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ARTICLE

Factors Influencing Lowland Rice Farmers' Productivity: Evidence from East Kalimantan, Indonesia

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ABSTRACT

The purpose of this study was to analyze the factors affecting the productivity of rice farmers. This study employed a quantitative research design with an inferential statistical approach using SmartPLS. The research was conducted in five rice farming areas in Kutai Kartanegara Regency, East Kalimantan Province, Indonesia, with a sample size of 146 respondents. The results indicate that extension communication has a positive and significant effect on farmers' knowledge. However, the effect on farmers' skills is positive but not significant. Extension communication has a negative and insignificant effect on innovation adoption, and a positive but insignificant effect on farmer productivity. The effect of farmers' knowledge on innovation adoption was negative and an insignificant, while its effect on farmer productivity was positive but not significant. In contrast, the effect of farmers' skills on innovation adoption and farmer productivity was positive and significant. This study has several limitations. First, it focuses only on rice farmers in the five agricultural areas designated by the Kutai

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Kartanegara Regency government, so the results cannot be generalized to other areas with different conditions. Second, this study does not consider external factors that may influence the successful adoption of agricultural technology innovations, such as government policies, market access, and weather conditions.
Keywords: Extension Communication; Farmer Knowledge; Farmer Skills; Innovation Adoption; Productivity

1. Introduction

The agricultural sector has been recorded as the second largest contributor to the Gross Regional Domestic Product (GRDP). It also plays an important role in the economy of Kutai Kartanegara Regency, East Kalimantan Province, Indonesia [1]. Geographically, Kutai Kartanegara Regency possesses substantial potential for rice fields. To optimize agricultural production and productivity, the regency government has designated several subdistricts as rice field agricultural areas, namely Sebulu, Muara Kaman, Loa Kulu, Tenggarong, Tenggarong Seberang, and Marang Kayu. Nevertheless, rice production and productivity in these areas have not yet achieved the targeted optimal levels. According to data from the Central Statistics Agency (*BPS*) of East Kalimantan for 2025, average rice paddy production in Kutai Kartanegara Regency is 4.09 tons per hectare. This level remains significantly below the expected minimum standard of 5 to 6 tons of dry unhusked rice (*GKP*) per hectare [2]. Various factors contribute to suboptimal agricultural production, including insufficient knowledge, inadequate skills, and low levels of farmer adoption of modern technology. Therefore, efforts to optimize rice paddy production and productivity in Kutai Kartanegara Regency should focus on accelerating the adoption of technological innovations and enhancing the quality of human resources in the rice paddy sector. Productivity can be defined as a measure of the quality and quantity of work performed, while also considering the costs of the resources utilized. In other words, productivity is a concept that expresses the ratio of total output to weighted average input [3,4]. Productivity is influenced by knowledge, skills, abilities, attitudes, and behaviors. Gomes and Sukirno stated a similar view, emphasizing that productivity is determined by several factors, with technological advances, knowledge, skills, and organizational improvements being the most significant [5,6]. Modern technology plays a significant role in enhancing farmer productivity. Consequently, the adoption of technology exerts a considerable effect on improving agricultural performance [7–12]. Conversely, empirical evidence also indicates that the adoption of agricultural technology does not have a significant impact on farmer productivity [13,14].

Farmers' skills in managing their rice farms also influence their productivity. The more skilled the farmers are, the higher their productivity will be. According to Spencer & Spencer, skills are defined as the ability to perform a series of specific physical or mental tasks [15]. Farmers' skills are closely related to productivity and have been shown to exert a significant effect on it [16–19]. However, under certain conditions, farmers' skills may not significantly increase productivity. For instance, Paulina et al. reported that farmers' skills had no significant effect on productivity [20]. Furthermore, Rogers states that skills are part of behavioral change within the psychomotor domain, which occurs after changes in the cognitive and affective domains. Skills are developed through an effective two-way communication process [21], in which farmers not only receive information but also understand and are able to apply it in practice. This supports the view that skills in innovation adoption are the result of dynamic and continuous social interaction. The communication process that seeks to change behavior to become more agile, fast, and precise in the comprehensive use of agricultural technology from land preparation to harvesting and post-harvest activities aimed at maximizing production is referred to as farmer skills [22]. Farmer skills influence innovation adoption therefore, it can be concluded that skills have a significant effect on farmers' adoption of innovation [23].

Farmers' knowledge also influences the adoption of innovations that can enhance productivity. Possessing adequate knowledge is essential for farmers, as it contributes not only to improved productivity but also to better welfare. When effectively applied, farmers' knowledge has a significant impact on productivity [20,24,25]. Conversely, when not effectively applied, its impact becomes insignificant [16], Knowledge strongly shapes farmers' adoption of new technologies, since higher levels of knowledge broaden their insights and enable them to be more receptive and open to technological advancements and developments in agriculture [26]. The findings of Noviyanti et al. emphasize that education, in terms of knowledge mastery, has a positive and significant effect on innovation adoption [24]. Additional empirical evidence further indicates that farmers' knowledge influences their intention to implement Good Agricultural Practices [27].

In summary, knowledge has a significant influence on the adoption of innovation [28–30]. Agricultural extension seeks to provide farming families with new knowledge and skills that are relevant to their interests and needs. To achieve this, extension activities require appropriate communication strategies, as these are essential for transferring technical knowledge and skills to farmers and enabling them to adopt technological innovations in the agricultural sector. Communication processes generate patterns, and from these, suitable and practical models can be identified for use in extension activities [31]. Hence, understanding appropriate communication processes serves as a crucial foundation for developing an efficient and participatory extension approach. Ultimately, the right communication strategy has a significant effect on farmer productivity [32,33].

Farmer productivity is also influenced by the communication of extension workers in facilitating the adoption of agricultural technology innovations. Agricultural extension activities require appropriate communication strategies, as their primary objective is to transfer knowledge and technical skills to farmers so that they can adopt technological innovations in the agricultural sector. Empirical studies show that extension workers' communication has a significant effect on the adoption of agricultural innovations [11,34–36]. whereas ineffective communication results in an insignificant impact on innovation adoption[26,36]. The communication strategies employed by extension workers also shape farmers' skills in adopting modern agricultural technologies to enhance their productivity. Empirical evidence further demonstrates that extension worker communication positively and significantly affects farmer skills [32,37,38]. Similarly, farmer knowledge is positively and significantly impacted by extension workers' communication strategy [39–42]. Effective communication strategies depend on several factors, including clarity and relevance of messages, the use of familiar media, the promotion of two-way interactions, and their continuous implementation. The ultimate objective of these strategies is to ensure that messages are received, understood, and positively responded to by farmers [21]. Accordingly, this study aims to analyze the factors that influence the productivity of rice farmers.

1.1. Research Conceptual Framework

The research concept was developed based on theoretical and empirical studies on productivity, innovation adoption, skills, knowledge, and communication. The theoretical foundation for this study draws primarily on Rogers' communication theory, which posits that effective communication is closely associated with farmers' knowledge, skills, technological innovation adoption, and productivity [21]. The theory of knowledge and skills refers to Spencer & Spencer's theory [15]. The concept of productivity further refers to the frameworks proposed by Mathis and Jackson [3] as well as Samuelson and Nordhaus [4]. To formulate the research hypotheses, several empirical studies were reviewed. The relationship between extension communication and farmers' knowledge is supported by findings from Virdayanti et al. [39]. The link between communication and farmers' skills is informed by empirical works conducted by Suangita et al. [37]. Empirical studies examining the relationship between communication and innovation adoption include those by Nugroho et al. [11]. The relationship between knowledge and productivity refers to the study by Khusna et al. [32]. Research exploring the association between farmers' knowledge and innovation adoption draws on findings by Muhyidin et al. [29]. Further evidence regarding the link between farmers' knowledge and productivity is provided in the works of Nasution et al. [25]. Empirical studies examining the relationship between farmers' skills, innovation adoption, and productivity include research by Yuswandi et al. [17]. Finally, the relationship between innovation adoption and productivity is supported by studies conducted by Irfansyah et al. [7].

Furthermore, the relationships between variables that form the conceptual framework of this study are presented in **Figure 1.** This study consists of five latent variables, namely:

1) Extension worker communication (X), with indicators: farmers' readiness to accept the material presented by extension workers (X11), extension workers' active involvement in communication (X12), farmers' active involvement in communication (X13), and provision of extension material according to farmers' needs (X14).
2) Farmer knowledge (Y1), measured by the following indicators: understanding the purposes, objectives, and stages of agricultural innovation (Y11), ability to explain the material provided by extension workers to others (Y12), understanding the benefits of innovations presented by extension workers (Y13), and increased knowledge after attending extension sessions (Y14).
3) Farmer skills (Y2), with indicators: ability to overcome technical problems that arise when implementing innovations (Y21), use of irrigation systems (Y22), harvesting according to the proper harvest time (Y23), and improved management of harvests (Y24).
4) Innovation adoption (Y3), with indicators: ability to procure seeds independently (Y31), use of rice planting tools (Y32), use of tools for fertilizing (Y33), use of tools for pest and disease control (Y34), and use of drying tools (Y35).
5) Farmer productivity (Y4), with indicators: increased rice productivity (Y41), increased farming income (Y42), more efficient farming practices (Y43), and an increased cropping index (Y44).

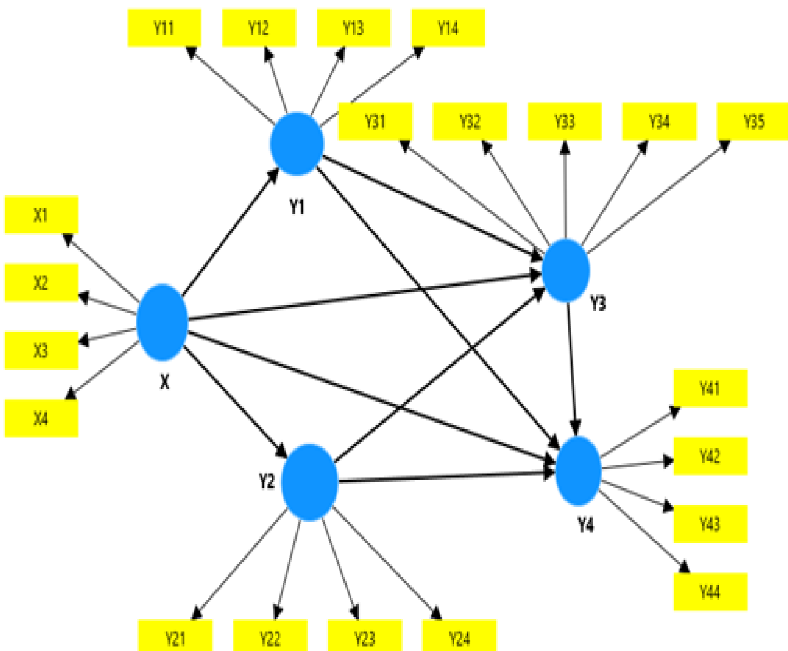

Figure 1. Research conceptual framework.

1.2. Research Hypothesis

Based on the research conceptual framework, the proposed hypotheses are as follows:

H1. *Extension worker communication (X) has a positive and significant effect on farmer knowledge (Y1).*

H2. *Extension worker communication (X) has a positive and significant effect on farmer skills (Y2).*

H3. *Extension worker communication (X) has a positive and significant effect on innovation adoption (Y3).*

H4. *Extension worker communication (X) has a positive* *and significant effect on farmer productivity (Y4).*

H5. *Farmer knowledge (Y1) has a positive and significant effect on innovation adoption (Y3).*

H6. *Farmer knowledge (Y1) has a positive and significant effect on farmer productivity (Y4).*

H7. *Farmer skills (Y2) have a positive and significant effect on innovation adoption (Y3).*

H8. *Farmer skills (Y2) have a positive and significant effect on farmer productivity (Y4).*

H9. *Innovation adoption (Y3) has a positive and significant effect on farmer productivity (Y4).*

2. Materials and Methods

2.1. Research Designed

This study employed a quantitative research design [43]. The research was carried out in five rice farming areas, namely the subdistricts of Tenggarong, Loa Kulu, Tenggarong Seberang, Sebulu, Muara Kaman, and Marang Kayu in Kutai Kartanegara Regency, East Kalimantan Province, Indonesia. The total population of rice farmers in these areas was 820. The sample size was determined using the Slovin formula [44], with a margin of error of 7.5%, resulting in a sample of 146 farmers.

2.2. Questionnaires

The research instrument in this study was a questionnaire developed by the researcher. Prior to its use, the instrument was tested for validity and reliability. The validity test was conducted through item analysis, in which each questionnaire item was examined by calculating the Pearson Product Moment correlation coefficient. The correlation coefficient for each item was computed based on the total response scores of all respondents and then compared with the critical r-value corresponding to the appropriate degrees of freedom and significance level. An item was considered valid if its correlation coefficient exceeded the critical value. In this study, items with a correlation coefficient greater than 0.30 were deemed valid [45]. The validity test, conducted using data from 30 respondents during the pre-survey, showed that all items in the instrument met the validity criteria, as presented in **Table 1**.

Table 1. Instrument validity test results.

No.	Indicator	R-Value	Decision
1	X1	0.62	Valid
2	X2	0.73	Valid
3	X3	0.73	Valid
4	X4	0.70	Valid
5	Y11	0.66	Valid
6	Y12	0.64	Valid
7	Y13	0.69	Valid
8	Y14	0.68	Valid
9	Y21	0.67	Valid
10	Y22	0.73	Valid
11	Y23	0.88	Valid
12	Y24	0.51	Valid
13	Y31	0.73	Valid
14	Y32	0.80	Valid
15	Y33	0.81	Valid
16	Y34	0.64	Valid
17	Y35	0.93	Valid
18	Y41	0.76	Valid
19	Y42	0.85	Valid
20	Y43	0.59	Valid
21	Y44	0.69	Valid

Source: Researchers' analysis (2025).

The next step was to test the reliability of the instrument. Reliability testing was conducted using the split-half technique. For this purpose, the items for each variable were divided into two groups, namely the odd-numbered items and the even-numbered items. The total score for each group was then obtained by summing the item scores. Subsequently, the correlation between the total scores of the odd and even groups was calculated. This correlation coefficient was then adjusted using the Spearman–Brown formula, as shown below [45].

$$ri = \frac{2.rb}{1 + rb} \quad (1)$$

Notes:

ri = internal reliability of the entire instrument

rb = Pearson correlation between the first and second halves

r table = 0.36

Using the SPSS software (version 26), the reliability test of the instrument was conducted with 30 respondents in the pre-survey. The obtained correlation coefficient was 0.80 (**Table 2**). After applying the Spearman–Brown formula (Equation 1), the reliability coefficient increased to 0.89. Therefore, the research instrument was considered reliable, as the reliability coefficient met the acceptable criteria.

Responses to the questionnaire items were measured using a Likert scale [45]. Each item, representing statements or questions corresponding to the indicators of the respective variables, was scored on a scale from one (1) to five (5), where 1 Strongly Disagree, 2 Disagree, 3 Neutral, 4 Agree, and 5 Strongly Agree.

The respondents selected for this study were administrators of farmer groups and farmer group associations in the five regions. As shown in **Table 3**, the majority of respondents were male (89.73%), predominantly within the age range of 41–50 years, most were high school graduates, and had more than 10 years of experience in rice farming. The description of the variables and their measurements is presented in **Table 4**.

Table 2. Instrument reliability test results.

Correlations			
		Total Odd	Total Even
Total Odd	Pearson Correlation	1	0.80
	Sig. (2-tailed)		0.00
	N	30	30
Total Even	Pearson Correlation	0.80	1
	Sig. (2-tailed)	0.00	
	N	30	30

Source: Researchers' analysis (2025).

Table 3. Respondent characteristics.

Variable	**Indicator**	**Frequency**	**Percentage (%)**
Gender	Male	131.00	89.73
	Female	15.00	10.27
	Total	146.00	100.00
Age (Years)	< 30	0.00	0.00
	31 – 40	13.00	8.90
	41 – 50	68.00	46.58
	51 – 60	52.00	35.62
	> 61	13.00	8.90
	Total	146.00	100.00

Table 3. *Cont.*

Variable	Indicator	Frequency	Percentage (%)
Education	< Elementary	9.00	6.16
	Elementary	28.00	19.18
	Junior High	39.00	26.71
	Senior High	51.00	34.93
	Bachelor	19.00	13. 01
	Total	146.00	100.00
Farming Experience	< 10	12.00	8.22
	10–15	55.00	37.67
	16–20	36.00	24.66
	21–25	13.00	8.90
	> 25	30.00	20.55
	Total	146.00	100.00

Source: Researchers' analysis (2025).

Table 4. Description of variables.

Variable	Indicator		Score					Total
			1	2	3	4	5	
X (Extension Communication)	X11	f	1.00	2.00	5.00	80.00	58.00	146
		%	0.68	1.37	3.42	54.79	39.73	100
	X12	f	3.00	3.00	3.00	46.00	91.00	146
		%	2.05	2.05	2.05	31.51	62.33	100
	X13	f	2.00	2.00	5.00	66.00	71.00	146
		%	1.37	1.37	3.42	45.21	48.63	100
	X14	f	2.00	1.00	9.00	75.00	59.00	146
		%	1.37	0.68	6.16	51.37	40.41	100
	X15	f	2.00	0.00	3.00	68.00	73.00	146
		%	1.37	0.00	2.05	46.58	50.00	100
Y1 (Knowledge)	Y11	f	1.00	3.00	12.00	94.00	36.00	146
		%	0.68	2.05	8.22	64.38	24.66	100
	Y12	f	2.00	1.00	26.00	88.00	29.00	146
		%	1.37	0.68	17.81	60.27	19.86	100
	Y13	f	2.00	0.00	10.00	76.00	58.00	146
		%	1.37	0.00	6.85	52.05	39.73	100
	Y14	f	1.00	3.00	11.00	102.00	29.00	146
		%	0.68	2.05	7.53	69.86	19.86	100
	Y15	f	2.00	0.00	11.00	73.00	60.00	146
		%	1.37	0.00	7.53	50.00	41.10	100
Y2 (Skills)	Y21	f	1.00	7.00	26.00	87.00	25.00	146
		%	0.68	4.79	17.81	59.59	17.12	100
	Y22	f	4.00	4.00	26.00	81.00	31.00	146
		%	2.74	2.74	17.81	55.48	21.23	100
	Y23	f	1.00	11.00	19.00	79.00	36.00	146
		%	0.68	7.53	13.01	54.11	24.66	100
	Y24	f	1.00	3.00	14.00	86.00	42.00	146
		%	0.68	2.05	9.59	58.90	28.77	100

Table 4. *Cont.*

Variable	Indicator		Score 1	2	3	4	5	Total
Y3 (Innovation Adoption)	Y31	f	13.00	22.00	42.00	55.00	14.00	146
		%	8.90	15.07	28.77	37.67	9.59	100
	Y32	f	16.00	48.00	40.00	28.00	14.00	146
		%	10.96	32.88	27.40	19.18	9.59	100
	Y33	f	19.00	45.00	48.00	29.00	5.00	146
		%	13.01	30.82	32.88	19.86	3.42	100
	Y34	f	17.00	32.00	45.00	40.00	12.00	146
		%	11.64	21.92	30.82	27.40	8.22	100
	Y35	f	18.00	36.00	44.00	33.00	15.00	146
		%	12.33	24.66	30.14	22.60	10.27	100
Y4 (Productivity)	Y41	f	1.00	11.00	22.00	75.00	37.00	146
		%	0.68	7.53	15.07	51.37	25.34	100
	Y42	f	0.00	6.00	23.00	75.00	42.00	146
		%	0.00	4.11	15.75	51,37	28.77	100
	Y43	f	0.00	8.00	13.00	82.00	43.00	146
		%	0.00	5.48	8.90	56.16	29.45	100
	Y44	f	0.00	5.00	21.00	75.00	45.00	146
		%	0.00	3.42	14.38	51.37	30.82	100

Source: Researchers' analysis (2025).

2.3. Analysis Approach

The data were analyzed using Structural Equation Modeling (SEM) with the SmartPLS version 4 software to test the proposed hypotheses. SEM is a multivariate statistical technique that combines factor analysis and regression (correlation) analysis to examine relationships among variables in a model, both between indicators and constructs as well as between constructs. The use of SmartPLS was considered appropriate because it offers several advantages, particularly its ability to estimate models simultaneously compared to conventional regression analysis [46]. To apply SmartPLS, several requirements must be satisfied, including: (1) factor loading (LF) values greater than 0.70 (LF > 0.70), (2) composite reliability (CR) ≥ 0.70, (3) rho_A ≥ 0.70, (4) Cronbach's Alpha ≥ 0.70, (5) average variance extracted (AVE) ≥ 0.50, (6) acceptable cross-loading, (7) Fornell–Larcker criterion, and (8) heterotrait–monotrait ratio (HTMT) < 0.90 [47]. Based on the statistical test results, all criteria were fulfilled, with LF > 0.70, CR > 0.70, rho_A > 0.70, Cronbach's Alpha > 0.70, Fornell–Larcker values within the acceptable range, and HTMT < 0.90. Hence, the model validity and reliability requirements were met, allowing the analysis to proceed.

3. Results

3.1. Evaluation of Measurement Model

Construct validity and reliability tests were conducted to assess the appropriateness of the measures used to capture the overall variables and the variation across items. The measurement model is presented in **Figure 2**.

The measurement criteria employed in this study included factor loading values, Cronbach's Alpha, rho_A, Average Variance Extracted (AVE), composite reliability, Heterotrait–Monotrait Ratio (HTMT), Fornell–Larcker criterion, and cross-loading. Validity of items in measuring latent variables was assessed through convergent validity tests, which are based on factor loading and AVE values. An indicator is considered valid if the outer loading value exceeds 0.70 and the AVE value exceeds 0.50 [47]. Based on the SmartPLS version 4 algorithm test, the factor loading (LF) values for all indicators were above 0.70, indicating good convergent validity. The factor loading values ranged from 0.74 to 0.86 (**Table 5**). For example, indicator X1 had a factor loading of 0.758, which confirms its validity in measuring the construct X. The interpretation of factor loadings can also be viewed in terms of item communality. Specifically, the communality of X1 is $0.76^2 = 0.58$, meaning that 57.5% of the variance in X1 is explained by construct X. Similar interpretations apply to the other indicators. Furthermore, the AVE values of all constructions exceeded the threshold of 0.50, ranging from 0.61 to 0.65. This indicates that, on average, more than 60% of the variance in the indicators is explained by their respective constructs. For instance, the AVE value for construct X was 0.61 (0.61 > 0.50), signifying that the variation of items X1, X2, X3, and X4 accounted for 61% of the construct. Thus, it can be concluded that the convergent validity of all variables in this study is acceptable.

The next stage of evaluation is discriminant validity, which is conducted to ensure that each construct in the latent model is empirically distinct from the other constructs. Discriminant validity also serves to confirm the accuracy of the measurement instrument in differentiating between constructs. In this study, discriminant validity was assessed using three approaches: the Fornell–Larcker criterion, the Heterotrait–Monotrait Ratio (HTMT), and cross-loading analysis. The results of the Fornell–Larcker criterion and HTMT calculations using SmartPLS version 4 are presented in **Table 6**.

First the Fornell–Larcker criterion was evaluated by comparing the square root of the Average Variance Extracted (AVE) with the correlations between constructs. The results showed that the square root of the AVE for extension communication (X) was 0.78, which was greater than its correlations with knowledge (Y1 = 0.59), skills (Y2 = 0.14), innovation adoption (Y3 = −0.09), and productivity (Y4 = 0.19). Similar patterns were observed for the other constructs, indicating that the Fornell–Larcker criterion was satisfied. Second, the HTMT values were examined. The results indicated that all HTMT values for construct pairs were below the threshold of 0.90, thereby confirming discriminant validity based on the HTMT criteria. Third, cross-loading analysis was conducted to assess discriminant validity at the indicator level. The results demonstrated that all measurement items loaded more strongly on their respective constructions than on other constructs. This indicates that each indicator is uniquely associated with its intended construct. Thus, the overall findings confirm that the discriminant validity requirements for this study have been fully met.

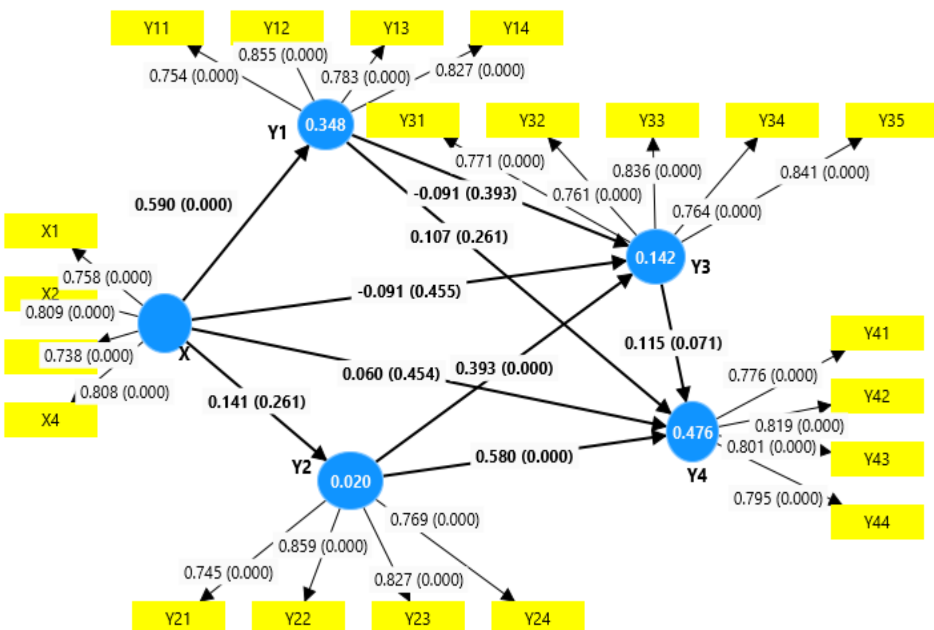

Figure 2. Measurement model.

Source: Researchers' analysis (2025).

Table 5. Measurement model.

Variable	Meas. Items	Indicator	LF	Cronbach's Alpha	Rho_A	CR	AVE
X (Extension Communication)	X1 < – X	X1	0.76	0.79	0.80	0.86	0.61
	X2 < – X	X2	0.81				
	X3 < – X	X3	0.74				
	X4 < – X	X4	0.81				
Y1 (Knowledge)	Y11 < – Y1	Y11	0.75	0.82	0.82	0.88	0.65
	Y12 < – Y1	Y12	0.86				
	Y13 < – Y1	Y13	0.78				
	Y14 < – Y1	Y14	0.83				
Y2 (Skills)	Y21 < – Y2	Y21	0.76	0.81	0.81	0.88	0.64
	Y22 < – Y2	Y22	0.86				
	Y23 < – Y2	Y23	0.83				
	Y24 < – Y2	Y24	0.77				
Y3 (Innovation Adoption)	Y31 < –Y3	Y31	077	0.86	0.87	0.90	0.63
	Y32 < –Y3	Y32	0.76				
	Y33 < –Y3	Y33	0.84				
	Y34 < –Y3	Y34	0.76				
	Y35 < –Y3	Y35	0.84				
Y4 (Productivity)	Y41 < –Y4	Y41	0.78	0.81	0.81	0.88	0.64
	Y42 < –Y4	Y42	0.82				
	Y43 < –Y4	Y43	0.80				
	Y44 < –Y4	Y44	0.80				

Source: Researchers' analysis (2025).

Table 6. Discriminant validity.

Fornell-Larcker Criterion					
	X	Y1	Y2	Y3	Y4
X	0.78				
Y1	0.59	0.81			
Y2	0.14	0.40	0.80		
Y3	−0.09	0.01	0.34	0.80	
Y4	0.19	0.38	0.67	0.31	0.80
HTMT					
X					
Y1	0.72				
Y2	0.16	0.50			
Y3	0.12	0.13	0.38		
Y4	0.23	0.46	0.81	0.34	

Source: Researchers' analysis (2025).

Reliability testing was conducted to assess the accuracy and consistency of the measurement instruments in capturing the latent variables. Three criteria were employed to evaluate construct reliability: Cronbach's Alpha, composite reliability (CR), and rho_A. The thresholds used were CR > 0.70, Cronbach's Alpha > 0.70, and rho_A > 0.70. The results of data processing using SmartPLS version 4.0 (**Table 5**) indicated that all latent variables in this study met the established reliability standards. Specifically, the values of Cronbach's Alpha, composite reliability, and rho_A for each construct were above the minimum threshold, confirming that the constructs were measured consistently and reliably.

3.2. Evaluation of the Structural Model

The evaluation of the structural model includes a multicollinearity test by looking at the inner VIF value, with a criterion of VIF < 5. **Table 7** shows a VIF value of less than 5. This means that there is no multicollinearity problem. The path coefficient of the influence of agricultural extension communication strategies (X) on Knowledge (Y1) is the most dominant at 0.59 with a significance of p-value < 0.05 (0.00 < 0.05) (refer **Table 7**). **Table 7** also shows that other variables also have a significant effect, namely the effect of skills (Y2) on the adoption of innovations by rice farmers (Y3), and the effect of skills (Y2) on increasing rice productivity (Y4).

To assess the effect size of the direct effect, we used the f-squared (f^2) effect size measure with criteria for the direct effect as proposed by Hair, namely 0.02 = low, 0.15 = moderate, and 0.35 = high [47]. Based on **Table 7**, the f-squared with a low effect is the effect of X on Y2, the effect of X on Y3, the effect of X on Y4, the effect of Y1 on Y3, and the effect of Y1 on Y4. The f square with a moderate effect is the effect of Y2 on Y3. Furthermore, the effects with a high category are the effect of X on Y1 and the effect of Y2 on Y4.

To read the results of the 95% confidence interval test in SmartPLS, look at the lower bound and upper bound values of the interval. Based on **Table 7**, the 95% confidence interval for the effect of X on Y1 is between 0.38 and 0.78. This means that if the agricultural extension communication strategy (X) is improved through various activities, its effect on knowledge (Y1) will increase to 0.78.

Structural models describe the relationships between latent variables. One way to test the model internally is by assessing the R square (R^2). According to Chin, the model fit criteria using R square are as follows: an R^2 value of 0.67 is categorized as "good," an R^2 value of 0.30 is in the "moderate" category, and an R^2 value of 0.19 is in the "weak" category [48]. Based on the results of the data analysis presented in **Table 7**, the R^2 value for the effect of X on Y1 is 0.35, indicating that the model is in the moderate category. The effect of X on Y2 is 0.02, which falls into the weak category. The effect of X on Y3 is 0.14, also in the weak category. Meanwhile, the effect of X on Y4 is 0.48, which is categorized as moderate.

In SmartPLS, Q-square (Q^2) is a measure of the structural model's ability to reconstruct the observed values in the data. In other words, PLS Predict (Q^2) is a form of model validation that describes the predictive power of the proposed PLS model. **Table 7** shows that the Q^2 value is greater than zero, thus it can be said that the model has good predictive relevance. Another way to evaluate PLS Predict is by comparing the RMSE and MAE values in PLS with those in LM (linear regression). If the values are lower, it indicates that the model has better predictive power. Furthermore, if most of the values are low, it indicates that the PLS model has medium predictive power [47]. **Table 8** shows that the PLS model has better predictive power.

Table 7. Evaluation of the structural model.

Hypothesis	**Path. Coef.**	***P* Value**	**95 % Path Coefficient**		***T*-Stat**	**VIF**	f^2	R^2	Q^2
			2.5%	97.5%					
X									0.33
X – > Y1	0.59	0.00	0.38	0.78	5.60	1.00	0.53		
X – > Y2	0.14	0.26	−0.06	0.42	1.13	1.00	0.02		
X – > Y3	– 0.09	0.44	−0.29	0.16	0.77	1.56	0.01		
X – > Y4	0.06	0.12	−0.01	0.46	1.56	1.57	0.00		
Y1								0.35	0.41
Y1 – > Y3	– 0.09	0.39	−0.30	0.12	0.86	1.83	0.01		
Y1 – > Y4	0.11	0.32	−0.09	0.29	0.99	1.84	0.01		
Y2								0.02	0.40
Y2 – > Y3	0.39	0.00	0.26	0.56	4.92	1.21	0.15		
Y2 – > Y4	0.58	0.00	0.43	0.75	7.63	1.39	0.46		
Y3								0.14	0.43
Y3 – > Y4	0.12	0.07	−0.01	0.24	1.81	1.17	0.022		
Y4								0.48	0.38

Source: Researchers' analysis (2025).

Table 8. Q^2, RMSE, and MAE values.

	Q^2 **Predict**	**PLS-SEM_RMSE**	**PLS-SEM_MAE**	**LM_RMSE**	**LM_MAE**
Y11	0.23	0.67	0.49	0.69	0.51
Y12	0.26	0.62	0.46	0.62	0.45
Y13	0.14	0.60	0.42	0.62	0.43
Y14	0.14	0.67	0.52	0.68	0.52
Y21	−0.04	0.79	0.54	0.81	0.56
Y22	−0.05	0.89	0.59	0.90	0.61
Y23	−0.05	0.89	0.60	0.90	0.62
Y24	−0.02	0.73	0.51	0.74	0.51
Y31	−0.02	1.12	0.93	1.15	0.95
Y32	−0.00	1.16	0.96	1.20	0.99
Y33	−0.01	1.05	0.89	1.07	0.89
Y34	−0.01	1.15	0.92	1.17	0.95
Y35	−0.01	1.19	0.96	1.24	0.99
Y41	−0.01	0.88	0.62	0.90	0.66
Y42	−0.05	0.81	0.58	0.81	0.59
Y43	−0.03	0.79	0.54	0.81	0.56
Y44	−0.04	0.78	0.57	0.80	0.57

Source: Researchers' analysis (2025).

3.3. Robustness Check

Robustness checks in this study were conducted by examining the linearity and endogeneity of the model. Linearity was assessed based on the quadratic effect, if it was not significant, then the linearity effect of the model was fulfilled (robust). Conversely, if the quadratic effect was significant, the linearity assumption was not fulfilled. The results of testing the *p*-value of the quadratic effect of X on Y1, Y2, Y3, and Y4 ($p > 0.05$), the effect of Y1 on Y3 and Y4, the effect of Y2 on Y3, and the effect of Y3 on Y4 show that all are not significant (QE > 0.05) (**Table 9**). Based on these results, it can be concluded that the model is linear or that the model's linearity effect is fulfilled (robust).

Table 9. Robustness check (Linearity and Endogeneity).

	Original Sample (O)	**Sample Mean (M)**	**Standard Deviation (STDEV)**	***T* Statistics (|O/STDEV|)**	***P* Values**
X – > Y1	0.60	0.51	0.31	1.96	0.05
X – > Y2	−0.35	−0.27	0.27	1.27	0.21
X – > Y3	0.16	0.12	0.26	0.61	0.54
X – > Y4	−0.16	−0.12	0.20	0.80	0.42
Y1 – > Y3	−0.39	−0.36	0.24	1.60	0.11
Y1 – > Y4	0.05	0.06	0.21	0.24	0.81
Y2 – > Y3	0.12	0.19	0.37	0.31	0.75
Y2 – > Y4	0.64	0.66	0.31	2.10	0.04
Y3 – > Y4	−0.01	0.01	0.56	0.01	0.99
GC (Y3) – > Y4	0.13	0.12	0.58	0.23	0.82
GC (Y2) – > Y3	0.29	0.21	0.36	0.78	0.43
GC (Y2) – > Y4	−0.11	−0.13	0.28	0.39	0.70
GC (X) – > Y1	−0.01	0.08	0.23	0.04	0.97
GC (X) – > Y2	0.49	0.44	0.21	2.28	0.02
GC (X) – > Y3	−0.22	−0.19	0.21	1.09	0.28
GC (X) – > Y4	0.21	0.19	0.15	1.36	0.16
GC (Y1) – > Y3	0.29	0.27	0.23	1.26	0.21
GC (Y1) – > Y4	0.09	0.08	0.19	0.47	0.64

Source: Researchers' analysis (2025).

3.4. Hypothesis Testing

PLS-SEM does not assume that the data are normally distributed therefore, the hypothesis testing procedure uses a non-parametric approach, namely bootstrapping. This procedure serves as an alternative to exact hypothesis testing methods when the sampling distribution of the data is unknown. Bootstrapping is carried out by sampling and resampling p times (generally 5000), which is useful for creating standard errors and parameter estimates. The test results are evaluated using *t*-values for two-tailed tests, namely 1.65 (significance level = 10%), 1.96 (significance level = 5%), and 2.58 (significance level = 1%). SmartPLS also provides p-values for each evaluation, which are compared with the predetermined alpha levels (0.05 or 0.01). If the *p*-value < 0.05, it indicates a significant influence between variables. The bootstrap method can be selected between the Bias Corrected and Accelerated (BCA) method and the percentile method. The BCA method is recommended because, in certain situations, abnormal data distributions can affect PLS estimates, resulting in peaked and skewed distributions. By applying the BCA method, the results of the confidence interval parameter estimates can be scaled and adjusted more accurately.

The *T*-value used is 1.96 at an alpha value of 0.05. In addition to assessing the *T*-statistics, significance can also be seen from the P-value. If the P-value is < 0.05, it is considered significant, and vice versa. **Table 7** shows the T-statistic value for testing the hypothesis that extension worker communication (X) has a positive and significant effect on farmers' knowledge (Y1). This is indicated by the calculated T-statistic being greater than the table *T*-statistic (5.60 > 1.96), the *P*-value being less than 0.05 (0.00 < 0.05), and the path coefficient value being 0.59. The hypothesis that extension worker communication (X) has a positive but insignificant effect on farmer knowledge (Y2) is rejected. This is indicated by a path coefficient value of 0.14 and a *p*-value of 0.26 (0.26 > 0.05), and a *T*-statistic value of 1.13 (1.13 < 1.96). The hypothesis of the effect of extension communication (X) on innovation adoption (Y3) is negative and insignificant, so the hypothesis is rejected. This is indicated by a path coefficient value of -0.09, a *p*-value of 0.44 (0.44 > 0.05), and a *T*-statistic value of 0.77 (0.77 < 1.96). The hypothesis of the effect of extension communication (X) on farmer productivity (Y4) is positive but not significant, so the hypothesis is rejected. This is indicated by a coefficient value of 0.06, a *P*-value of 0.12 (0.12 > 0.05), and a *T*-statistic value of 1.56 (1.56 < 1.96). The hypothesis of the effect of farmer knowledge (Y1) on innovation adoption (Y3) is negative and insignificant; the hypothesis is rejected. This is indicated by a path coefficient value of −0.09, a *p*-value of 0.39, and a *T*-statistic value of 0.86 (0.86 < 1.96). The hypothesis of the effect of farmer knowledge (Y1) on farmer productivity (Y4) is positive but not significant, so the hypothesis is rejected. This is indicated by a path coefficient value of 0.11, a *p*-value of 0.32 (0.32 > 0.05), and a *T*-statistic value of 0.99 (0.99 < 1.96). The hypothesis of the effect of farmer skills (Y2) on innovation adoption (Y3) is positively and significantly influential; the hypothesis is accepted. This is indicated by a path coefficient value of 0.39, a *p*-value of 0.00 (0.00 < 0.05), and a *T*-statistic value of 4.92 (4.92 > 1.96). The hypothesis of the influence of farmer skills (Y2) on farmer productivity (Y4) is positive and significant, as indicated by a path coefficient value of 0.58, a *p*-value of 0.00 (0.00 < 0.05), and a *T*-statistic of 7.63 (7.63 > 1.96). The hypothesis of the effect of innovation adoption (Y3) on farmer productivity (Y4) is positive but not significant, as indicated by a path coefficient value of 0.16, a *P*-value of 0.07 (0.07 > 0.05), and a *T*-statistic value of 1.81 (1.81 < 1.96).

4. Discussion

4.1. Analysis of the Effect of Agricultural Extension Communication Strategies (X) on Rice Farmers' Knowledge (Y1)

The influence of extension communication (X) has a positive and significant effect on farmers' knowledge (Y1). This statement implies that if various agricultural extension strategies are provided to farmers, it will result in a significant increase in the knowledge of rice farmers in five agricultural areas. Based on the respondents' answers, agricultural extension communication strategies have been implemented well. This means that agricultural extension workers have carried out various activities that can increase the knowledge of rice farmers in rice cultivation to enhance productivity. Various communication strategies can be carried out by field extension workers, such as direct extension in the field, the use of print media, and the use of information technology. Agricultural extension workers can hold group meetings with farmers to discuss more efficient rice cultivation techniques. At these meetings, extension workers not only provide information but also encourage farmers to share their experiences and challenges. In this way, farmers feel involved and motivated to learn more, which in turn increases their knowledge of good agricultural practices.

The use of social media as a communication tool can be implemented more effectively by extension workers. In today's digital age, many farmers are beginning to access information through online platforms. Competent agricultural extension workers utilize social media to disseminate the latest information on cultivation techniques, fertilization, and pest control. In this way, information can reach farmers in remote areas who may not be able to attend face-to-face meetings. This demonstrates that diverse and adaptive communication strategies can significantly improve farmers' knowledge. The success of agricultural extension workers' communication strategies depends not only on the methods used but also on their ability to understand the characteristics and needs of farmers. Extension workers who are able to adapt to local conditions, understand local culture, and establish good relationships with farmers are more likely to succeed in enhancing farmers' knowledge. According to Rogers, communication is crucial to the decision-making process for innovation since it generates new information [21]. Farmers who communicate well are more likely to be knowledgeable about adopting agriculture, according to Tran et al.'s study on the factors influencing agricultural adoption in Vietnam [49]. Thus, it can be concluded that the communication strategies of agricultural extension workers play a very important role in increasing the knowledge of rice farmers. With the right approach, extension workers can help farmers not only to better understand cultivation techniques but also to be inspired to continue learning and innovating. This increase in knowledge, in turn, has the potential to enhance agricultural productivity and the overall welfare of farmers.

The findings of this study emphasize the importance of innovation in communication strategies and the need for extension workers to continue adapting to the times in order to make a greater contribution to the agricultural sector in the five agricultural areas of Kutai Kartanegara Regency in particular and in Indonesia in general. These findings are in line with previous research indicating that the communication strategies implemented by field agricultural extension workers have a significant impact on motivating and fostering farmer groups [39]. Other studies also report that farmers agree with the strategies used by extension workers [40].

4.2. Analysis of the Effect of Agricultural Extension Communication Strategies (X) on Rice Farmers' Skills (Y2)

The results of the study indicate that the effect of extension communication (X) on farmers' skills (Y2) is positive but not significant. This positive relationship means that if agricultural extension communication strategies are improved through various activities, the skills of rice farmers will increase, albeit insignificantly. Based on the interview results presented in **Table 4** (descriptive variables), there is a tendency for farmers to possess skilled or highly skilled abilities in rice cultivation. Although various extension worker communication strategies were implemented to improve farmers' skills, the improvement was not significant. One of the factors influencing this condition is that the age of the farmer respondents is relatively high. Research shows that older farmers tend to be more conservative in accepting change and may have limitations in adapting to new technologies or methods introduced by extension workers. In contrast, younger farmers tend to be more open to innovation and quicker to absorb the skills conveyed by Field Agricultural Extension Workers. For example, young farmers who participate in technology-based training programs, such as the use of applications for monitoring land and weather conditions, can quickly implement new techniques that may increase rice productivity. Thus, it is important to consider the demographics of farmers when designing more effective communication strategies. Another factor that may influence the insignificance of these results is the lack of support from the government or related institutions in terms of providing adequate resources and facilities for training.

Considering the findings of this study, extension workers need to adapt their communication style to suit the background and experience of farmers. The use of simple language and concrete examples of successful practices can help farmers better understand and apply the knowledge and skills they have acquired. Although there is a positive influence between agricultural extension workers' communication strategies and the skills of rice farmers, this influence has not yet reached a significant level. This indicates the need to improve the communication approaches used, while also taking into account demographic factors and the support required to enhance the effectiveness of training. With more focused and collaborative efforts, it is expected that farmers' skills will improve significantly, which will ultimately have a positive impact on rice productivity and farmers' welfare. The findings of this study are consistent with previous research indicating that the strategies used by extension workers can improve farmers' skills [37]. Other studies related to the role of agricultural extension workers' communication strategies in enhancing farmers' skills were conducted by Khusna et al. [32] and Suadnya et al. [38].

4.3. Analysis of the Effect of Agricultural Extension Communication Strategies (X) on the Adoption of Innovations by Rice Farmers (Y3)

Based on the results of the study, it was found that the influence of extension communication (X) on innovation adoption (Y3) was negative and insignificant. The hypothesis was therefore rejected. This condition can be interpreted to mean that increasing various extension communication strategy activities carried out by extension workers does not necessarily impact the adoption of rice field innovations; in fact, it may result in a decrease in innovation adoption among rice farmers. Several factors could contribute to this outcome. One is farmer fatigue in adopting innovations or the absence of modern innovations that are suitable for farmers in this region. Fatigue can be understood as a condition in which farmers feel they have received too much information or too many new methods that are no longer interesting. For example, if agricultural extension workers continuously offer the same or similar technologies without considering the specific needs and context of farmers, the farmers tend to ignore the information. This is particularly true if the innovations offered are unsuitable for local conditions or do not provide clear benefits. Another factor contributing to the low level of innovation adoption is the lack of access to resources needed to implement the innovations, such as capital, tools, or adequate technical knowledge. Even when extension workers introduce new rice varieties that are more resistant to pests, farmers may still prefer to use older varieties with which they are more familiar. Limited access to resources or insufficient knowledge on proper care of new varieties can prevent farmers from adopting innovations effectively. In this case, the communication strategies of extension workers need to be strengthened by providing more comprehensive support, including practical training and assistance in procuring necessary resources. Farmers' decisions to adopt innovations are influenced not only by the information they receive but also by existing social norms and customs. If a farming community has strong traditions in farming methods that have proven effective, they may be reluctant to try new methods, even if evidence shows these methods are more productive. Therefore, agricultural extension workers need to understand these social dynamics and design communication strategies that are not only informative but also sensitive to local values and traditions.

In order to improve the effectiveness of agricultural extension communication strategies, a more integrated and participatory approach is needed. Extension workers must involve farmers in the innovation development process so that farmers feel they have a stake in the changes taking place. Extension workers can hold forums or discussion groups where farmers share their experiences. This allows extension workers to better understand farmers' needs and tailor their communication strategies to be more relevant and engaging. Based on the results of statistical tests, agricultural extension workers' communication strategies do not have a significant effect on the adoption of innovations by rice farmers, highlighting opportunities for evaluation and improvement. It is important for extension workers to understand the factors that influence farmers' saturation and reluctance to adopt innovations. By adopting a more participatory approach that is sensitive to the local context, it is hoped that innovation adoption will increase and provide greater benefits for rice farmers. Research related to the relationship between agricultural extension workers' communication strategies and farmers' innovation adoption indicates that the right communication strategy in dissemination should be carried out using various methods [50]. The findings of this study align with previous studies reporting that extension communication has a significant effect on innovation adoption [11,34,35,51]. Ineffective communication, however, will result in an insignificant effect of communication on innovation adoption [26,36].

4.4. Analysis of the Effect of Agricultural Extension Communication Strategies (X) on Increasing Rice Field Productivity (Y4)

The results of the study show that the effect of extension communication (X) on farmer productivity (Y4) is positive but not significant. These findings differ from those of Dwipayasa et al., who studied agricultural extension workers' communication strategies in disseminating rice productivity improvements in Subak Anggabaya, Denpasar City. Dwipayasa et al. found that agricultural extension workers' communication strategies had a positive and significant effect on rice productivity improvements [33]. In general, extension worker communication has a positive and significant relationship with increased productivity. However, in the case of rice farming in Kutai Kartanegara Regency, East Kalimantan Province, Indonesia, the opposite is observed. The effect of extension worker communication on productivity improvement is positive but not significant. This means that even if communication strategies are improved, the resulting increase in productivity remains insignificant.

Extension workers serve as a link between the knowledge and practices needed to improve agricultural yields. They are tasked with disseminating relevant information, providing training, and supporting farmers in applying new technologies. However, conditions in the rice-growing areas of Kutai Kartanegara Regency present a different phenomenon. In this area, the effect of extension worker communication on productivity improvement has proven to be insignificant, raising important questions about the factors influencing this outcome. One aspect that needs to be analyzed is how extension workers communicate with farmers in the area. Effective communication often involves two-way interaction, where extension workers not only convey information but also listen to the needs and challenges faced by farmers. Based on interviews with several respondents, communication in Kutai Kartanegara Regency is ineffective and suboptimal. If extension workers focus primarily on conveying technical information without considering local conditions and the specific needs of farmers, the information may not be relevant. This can lead to confusion or even rejection by farmers, which in turn does not improve productivity. For example, if extension workers encourage the use of new rice varieties unfamiliar to farmers, without explaining the benefits and proper cultivation methods, farmers may prefer to continue using familiar varieties. This illustrates that communication can fail to enhance productivity, even when communication strategies are improved. Extension workers who merely give instructions without involving farmers in the decision-making process can create dissatisfaction. Farmers' dissatisfaction with extension worker communication can also arise from a lack of feedback. In many situations, farmers possess valuable experience or knowledge about effective agricultural practices. If extension workers do not create opportunities for farmers to share these experiences, the potential for collaboration and mutual learning is lost. This can result in farmers feeling ignored, which may ultimately lead to a decline in productivity.

4.5. Analysis of the Influence of Rice Farmers' Knowledge (Y1) on the Adoption of Innovations by Rice Farmers (Y3)

The results of the study show that the influence of farmers' knowledge (Y1) on the adoption of innovations (Y3) is negative and insignificant. Essentially, knowledge greatly determines a person's competence. Farmers' ability to adapt to technological innovations in rice farming largely depends on their knowledge. The more knowledge farmers possess, the greater their potential to adopt technological innovations. However, the findings of this study indicate that even when farmers' knowledge is increased through various activities, their ability to adopt innovations in this agricultural area decreases, although the decrease is not significant. This phenomenon can be explained by several factors, including resistance to change, incompatibility between newly acquired knowledge and existing local practices, and external influences such as economic and social conditions that affect farmers' decisions.

The success of adopting technological innovations depends not only on knowledge but also on the social and economic conditions of farmers in this region. In the rice-growing areas of Kutai Kartanegara Regency, several villages still face limitations in infrastructure and resources. Although farmers may possess good knowledge of modern agricultural technologies, they are often unable to apply it effectively due to infrastructural or financial constraints. Therefore, relevant parties, such as the government and private organizations operating in this area, need to provide assistance to support the adoption of rice field technological innovations. In summary, increased knowledge does not always guarantee enhanced innovation capabilities, particularly when complex external and internal factors are involved. A holistic approach is therefore required to support farmers in the technology adoption process, including the provision of adequate infrastructure, improved market access, and a deeper understanding of how these changes can benefit farmers in the long term. The findings of this study differ from previous research, which reported that knowledge has a positive and significant effect on innovation adoption [24]. Similarly, other studies indicate that farmers' knowledge influences their intention to implement the Application of Good Agricultural Practices [27]. Other research suggests that farmers with broader knowledge are more likely to adopt climate-smart agroforestry [52]. Similarly, credible farmer knowledge can facilitate technology adoption [53].

4.6. Analysis of the Effect of Rice Farmers' Knowledge (Y1) on Rice Productivity (Y4)

The findings of this study indicate that the effect of farmers' knowledge (Y1) on rice productivity (Y4) is positive but not significant. The influence of rice farmers' knowledge on productivity aligns with the majority of respondents' answers regarding knowledge and productivity, which tended to be positive. If rice farmers' knowledge is improved through various activities, it can positively affect productivity, although the effect is not statistically significant. Analyzing these conditions in the context of rice-based agricultural development in this region underscores the need for more effective efforts to enhance farmers' knowledge, particularly regarding the adoption of innovations, to increase rice productivity. Understanding farmers' knowledge of rice cultivation techniques, fertilization, pest control, and water management is critical, as these factors directly impact crop yields. For example, farmers who are trained to use organic fertilizers correctly can produce higher-quality and more competitive rice. However, despite the generally positive responses from respondents regarding knowledge and productivity, the results suggest that knowledge alone is insufficient to significantly increase productivity. Other limiting factors include farmers' restricted access to the latest information and innovative agricultural techniques. Traditional farming methods may no longer be adequate in addressing modern challenges, such as climate change and increasingly sophisticated pest problems. Therefore, efforts to enhance farmers' knowledge through training, demonstration plots, and field visits remain essential. Training programs that include demonstrations of good agricultural practices can help farmers better understand and apply the knowledge they have acquired, thereby supporting potential productivity improvements.

In addition, the government and relevant institutions must provide support to encourage farmers to adopt innovations. This support can include access to high-quality seeds, modern agricultural tools, and improved irrigation facilities. With these resources, farmers are more likely to apply their knowledge effectively in daily agricultural practices. Furthermore, efforts to improve farmers' knowledge should not be limited to technical agricultural skills but also include understanding of market dynamics and farm management. Farmers with greater knowledge of market analysis and marketing strategies are better equipped to sell their crops at favorable prices. Therefore, a comprehensive enhancement of knowledge can have a more substantial impact on both productivity and farmers' welfare. Although the results of this study indicate that the effect of farmers' knowledge on rice productivity is positive but not statistically significant, it highlights the importance of knowledge as an initial step in improving productivity. Through training programs, government support, and community-based initiatives, farmers are expected to adopt innovations that can enhance crop yields. Consequently, prioritizing efforts to improve farmers' knowledge is essential for the development of rice-based agriculture in this region, aiming to achieve higher productivity and overall welfare. These findings contrast with previous studies that reported a significant effect of knowledge on increasing farmers' production [17,25].

4.7. Analysis of the Influence of Rice Farmers' Skills (Y2) on the Adoption of Innovations by Rice Farmers (Y3)

Based on the research results, it was found that the influence of farmers' skills (Y2) on the adoption of innovations (Y3) is positive and significant. These statistical findings align with respondents' answers regarding farmers' skills and their adoption of innovations, which tended to be positive. Farmers' skills in managing rice cultivation, grounded in the principles of the "five principles of farming", strongly influence the adoption of innovations. This approach integrates various aspects of rice cultivation, including the selection of superior varieties, soil management techniques, pest and disease control, as well as water and fertilizer management. Farmers who are skilled in environmentally friendly pest control techniques are more likely to adopt organic pesticides or new integrated pest management methods. By possessing these skills, farmers not only improve their yields but also contribute to environmental sustainability. Farmers' skills encompass not only technical knowledge but also the ability to adapt to change. For instance, in response to increasingly evident climate change, farmers who are highly skilled in risk management and adapting to unpredictable weather conditions are more likely to adopt innovations that help them overcome these challenges. Farmers knowledgeable about drought-resistant rice varieties can quickly switch to these varieties when faced with prolonged dry seasons. This demonstrates that skills play a crucial role not only in the application of agricultural techniques but also in strategic decision-making. The relationship between skills and innovation adoption illustrates that farmers' skills act as a bridge connecting knowledge and practice. When farmers possess strong skills, they can not only understand the theory behind innovations but also apply them effectively in daily practice. Survey responses showed that skilled farmers feel more confident in adopting new technologies. This confidence encourages them to try new methods that may have previously been considered too risky. This evidence reinforces the perspective that skills in innovation adoption are the result of dynamic and continuous social interaction. Therefore, it can be concluded that farmers' skills have a significant effect on innovation adoption [23].

4.8. Analysis of the Effect of Rice Farmers' Skills (Y2) on Increasing Rice Productivity (Y4)

The findings of this study indicate that the influence of farmer' skills (Y2) on rice productivity (Y4) is positive and significant. These findings are highly relevant in the context of modern agriculture, where farmers' technical and managerial skills are crucial for achieving optimal results. This study aligns with previous research showing that skills have a significant effect on increasing productivity [17,18]. The more farmers' skills are enhanced through various activities, the greater the increase in productivity. Improved farmer skills contribute to higher productivity. Specifically, in the rice-based agricultural development area of Kutai Kartanegara Regency, farmer skills were found to have a positive and significant effect on productivity. Although the skills of rice farmers in this region are already considered good, continuous efforts are needed to further improve skills to keep pace with modern technological innovations. An example of modern technology applications in rice farming is the use of drones for land monitoring and pesticide spraying. When farmers are trained to operate this technology, they can manage their fields more efficiently and effectively. Additionally, information technology, such as agricultural applications, can assist farmers in planning planting and harvesting schedules based on weather data, thereby optimizing agricultural yields. Improving farmers' skills is not limited to technical expertise but also encompasses better farm management. With enhanced market knowledge, farmers can set more competitive prices for their products and mitigate losses due to price fluctuations. Improved marketing skills also allow farmers to reach broader markets, both locally and internationally. The skills of rice farmers have a significant influence on rice productivity. This study demonstrates that training and education aimed at enhancing skills can yield substantial positive impacts. By integrating traditional skills with modern technology, farmers can not only increase yields but also improve the quality and competitiveness of their products. Therefore, investment in improving farmers' skills should be a priority for the government and related institutions to boost overall agricultural productivity.

4.9. Analysis of the Effect of Rice Farmers' Adoption of Innovation (Y3) on Rice Productivity (Y4)

Based on the results of this study, the adoption of innovation (Y3) has a positive but insignificant effect on rice productivity (Y4). In this study, the technology adoption variables discussed to improve rice productivity include the use of hand tractors, independently cultivated seeds, rice planting tools such as rice transplanters, tools for fertilizing, tools for pest and disease control, harvesting tools such as threshers and combine harvesters, drying tools, and the availability of appropriate grain storage barns. These positive results are also reflected in respondents' generally positive responses. This indicates that the implementation of modern technological innovations in rice farming in this region has the potential to increase productivity. However, the increase in innovation adoption is not yet significantly accompanied by an increase in productivity, suggesting the need for more intensive efforts to encourage the adoption of technology. The study results highlight the positive potential of technology adoption, but in reality, many farmers have not fully switched to modern tools. Interviews with respondents revealed that many farmers still lack access to rice transplanters, threshers, and combine harvesters. Moreover, newer technologies such as drones are still in the introductory stage and have not been widely adopted. This demonstrates that although technological innovation has great potential to enhance productivity, low adoption remains a critical challenge. To overcome this issue, the involvement of government agencies and the private sector is essential. Training and extension programs for farmers on the benefits and proper use of modern technology should be strengthened. Additionally, financial incentives for purchasing modern agricultural tools could also facilitate greater technology adoption. According to research by Surendran-Padmaja et al., innovations that meet smallholder farmers' diverse demands lead to higher productivity [54]. Thann et al. also discovered that agricultural performance is enhanced by technological innovation. This result is different from studies that reported the impact of innovation uptake [55]. The findings of this study differ from previous studies which reported that farmers' adoption of innovations significantly increases rice productivity [7–12]. Conversely, there is also empirical evidence indicating that the adoption of agricultural technology does not significantly affect productivity [13,14]. Technological innovation holds great potential to enhance agricultural productivity, especially in rice cultivation. However, realizing this potential requires more intensive efforts to promote technology adoption among farmers. With adequate support from the government and private sector, combined with increased awareness and understanding of the benefits of technology among farmers, it is expected that productivity in rice farming in this region can increase significantly. Such improvements would not only benefit individual farmers but also contribute to food security and the national economy. Productivity among rice farmers can be raised with the help of ASEAN Member States (AMS) in promoting technology adoption [56]. In terms of technology adoption, ASEAN nations have significantly increased their usage of post-harvest rice technology [57]. Additionally, Chang et al.'s research indicates that rice productivity rises when sustainable agricultural practices (SAPs) are implemented; nevertheless, Southeast Asia has a low degree of SAP adoption [58].

5. Conclusion

The study concludes that the effect of agricultural extension communication strategies (X) on the knowledge of rice farmers (Y1) is positive and significant. This is indicated by the calculated *T*-value being greater than the T-table value (5.60 > 1.96), the *P*-value being less than 0.05 (0.00 < 0.05), and the path coefficient value being 0.59. Agricultural extension workers have carried out various activities that increase the knowledge of rice farmers regarding rice cultivation to enhance productivity. Various communication strategies can be implemented by field extension workers, such as direct extension in the field, the use of print media, and the use of information technology.

The effect of extension communication (X) on farmer skills (Y2) is positive but not significant. The calculation results obtained a path coefficient value of 0.14, a *P*-value of 0.26 (0.26 > 0.05), and a *T*-statistic value of 1.13 (1.13 < 1.96). This positive relationship indicates that even though various extension communication strategies were implemented to improve farmers' skills, the improvement in skills was not significant.

The effect of extension communication (X) on innovation adoption (Y3) was negative and insignificant. The path coefficient value was −0.09, the P-value was 0.44 (0.44 > 0.05), and the *T*-statistic value was 0.77 (0.77 < 1.96). This suggests that increasing extension communication activities does not have a positive impact on innovation adoption in fact, adoption may decline. This may be due to farmer satisfaction in receiving new innovations or the absence of modern innovations that are adoptable in this region.

The effect of extension communication (X) on innovation adoption (Y3) is negative and insignificant. The results of the study show a path coefficient value of −0.09, a *P*-value of 0.44 (0.44 > 0.05), and a *T*-statistic value of 0.77 (0.77 < 1.96). The meaning contained in these research results is that if various extension communication strategy activities carried out by extension workers are increased, it will not have an impact on the adoption of rice field innovations in fact, the adoption of innovations by rice farmers will experience a decline. Various things can happen, caused by saturation on the part of farmers in the context of innovation adoption or the fact that there are no more modern innovations that can be adopted by farmers in this region.

The effect of extension communication (X) on farmer productivity (Y4) is positive but not significant. Based on the statistical test results, the path coefficient value is 0.06, the *P*-value is 0.12 (0.12 > 0.05), and the *T*-statistic value is 1.56 (1.56 < 1.96). This means that if communication strategy activities are increased, productivity will increase insignificantly.

The effect of farmer knowledge (Y1) on innovation adoption (Y3) is negative and insignificant. This is indicated by a path coefficient value of −0.09, a *P*-value of 0.39, and a *T*-statistic value of 0.86 (0.86 < 1.96). Farmers' ability to adapt to technological innovations in rice farming is largely determined by their knowledge. The greater the farmers' knowledge, the greater their ability to adopt technological innovations. However, the results of this study show that when farmers' knowledge is increased through various activities, their ability to innovate in this agricultural area decreases, although the decrease is not significant.

The influence of farmers' knowledge (Y1) on farmers' productivity (Y4) is positive but not significant. The study results show a path coefficient of 0.11, a *P*-value of 0.32 (0.32 > 0.05), and a *T*-statistic of 0.99 (0.99 < 1.96). The effect of rice farmers' knowledge on productivity improvement is positive, consistent with the majority of respondents' answers regarding knowledge and productivity, which tended to be positive. Thus, if rice farmers' knowledge is enhanced through various activities, it will positively affect productivity, although the effect is not statistically significant.

Based on the research results, the path coefficient was 0.580, the *P*-value was 0.000 (0.000 < 0.05), and the *T*-statistic was 7.63 (7.63 > 1.96). These results indicate that the influence of farmer skills (Y2) on farmer productivity (Y4) is positive and significant. Enhancing farmer skills through various activities will significantly increase productivity. It is evident that improving farmers' skills leads to higher productivity.

The effect of innovation adoption (Y3) on farmer productivity (Y4) is positive but not significant. The path coefficient is 0.12, the *P*-value is 0.07 (0.07 > 0.05), and the *T*-statistic is 1.81 (1.81 < 1.96). These results indicate the positive potential of technology adoption however, in practice, many farmers have not fully transitioned to modern technologies. Interviews with respondents revealed that a significant number of farmers still lack access to rice transplanters, threshers, and combine harvesters.

The novelty of this research lies in highlighting the importance of effective communication in increasing farmers' knowledge, although its impact on skills and productivity requires further investigation. This study also revealed that an increase in knowledge does not necessarily lead to higher innovation adoption, a phenomenon rarely discussed in previous literature.

This study has several limitations. First, it focuses exclusively on rice farmers in areas designated by the Kutai Kartanegara Regency government, which limits the generalizability of the results to other regions with different conditions. Second, it does not account for external factors that may influence the successful adoption of agricultural technology innovations, such as government policies, market access, and weather conditions.

The following are some recommendations that can be made, particularly for practitioners and policymakers. It is important to modify communication tactics according to the social and cultural background of the area. To create programs that are more applicable and well-liked by farmers, extension agents must have a thorough understanding of the dynamics of the local community. Extension agents should receive training on how to successfully interact with farmers in addition to providing information. The efficiency of extension services will be substantially increased with the help of training programs that emphasise effective communication and interpersonal skills. Enhancing farmer skills should be more successful when practice-based learning approaches are used. Programs for field demonstration that leverage new technologies can boost farmers' trust in innovation. Collaboration and support among farmers can be increased by promoting the establishment of robust farmer groups. This will make it easier to implement innovations and disseminate knowledge. To improve access to contemporary agricultural techniques and technologies, extension agents should interact with public and commercial organisations. Farmers will be able to cultivate rice more effectively and productively thanks to this.

Author Contributions

Conceptualization, I.B.M.A.D., I.R., and Y.P.; methodology, I.B.M.A.D. and Y.P.; software, I.B.M.A.D. and A.A.; validation, I.B.M.A.D., I.R., S., and A.A.; formal analysis, I.B.M.A.D.; investigation, I.R., S., and A.A.; resources, I.R. and E.R.; data curation, I.B.M.A.D., A.A., and E.R.; writing—original draft preparation, I.B.M.A.D.; writing—review and editing, I.B.M.A.D., I.R., S., and A.A.; visualization, I.B.M.A.D.; supervision, S. and A.A.; project administration, S., A.A., and E.R.; funding acquisition, I.R., S., and A.A. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement

Not applicable.

Informed Consent Statement

Prior to data collection in the field, the researcher followed up on the Cooperation Agreement between the Faculty of Agriculture, Kutai Kartanegara University, and the Department of Agriculture and Animal Husbandry of Kutai Kartanegara Regency number UKT-048/PKS/D-FP/V/2025 and B.485/DISTANAK/SET/500.6.1/V/2025. The data collected consisted of primary data obtained through Focus Group Discussions (FGDs). Subsequently, the Faculty of Agriculture, Kutai Kartanegara University, submitted requests to the respective sub-districts with letters number UKT-359/01-A-3/VII/2025, UKT-360/01-A-3/VII/2025, UKT-371/01-A-3/VIII/2025, UKT-372/01-A-3/VIII/2025, UKT-373/01-A-3/VIII/2025, UKT-380/01-A-3/VIII/2025, and UKT-381/01-A-3/VIII/2025. The respondents subsequently gave their consent to participate in the data collection and research activities. A full ethical approval request was submitted to the Research Ethics Review Board at the Institute for Research and Community Service, Kutai Kartanegara University, and ethical approval was subsequently granted on July 12, 2025, under approval number 90.1/KET.P/UKT-LPPM/VII/2025.

Data Availability Statement

In this study, the data collected were primary data obtained through Focus Group Discussions (FGDs) with farmer group administrators, Farmer Group Associations, and Field Agricultural Extension Workers in five rice farming areas in Kutai Kartanegara Regency, East Kalimantan Province, Indonesia. The collected data were then tabulated and analyzed using semPLS version 4.0. Although we encourage and promote transparency for further research, due to confidentiality agreements with participants, we are unable to share the data with third parties. Therefore, no public dataset is available from this study.

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Conflicts of Interest

The authors declare that there are no conflict of interest.

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