks when the price of one of the commodities plummets or extreme weather disturbances occur that affect the productivity of the main crop. This strategy is in line with the principles of portfolio risk mitigation common in subsistence and semi-commercial farming systems.

The second strategy that is quite widely practiced is the use of local inputs such as local seeds that are more resistant to specific environmental conditions as well as homemade organic fertilizers, which are used by 32.0% of respondents. This strategy reflects farmers' tendency to reduce dependence on external inputs whose prices are volatile. In addition, the use of local inputs is considered more economical and adaptive to the characteristics of local agroecosystems.

Meanwhile, 22.7% of farmers chose a strategy to change their planting patterns, including changes in planting schedules, crop rotation, or shifting main crop types to varieties that are more resistant to drought or high rainfall. This strategy represents a form of direct response to the real impacts of climate change, such as the uncertainty of the rainy season and more unpredictable pest attacks. Farmers who have experienced the impact of climate disasters tend to choose this strategy because it directly responds to the technical aspects of cultivation.

Table 2. Distribution of Smallholder Adaptation Strategies

Adaptation Strategy	Frequency	Percentage (%)
Diversification of farming	68	45,3
Use of local inputs	48	32,0
Changes in planting patterns	34	22,7
Total	150	100

By looking at this distribution, adaptation strategies are contextual and highly dependent on the capacity of farmers, both in terms of resources (land, capital), information, and experience in dealing with change. These three strategies are not exclusive; In practice, some farmers combine two or more strategies to increase their economic resilience. These findings provide an

important picture that adaptation to external risks is not linear, but rather the result of complex socio-economic calculations.

Results of Multinomial Logistic Regression Analysis

To understand the influence of socioeconomic factors on the choice of adaptation strategies of smallholders, this study uses multinomial logistic regression, with dependent variables in the form of three categories of adaptation strategies: diversification of farming (as a reference), use of local inputs, and changes in planting patterns. Independent variables include education level, land area, access to market information, and experience with climate disasters.

This model aims to estimate the probability of choosing an adaptation strategy compared to a reference strategy (business diversification), based on the characteristics of farmers. The regression results are presented in the form of a logite coefficient (β) and significance value (p-value), which describes the strength and direction of influence of each predictor variable on the two categories of comparative strategies.

Table 3. Results of Multinomial Logistics Regression on Adaptation Strategies

Variabel	Local (β)	Input Sig.	Pola (b)	Tanam Sig.
Education (high school and above)	-0.742	0.021*	0.355	0.137
Land Area (>1.5 ha)	1.014	0.004*	0.298	0.211
Access Market Information	0.855	0.008*	0.647	0.031*
Experiencing Climate Disasters	0.437	0.103	1.113	0.002*

a) The Influence of Education on Adaptation Strategies

The negative coefficient in the category of local input use (β = -0.742; p = 0.021) indicates that farmers with higher education are less likely to choose local input use strategies, and prefer to diversify farming as an adaptive approach. This is likely because farmers with higher education backgrounds have a better understanding of economic risks as well as access to more diverse business opportunities outside of core agriculture.

b) The Influence of Land Area on Strategy Choices

Farmers who have more land (>1.5 ha) significantly prefer the use of local inputs to diversify their businesses (β = 1,014; p = 0.004). This can be explained that large landowners tend to focus on the internal efficiency of the production system through controlling input costs, such as utilizing organic fertilizers or local seeds that are cheaper but still productive. They are not too encouraged to look for business alternatives outside of agriculture.

c) Access to Market Information as a Determinant of Adaptation

Access to market information had a significant effect on two strategies: local inputs ($\beta = 0.855$; $p = 0.008$) and changes in planting patterns ($\beta = 0.647$; $p = 0.031$). This suggests that farmers who have good market access are more likely to adjust cultivation strategies and inputs based on current market conditions. They can adjust the planting time, variety type, or even inputs based on market demand and commodity price dynamics.

d) The Influence of Experience on Climate Disasters

Respondents who had experienced significant climate disasters were more likely to choose a change in planting pattern than business diversification ($\beta = 1{,}113$; $p = 0.002$). This confirms that first-hand experience of disasters triggers technical adaptive responses, such as changing planting schedules or replacing crop types with varieties that are more resistant to extreme weather. This strategy is more direct and reactive to climate change.

DISCUSSION

The findings of this study show that smallholders face not only the risks of climate change directly, but also the uncertainty of commodity prices that exacerbate their economic vulnerability. The three adaptation strategies adopted by diversifying farming businesses, using local inputs, and changing planting patterns represent a collective response to these dual pressures. These findings reinforce the argument that farmer adaptation strategies are multidimensional and influenced by the interaction between internal (farmer characteristics) and external (market and climate) factors (Jain et al., 2024).

Business diversification as the most dominant strategy shows that farmers seek to spread economic risks through the expansion of business types, including non-agricultural businesses. This strategy is consistent with the results of studies in South Asia and Sub-Saharan Africa that found that diversification can be a safety net in the event of crop failure due to extreme weather or a drop in the price of major commodities (Adger et al., 2020; Aryal et al., 2022). Farmers with access to higher education appear to be more likely to adopt this strategy, suggesting that economic literacy and exposure to market opportunities are important elements in the formation of adaptive behavior.

The regression results showed that farmers with a high school education level or higher, tended to avoid using local inputs and chose diversification as the main strategy. This suggests that education plays a role as a proxy for cognitive capacity in understanding risks and evaluating adaptation alternatives (Ndambiri et al., 2023). Higher-educated farmers are likely to have access to external sources of information and a wider economic network, as well as have a preference for adaptation strategies that have the potential to provide higher returns in the long run.

However, this trend also indicates the potential exclusion of low-educated farmers from more complex, market-based adaptation strategies. The implication of the policy is the need for training and extension interventions that are adaptive

to farmers' education levels, to avoid adaptation inequalities in agricultural communities (Chaudhary et al., 2023).

Land area has proven to be a significant factor in the selection of strategies for using local inputs. Farmers who manage more than 1.5 hectares of land tend to maximize production efficiency through a cheaper and more accessible local input approach. This reflects the preference for internal efficiency over business expansion, and shows that economies of scale play a role in the chosen strategy. Studies in India show similar results, where farmers with larger land have greater flexibility in managing production risks (Manogna et al., 2025).

Access to market information has a significant influence on two strategies: the use of local inputs and changes in planting patterns. Farmers who have access to information can make cultivation adjustments according to demand and price dynamics. Market information serves as an economic early warning tool, allowing farmers to adapt not only to the climate, but also to price volatility (Van der Ploeg et al., 2022). Consequently, risk communication strategies and strengthening information networks are crucial in increasing the adaptive capacity of smallholders in the digital era.

Another important finding suggests that first-hand experience of climate disasters significantly increases the tendency to choose planting pattern change strategies. This emphasizes the importance of experience as a form of experiential learning in adaptation (Karki & Joshi, 2023). Farmers who have been affected by disasters are more responsive in changing planting schedules or choosing plant varieties that are more resistant to environmental pressures. These responses are both technical and reactive, and can be used as an early indicator for the development of community-based adaptation warning models.

Some of the limitations include that this study uses cross-sectional data, so that it is not able to capture the dynamics of adaptation longitudinally, the adaptation strategies studied are still limited to three dominant categories and do not include a more complex variation of adaptive strategy combinations, although the multinomial logistic regression approach is quite strong in explaining the relationship between variables, the qualitative dimension of farmer decisions is not reached by this approach.

For further research, it is recommended to use mixed methods design to combine quantitative data and qualitative narratives to understand the dynamics of adaptation decisions more completely. In addition, the data panel approach can provide a better understanding of changes in adaptation strategies over a period of time. The use of digital technologies such as geographic information systems and satellite data can also enrich more precise spatial-based adaptation models.

CONCLUSION AND RECOMMENDATION

This study concludes that the adaptation strategies carried out by smallholders in the face of climate change and commodity price uncertainty are diverse and influenced by a combination of internal and external factors. The three main strategies that are predominantly adopted are diversification of

farming businesses, the use of local inputs, and changes in planting patterns. Through multinomial logistics regression analysis, it was found that education level, land area, access to market information, and experience of climate disasters have a significant influence on the selection of adaptation strategies.

In particular, farmers with higher levels of education tend to choose business diversification, while farmers with larger land prefer efficiency through the use of local inputs. Access to market information has been proven to expand the flexibility of technical and economic adaptation, while experience of climate disasters is a strong driver in the selection of adaptive strategies based on planting patterns.

These findings make a theoretical contribution to the development of risk-based agricultural economics studies, as well as provide a strong empirical basis for the formulation of adaptive agricultural policies at the local and national levels. This research emphasizes the importance of an adaptation approach that is contextual, based on farmer capacity, and supported by an inclusive information, education, and institutional system. Agricultural development strategies going forward need to pay attention to the diversity of smallholder responses in the face of changing climate and market pressures.

FURTHER STUDY

Future research should examine the long-term effectiveness and economic sustainability of different adaptation strategies adopted by smallholders under varying climate and market conditions. Comparative studies across regions and commodities could reveal how socio-economic, cultural, and environmental contexts influence adaptation choices. Integrating climate modeling with farm-level economic simulations may also help predict the resilience of different strategies under future scenarios. In addition, exploring the role of institutional support, digital technologies, and farmer-to-farmer knowledge exchange could provide valuable insights for designing targeted, capacity-based agricultural policies that strengthen smallholder resilience to climate and price volatility.

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