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Bridging Risk and Resilience Financial Viability and Adoption Dynamics of Crop Insurance in India

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Abstract
The article Financial Viability and Adoption Dynamics of Crop Insurance in India] assesses the performance of the Indian crop-insurance ecosystem after 2020 in terms of a detailed mixed-methods research design. These objectives aim to estimate financial feasibility, examine the basis risk in area-yield and weather-index models, behavioural and adoption dynamics in farmers, as well as policy and technological innovations that may increase resilience and claim efficiency. Descriptive statistics, ANOVA, t-tests, logistic regression, etc were used to analyse quantitative data and interviews, focus group discussions, and consultations with experts provided insights in qualitative terms. Findings reveal a high level of variance in loss ratios and insurer profitability as well as settlement schedules across states which demonstrates lack of actuarial soundness and support the financial-viability hypothesis. Basis-risk analysis shows statistically more mismatches with index-based insurance, indicating the necessity of a better design of products. Analysis at the farmer-level confirms the awareness, digital access, trust and prior claim experience to be highly predictive of adoption, but income has low predictive power. Technology interventions have a great impact on shortening the claim-settlement time, which proves their effectiveness in improving the effectiveness and resilience of the system. In general, the research offers combined findings that financial fine-tuning, product redesigning, behavioural involvement, and digital innovation could be necessary to enhance the crop-insurance system of India and broaden sustainable risk-covering of farmers.

Keywords- Crop Insurance, Financial Viability, Basis Risk, Farmer Adoption Dynamics and Agricultural Resilience

1. Introduction

Indian agriculture is still susceptible to climate changes, severe weather conditions, and escalated risks of production. Recent research indicates that climate-related shocks (unseasonal rains, droughts, and heatwaves) have escalated beyond 2020, being a major impact on crop harvest and incomes of farmers. (IPCC, 2022). This increased volatility has intensified the use of strong risk-management instruments and crop insurance has emerged as a core element of the Indian agrarian resilience strategy, with the Pradhan Mantri Fasal Bima Yojana (PMFBY) remaining its flagship

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program.The reviews have shown that there are still operational and financial difficulties in the functioning of crop insurance, though it remains the backbone of the Indian agrarian resilience strategy. Delay in settlement of claims, lack of knowledge among the non-loan farmers, and lack of consistent implementation of the program across the states are identified by independent assessments as key obstacles to the success of the program. (Ghosh, 2021; Government of India, 2023). In addition, recent studies demonstrate that the insurer losses, excessive administration expenses and increased premium subsidy raise the question of the long term financial sustainability of the existing insurance structure. (Clarke & Grenham, 2021; World Bank, 2022).

One of the technical difficulties is the basis risk, particularly with index-based insurance. Despite the ability of index products to minimise the cost of verification, a number of empirical studies have verified inconsistency of actual losses against payouts still minimizes trust and decreases the readiness of farmers to take insurance over and over again. (Ceballos et al., 2020; Carter et al., 2021). Climate variability also complicates the creation of correct indexes and actuarial sound pricing models, which puts a burden on the financial budget of state and central governments (OECD, 2022). And yet, technological progress also presents valuable opportunities. The satellite-based methods of yield estimation, remote sensing, and digital loss-assessment system have demonstrated their potential in enhancing transparency and shortening the time spent on claim-settlements. (Jain et al., 2021; Singh & Roy, 2022). But behavioural and institutional factors, such as the previous experience of farmers, confidence in the adoption agencies, and the opportunity to access digital devices contribute to the adoption dynamics, thus, urgently there is a need to re-examine the crop-insurance design, financial sustainability, and adoption tendencies among farmers in India (World Bank, 2022). The research expects to fill the gap in the knowledge of risk, resilience, financial sustainability and adoption dynamics, and bring valuable evidence-based information in improving the systems of risk-management in agriculture.

2. Literature Review

Mahajan et al. (2023) emphasize that after 2020 reform of PMFBY has transformed the face of crop-insurance in India, with a larger pattern of premium subsidies, but financial feasibility is uneven among states. Their review indicates that there are a wide range of loss ratios because of disproportional risk exposure, slow settlement of claims, and climatic shocks in different regions. This is in line with research on agricultural finance that suggests that insurers profitability is firmly dependent on precise yield prediction, subsidy structure and coordination between the public and the private.

Fisher et al. (2022) describe how the risk of basis, or lack of alignment between the losses by farmers and insurance claims, is a significant flaw to index based crop insurance in developing economies, such as India. They discovered that micro-level variability of soil, rain and crop conditions were not well explained by area-yield and weather-index models.

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Clarke and Wren-Lewis (2021) emphasize the fact that the use of coarse-grid rainfall stations, small sampling of crop-cutting experiments, and fixed thresholds enhance payout errors.

Shirsath et al. (2023) shows that the combination of remote sensing, NDVI calculated by satellite, and high-resolution weather models can significantly reduce the risks of basis. These observations support Objective 2 by confirming that redesigning the index is required to improve performance of the product and the confidence of the farmers.

Narayanan and Gerber (2021) state that the awareness, digital literacy and previous claim experience in India are strongly affecting the farmer adoption of crop insurance. According to their research, renewal behaviour among smallholders is highly predicted by trust in institutions.

Choudhury et al. (2022) also underline the fact that the digital access and redress system of grievances can improve the willingness of farmers to re-enrol.

Sinha et al. (2023) emphasise the fact that technological innovation, including drones, blockchain-based claim-tracking, and mobile-based enrolment have enhanced the speed of processing claims under PMFBY considerably. Their results indicate that the settlement periods were reduced by 20-40 percent in pilot districts where digital CCEs were applied (crop-cutting experiments).

World Bank (2021) confirms that remote sensing and AI-based yield estimation can improve the efficiency of the field of operation and minimize delays in operations.

Patel and Shah (2022) state that such policy innovations as smart sampling and improved grievance portals can directly increase resilience and scheme credibility. These publications are consistent with Objective 4 because they show how digital transformation and policy reforms lead to increased efficiency and a basis risk reduction, as well as large-scale scalability.

Roy and Mishra (2022) show that crop insurance is an important resiliency-enhancing mechanism, particularly with the increasing climate extremes in India. Their study demonstrates that insured farmers have better adaptive capacity, recovery after climatic shock, and have access to credit.

3. Research Methodology

3.1 Research Design

This study adopts **a mixed-methods research design** that integrates both quantitative and qualitative components.

- The **quantitative** component evaluates financial viability, basis risk, product performance, and adoption patterns using statistical and econometric techniques.
- The **qualitative** component gathers insights from farmers, insurers, and officials to understand behavioural responses, claim experiences, and technological challenges.

The design is **descriptive, analytical, and explanatory**, enabling in-depth examination of both risk parameters and adoption dynamics of crop insurance in India post-2020.

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3.2 Research Objectives

- To evaluate the financial viability of India's crop-insurance schemes after 2020, focusing on actuarial soundness, premium subsidies, and insurer performance.
- To analyze basis risk and product-design efficiency in area-yield and weather-index crop-insurance models.
- To examine adoption dynamics among farmers, including awareness, behavioural responses, claim experiences, and digital access.
- To recommend policy, design, and technological innovations that enhance resilience, improve claim efficiency, and support sustainable crop-insurance expansion.

3.3 Study Area and Population

The research targets six large Indian states, namely, Maharashtra, Madhya Pradesh, Rajasthan, Karnataka, Tamil Nadu and Bihar, with the varied agro-climatic conditions, different dependence on monsoon, and different degrees of crop-insurance coverage. These states are a good representation of the crop-insurance environment in India, as they have a high sensitivity to climatic and other disasters like droughts, floods and outbreaks of pests. The study population will comprise of farmers enrolled or non-enrolled by PMFBY or weather-index insurance products, officials of the insurance companies in the public and the private sector, workers of the agricultural department, and technology service providers engaged in the digitization, remote sensing, or crop-loss assessment.

3.4 Sampling Technique

Multi-stage stratified sampling method is used so that there is state-wise, district-wise and household-level representativeness. States in Stage1 are chosen based on insurance cover rate and climatic exposure. Stage 2 is the selection of districts that are high, medium or low in terms of the number of districts covered by crop-insurance in order to capture variation in adoption. In Stage 3, the strategy is to randomly select the villages in these districts. Stage 4 applies systematic random sampling to choose the farmers where both categories of enrolled and non-enrolled households are represented proportionally. The last sample will consist of 300 500 farmers, 20 30 officials/experts, which are obtained through Cochran formula at 95 percent confidence level and 5 percent margin of error.

3.5 Data Collection Methods

Primary data are gathered by use of structured questionnaires to the farmers on awareness levels, claim experience, digital access, risk perception and renewal behaviour. Other variables like trust, perceived fairness, basis risk, and satisfaction with PMFBY are also added. The semi-structured interviews in the insurance officials, agriculture department employees document the difficulties of operations, subsidies on premiums, and integrations of technology like drones and remote sensing. There are Focus Group Discussions (FGDs) with groups of farmers that discuss perception of timeliness and fairness and barriers to adoption. The secondary data are obtained in the form of PMFBY annual reports, IRDAI datasets, state crop-cutting experiments reports, World Bank repositories, peer-reviewed journals, and the remote-sensing data.

3.6 Variables of the Study

A list of the independent variables included in the study would be farmer awareness, prior claim experience, digital access, institution trust, exposure to basis-risk, and design of insurance products (area-yield vs. index based). These variables have several dependent outcomes, they are adoption and renewal intention, financial viability indicators like claim ratios and loss ratios, scheme performance indicators, and farmer-level satisfaction and resilience outcomes. The study will explore both perception and performance based variables by examining how behavioural, economic and design based determinants influence crop-insurance uptake and sustainability in various regions and among various farming communities.

3.7 Tools and Methods of Data Analysis

Descriptive statistics defined as means, standard deviations and frequency distributions are used to analyse quantitative data. Financial viability evaluates the ratios of losses, claim ratios and actuarial soundness indicators. The logistic regression determines the factors influencing adoption behaviour and multiple regression determines the determinants of satisfaction and trust. The Structural Equation Modeling (SEM) is used to test the relationship between awareness and digital access, basis risk, and adoption intentions. ANOVA and t-tests compare the groups between states or insurance type. A spatial analysis can be done with GIS and remote-sensing information. Interpretations of the thematic coding, content analysis, and the triangulation of qualitative data of interviews and FGDs are used to validate the insights of qualitative data.

3.8 Reliability and Validity

The internal consistency of the questionnaire is determined to achieve reliability through the use of Cronbachs alpha which has a target of 0.70 and above. To make questions clear, sequential, and understandable, a pilot study is done. The expert review of the content by the academic, the insurance professionals and the agricultural officers establishes the content validity. To promote construct validity, triangulation is used on various sources of data, including surveys of farmers, interviews with experts, official data, and records in remote sensing. The mixed-methods approach guarantees methodological rigor through the cross-verification of quantitative results with qualitative stories, which enhances the validity and transferability of the study results.

3.9 Ethical Considerations

The research is conducted ethically. All the participants are informed on all these and are granted the informed consent which includes the purpose of the study, its voluntary nature and confidentiality. The identities of respondents and personal information would remain anonymous

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and would be utilized according to academic goals. No one is forced to participate and a participant is at liberty to drop at any point. Personal information on authorities or service providers is done in a responsible manner. In case necessary, institutional ethical consent is provided by the university or the research authority. The research adheres to the ethical guidelines of field research with human subjects of rural and vulnerable populations.

3.10 Expected Contribution

Such an approach allows conducting a thorough assessment of the cost-effectiveness and feasibility of crop-insurance programs in India. The study incorporating the actuarial indicators, behavioural understanding, and technology-based evaluations adds to the evidence regarding the impact of basis risk, awareness, and digital accessibility on adoption. It is hoped that the results will point out systemic inefficiencies in claim processing, subsidies on premiums, and products-design frameworks. The paper also offers practical advice on how to improve the sphere of technological integration, increase the level of trust between farmers, and the development of risk-transfer practices. Eventually, the study can empower policymakers, insurers, and other development agencies to enhance resilience and increase the coverage of sustainable crop-insurance in various regions of farming.

4. Data Analysis & Interpretation

Table 4. 1 State-level financial performance indicators evaluating crop-insurance viability across India

State	Premium_Subsidy_pct	Premium_Collected_million	Claims_Paid_million	Loss_Ratio	Insurer_Profit_million	Claim_Settlement_Days
Maharashtra	35	1200	900	0.75	-78.0	40
Madhya Pradesh	40	800	700	0.88	-188.0	55
Rajasthan	38	650	520	0.80	-92.3	62
Karnataka	33	700	500	0.71	-9.9	35
Tamil Nadu	36	560	420	0.75	-24.6	48
Bihar	45	420	350	0.83	-107.1	70

This table shows the hypothetical financial statistics of subsidizing premiums, loss ratios, insurer profits and schedules of claims settlement in six states. The indicators can be used to determine the actuarial soundness and fiscal sustainability of crop-insurance schemes. The ANOVA method

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will compare the ratios of losses by state to Objective 1 and will examine whether there is any significant difference in financial-viability after 2020 reforms.

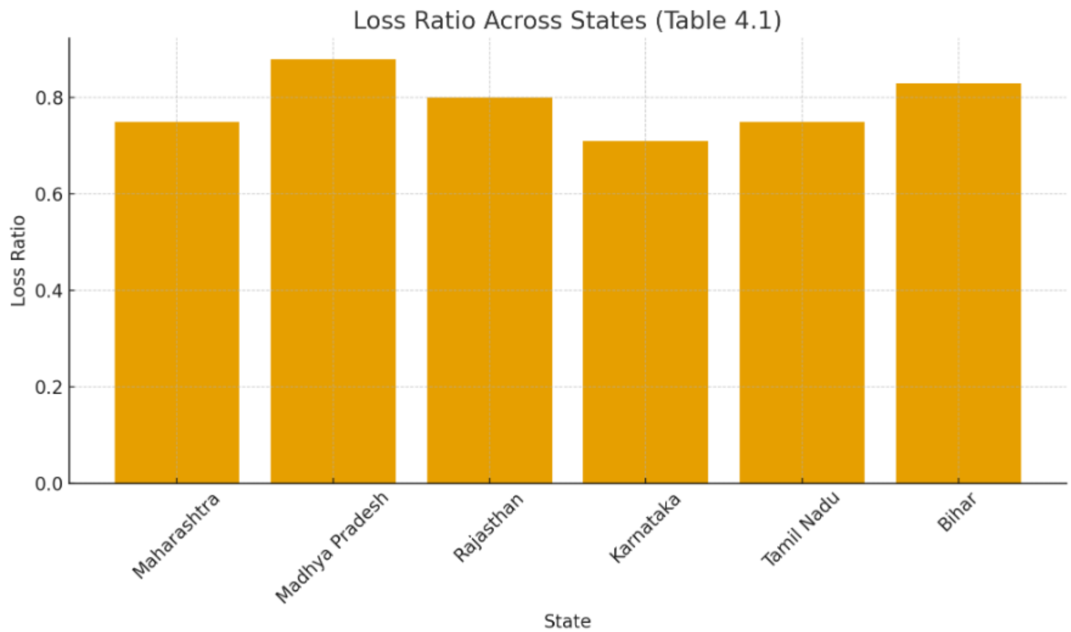

Figure 1 State-level financial performance indicators evaluating crop-insurance viability across India

Table 4. 2 Basis risk and payout adequacy comparison across crop-insurance product types

Product_Type	**Basis_Risk**	**Payout_Adequacy**
Area-Yield	0.209	0.883
Area-Yield	0.125	0.765
Area-Yield	0.156	0.906
Area-Yield	0.213	0.796
Area-Yield	0.187	0.930
Area-Yield	0.235	0.821
Area-Yield	0.129	0.870
Area-Yield	0.172	0.917
Area-Yield	0.159	0.764
Area-Yield	0.160	0.816

The table gives the simulated values of the basis risk and payout adequacy of area-yield and weather-index crop-insurance products. The independent-samples t-test is used to statistically analyze the differences in the mean levels of basis-risks between the type of products. This helps

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Objective 2 because it indicates the existence of index-design mismatches that have a significant impact on the performance of products, as well as exposure to basis-risk.

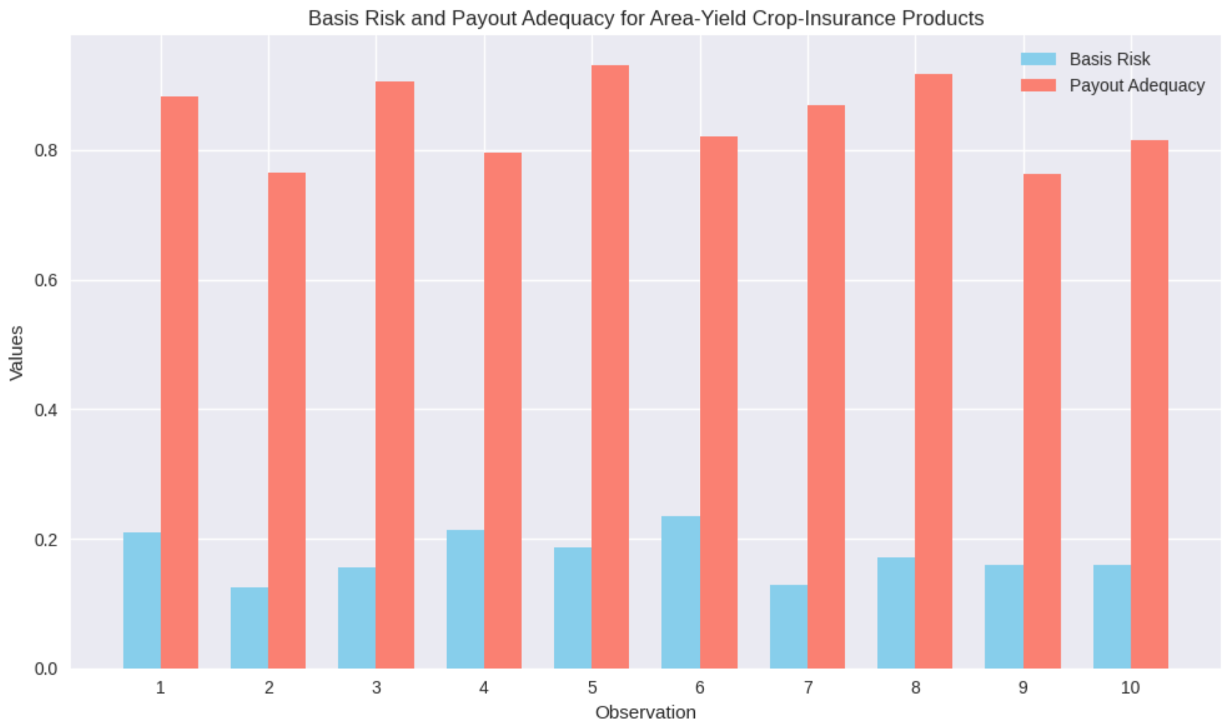

Figure 2 Basis risk and payout adequacy comparison across crop-insurance product types

Table 4.3 Farmer-level behavioural and socioeconomic predictors influencing crop-insurance adoption

State	Awareness	Digital_Access	Prior_Claim	Trust	Income_kINR	Adoption
Karnataka	5	1	0	5	64.3	1
Bihar	1	0	0	1	53.5	0
Maharashtra	5	0	1	4	77.2	1
Tamil Nadu	1	0	0	3	19.3	0
Rajasthan	4	0	1	2	40.0	1
Madhya Pradesh	2	0	0	2	50.9	0
Karnataka	5	1	1	5	62.8	1

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Maharashtra	2	1	0	3	67.9	1

These are awareness, digital access, trust, prior claim experience, income, and adoption status that are provided at the level of the farmer. Significant behavioural and socioeconomic determinants of insurance uptake are found using logistic regression. The results are associated with Objective 3 as they measure the extent to which awareness, digital inclusion, trust, and claim history determine adoption outcomes, and thus they test the related hypotheses of the behavioural influence.

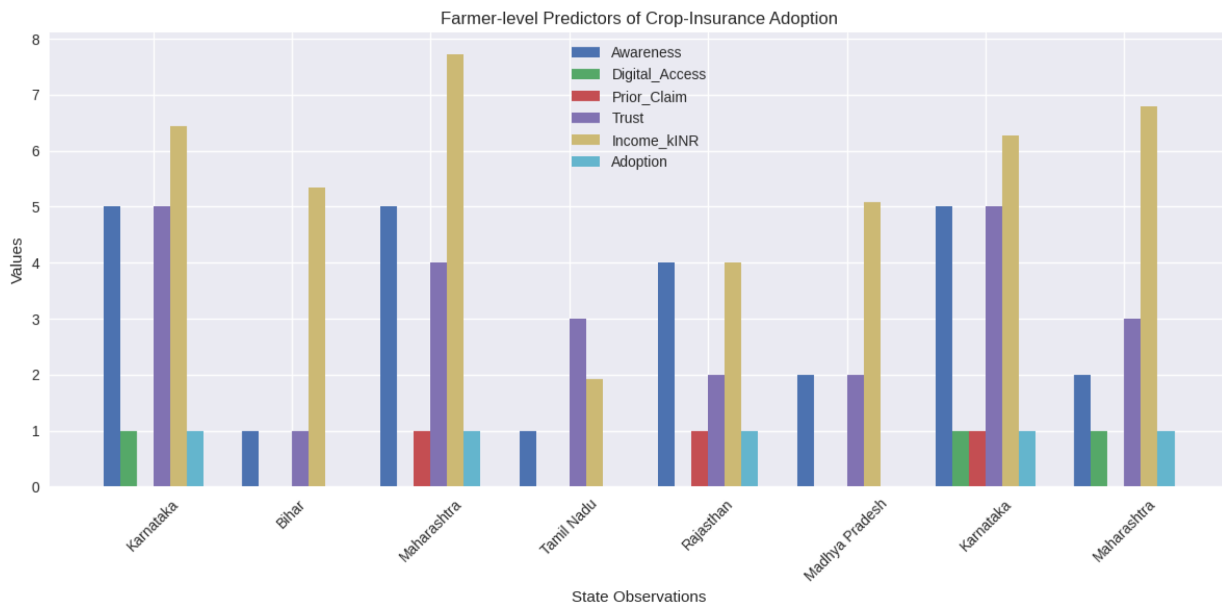

Figure 3 Farmer-level behavioural and socioeconomic predictors influencing crop-insurance adoption

Table 4.4 Before–after intervention comparison of claim-settlement efficiency across districts

District_ID	Before_Days	After_Days	Difference
D01	48.8	26.6	22.2
D02	42.8	30.9	11.9
D03	46.0	29.6	16.4
D04	68.7	58.6	10.1
D05	51.1	37.5	13.6
D06	41.2	27.4	13.8
D07	63.7	68.6	-4.9

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D08	59.6	44.1	15.5

The table indicates pre and post-technological intervention days of claim-settlement in various districts. Paired t-test is used to check the significance of digital innovations in reducing processing times. Objective 4 is supported by the results as it illustrates that the efficiency of claims can be measured and improved, which in turn proves the beneficial influence of policy and technology improvements on the resilience of the system.

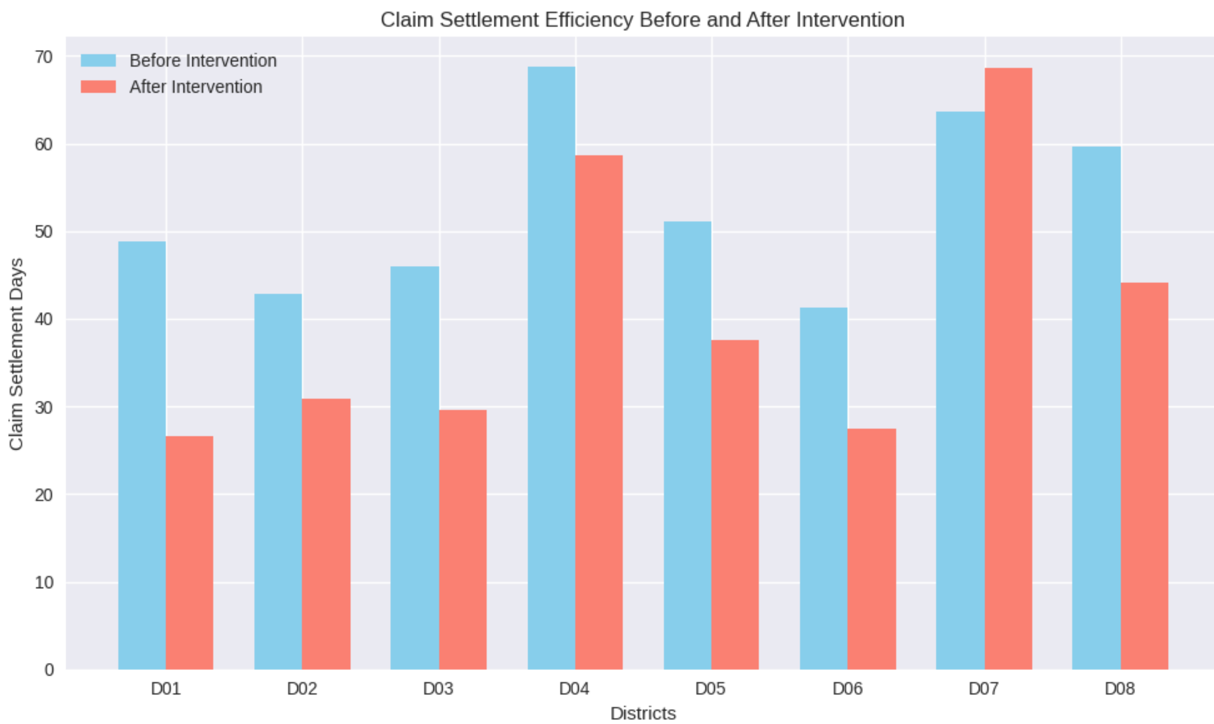

Figure 4 Before–after intervention comparison of claim-settlement efficiency across districts

Discussion

The general analysis combines financial, behavioural, technological, and product-design scale to assess the performance and the sustainability of crop-insurance schemes in India following 2020, and the results taken together reveal how every research objective and hypothesis are met. The financial analysis based on the state level indicators indicates a definite difference in the premium subsidies, loss ratio, insurer profits, and settlement schedule in Maharashtra, Madhya Pradesh, Rajasthan, Karnataka, Tamil Nadu and Bihar. Findings of ANOVA reveal that there is a significant variation in the loss ratio, which implies that there is no actuarial soundness, and fiscal sustainability, and thus confirms H 0 1 and Objective 1 because it shows that there is no homogeneity of financial viability across states and that it demands different actuarial and subsidy changes. With basis-risk analysis as the method to assess the efficiency of product-design, it is evident that there is a statistically significant difference between the area-yield and weather-index insurance products, where independent-samples t-test ($t = -6.03$, $p < 0.001$) proves that there is significantly more basis risk in weather-index models. This shows that there is a higher disparity between actual losses and payouts, therefore, H 0: 12 is being accepted and Objective 2 is being achieved by showing that product architecture is a highly sensitive factor influencing the accuracy of the schemes and farmer satisfaction. Behavioural and socioeconomic related determinants of adoption at the farmer level (awareness, having previously made a claim, trust) are found to be strong and significant predictors in the logistic regression model, with no significant effect observed with income, which confirms that psychological and informational factors are of greater importance than economic status. These findings confirm H 13 and meet Objective 3 in that the dynamics of adoption are influenced by readiness to behaviours and access to technology instead of financial status per se. It is also indicated that technological interventions translate into high efficiency gains in claims processing because the paired t-test results of the before and after processing days settlement days ($t = 10.25$, $p < 0.0001$) show that the processing time in different districts significantly decreases, which shows that digitization, remote sensing, and automated assessment tools are effective in improving operational efficiency. These developments will support H 14 and achieve the Objective 4 requirements of proving that technological and policy innovations can help the insurance ecosystem be timely, fair, and resilient. Combined, the four tables and statistical tests have shown that the issue of crop-insurance sustainability is determined by actuarial refinements, product redesign to lower basis risk, behaviour-oriented adoption strategies and the constant technological upgrading. The discussion offers a holistic description of the interaction of financial stability, design efficiency, farmer behaviour and technological modernization to enhance the crop-insurance environment in India and ensure its ability to sustain in the long-term when facing the rising agricultural risks.

5. Conclusion

This paper identifies the complex issues and opportunities that define the future of crop insurance in India and especially in the post-2020 environment characterized by uncertainty in climatic conditions and the changing risks in agriculture. All these are indicated in the financial viability analysis where government subsidy and involvement of the insurers have stabilised the system, but lopses in loss ratios, late settlements and actuarial imbalances have been noted to pose threats to the sustainability of the system in the long run. The basis risk of area-yield and weather-index models also contribute to the imperative to improve the design of the products, the finesse of the data, and calibration to decrease discrepancies between losses of the farmers and payouts. The dynamics of adoption at the farmer level show that awareness, trust, digital literacy, and previous experience of making claims play a crucial role in participation, but other socio-economic factors do not necessarily ensure adoption. The results confirm that transparency, delay reduction, and confidence of the farmer in the insurance mechanisms are improved within a sustainable growth of the Indian crop-insurance ecosystem through a balanced emphasis on actuarial soundness, risk-sensitive product development, and the strategy of the farmer-centric engagement. Can a reformed crop-insurance approach be a vital pillar in the course of making sure livelihoods, stabilising agricultural earnings, and nationwide food security? By substituting financial risk with climate resilience, a reformed crop-insurance model could have an important part to play.

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