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Can index insurance keep up with climate change? Rethinking historical data models

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1 Introduction

Climate change is significantly altering agricultural production by shifting weather patterns, increasing the frequency and severity of extreme weather events (Tack and Ubilava, 2015; Kath et al., 2018; Pan et al., 2022). With recent events threatening global food security and the stability of farmers' incomes (Benso et al., 2023; Eltzarov et al., 2023; Heilemann et al., 2024), there is a pressing need to rethink agricultural risk financing. In particular, insurance relies on historical yields and weather patterns, which are essential for developing strategies to better understand the expected cost of future adverse events.

While the global insurance protection gap has increased over the years (Swiss Re, 2025), alternative risk financing solutions like index or parametric agricultural insurance is seen to become a more broadly adopted tool (Benso et al., 2023; Li et al., 2022; Kath et al., 2018, 2019). Unlike traditional indemnity crop insurance that covers realized crop losses after a loss settlement, index insurance pays out a predetermined amount to farmers when the pre-agreed trigger on weather measurements, such as rainfall or temperature, has breached the threshold. Index insurance offers several compelling advantages. It ensures transparency, as payouts are directly linked to the performance of a predefined index. It is cost-efficient, eliminating the need for onsite loss assessments. By relying on objective data rather than self-reported losses, it reduces moral hazard and accelerates claim settlements. Furthermore, it facilitates broader coverage, particularly for smallholder farmers, by avoiding the logistical challenges of traditional insurance models that require extensive field evaluations.

However, index insurance has its shortcomings. A major weakness in its design is the reliance on historical yield and climate data to set payout triggers and determine appropriate pricing (Kath et al., 2018; Tan and Zhang, 2024). The effect of climate change is making past trends less reflective of future trends, increasing the mismatch between payouts and actual losses, a concern known as basis risk (Bucheli et al., 2022; Singh and Agrawal, 2019; Osgood et al., 2024). For farmers, high basis risk translates into paying for coverage that may not payout in a bad year. In addition to basis risk, index insurance faces pricing challenges under non-stationary climate conditions, affordability constraints as premiums rise, and institutional barriers such as limited data infrastructure, regulatory fragmentation, and delivery inefficiencies (Miranda and Farrin, 2012; Singh and Agrawal, 2019). These limitations raise a fundamental question: Can index insurance relying on historical data still offer protection for farmers in a future of unprecedented climate change?

Addressing this question is critical for researchers, policymakers, and the insurance industry engaged in climate adaptation and mitigation for agriculture. While a growing body of research has recognized the limitations of relying on historical data (Kath et al., 2018; Osgood et al., 2024), this paper argues that overcoming these barriers requires a multidimensional approach. We propose three interdependent levers for redesigning index insurance to better manage the escalating risks of climate change in agricultural production: (1) technological innovations to enhance real-time risk assessment, (2) actuarial reforms to incorporate climate-adjusted pricing and forward-looking risk models, and (3) policy interventions to incentivize adoption and build resilience. Together, these levers can bridge the gap between risk transfer mechanisms and climate resilience, ensuring the long-term viability of index insurance in the face of future climate impacts.

2 Technological innovations

2.1 Limitations of traditional approaches

Index insurance requires historical weather and yield data to establish statistical relationships between selected indices (e.g., rainfall, temperature) and agricultural losses (Kath et al., 2018; Bucheli et al., 2021; Tan and Zhang, 2024; Kanchai et al., 2024). These relationships inform critical contract parameters, including payout triggers, compensation levels, and premium rates (Kath et al., 2018; Kanchai et al., 2024). For example, studies on sugarcane in Australia employed 80 years of historical climate and yield data to calibrate an excessive rainfall index (Kath et al., 2018), while drought insurance for wheat relied on 31 years of analogous data (Kath et al., 2019). Underpinning this approach is the assumption that past weather-yield dynamics and extreme event distributions remain stable over time (Tan and Zhang, 2024; Williams and Travis, 2019). Yet, this assumption is becoming untenable in the face of climate change. Rapidly shifting climatic patterns are not only elevating the frequency of extreme weather events but also amplifying their severity (Kath et al., 2018; Pan et al., 2022; Benso et al., 2023; Eltazarov et al., 2023). Consequently, historical datasets may fail to accurately capture future risks (Tan and Zhang, 2024; Williams and Travis, 2019; Osgood et al., 2024). This discrepancy can lead to systemic underestimation of liabilities, resulting in mispriced insurance products that jeopardize insurer solvency (Tack and Ubilava, 2015; Osgood et al., 2024). Alternatively, insurers may be compelled to raise risk premiums to compensate for the uncertainty of future losses, potentially reducing affordability and accessibility for farmers.

Applications of index insurance in the real world have varying outcomes. For instance, effective schemes in India and Kenya have realized increased farmer resilience with the utilization of satellite-based drought indices (Murthy et al., 2024; Singh and Agrawal, 2019). Conversely, other failed applications in West Africa and Southeast Asia reveal some of the challenges, such as index calibration challenges and farmer mistrust that led to low adoption and user dissatisfaction (Bucheli et al., 2022; Osgood et al., 2024). These cases indicate the importance of context-specific design and participatory approaches.

2.2 Innovative approaches for climate-resilient index insurance

The accelerating effects of climate change require major reforms in the design and implementation of index insurance schemes. A growing body of research shows that traditional single-variable indices such as seasonal rainfall totals are increasingly insufficient to capture complex non-linear relationships between climate variables and agricultural outcomes (Singh and Agrawal, 2019; Tsiboe et al., 2023). This constraint has prompted the development of more sophisticated indices that better reflect biophysical reality, including growing degree days calibrated to crop phenology (Conradt et al., 2015), composite indices incorporating multiple climatic variables (Murthy et al., 2024), and indices for specific climatic events such as heat waves and precipitation (Benso et al., 2023).

Recent advances in data availability and analytical techniques are changing the concept of index insurance design. Satellite-derived remote sensing data now allow for near-real-time monitoring of soil moisture, vegetation health, and microclimate conditions at unprecedented spatial resolution (Abdi et al., 2022; Osgood et al., 2024). Combined with gridded climate model output (Pan et al., 2022; Eltazarov et al., 2023), these data sets allow for a more accurate assessment of the risks while addressing the critical problem of baselines in regions where data is scarce. Analytic innovation is also transforming, with AI and machine learning algorithms showing particular promise in capturing complex non-linear weather patterns that are often overlooked by traditional statistical methods (Chen et al., 2024; Tan and Zhang, 2024). Further methodological advances, including crop models (Will et al., 2021), quantile regression for extreme event analysis (Kath et al., 2018; Abdi et al., 2022) and dynamic factor models for multivariate climate integration (Li et al., 2022), allow for more robust modeling of extreme events.

2.3 Addressing compound risks and systemic challenges

As climate change progresses, agricultural systems increasingly face compound risks characterized by simultaneous or sequential hazards, which is a major constraint for index insurance products that use a single index (Benso et al., 2023). The use of single indices leaves farmers exposed to other climate threats. Emerging solutions include the development of composite indices integrating multiple stress factors (e.g., heat and humidity stress) and innovative triggers that account for the sequence of hazards (Kanchai et al., 2024; Kath et al., 2018). However, these technological innovations need to be accompanied by equally important actuarial reforms.

3 Actuarial reforms

3.1 Consequences of mispriced index insurance in a non-stationary climate

Recent evidence in India has shown that farmers have suffered crop losses due to climate-related factors such as droughts, floods,

TABLE 1 Three levers for climate-resilient index insurance.

Lever	Current limitations	Proposed solutions	Key studies
Technological	Sparse weather stations; single-index triggers	Satellite remote sensing, machine learning for composite indices	Abdi et al., 2022; Benso et al., 2023
Actuarial	Historical data misprices future risks	IPCC scenario integration, extreme-event pricing	Osgood et al., 2024; Kath et al., 2018
Policy	Fragmented subsidies, low adoption	Participatory design, subsidies tied to climate-smart practices, and increasing awareness	Singh and Agrawal, 2019; Jensen and Barrett, 2017

hailstorms, and pest infestations (Reddy, 2025). Critically, climate change does not only increase extreme weather events, but also changes the underlying relationships between climate variables and agricultural performance. Changing seasons, new damage thresholds and changing patterns of water availability (Tan and Zhang, 2024; Wang et al., 2021; Bucheli et al., 2022) are weakening the predictive power of the historical models. For example, rising temperatures in the US are already projected to cause higher crop insurance premiums (Tack et al., 2018). The reliance on outdated data exacerbates the basis risk, which undermines the value of the instrument as a risk management tool (Tappi and Santeramo, 2022; Tsiboe et al., 2023; Chen et al., 2024). Recent years, which better reflect current climatic conditions and technological developments, may provide more relevant insights than remote historical records (Tan and Zhang, 2024). Given these concerns, it is prudent for actuarial models to integrate forward-looking methods.

3.2 Forward-looking approaches to actuarial modeling

The non-stationary nature of modern climate systems makes historical data insufficient for insurance purposes (Tappi and Santeramo, 2022). Forward-looking approaches must explicitly include climate projections through three key mechanisms: (1) statistical adjustment of historical data using for example the Intergovernmental Panel on Climate Change (IPCC) climate scenarios, (2) simulation of yield responses under future climatic conditions, and (3) systematic testing of insurance portfolios against high-impact climate scenarios (Osgood et al., 2024; Benso et al., 2023; Zhang et al., 2022; Tan and Zhang, 2024). This paradigm shift from reactive to anticipatory risk modeling strengthens index insurance's resilience to climate shocks. However, realizing this resilience in practice requires policy interventions.

4 Policy interventions

To make index insurance more effective in a changing climate, policymakers must prioritize investment in high-quality, high-resolution climate and yield data and ensure its open access to support robust index design (Bucheli et al., 2021, 2022). Enhancing cooperation between researchers, insurers, and governments will be crucial to addressing the technical and institutional challenges of scaling up these solutions (Singh and Agrawal, 2019; Pan et al., 2022). Key priorities include the refinement of advanced statistical and machine learning models for yield prediction (Chen et al., 2024; Tan and Zhang, 2024), the integration of climate

projections into risk modeling, and the development of multi-hazard insurance frameworks (Benso et al., 2023). Supportive policies must be carefully designed to avoid disincentivizing climate-adaptive practices and ensure long-term resilience while encouraging short-term risk transfer. This can be achieved through education interventions that increase awareness for a better understanding of index insurance products (Jensen and Barrett, 2017; Janzen et al., 2021).

5 Future directions for climate-resilient index insurance

Table 1 synthesizes the limitations of current index insurance systems and the innovations needed across technological, actuarial, and policy domains to address climate non-stationarity. These levers are interdependent, for instance, actuarial reforms depend on technological advances in data collection, while policy must incentivize their adoption.

Perhaps more importantly, the increasing technical complexity of modern insurance products raises important questions about farmers' understanding, trust, and perceived fairness and value-for-money (Linhoff et al., 2023; Sibiko et al., 2018). These challenges demand greater emphasis on participatory design and transparency of policy (Singh and Agrawal, 2019). Furthermore, the role of the subsidies need to be reconsidered carefully so that they subsidize the equitable sharing of resilience and promote uptake and climate-resilient practices without creating distortions in the market. In conclusion, the effectiveness of index insurance in a changing climate environment is limited by its reliance on historical data. Therefore, incorporating technological innovation, actuarial reform, and policy levers in designing index insurance can help cope with future climate disruptions. It should, however, not be viewed as a standalone solution but integrated into the broader resilience strategy.

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