Impacts and synergies of weather index insurance and microcredit in rural areas: a systematic review

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Abstract

Weather constitutes a major source of risks facing households in rural areas, which are being amplified under climate change. In this context, two main rural financial services, weather index insurance and microcredit, have been increasingly adopted by farmers worldwide. However, the understanding of the socioeconomic and ecological impacts of these rural finance schemes, including potential maladaptive outcomes, remains ambiguous. We review the recent literature on weather index insurance and microcredit for farmers and find that both rural financial services have positive economic impacts, though benefits to the poorest populations remain controversial. Moreover, their impacts on the ecological systems are less studied and are found to be mainly negative. In addition, considering that both financial instruments have strengths and limitations, we argue that combination schemes (e.g. a hybrid product) may generate positive synergistic effects on building socioeconomic resilience to climate risks in agricultural regions. However, this may also add new economic risk to local financial institutions. This comprehensive review provides a reference for the potential benefits and risks of agricultural finance innovations. Further studies on the ecological impacts of rural financial services and the synergistic effects of the combination on socioeconomic and ecosystem resilience in rural contexts are needed to fill the current research gap.

1. Introduction

Climate variability and hazards constitute a major source of risks facing households in rural areas. Climate change, especially the growing frequency and scale of climate extremes such as droughts and floods, poses an enormous threat to agricultural production and food security worldwide (Lobell and Asner 2003, Lobell et al 2013, Lesk et al 2016, Hasegawa et al 2021), despite that certain crops and regions may benefit to some extent from the change in climate patterns (Kucharik 2008, Kucharik and Serbin 2008, Jägermeyr et al 2021). Globally nearly all major crops, including maize, soybean, and rice, are projected to suffer yield decreases, which coupled with climate-driven price fluctuations in agricultural markets, would have amplifying negative effects on the livelihood of small farmers (Zhao et al 2021, Wang et al 2022). Together with climate change, unsustainable agricultural policies and practices have already led to land and forest degradation, and loss of ecosystem services and biodiversity (IPCC 2022). Rural communities in developing countries, especially the poorest populations, are highly vulnerable to climate change and its impacts on nature and human systems, as they have limited capacities to respond to shocks and cope with progressing environmental degradation (IPCC 2022).
Empirical evidence shows that low-income rural households are more likely to adopt ‘low-risk, low-return’ strategies (such as using a low-risk and low-profit crop or technology) to manage shocks, which may reduce the likelihood of asset accumulation that is necessary for escaping chronic poverty in the long term (Barnett et al 2008). These households may also choose to reduce their expenditure on education, food, and healthcare as coping strategies (Barrett et al 2006, Janzen and Carter 2019), which is considered to be harmful for human capital accumulation in both the current and next generations, thus further trapping the households in multidimensional poverty (Hoddinott 2006). Informal risk-sharing mechanisms through mutual assistance are often key risk-coping strategies in rural regions (Bhattamishra and Barrett 2010), which, however, cannot effectively function in the case of covariate catastrophic risks (e.g. floods and typhoons) in which most households suffer from significant losses (Barrett 2011).

Over the last two decades, rural finance services have developed as potential alternative solutions for farmers to address climatic variability and reduce poverty (Banerjee et al 2015, Bhuyian et al 2015, Akotey and Adjasi 2016, Wahab et al 2018). They may complement conventional risk management strategies, such as increasing hay input and decreasing stocking rates (Vroege et al 2019). In particular, microcredit and, more recently, weather index insurance (WII hereafter), have gained increasing attention because of their potential to reduce climate-related uncertainties and strengthen resilience to climate extremes, although they are not without weaknesses (Pitt and Khandker 1998, Montgomery and Weiss 2011, Peterson, 2012, Imai and Azam 2012, Sneath 2012).

Microcredit and WII play an important role in dealing with extreme events, working as ex-ante and ex-post financing sources (Mechler et al 2010). They have positive impacts on shielding locals from the negative effects of climatic variability and market fluctuation (Pitt and Khandker 1998, Eriksen et al 2005, Ravera et al 2011, Sneath 2012, Wahab et al 2018) and have been increasingly used to improve the adaptive capacity of farmers and to strengthen the resilience of agricultural systems to address weather risks. For example, microcredit and WII could provide funds to locals for production recovery after climate disasters. They have the potential to contribute to the achievement of several UN Sustainable Development Goals (SDGs) including SDG 1 No poverty, SDG 2 Zero Hunger, SDG 8 Decent work and economic growth, and SDG 13 Climate action, among others (Wanczeczek et al 2017).

Both finance products have shown positive socioeconomic effects, which, however, may be offset by their weaknesses such as low access and affordability, thus challenging their sustainability. For example, a study found that farmers cannot afford WII due to the lack of funds to pay the upfront premium of insurance (Shee et al 2015). Likewise, the uptake of microcredit may increase the vulnerability of herders to climate change and market price fluctuations, because their repayment ability would decrease in case of disastrous climate shocks, which would, in turn, result in an increased debt (Zhang et al 2018, Li and Li 2021, Lu et al 2021). In the case of WII (Shee et al 2015), if farmers could borrow microcredit, they would have funds to pay an upfront WII premium; while in the case of microcredit, if herders can buy WII, they can obtain payments from WII to compensate for losses caused by natural disasters, and, hence, reduce repayment burden of microcredit. Therefore, microcredit provides an ex-ante financial source while WII provides ex-post finance support.

Importantly, some studies find a link between finance schemes and unsustainable agricultural practices and environmental degradation such as increased pressure on land and water resources, and their pollution (Anderson et al 2002, Felix et al 2017, Müller et al 2017). Yet, environmental sustainability and contribution to ecosystems resilience of agricultural finance services are critical to tackling the climate, food, and water security crises both locally and on a global scale.

Against this backdrop, we explore the research question: Would a combination of WII and microcredit (e.g. a hybrid product) be able to overcome their respective limitations and generate possible positive synergies in addressing weather risks in climate-vulnerable rural areas? To answer this question, we first examine empirical evidence for the use, limitations, and socioeconomic and ecological impacts of the two agricultural financial services based on a systematic review of academic literature published from 2000 to 2020, including a total of 360 articles. Second, we analyze the potential synergies of both finance schemes by proposing an analytical framework and referring to empirical observations. We aim to provide, for the first time to the authors’ knowledge, a comprehensive review of the potential synergies of combined finance services.

Our results show that studies on weather index insurance and microcredit are largely (approximately 93%) concentrated on their socioeconomic impacts, but rarely (7%) on their ecological effects. Moreover, we find that most empirical research explores finance schemes for crop production, followed by livestock production and forestry. Few empirical research on finance for aquaculture and fisheries was detected during the systematic review, and this result is similar to what Vyas et al (2021) found.

Our results further suggest that, first, both WII and microcredit have been increasingly used to improve the coping and adaptive capacities of farmers to address weather risks. Both instruments have been found to have positive socio-economic effects as they cushion the direct impacts of weather disasters.
on households, while their impacts on the long-term resilience of ecological systems remain less understood. Second, as empirically observed, insured households and those with credit are likely to increase their investment in agricultural production (i.e. especially using more fertilizers), which could benefit farmers in locations where fertilizers are used far below the optimal level. However, it is important to note that both instruments may bear the risk of maladaptation associated with intensifying ecological stress, particularly in pastoral areas, as the natural self-recovery mechanisms could be disrupted. Third, the review reveals that though with great potential as climate risk management tools, the positive socioeconomic effects of both WII and microcredit are offset by some caveats, such as low affordability of WII premiums and high default risks of microcredit. We then conclude that a combination of WII and microcredit is likely to generate positive synergies in addressing such problems while contributing to rural development. However, this approach may be challenged by increased financial risk to local financial institutions and a lack of empirical evidence on possible negative effects on ecosystem health and long-term ecological resilience pointing to potential maladaptive risks.

2. Methods

The analysis presented in this paper is based on a systematic review of published articles in peer-reviewed journals that address issues related to weather index insurance and microcredit in the recent 20 years (2000–2020). Using the Web of Science database, we considered only articles written in English and focused on the role of finance in managing climate risk in rural areas.

As a first step, we performed a keyword search in the title, abstract, and keywords. The search orders entered into the database of Web of Science were as follows:

\[
TS = \text{(microcredit} * \text{OR microcredit} * * \text{OR microcredit} * * * \text{OR microfinance OR micro finance} \text{OR micro-finance} \text{OR microloan} * \text{OR micro loan} * * \text{OR micro-loan} * * * \text{OR micro-debt} * \text{OR micro debt} * * \text{OR micro-debt} * * * \text{AND TS} = \text{(rural) AND TS} = \text{(climate change OR adaption OR vulnerability OR disaster} * \text{OR drought OR uncertainty OR resilience OR variability OR vulnerable OR weather)}
\]

and

\[
TS = \text{(index-based insurance) OR TS} = \text{(weather index insurance) OR TS} = \text{(index-based livestock insurance) AND TS} = \text{(rural) AND TS} = \text{(climate change OR adaption OR vulnerability OR disaster} * \text{OR drought OR uncertainty OR resilience OR variability OR vulnerable OR weather)}
\]

We conducted a search in July 2021 to identify relevant literature published between 2000 and 2020. The database included 472 documents: among them, 115 focus on microcredit and 357 focus on weather index-based insurance.

At this stage of the review process, we analyzed the most cited terms in the references of the articles included in the database to understand trends in the published literature on the topic. As figure A.1 shows in the appendix, ten main clusters of the most cited terms in the references of the articles on WII can be identified. The cluster contains multiple aspects, including weather risks, pastoralism, willingness to pay, and innovation (e.g. #1 climate change, #8 weather risk, #9 willingness to pay, and so on). The crop insurance cluster (#5) appears to have the longest history while publications on willingness to pay (#9) are gaining increasing attention in recent years. The results further indicate that Ethiopia and China are the hot spots for published articles on WII.

In addition, figure A.2 shows the nine main clusters of the most cited terms in the references of the articles on microcredit that can be identified. The cluster contains multiple aspects, including climate change, flood, adaptation, and index insurance (e.g. #1, #3, #6, and #7). The microcredit cluster (#0), India cluster (#2), and flood cluster (#3) appears to have the longest history while adaptation (#6) and index insurance (#7) are gaining increasing attention in recent years.

The top 25 keywords with the strongest citation bursts of WII include ‘crop’, ‘adverse selection’, and ‘grassland’; the top 25 keywords used about microcredit are ‘poverty’, ‘flood’, ‘prevention’, and ‘community empowerment’ (figures A.3 and A.4).

As a second step, we conducted a so-called ‘backward procedure’ through an iterative review of the references from the documents retrieved during the first step to capture articles that may not have been detected during the keyword search (Gutiérrez-nieto and Serrano-cinca 2019). We identified 47 additional articles through this procedure that were added to the database.

During the third step, we reviewed the abstracts of all 519 articles in the database and selected those reporting on the socioeconomic and ecological impacts of microcredit or (and) WII. We further included publications on the basis risks in weather index insurance, due to its relevance for understanding socioeconomic and ecological impacts. This provided a dataset of 360 documents, among which 216 focused on WII and 144 focused on microcredit.

A total of 21 literature studies discussed the potential synergies between these two financial services. We acknowledge that the number of microcredit articles included in the systematic review is much smaller compared to the large body of existing literature on this microfinance instrument. Nevertheless, the ambition of this research is to capture the role of microfinance in managing climate risks in rural regions. Therefore, the sample size used in the analysis
corresponds to the volume of studies with a specific focus on this topic.

As a next step, we extracted and examined the empirical studies listed in the database (315 out of 360). Among the reviewed papers, 180 provide empirical evidence on the impact of WII and 135 on the impact of microcredit and focus mainly on developing countries. The top three countries for WII study cases are Ethiopia, India, and China, while for microcredit, these are Bangladesh, India, and China. All details of the study cases’ geographic locations are shown in figure A.5.

A close examination of the identified 315 empirical studies showed that their number has grown significantly during the last two decades (figure A.6). A milestone of the growth was after 2005, the Year of Microcredit as designated by the United Nations. Another milestone, particularly for the growth of research on WII was 2019. This might have been influenced by the launch of the InsuResilience Global Partnership for Climate and Disaster Risk Finance and Insurance Solutions at the United Nations Climate Conference in 2017, which aims to strengthen the resilience of the poor and vulnerable people to climate risks through climate and disaster risk finance and insurance. Among other goals, the initiative seeks to significantly expand insurance coverage in developing countries.

Regarding methodologies used in WII and microcredit impact assessment research, qualitative, quantitative, and mixed methods are jointly used. Most researchers use interviews (Coppock and Desta 2013, Kohli et al 2017) and focus group discussions (Gnauck et al 2013, Shee et al 2015) to collect qualitative data. Case studies (Moser et al 2015), document analysis (Moser et al 2015), and participatory approaches are also used (Chowdhury et al 2016) to analyze both WII and microcredit impacts. In terms of quantitative methods, the majority of the studies are based on surveys (Anderson et al 2002, Akotey and Adjasi 2016, Al-Shami et al 2017) and field experiments (Giné and Yang 2009, Cole et al 2017). Primary methods for data analysis include statistical analysis (Anderson et al 2002, Jain and Mansuri 2003), economic models (Jain and Mansuri 2003, Carter et al 2007, Castellani and Cincinelli 2015, Carter et al 2016, Bertram-Huemmer and Kraehnert 2018), and simulation models (Siebert 2016). Mixed methods are also commonly used in impact assessment research to overcome single-method drawbacks (Amare et al 2019, Ullah et al 2020).

Finally, we conducted a keyword co-occurrence network to retrieve the key socioeconomic and ecological impacts recorded among the documents. The interactions among coupled climate, ecological and human systems shape the risk patterns across temporal and spatial scales whereas human activities can mitigate various risks or exacerbate them through maladaptation (IPCC 2022). This is of particular relevance to agricultural insurance programmers as ‘adverse social-ecological effects can arise alongside productivity gains or welfare improvements’ (Müller et al 2017, p 25). Therefore, in this research, we look into the effects of agricultural finance services on livelihood and local socio-economic patterns (e.g. poverty levels, production and consumption patterns, and access to agricultural innovation); and on ecosystems including the environment (soil, water, and natural vegetation) as well as on farmers’ behavior (land use and agro-practices). After reviewing all the documents, we extracted the impact-relevant keywords from these papers, each of which was then categorized into a group at the top level. The results of this step are shown in the next section. Appendix S1 shows more details and results of the methodological approach we applied for the systematic review and appendix S2 presents the database of all literature on insurance and microcredit we collected.

3. Socioeconomic and ecological impacts of WII and microcredit

3.1. Brief background on WII and microcredit

Unlike traditional agricultural insurance schemes, the payments of WII are triggered by a predetermined index (e.g. the amount of rainfall over a specified period or the level of typhoon). These indexes are designed easy to measure and independent of household loss. In this manner, WII could effectively reduce the moral hazard and adverse selections that characterize traditional agricultural insurance, which provides payments to farmers based on individual household loss and costs involved in the loss assessment. WII has been found to have positive impacts on encouraging agricultural input, increasing technological adaptation, smoothing consumption, and altogether improving the welfare and enhancing the resilience among the insured rural population (Karlan et al 2014, Hansen et al 2019, Janzen and Carter 2019). As a result, WII has been gaining increasing attention during the last decade.

Microcredit, in a way of small loans given to poor people, was initially aimed towards poverty alleviation. The first modern microcredit practice was in 1976 when Professor Mohamed Yunus of Bangladesh designed a credit system for the poor in his research project, and in 1983 the Government of Bangladesh established the Grameen Village Bank to practice and promote Professor Yunus’s project (Grameen Bank 2020). Since then, microcredit has emerged and evolved all over the world. Microcredit does not require collateral, and the interest rate is low compared with other credit modalities, to keep the program sustainable instead of pursuing big profits for the banks (Grameen Bank 2020). Although it was initially designed to reduce poverty, in recent decades, it has been found to also have a function of shielding locals from the negative effects of climatic variability...
and market fluctuation (Ravera et al. 2011, Sneath 2012, Bhuyian et al. 2015) and has been increasingly used to improve the adaptive capacity of farmers and to increase the resilience of agricultural systems to address weather risks (Pitt and Khandker 1998, Khandker 2005, Imai and Azam 2012).

WII is largely promoted by governments and international organizations through subsidies, particularly in developing countries (Giné et al. 2008, Cole et al. 2013, Vroege et al. 2019). For example, the World Bank Group introduced index insurance in its portfolio as early as 2000 (World Bank 2016). Since then, the bank has worked with multiple stakeholders to promote and develop index insurance programs. Similarly, microcredit is provided, subsidized, and supported mainly by governments, international organizations, and international donors (World Bank 1994, Turner and Williams 2002, Ojiako and Ogbugwka 2012, Addison and Brown 2014). The International Year of Microcredit 2005, an initiative of the United Nations (United Nations, 2004), has since raised public awareness of microcredit.

3.2. Socioeconomic impacts of WII

Over the last two decades, WII has been significantly developed across the world, and cumulative studies have focused on the examination of its socioeconomic impacts. Generally, considerable positive contributions have been found, including an increase in household income, protection of assets, and adoption of riskier and more profitable agricultural practices to better cope with climate risks.

In the last decade, WII has shown important impacts on household income in Africa. Though these are not consistently positive during all season/year cycles, empirical evidence shows that the income effects are significantly positive during drought years, e.g. a case from Ethiopia (Matsuda et al. 2019), or after drought seasons due to the increase in farmers’ ability to generate income (as presented in a case from Kenya (Janzen and Carter 2019)). Similar results are also observed beyond Africa. For example, a rainfall index insurance developed based on 80 years of historical data on climate and sugar cane yield from northern Australia was tested, and the results suggested that, on average, farmers were better off by 269.85 AUD ha⁻¹ if insured for the years with excessive rainfall, illustrating the viability of the WII in helping farmers manage weather risks (Kath et al. 2018). Dairy producers with WII in America are also found to be better off in terms of household income; the results stand even when the premiums are high and spatial- and temporal-based risks are considered (Deng et al. 2007).

WII, particularly index-based livestock insurance (IBLI) in pastoral areas in developing countries, has the potential to relieve the socioeconomic pressure on households following a disaster and thus protect rural communities from the destabilization of assets and consumption, which is the conventional way local households cope with weather disasters when uninsured (Janzen and Carter 2019). With the IBLI, livestock farmers can maintain their herd size which enhances their capacity to generate income after a disaster. In Kenya, for example, a study demonstrates that insured households (via IBLI) were less likely to sell livestock-productive assets during weather disasters, which enabled them to recover fast from the experienced shock (Jensen et al. 2017a). Similarly, in Mongolia, by providing in-time IBLI payouts following a weather shock, rapid herd recovery has been observed (Bertram-Fuemmer and Kraehnert 2018).

WII has also been linked to increased technology adoption and risk-taking among insured households. Farmers in developing countries are likely to engage in low-risk and low-return agricultural practices, which may trap them in persistent poverty (Dercon and Christiaensen 2011, Barrett and Carter 2013). Studies suggest that WII has enabled small agricultural producers to increase risk-taking behaviors (Haile et al. 2020), such as investing in new and usually risky methods and technologies (Karlan et al. 2014, Hansen et al. 2019). Adoption of new technologies (such as using climate-resilient seed varieties) can then foster agricultural development and increase locals’ coping capacity to climate shocks. For example, following the principle of WII, Mobarak and Rosenzweig (2013) designed a monsoon insurance, offering cash payments to insured holders once rainfall was delayed beyond a predefined monsoon onset date; they found that the insurance inspired farmers to take crops or technologies that are riskier but with higher average returns. Based on theoretical models, Carter et al. (2016) argue that index insurance could enhance small farmer households to improve technology adaptation. However, they also highlighted that the insurance works only under the situation that the index is well-designed and the households’ substantial amount of risk is covered by insurance. In the experimental research conducted in northern Ghana, Karlan et al. (2014) randomly assigned farmers cash grants and (or) rainfall index insurance, and the results showed that insurance has resulted in larger agricultural investment and riskier agricultural production decisions.

The above three socioeconomic impacts, i.e. increasing household income, protecting assets, and increasing technology adoption and agricultural investment, are the most mentioned based on our database (Please see table 1). Other socioeconomic impacts include smoothing consumption and enhancing food security and children’s health, which are sporadically discussed. While it is worth noting that the opposite evidence was also recorded, which for example includes limited access and unfairness, as the poorest were found to benefit the least from them. We will return to this point with details in the next sections.
Table 1. Socioeconomic and ecological impacts of index insurance and microcredit.

| Impacts                      | Ref. of weather index insurance | Ref. of microcredit |
|------------------------------|---------------------------------|--------------------|
|                              | Positive | Negative | No. effect or uncertain effect | Positive | Negative | Sum of positive | Sum of negative | Sum of no effect |
| Socioeconomic impacts        |          |          |                                  |          |          |                  |                  |                |
| Household income             | 86       | 3        | 2                                 | 88       | 12       | 17              | 174              | 4               |
| Agricultural investment      | 15       | 1        | 0                                 | 9        | 2        | 1               | 24               | 3               |
| Asset protection             | 10       | 0        | 0                                 | 11       | 0        | 0               | 21               | 0               |
| Adoption of new methods and technologies | 17       | 2        | 2                                 | 4        | 0        | 0               | 21               | 2               |
| Consumption                  | 2        | 0        | 0                                 | 15       | 1        | 5               | 17               | 5               |
| Production                   | 10       | 0        | 0                                 | 2        | 1        | 0               | 12               | 1               |
| Food security                | 1        | 0        | 0                                 | 10       | 3        | 0               | 11               | 3               |
| Child health                 | 1        | 0        | 0                                 | 3        | 1        | 0               | 4                | 1               |
| Ecological impacts           | 1        | 6        | 0                                 | 2        | 6        | 0               | 3                | 12              |
| Soil and water               | 0        | 3        | 0                                 | 0        | 4        | 0               | 0                | 7               |
| Land management              | 0        | 2        | 0                                 | 3        | 1        | 0               | 2                | 2               |
| Grassland sustainability     | 0        | 2        | 0                                 | 0        | 1        | 0               | 0                | 3               |
| Change of land use           | 1        | 0        | 0                                 | 0        | 0        | 0               | 1                | 0               |

3.3. Socioeconomic impacts of microcredit

Overall, existing studies illustrate the positive income impacts of microcredit. Households’ income is increased as farmers use loans to make agricultural investments such as in production supplies and equipment (Chan and Ghani 2011, Khandker 2012), while pastoralists buy livestock (Khandker and Koolwal 2016). Microcredit is also helpful to diversify farmers’ income including from nonfarm activities (Khandker and Koolwal 2016, Luan and Bauer 2016) such as operating small businesses (Al-Shami et al 2017) as a risk reduction strategy. Altogether, microcredit has the potential to improve households’ income and help farmers escape from the poverty trap (Ahmed et al 2016, Chirambo 2017, Abraham and Fonta 2018). This microfinance instrument has been found to protect assets from sale when farmers experience climate-related shocks, which enhances their resilience to the impacts of climate change. For example, pastoralists do not need to sell more livestock than usual when facing hazards, which strengthens their capacity to recover from shocks (Lybbert et al 2004). Microcredit can also promote asset accumulation by supporting productive activities and procuring livestock and microenterprise asset investment (Coppock and Desta 2013, Oladele and Rahman 2013, Chirambo 2017). Women particularly benefit from microcredit, as many microcredit services are supporting them to invest in agricultural production (Al-Shami et al 2017).

Microcredit could support technology promotion, as it breaks the limits of capital to support technology adoption and transfer. For example, the availability of microcredit was found to help the extension of solar water pumping systems in Burkina Faso, which facilitated the local agricultural irrigation, and consequently mitigated the negative effects of climate change (James 2010, Chirambo 2017, Yamegueu et al 2019).

In addition to the three most mentioned points above, positive effects on multidimensional poverty reduction (improved food security and access to health) and gender equality (women empowerment) are empirically observed as well (Doocy et al 2005, Karlan and Zinman 2011, Amersdorffer et al 2015, Antwi-Agyei et al 2015, Mtenga et al 2018). In terms of negative effects, limited access and benefits to the poorest compared to relatively wealthy households have been recorded (Coleman 2006, Kondo et al 2009), which will be addressed in the fourth section.

3.4. Ecological impacts of WII and microcredit

While the socioeconomic impacts of WII and microcredit are relatively well studied, less focus has been given to their ecological impacts, both short term and long term. Table 1 summarizes the number of references reporting each of the impacts. It shows that the studies on weather index insurance and microcredit are largely (approximately 93%) concentrated on their socioeconomic impacts, but rarely (7%) on their ecological effects. The limited number of studies, which assess the ecological impacts of these two finance instruments, point to several negative effects but also some positive observations. For example, financial services might lead to ecological degradation in pastoral areas after experiencing extreme weather events, which could deepen existing or create new
vulnerabilities to climate change. As illustrated above, with microcredit and (or) WII, herders could avoid selling and slaughtering animals during and after the disaster (Jensen et al 2017a, Bertram-Huemmer and Kraehnert 2018). Therefore, herd sizes could be maintained or even increased despite experienced hazards, which is economically profitable for herders in the short-term, however, large herds could disrupt the natural recovery dynamics of grassland, thus endangering its long-term carrying capacity and increasing the risk of ecological instability (Felix et al 2017, Zhang et al 2018, John et al 2019, Li and Li 2021, Lu et al 2021).

In addition, several studies reveal that in agricultural areas, insured farmers are more likely to use fertilizers and pesticides compared to uninsured producers. In the US, for instance, chemical use for farmlands was found to be significantly higher among insured farmers than those without insurance, to be specific, more nitrogen (19%) and pesticides (21%) were applied per acre (Horowitz and Lichtenberg 1993). Similar findings in other countries are reported, such as in Southern Italy (Capitanio et al 2015) and in Niger (Leblois et al 2014). Likewise, microcredit also promotes an increased use of fertilizers and pesticides (Abraham and Fonta 2018). For example, in Ethiopia, 31% of the clients of one financial scheme used loans to purchase fertilizer (Doocy et al 2005). Arguably, this can help farmers in many poor regions, like in parts of Africa, where the use of fertilizers and other modern agricultural inputs by smallholder producers is often far below the global average level and optimal values (Kathage et al 2016, Sibiko and Qaim 2020). However, there is a need for careful consideration of this issue in the design of financial products.

Microcredit has been also associated with a negative impact on water resources. In India, for instance, microcredit was linked to unsustainable water well drilling, which in turn has resulted in the depletion of shallow aquifers and consequently increased the vulnerability of farmers in the region in the long run (Taylor 2013).

Insurance may incentivize unsustainable land use practices that lead to maladaptive outcomes (Müller et al 2011). For instance, insured Indian farmers are found to be likely to take significantly less risk mitigation actions (Mobarak and Rosenzweig 2013), or to invest in highly profitable and riskier agricultural production than non-insured ones (Cole et al 2017). In this way, insurance could economically benefit individual farmers by eliminating the weather risk, while decreasing the resilience of both ecosystems and the human systems depending on them in the long term.

It is important to note that, not all the studies report negative ecological impacts. For example, Chantarat et al (2011) established that WII against windstorms could support ‘community-based nest restoration programs’ to protect hornbills and thus generate dual positive impacts—ecological conservation and aid for poor households. Outside the context of climate risk, Anderson et al (2002) suggest that microcredit schemes can increase farmers’ income and consequently ownership or access to land, natural resources, and technology, which in turn may encourage stewardship of these productive assets in the long term.

Overall, the reviewed literature suggests that the ecological impacts of rural financial services are conditioned by local specifics and types of agricultural activities, which requires context-specific studies in future research.

We also find that most empirical studies are about crop production, followed by livestock production and forestry communities. We did not detect empirical studies, which examine the impact of WII and microcredit on aquaculture and fisheries-dependent livelihoods.

4. Limitations of WII and microcredit

One big issue that hinders the promotion of WII and microcredit is the time mismatch of WII’s and microcredit’s fund demand and households’ cash in hand. For example, farmers in developing countries generally cannot afford the up-front premium for insurance and have difficulty repaying microcredit after climate disasters.

Insurance premium has been seen as an important determinant for increasing WII coverage (Cole et al 2013, Takahashi et al 2020). Globally, access to WII in the agricultural sector is limited, even with heavy subsidies (Giné and Yang 2009,Binswanger-Mkhize 2012, Cole et al 2013, IPCC 2014, Amare et al 2019, King and Singh 2020). One of the main reasons is that low-income farmers in developing countries have limited access to WII without a subsidy or other supporting measures, for example, social protection (Väänänen et al 2019), because of fund constraints to afford the up-front premium for insurance (Belissa et al 2019, Ali et al 2020).

High default risk taken by microfinance institutions (i.e. inability for debt payment by borrowers), especially such shaped by increasing climate disasters, has been one of the most important factors obstructing microcredit’s sustainability. The accessibility of microcredit is low thus, private loans remain the dominant type in rural credit markets worldwide (Amjad and Hasnu 2007, Armendáriz and Marc 2011, Guerin et al 2012, Chen and Jin 2017). One important reason is that microcredit providers are reluctant to issue loans to farmers due to high default rates, in particular those living in climate-vulnerable areas. When encountering weather disasters, farmers have higher loan default rates because agriculture production is negatively affected, which increases the risk of failure in the credit markets (Adjognon et al 2020).
barrier to formal access to financial services reduces the ability of farmers to address climate change and make agricultural investments (Antwi-Agyei et al 2015, Castellani and Cincinelli 2015).

In addition to the time mismatch discussed above, WII and microcredit both have their own design limitations. WII has widely suffered from basis risk (Mollmann et al 2018), which refers to the potential mismatch between the index-based payoffs and the actual losses of households (Vroege et al 2019). For example, farmers who suffer from a heavy drought might not receive payments if the weather index fails to detect the actual rainfall on the territory of their farms. Basis risk has been an important issue limiting farmers’ interest in WII, which has emerged as a key determinant of WII promotion. Multiple factors result in basis risk, including complex index and model design, spatial and temporal heterogeneity, and inadequate data availability (Kost et al 2012, Castaneda-Vera et al 2014). Yet, the increasing availability of climate data and integration of satellite technology observed in recent years, are expected to result in reduced basis risk and potentially improved take-up rates of this type of insurance (Vroege et al 2019). Emerging methodological and technological solutions include: (a) use of advanced indices such as the vegetation health index (Bokusheva et al 2016), forage production index (Roumiguie et al 2015), normalized difference vegetation index (Carter et al 2017) and a combination of various indices instead of a single index (Boken 2019); (b) development of statistical models (Conradt et al 2015) and simulation models (Meze-Hausken et al 2009); (c) machine learning (Biffis and Chavez 2017); (d) remote sensing (Boyd et al 2019); and (e) integrating farmer information into insurance design (Born et al 2019).

Importantly, microcredit has been linked to increased economic vulnerability and maladaptation. A study finds a mismatch of microcredit repayment requirements with the local production cycle and climate variability (Lu et al 2021), which makes farmers struggle to repay loans. In particular, the research findings illustrate that while farmers borrow loans to purchase hay as a climate coping strategy, they need to repay some loans each year before the time they generate cash by selling livestock. The climate variability makes their profit and loan repayment ability uncertain. Another study shows that some farmers sell their assets such as houses and land to repay loans (Banerjee and Jackson 2017). In addition, empirical literature provides evidence that when poor farmers have an overdue burden, they are forced out of the microcredit system due to repayment default, and some will choose long-term migration to dodge debts (Kabir et al 2018, Lu et al 2021), thus microcredit may further trap the poorest in poverty. Therefore, local production, climate, and livelihood patterns should be considered in the design of microcredit products.

Finally, the trust of consumers in financial institutions has been noted in the literature as an important factor in low willingness to adopt financial services. Karlan et al (2014) find that some farmers in Northern Ghana do not trust insurance institutions due to past negative experiences of insufficient payments.

5. Synergies between WII and microcredit

How could the above-discussed limitations be tackled? In this section, we provide a theoretical framework through which we examine empirical observations and analyze whether a combination of WII and microcredit might bear the potential to solve the time mismatch problem and generate socioeconomic benefits. We further discuss the environmental sustainability considerations of combined schemes.

5.1. A theoretical framework for understanding synergies

As mentioned in the fourth section, farmers in developing countries have fund constraints for paying the WII premium, even though WII is an important ex-ante strategy to adapt to climate change. On the one hand, microcredit, as an ex-ante financing source, provides funds to the poor to relieve fund constraints, which could help them to pay their insurance premiums. However, farmers generally have a low microcredit access rate due to high default risk. WII, on the other hand, as an ex-post financing source, provides payments after weather disasters, which could ease the repayment burdens and thus decreases their vulnerability to natural disasters. Therefore, a combined financial product would solve the time mismatch constraints and generate: (a) potential theoretical synergies, including increasing access rate, especially among the poor, and improving the rural economy; and (b) potential practical challenges, in particular through creating additional socioeconomic risks of financial institutions. We provide more analysis and evidence below.

5.2. Combined finance schemes: potential for overcoming limitations

To date, only a few studies examine combined finance schemes (21 articles in our database). The number of studies, which look into the effects of WII on microcredit access and repayment burden is also limited. Nevertheless, we propose that the combination of WII and microcredit should allow for overcoming the time mismatch of fund demand and cash in the hand of farmers, which has been shown on the left part in figure 1. First, microcredit has the potential to relieve farmers’ fund constraints to pay upfront premiums of WII. Empirical observations support such a hypothesis by showing that microcredit can solve the liquidity constraints that farmers face and can motivate their willingness to participate in WII (Shee et al 2015, BalmaIssaka et al 2016). A case
study from Togo indicates that farmers are more willing to pay for WII when combined with microcredit (Ali et al. 2020).

Second, the default risk associated with vulnerability to climate hazards that surrounds access of farmers to microcredit could be reduced through WII. On the demand side, the introduction of WII may become a potential solution to relieve the credit constraints of farmers. For example, in pastoral areas, access to WII has been linked to a decrease in cash savings and livestock holding, which are seen as substitutions for insurance and other risk-coping strategies (Jensen et al. 2017a; Matsuda et al. 2019). In Kenya, empirical studies based on a randomized controlled trial have found that the uptake rate for a bundled credit with WII was significantly higher than that of the traditional credit (Ndewga et al. 2020).

On the supply side, WII may create favorable market conditions for the supply of microcredit. As illustrated in section 4, microcredit institutions are reluctant to offer loans to the poor in climate-sensitive areas; however, they are more willing to provide credit to those insured by WII because of the relieved debt burden and decreased default risk (Hazell and Hess 2010). For example, a study from Mongolia shows that index insurance could relieve credit constraints and reduce loan default risks after weather disasters through insurance payments (Bertram-Huemmer and Kraehnert 2018). As a result, credit suppliers are more willing to provide credit to those with insurance because the insurance reduces collateral requirements.

5.3. Potential impacts of combined financial schemes
In the recent decade, increasing studies, though remain limited, have explored the impacts of combined financial products on agricultural productivity and rural livelihood, and shed light on the potential impacts on wider socioeconomic and ecological systems.

5.3.1. Increase access rates of WII and microcredit
Throughout the world, a few attempts have been made to improve access to credit by integrating it with traditional insurance, but most have failed as both instruments are subject to the same limitations (i.e. moral hazards and covariance risks as discussed earlier in this paper) (Binswanger-Mkhize 2012). However, the replacement of traditional insurance with WII may be a solution because of the properties of WII (i.e. reduced moral hazard and low loss assessment costs), and the fact that index insurance is re-insurable (Binswanger-Mkhize 2012). Combining weather insurance into a credit contract may help balance business and microcredit risks, particularly when the insurance is for low-frequency or rare weather risks (Turvey 2008). In addition, from the perspective of financial suppliers, as trust in a service provider is essential in purchasing decisions (Chaudhuri and Holbrook 2001), it might be easier to promote either WII or microcredit in a region where the other service has established trust and loyalty of customers (Rossel-Cambier 2012).

5.3.2. Provide benefits to the poor
As specified among existing studies, either WII or microcredit, when stand-alone, seems to have a limited benefit to the poorest population. There is a question that if, and if so, to what extent, WII could emerge as a game-changing innovation for low-income households to cope with weather shocks, particularly as an alternative solution to traditional insurance schemes, which are often ineffectual due to high costs and low returns (Tadesse et al. 2015). Unfortunately, empirical observations convey a rather pessimistic image of the potential of WII to the poor, mainly because of the low availability and affordability of insurance for the poor (Jensen et al. 2017b), and therefore lead to inequality, as the poorest benefit the least from climate risk insurance.

Some empirical studies suggest that among the reasons for the limited benefits of index insurance to the poor are credit and cash constraints (Binswanger-Mkhize 2012, Chantarat et al. 2017). For example, in Kenya, even with IBLI, the poorest households are likely to be trapped in poverty because they do not have enough funds to invest in income-generating production, leading to difficulty...
to escape poverty traps (Chantarat et al 2017). The poorest rural households are particularly susceptible to weather risks, no matter whether they are involved in agricultural production or not (Barnett and Mahul 2007). It is often found that it is difficult for those trapped in poverty to restart accumulating productive assets after experiencing climate-related disasters (Carter et al 2007).

Likewise, studies indicate that microcredit has a significant positive impact on the income and expenditure of rich families while hurting low-income families (Coleman 2006, Kondo et al 2008). Low-income families are more likely to decrease income and assets and recover slowly after climate disasters, leading to high default risks and repayment burdens. Microcredit even increases farmers’ vulnerability to poverty when farmers use loans to consume instead of to create income-generating activities (Bylander 2015, Banerjee and Jackson 2017, Han et al 2019).

On the positive side, in some countries in Africa, such as Ethiopia, Kenya, and Ghana, the combination of index insurance and microcredit has been found to enhance new agricultural technology adoption and benefit the poor to escape poverty traps (Tadesse et al 2015, Akotey and Adjasi 2016). From a theoretical perspective, WII would be more effective to improve farmers’ living standards if WII were interlinked with credit in sub-Saharan Africa (Carter et al 2016). Yet, the synergistic effect of combined schemes on the poorest communities remains empirically under-studied.

5.3.3. Improve agricultural production and rural economy
A combination of microcredit and insurance may also have impacts on the rural economy by increasing agricultural investment and new technology adoption. As was found by McIntosh et al (2013), in Ethiopia, significant profitable opportunities for the use of fertilizer in highland areas exist, which however is conditioned by risk factors and credit constraints; WII might become an effective tool to expand agricultural credit, and thus increase agricultural productivities by increasing input use. The study found that farmers with credit interlinked with WII improved the adoption rate of fertilizer compared to those with standalone insurance. Consistently, in Kenya, research shows that insured loans have been able to enhance the access of local farmers to agricultural technologies (Tadesse et al 2015). By modeling index insurance as a meso-level product, through which microcredit providers are protected by purchasing WII coverage equal to principal plus interest, Farrin and Miranda (2015) argue that a combination of credit, insurance, and savings could be instrumental in the risk management of farmers while promoting technology adoption, which would increase household income and consumption in the long term. In addition, the potential synergies of a combination of these two services have been found to improve household livelihood and promote poverty reduction, hence contributing to local economies (Shee and Turvey 2012).

5.3.4. Bear possible socioeconomic risks to financial institutions
As illustrated above, existing empirical observations, though limited, suggest that incorporating insurance into credit products may encourage WII uptake and the buy-in of microcredit among farmers, and decrease credit default risks, implying a win-win situation for both farmers and financial service providers. In recent years, some financial institutions in developing countries have transitioned from lending only to offering diverse financial products. The supply of at least two financial products comprises the portfolio of financial services (Rossel-Cambier 2012). Importantly though, a combination of microcredit and WII bears the risk of creating an additional layer of socioeconomic risks for financial institutions practically. These include reduced transparency (e.g. monitoring of the subsidization of the different schemes), new management challenges or increased complex performance supervision, as well as more fragile socioeconomic sustainability because adding services may result in additional risks and complexity (Rossel-Cambier 2012).

In addition, one finance product may be damaged by customers’ dissatisfaction with another product. For example, Giné and Yang (2009) show surprising results that credit for purchasing a high-yielding crop had a higher take-up rate compared to a similar credit package combined with weather insurance in Malawi. This result contradicts the common understanding (and also their hypothesis) that insurance would increase the willingness of farmers to invest in a riskier but higher-yielding crop. The authors suggest that mistrust in theinsuring organization may have reduced the product take-up rates, which implies that mistrust and dissatisfaction with one service may influence the interests of farmers in other financial services, pointing to possible negative synergies. Another study from Malawi highlights that combined products could be complicated for farmers to understand, which reduces their willingness to buy them (Fuchs and Wolff 2011). Therefore, the provision of training on financial literacy for farmers is an important enabling factor for increasing the take-up rates of combined products.

It is key to remind that a combination of WII and microcredit cannot solve all product limitations. For example, we mentioned in the fourth section that WII and microcredit both have their own design constraints. There are other potential ways to solve these limitations, such as using remote sensing to reduce WII basis risks, adjusting microcredit lending practices to match the local production cycle and climate conditions, and increasing support from
governments (Bokusheva et al 2016, Wen et al 2019, Lu et al 2021).

5.3.5. Bring maladaptation risks to environmental sustainability
As highlighted earlier, research on the ecological impacts of finance schemes is scarce. Potential positive impacts of microcredit on environmental resources include reduced deforestation or adoption of more sustainable agricultural practices like crop rotation and organic farming, yet potential significant negative impacts include overuse of land resources, pressure on water resources, and increased use of fertilizers and pesticides with further implications for human and ecological health (Anderson et al 2002). Similar negative environmental effects of insurance have been identified including wider consequences such as loss of agrobiodiversity and land degradation in the long term (Müller et al 2017).

To our knowledge, however, nearly no peer-reviewed studies look into the synergies of WII and microcredit from an environmental sustainability perspective. Below, we highlight some potential positive effects but also risks of maladaptation.

In pastoral areas, the combined impacts of WII and microcredit could be complex. On the one hand, the combination might lead to a high ecological risk such as overgrazing as both products could be associated with such negative effects. On the other hand, a combination could also reduce overgrazing. Take pastoral communities in Inner Mongolia of China as an example, herders use microcredit as a way to deal with climate risks (Zhang et al 2018, Li and Li 2021, Lu et al 2021). They borrow microcredit in case they need to buy hay to support their livestock husbandry after climate disasters and maintain high stocking rates to repay microcredit. If they have WII, the risk of being unable to repay the credit is eliminated, and thus herders do not need to maintain a high stocking rate. So, the decrease in stocking rate may generate a positive environmental impact in regions. Similarly, in crop areas, the combined impacts could be positive and negative, depending on the type of agricultural activities, e.g. fertilizer and pesticides use vs. ecological conservation approaches (Chantarat et al 2011, Leblois et al 2014, Abraham and Fonta 2018).

To avoid such risks, environmental sustainability should be an integral part of designing and evaluating the impacts of combined products. Incentives or regulations should be given to financing providers for improving product design toward ecological conservation, particularly in ecologically vulnerable locations. For instance, Müller et al (2017) suggest the use of holistic biophysical and socioeconomic indicators in impact assessment studies, as well as principles and recommendations for improved (insurance) design including tying insurance ‘to ecologically sound strategies’. Meanwhile, properly designed ecological indexes could be employed to encourage more environmental-friendly land use behaviors of consumers. For example, when insurance payments are tied to specific conservation requirements, they could prevent consumers from over-exploitation as coping strategies, and instead, empower them to be agents of ecological restoration (Chantarat et al 2011). In addition, some studies propose certain restrictions for the purchase of insurance to reach an optimal balance between socioeconomic benefit and ecological uncertainty. For example, John et al (2019) suggest restricting the number of animals that can be insured by each household. Müller et al (2011) advocate for insuring only severe drought, as a low payout threshold (i.e. modest droughts) is found to create incentives for consumers to use land less sustainably. Another example is the emergence of ‘green microfinance’. In Nicaragua, farmers committing to adopt conservation and sustainable production practices to protect soil and water can obtain microcredit with a lower interest rate (Hammill et al 2008).

6. Discussions and conclusions
There is a growing recognition of the need for designing finance services that promote sustainable development under the growing challenges of climate change. Rural financial services such as WII and microcredit are promising tools for addressing poverty and enhancing the coping and adaptive capacities of farmers to respond to climate variability and extremes. Against this backdrop, the objective of this paper is to explore the potential synergies of WII and microcredit, based on a systematic review and analysis of published literature. The review seeks to capture the socioeconomic and ecological impacts and challenges associated with the promotion of these instruments in agricultural regions threatened by climate change and extremes.

The impacts of rural financial services on ecological systems are yet well understood. Most of the reviewed articles do not take into consideration the impacts of WII and microcredit on the environment, such as increased fertilizer and pesticide use, or unsustainable production intensification. Despite the limited evidence, existing studies do raise a concern about the long-term effects of rural financial services and call for a more careful design of financial products by considering potential ecological impacts. There is also a growing interest in linking these financial services to environmental conservation initiatives or designing microinsurance schemes for ecosystem-based adaptation (e.g. see Beck et al 2019). That being said, a holistic approach to impact assessment, capturing both the socioeconomic and ecological components of rural systems (as emphasized by Müller et al 2017) could contribute to an improved understanding of the role of rural financial services in addressing climate risks in the long term. Future
studies could explore the optimal balance between economic benefit and maladaptation risk.

Another important finding of this article is that the WII can help address certain challenges of microcredit and vice versa. Rural populations in developing countries are vulnerable to weather extremes, particularly the poor and marginalized groups, who also typically lack access to financial services (i.e. access barriers to credit and limited options for WII) that could effectively support their risk management strategies and adaptive capacity. Credit suppliers are reluctant to provide loans to vulnerable households because of the high risk of non-repayment in the face of weather disasters; WII providers encounter low demand due to the cash constraints of rural households. Linking microcredit and WII could generate possible positive synergies by relieving the cash constraints faced by insurance consumers and reducing the repayment burden of the credit takers. In this way, the accessibility and affordability of both WII and microcredit could be increased, as the combination of these two could solve the time mismatch issues troubling each of them.

We further explore whether a combination of WII and microcredit could generate synergies, which are so far understudied. We find that a combination can generate possible positive synergies, in terms of reducing poverty, improving the livelihood of farmers, encouraging WII and microcredit uptake, and decreasing microcredit default risks, consequently creating a win-win situation for both farmers and financial services providers. Yet, a combined scheme may involve practical challenges. For example, it may lead to increased socioeconomic vulnerability of local financial institutions, due to additional risks and complexity. In addition, there remain unclear regarding their ecological impacts. However, the number of studies focusing on the combination of WII and microcredit and their socioeconomic and ecological impacts is limited. In this regard, this research provides a reference for future studies on innovative financial services to address climate risks in rural areas more effectively.

Data availability statement

All data that support the findings of this study are included within the article (and any supplementary files).

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Conflict of interest

Authors declare no competing interests.

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References

Abraham T and Fonta W 2018 Climate change and financing adaptation by farmers in northern Nigeria Financ. Innov. 4 17
Addison J and Brown C 2014 A multi-scaled analysis of the effect of climate, commodity prices and risk on the livelihoods of Mongolian pastoralists J. Arid Environ. 109 54–64
Adjognon G S, Liverpool-Tasie L S and Shupp R 2020 Productivity shocks and repayment behavior in rural credit markets: a framed field experiment J. Dev. Stud. 56 1909–26
Ahmed M K, Asadullah M N and Kambhampati U 2016 The effect of formal banks on household income and poverty in Bangladesh Malays. J. Econ. Stud. 53 173–93 (available at: https://search.informit.org/doi/pdf/10.3316/informit.530907694285489)
Akotey J O and Adiasi C K D 2016 Does microcredit increase household welfare in the absence of microinsurance? World Dev. 77 380–94
Al-Shami S S A, Majid I, Mohamad M R and Rashid N 2017 Household welfare and women empowerment through microcredit financing: evidence from Malaysia microcredit J. Hum. Behav. Soc. Environ. 27 894–910
Ali E, Egbendewe A Y G, Abdoulaye T and Sarpong D B 2020 Willingness to pay for weather index-based insurance in semi-subsistence agriculture: evidence from northern Togo Clim. Policy 20 534–47
Amare A, Simane B, Nyangaga J, Defisa A, Hamza D and Gurmesssa B 2019 Index-based livestock insurance to manage climate risks in Borena zone of southern Oromia, Ethiopia Clim. Risk Manage. 25 16
Amersdorffer F, Buchenrieder G, Bokusuheva R and Wolz A 2015 Efficiency in microfinance: financial and social performance of agricultural credit cooperatives in Bulgaria J. Oper. Res. Soc. 66 57–65
Amjad S and Hasnu S A F 2007 Smallholders’ access to rural credit: evidence from Pakistan Lahore J. Econ. 2 1–25
Anderson C L, Locker I and Nugent R 2002 Microcredit, social capital, and common pool resources World Dev. 30 95–105
Antwi-Agyei P, Dougill A J and Stringer L C 2015 Barriers to climate change adaptation: evidence from northeast Ghana in the context of a systematic literature review Clim. Dev. 7 297–309
Armendáriz B and Marc L 2011 Introduction and overview: an inquiry into the mismatch in microfinance The Handbook of Microfinance (Singapore: World Scientific) (https://doi.org/10.1142/9789814295666_0001)
Balmalissaka Y, Wumbel B L, Buckner J and Narrey R Y 2016 Willingness to participate in the market for crop drought index insurance among farmers in Ghana Afr. J. Agric. Res. 11 1257–65
Gnauck K, Ruiz J, Kellett N, Sussman A, Sullivan M A, Montoya M and Levin N 2013 Economic empowerment and AIDS-related stigma in rural Kenya: a double-edged sword? Cult. Health Sex. 15 851–65
Gramebank 2020 Founder (available at: www.grameen.com/ founder-2/) (Accessed 31 March 2020)
Guerin I, Roesch M, Venkatatrasubramanian G and D’Espallier B 2012 Credit from whom and for what? The diversity of borrowing sources and uses in rural southern India J. Int. Dev. 24 S122–37
Gutiérrez-Nieto B and Serrano-Cinca C 2019 20 years of research in microfinance: an information management approach Int. J. Inf. Manage. 178 183–97
Haile K K, Nilessen E and Tirivayi N 2020 Impact of formal climate risk transfer mechanisms on risk-aversion: empirical evidence from rural Ethiopia World Dev. 130 104930
Hammill A, Matthew R and McCarter E 2008 Microfinance and climate change adaptation IDS Bull. 39 113–22
Han J M, Wang J Q and Ma X Q 2019 Effects of farmers’ participation in inclusive finance on their vulnerability to poverty: evidence from qinba poverty-stricken area in China Emerg. Mark. Finance Trade 55 998–1013
Hansen J, Hellin J, Rosenstock J, Fisher E, Cairns J, Stirling C, Lamanna C, van Etten J, Rose A and Campbell B 2019 Climate risk management and rural poverty reduction Agric. Sys. 172 23–46
Hasegawa T, Sakurai G, Fujimori S, Takahashi K, Hijioka Y and Masui T 2021 Extreme climate events increase the risk of global food insecurity and adaptation needs Nat. Food 2 587–95
Hazzl P B R and Hess U 2010 Drought insurance for agricultural development and food security in dryland areas Food Secur. 2 395–405
Hoddinott J 2006 Shocks and their consequences across and within households in Rural Zimbabwe J. Dev. Stud. 42 301–21
Horowitz J K and Lichtenberg E 1993 Insurance, moral hazard, and chemical use in agriculture Am. J. Agric. Econ. 75 926–35
Imai K S and Azam M S 2012 Does microfinance reduce poverty in Bangladesh? New evidence from household panel data J. Dev. Stud. 48 633–53
IPCC 2014 Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (Cambridge: Cambridge University Press) p 688 (available at: www.ipcc.ch/report/ar5/wg2/)
IPCC 2022 Summary for policymakers Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change ed H O Pörtner et al (Cambridge: Cambridge University Press) p 3056
Jägermeyr J et al 2021 Climate impacts on global agriculture emerge earlier in new generation of climate and crop models Nat. Food 2 873–85
Jain S and Mansuri G 2003 A little at a time: the use of regularly scheduled repayments in microfinance programs J. Dev. Econ. 72 253–79
James P A S 2010 Using farmers’ preferences to assess development policy: a case study of Uganda Dev. Policy Rev. 28 359–78
Janzen S A and Carter M R 2019 After the drought: the impact of microinsurance on consumption smoothing and asset protection Am. J. Agric. Econ. 101 651–71
Jensen N D, Barnett C P and Mude A G 2018 Cash transfers and index insurance: a comparative impact analysis from northern Kenya J. Dev. Econ. 129 14–28
Jensen N, Ikegami M and Mude A 2017b Integrating social protection strategies for improved impact: a comparative evaluation of cash transfers and index insurance in Kenya Geneva Pap. Risk Insur. Issues Pract. 42 675–707
John F, Toth R, Frank K, Groeneveld J and Müller B 2019 Ecological vulnerability through insurance? Potential unintended consequences of livestock drought insurance Ecol. Econ. 157 357–68
Kabir M E, Serra-Ro Neumann S, Davey P, Hossain M and Alam M T 2018 Drivers and temporality of internal migration in the context of slow-onset natural hazards: insights from north-west rural Bangladesh Int. J. Disaster Risk Reduct. 31 617–26
Karlan D, Osei R, Osei-Akoto I and Udry C 2014 Agricultural decisions after relaxing credit and risk constraints J. Econ. 129 597–652
Karlan D and Zinman J 2011 Microcredit in theory and practice: using randomized credit scoring for impact evaluation Science 332 1278–84
Kath J, Mushag T, Henry R, Adayinka A and Stone R 2018 Index insurance benefits agricultural producers exposed to excessive rainfall risk Weather Clim. Extreme 22 1–9
Kathage J, Kassie M, Shiferaw B and Qaim M 2016 Big constraints or small returns? Explaining nonadoption of hybrid maize in Tanzania Appl. Econ. Perspect. Policy 38 113–31
Khandker S R 2005 Microfinance and poverty: evidence using panel data from Bangladesh World Bank Econ. Rev. 19 263–86
Khandker S R 2012 Seasonality of income and poverty in Bangladesh J. Dev. Econ. 97 244–56
Khandker S R and Koolwal G B 2016 How has microcredit supported agriculture? Evidence using panel data from Bangladesh Agric. Econ. 47 157–68
King M and Singh A P 2020 Understanding farmers’ valuation of agricultural insurance: evidence from Vietnam Food Policy 94 101861
Kohli A, Peroni N A, Remy M M, Alfred M B, Arsen B K, Nadine M B, Heri B J, Clivos M M and Glass N 2017 Adult and adolescent livestock productive asset transfer programmes to improve mental health, economic stability and family and community relationships in rural South Kivu Province, Democratic Republic of Congo: a protocol of a randomised controlled trial BMJ Open 7 e013612
Kondo T, Orbeta A, Dingcong C and Infantado C 2009 Impact of microfinance on rural households in the Philippines IDS Bull. 39 51–70
Kost A, Laderach P, Fisher M, Cook S and Gomez L 2012 Improving index-based drought insurance in varying topography: evaluating basis risk based on perceptions of Nicaraguan hillside farmers PLoS One 7 11
Kucharik C J 2008 Contribution of planting date trends to increased maize yields in the central United States J. Agron. 109 3122–37
Kucharik C J and Serbin S P 2008 Impacts of recent climate change on Wisconsin corn and soybean yield trends Environ. Res. Lett. 3 034003
Leblois A, Quirion P, Alhashim A and Traore S 2014 Weather index drought insurance: an ex ante evaluation for millet growers in Niger Environ. Res. Econ. 57 527–51
Lesk C, Rowhani P and Ramankutty N 2016 Influence of extreme weather disasters on global crop production Nature 52 84–87
Li Y and Li W 2021 Do fodder import and credit loans lead to increased maize yields in the central United States J. Dev. Econ. 157 357–68
Lu Y, Hunttinger L and Li W 2021 Microcredit programs may increase risk to pastoralist livelihoods in Inner Mongolia Ambio 51 1–15

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Y Lu et al
Luan D X and Bauer S 2016 Does credit access affect household income homogeneously across different groups of credit recipients? Evidence from rural Vietnam. J. Rural Stud. 47 186–203

Lyyvert T J, Barrett C B, Desta S and Layne Coppock D 2004 Stochastic wealth dynamics and risk management among a poor population. Econ. J. 114 750–77

Matsuda A, Takashashi K and Ikeyami M 2019 Direct and indirect impact of index-based livestock insurance in Southern Ethiopia Geneva Pap. Risk Insur. Issues Pract. 44 481–502

Mcintosh C, Sarris A and Papadopoulos F 2013 Productivity, credit, risk, and the demand for weather index insurance in smallholder agriculture in Ethiopia Agric. Econ. 44 399–417

Mechler R, Hochrainer S, Pflug G C, Lotsch A and Williges K 2010 Assessing the financial vulnerability to climate-related natural hazards World Bank Policy Res. Work. Pap. (available at: https://openknowledge.worldbank.org/handle/10986/9048)

Meze-Hausken E, Patt A and Fritz S 2009 Reducing climate risk for micro-insurance providers in Africa: a case study of Ethiopia Glob. Environ. Chang. Policy Dimens 19 66–73

Mobarak A M and Rosenzweig M 2013 Informal risk sharing, index insurance, and risk taking in developing countries Am. Econ. Rev. 103 375–80

Mollmann J, Buchholz M and Masshoff O 2018 Comparing the hedging effectiveness of weather derivatives based on remotely sensed vegetation health indices and meteorological indices Weather Clim. Soc. 11 33–48

Montgomery H and Weiss J 2011 Can commercially-oriented microfinance help meet the millennium development goals? Evidence from Pakistan World Dev. 39 87–109

Moser R, Barbosa M and Gonzalez L 2013 Microfinance and climate change impacts: the case of Agroamigo in Brazil Rev. Adv. Empres. 55 397–407

Mtenga S M, Pfeiffer C, Tanner M, Geuddels E and Merten S 2018 Linking gender, extramartial affairs, and HIV: a mixed methods study on contextual determinants of extramartial affairs in rural Tanzania Aids Res. Ther. 15 17

Müller B, Johnson L and Kreuer D 2017 Maladaptive outcomes of climate insurance in agriculture Glob. Environ. Change 46 23–33

Müller B, Quas M F, Frank K and Baumgärtner S 2011 Pitfalls and potential of institutional change: rain-index insurance and the sustainability of rangeland management Ecol. Econ. 70 2137–44

Ndewa M K, Shee A, Turvey C G and You L Z 2020 Uptake of insurance-embedded credit in presence of credit rationing: evidence from a randomized controlled trial in Kenya Agric. Financ. Rev. 80 745–66

Ojako I A and Ogbuga B C 2012 Economic analysis of loan repayment capacity of smallholder cooperative farmers in Yewa North local government area of Ogun State, Nigeria Afr. J. Agric. Res. 7 2051–62

Oladele O I and Rahman H 2013 A synopsis of information communication technologies applications in agro-based livelihoods in Nigeria Cases on Progressions and Challenges in ICT Utilization for Citizen-Centric Governance (Hershey, PA: IGI Global) pp 195–204

Peterson N D 2012 Developing climate adaptation: the intersection of climate research and development programmes in index insurance Dev. Change 43 557–84

Pitt M M and Khandker S R 1998 The impact of group-based credit programs on poor households in Bangladesh: does the gender of participants matter? J. Polit. Econ. 106 958–96

Ravera F, Tarrazon D and Simelton E 2011 Envisioning adaptive strategies to change: participatory scenarios for agropastoral semiarid systems in Nicaragua Ecol. Soc. 16 20

Rossel–Cambier K 2012 Can combined microfinance boost economic results? An empirical cross-sectional analysis Rev. Econ. Financ. 2 79–94 (available at: www.bapress.ca/ref/ref-2012-3/Can%20Combined%20Microfinance%20Boost%20Economic%20Results—An%20Empirical%20Cross-sectional%20Analysis.pdf)

Roumiguie A, Jacquin A, Sigel G, Poilve H, Lepoivre B and Hagoelle O 2015 Development of an index-based insurance product: validation of a forage production index derived from medium spatial resolution fCover time series Geosci. Remote Sens. 52 94–113

Shee A and Turvey C G 2012 Collateral-free lending with risk-contingent credit for agricultural development: indemnifying loans against pulse crop price risk in India Agric. Econ. 43 561–74

Shee A, Turvey C G and Woodard J 2015 A field study for assessing risk-contingent credit for Kenyan pastoralists and dairy farmers Agric. Financ. Rev. 75 330–48

Sibiko K W and Qaim M 2020 Weather index insurance, agricultural input use, and crop productivity in Kenya Food Sec. 12 151–67

Siebert A 2016 Analysis of the future potential of index insurance in the West African Sahel using CMIP5 GCM results Clim. Change 134 15–28

Sneath D 2012 The ‘age of the market’ and the regime of debt: the role of credit in the transformation of pastoral Mongolia Soc. Anthropol. 20 458–73

Tadesse M A, Shiferaw B A and Ernststein O 2015 Weather index insurance for managing drought risk in smallholder agriculture: lessons and policy implications for sub-Saharan Africa Agric. Food Econ. 3 26

Takahashi K, Noritoyo Y, Ikegami M and Jensen N D 2020 Understanding pastoralists’ dynamic insurance uptake decisions: evidence from four-year panel data in Ethiopia Food Policy 95 101910

Taylor M 2013 Liquid debts: credit, groundwater and the social ecology of agrarian distress in Andhra Pradesh, India Third World Q 34 691–709

Turner M D and Williams T O 2002 Livestock market dynamics and local vulnerabilities in the Sahel World Dev. 30 683–705

Turvey C G 2008 The pricing, structure, and function of weather-linked bonds, mortgages, and operating credit Agric. Financ. Rev. 68 135–50

Ullah K, Mohsin A Q, Saboor A and Baig S 2020 Financial inclusion, socioeconomic disaster risks and sustainable mountain development: empirical evidence from the Karakoram Valleys of Pakistan Sustainability 12 9737

United Nations 2004 UN lanches international year of microcredit 2005 (available at: https://press.un.org/en/2004/dev2492.doc.htm) (Accessed 1 August 2022)

Väänänen E, Net K, Costella C and de Suarez J M 2019 Linking climate risk insurance with shock-responsive social protection (available at: www.insuresilience.org/wp-content/uploads/2019/03/insuresilience_policybrief_1-2019_01932_web.pdf)

Vroege W, Dalhöns T and Finger R 2019 Index insurances for grasslands—a review for Europe and North-America Agric. Syst. 168 101–11

Vyas S, Dalhaus T, Kropff M, Aggarwal P and Meewissen M P 2021 Mapping global research on agricultural insurance Environ. Res. Lett. 16 103003

Wahab H, Bunyau W and Islam M R 2018 Microcredit for rural poverty alleviation and social well-being: a study of Sabah, Malaysia Asian Soc. Work Policy Rev. 12 4–16

Wanzecek S, Mccord M, Wiedmaier-Pfister M and Biese K 2017 As a federally owned enterprise, GIZ supports the German Government in achieving its objectives in the field of international cooperation for sustainable development Programme/Project Description: Sector Programme Global Programme/Project Description: Sector Programme Global Initiative for Access to Insurance (available at: https://us.milliman.com/-/media/milliman/pdfs/2021-articles/5-11-21-inclusive-insurance-and-the-sustainable-development-goals.ashx)

Wang X, Bodirsky B L, Müller C, Chen K Z and Yuan C 2022 The hedging effectiveness of weather derivatives based on weather-linked bonds, mortgages, and operating credit Agric. Financ. Rev. 68 135–50

Wanki C, Mccord M, Wiedmaier-Pfister M and Biese K 2017 Assessing the financial vulnerability to climate-related natural hazards World Bank Policy Res. Work. Pap. (available at: https://openknowledge.worldbank.org/handle/10986/9048)
World Bank W 1994 Mongolia Country Economic Memorandum: Priorities in Macroeconomic Management (Washington, DC: World Bank Group) (available at: http://documents.worldbank.org/curated/en/130331468758230988/Mongolia-Country-economic-memorandum-priorities-in-macroeconomic-management)

World Bank 2016 What can index insurance offer to development? (available at: www.worldbank.org/en/news/feature/2016/11/10/what-can-index-insurance-offer-to-development) (Accessed 1 August 2022)

Yamegoue D, Alokore Y and Corso G 2019 Potential of microfinanced solar water pumping systems for irrigation in rural areas of Burkina Faso Energy Sustain. Soc. 9 13

Zhang J, Huntsinger L, Li Y B and Li W J 2018 Is microcredit a form of risk for pastoral households of Inner Mongolia’s semiarid rangelands? Rangel. Ecol. Manage. 71 382–8

Zhao X, Calvin K V, Wise M A, Patel P L, Snyder A C, Waldhoff S T, Hejazi M I and Edmonds J A 2021 Global agricultural responses to interannual climate and biophysical variability Environ. Res. Lett. 16 104037