Agricultural and Food Economics
a SpringerOpen Journal

REVIEW Open Access

Weather index insurance for managing drought risk in smallholder agriculture: lessons and policy implications for sub-Saharan Africa

Million A. Tadesse[1*], Bekele A. Shiferaw[2] and Olaf Erenstein[3]

* Correspondence: mayten01@gmail.com
[1]Department of Statistics and Actuarial Science, University of Waterloo, 200 University Avenue West, N2L3G1, Waterloo, Ontario, Canada
Full list of author information is available at the end of the article

Abstract

This paper reviews recent advances in, and challenges for, weather index insurance for managing drought risk in smallholder agriculture, with a focus on sub-Saharan Africa. Despite its promise to integrate local agricultural risk smoothing with insurance principles, there remain many challenges to its mainstreaming in low income countries. Scaling up of weather index insurance pilot projects is particularly constrained by high-basis risk, related to the divergence between the calculated weather index and actual productivity loss on the farm. Various options may be considered to enhance uptake of weather index insurance. Linking reliable weather data with location-specific crop and agronomic conditions using flexible geospatial crop modeling tools is one option to reduce the basis risk. The other option is interlinking weather index insurance with credit or safety nets. In the end, insurance should be offered as part of a wider set of business services that provide real value to smallholders. Finally, the review acknowledges that the suggested conceptual solutions, especially interlinking index based weather insurance with credit will require more empirical evidence on the extent to which insurance would reduce the cost of borrowing and make credit more accessible to the smallholder farmers.

Keywords: Index-based weather insurance, Inter-linkage, Credit, Safety net, Sub-Saharan Africa

Introduction

There has been much enthusiasm for, and investigations of, the potential benefits of weather index insurance for agricultural risk transfer and mitigation in low income economies (Skees et al. 1999; Turvey 2001; Mahul 2001; Hess and Syroka 2005; World Bank 2005, 2011; Barnett et al. 2008; Carter 2009; IFAD and WFP 2010; Suarez and Linnerooth-Bayer 2010; Shee and Turvey 2012; Cole et al. 2013). Underlying this interest are the widespread welfare losses that arise from large scale covariate weather risks, particularly in low income countries where market imperfections limit effective risk transfer instruments. Smallholders face poverty traps and subsistence consumption constraints, making it difficult to mobilize savings to cope with weather shocks. Climate change exacerbates extreme weather events, further undermining the livelihoods of smallholders who typically depend on rain-fed agriculture (IPCC 2007; Barnett et al. 2008; Barr et al. 2010).

In addition to these general welfare and climate considerations, there is an economic interest in weather insurance: its potential to overcome the chronic problems of moral hazard, adverse selection and other forms of asymmetric information that affect credit and insurance markets in rural economies along with low administrative costs and ease in handling claims for indemnities. Weather index insurance payments are triggered by a single and easily observable and verifiable parameter (index) such as rainfall measurements or temperature records common to a particular village or region – which implies that individuals will not have the opportunity or incentive to manipulate records (Skees et al. 1999; Mahul 2001; Turvey 2001; Osgood et al. 2007; Miranda and Farrin 2012). In addition, most forms of moral hazard problems can be eliminated, monitoring costs are reduced, and because the payout is made in reference to the exogenously constructed index, often losses at the farm level do not have to be observed or verified, leading to more efficient and timely processing and payment of claims. These are key potential advantages of weather index insurance over traditional crop insurance schemes, but many pilot projects show that significant improvements in product design and implementation strategies are still needed, especially to enhance demand and uptake. Weather index insurance policy holders (households in a particular locality) will typically receive a payout if rainfall (and/or other weather variable) recorded at a representative weather station during the crop growing season is below the agreed threshold level (trigger point or strike value) (Skees et al. 1999; Turvey 2001; Mahul 2001). This assumes that the 'representative' station[1] also captures the covariate risks faced by villagers, and that these covariate risks are common. This, of course, is rarely the case in field conditions, implying that there may be households in a particular village with measureable volumetric loss who may not receive any payouts because the weather data recorded at the weather station is considered enough to support crop production (Barnett et al. 2008; Skees et al. 1999). This is referred to as basis risk and is most prominent in areas where climate variability is high (e.g. semi-arid areas or rain shadows near a mountain range).

A common assumption and perhaps quite problematic to crop insurance design is the reliance on a single weather station representing an area of 20–25 km radius (Gommes and Gobel 2013). Households and villages within this radius are expected to have homogenous topography and farming systems. However, this simplified assumption of homogeneity of farming systems in index development is problematic for countries with variable topography, soil conditions and more diverse agroecologies (Gommes and Gobel 2013). On the other hand, indices such as area yield index (Mahul et al. 2012) developed based on historical average yields for a given area and vegetation index (Turvey and Mclaurin 2012) developed using satellite images have important limitations. For example, average yields may not work when the production conditions are heterogeneous or satellite-based vegetation cover may not differentiate different stresses. However, recent advances in satellite technologies are believed to correct these imperfections (Barrett et al. 2012; Leblois and Quirion 2011) although its cost-effectiveness, correlation with the underlying production risk and ability to discriminate different crops will need to be tested.

Despite continued pilot testing of weather index insurance products in low income countries, its actual uptake has been far below expectations (Giné and Yang 2009; Binswanger-Mkhize 2012; Cole et al. 2013). The high price (premium) and lack of trust in the index and its ability to properly predict the risk of loss as well as the credibility of the insurance providers are key factors negatively influencing the demand for weather index insurance (Brans et al. 2010; Cole et al. 2013). Clarke (2011) shows that the low demand for weather index insurance by poor farmers is a rational response to basis risk. For higher uptake, weather index insurance should be cheaper than the current risk management practices of smallholders, such as reliance on social networks and self-insurance mechanisms by owning assets (Binswanger-Mkhize 2012). Others argue that promoting access to productive assets (e.g. land), credit, improved seeds, better agronomic practices and rural infrastructure are the key factors for the poor to build their own capital to self-insure in case of disaster. It is however difficult for the poor to build capital for climate risk management and risk transfers (insurance) in the short run as current consumption competes with future savings. Insurance and credit instruments for smallholders may need to be seen as essential complements rather than substitutes for risk-reducing and profitable technological innovations. This is particularly relevant as technological solutions per se will be inadequate in managing production risks caused by severe climate shocks and extreme events expected under progressive climate change.

In this paper, we review experiences in piloting weather index insurance products and examine how weather index insurance could contribute to managing drought risk in smallholder agriculture. We provide insights based on a review of literature, including case examples of weather index insurance pilots in Africa (particularly Ethiopia, Kenya, and Malawi).

The rest of the paper is organized as follows: Section 2 presents an overview of the traditional drought risk management strategies in smallholder agriculture as a backdrop for weather index insurance instruments, including moral hazard and adverse selection problems of traditional crop insurance; Section 3 summarizes conceptual issues around weather index insurance, its development and implementation challenges; in Section 4, we summarize weather index insurance pilots in three African countries and draw lessons and highlight challenges; in Section 5, we look into the prospects of interlinking insurance with credit or safety nets to stimulate wider uptake and discuss the implications for designing weather index insurance at different levels (macro, meso, and micro), before we conclude in the final section with some suggestions on the way forward.

Drought risk management strategies

Drought is the major risk in rainfed agriculture (World Bank 2005; Burke et al. 2010) – amounting to 83 % of all the risks in sub-Saharan African agriculture and bringing about 40 % of economic damages to smallholders (Burke et al. 2010). However, the omnipresence of drought in sub-Saharan African agriculture implies that weather index insurance does not come into a vacuum. Various drought risk management strategies already exist and weather index insurance needs to be contextualized to diverse settings. The present section first reviews some of the existing strategies at the household (micro-level) and community (meso-) level and potential contributions from external assistance (macro-level).

Household strategies (micro-level)

Households which specialize in farming are more vulnerable to the effects of weather variability compared to those which diversify (Hazell et al. 1986). However, diversification may result in lower yields and in lower income and assets, which could have been used for mitigating risks through financial markets, such as insurance. For instance, studies in India and Burkina Faso indicate that farmers sacrifice 12 % to 30 % of average income to reduce risk by relying on low-return low-risk production activities (Gautam et al. 1994; Sakurai and Reardon 1997; Rosenzweig and Binswanger 1993).

Hazell et al. (1986) are among the few who compare the costs of diversification with the benefits of crop insurance for managing the effects of drought risks. The more an area is suitable for a single crop (less diversified farming system), the higher its vulnerability to yield and price risk caused by drought. Smallholders being price takers and lacking basic market information implies that they should rely on diversification for adapting the effects of drought in the foreseeable future. This reinforces the need for improved varieties that are drought tolerant. Hence, the key challenge for crop/livestock breeders is to develop varieties capable of adapting to drought risk, while maintaining better yield and other desirable characteristics perceived by farmers. For instance, crop varieties with abiotic stress tolerance saved more than 50 % of the current yield loss in drought-prone areas (Wang et al. 2003). Hence, developing drought-tolerant varieties and investing in small-scale irrigation should also be key risk management strategies for low income countries in their medium- and long-term plans.

Community-based arrangements (meso-level)

Sharecropping is a traditional risk sharing arrangement in developing agrarian economies (Otsuka and Hayami 1993). Social capital and networks provide various community-based risk management arrangements, but, although effective in protecting against risks affecting households in isolation (Walker and Jodha 1986), they are not effective in protecting households from correlated risks, unless households have established networks outside of their community or regions (Morduch 1995; Battamishra and Barrett 2010). Climate variability is expected to reduce the effectiveness of traditional risk management strategies and may require a market-based risk management strategy, such as weather index insurance in agriculture (Skees et al. 1999; World Bank 2005; Linnerooth-Bayer et al. 2005; Meze-Hausken et al. 2009). However, the cost of insurance is expected to rise with an increase in the unpredictability of weather conditions that may call for a partial insurance subsidy using climate change adaptation funds for highly-vulnerable countries/regions (Linnerooth-Bayer et al. 2005; Hazell and Hess 2010). Thus, a balance between community-based risk management arrangements and market-based risk management strategies may benefit many households in low income countries.

External assistance (macro-level)

Low income countries may sometimes require external assistance to manage large scale disaster risks. An important challenge with this kind of risk management strategy is the time lag between a disaster and the arrival of donor funds and the required aid to save lives at risk (Linnerooth-Bayer et al. 2005). In widespread disaster situations, timing of interventions will have substantial impact on averting famine conditions as well as the ability of vulnerable households to withstand future shocks. In many cases, humanitarian assistance arrives late in the season and after people have already lost their most valuable assets such as livestock, or have a diminished health/nutritional status to a level that will undermine future recovery and resilience. In some cases, donor support may be limited either due to aid fatigue or the internal political conditions and insecurity in the affected country that may affect delivery of relief and development assistance. In such cases, the effectiveness of external assistance for disaster risk management is compromised. As an alternative strategy, international aid agencies have considered using weather index insurance instruments to pre-finance disaster relief services (Hess and Syroka 2005; World Bank 2005; Chantarat et al. 2007; Linnerooth-Bayer et al. 2005; Hazell and Hess 2010). For instance, in 2006, the World Food Program (WFP) purchased about US$1 million worth of weather index insurance premiums for Ethiopian farmers from the international re-insurer, Axa, with a maximum payout of US$7.1 million. Several other studies and pilot projects have also shown the relevance of weather index insurance for famine prevention and its effectiveness towards enhancing disaster risk management ability of low income countries (see Hess and Syroka 2005; World Bank 2005; Chantarat et al. 2007).

The African Risk Capacity (ARC), a specialized agency of the African Union, aims to develop a pan-African risk pooling and transfer instrument using weather index insurance to pre-finance disaster risks (e.g. drought, flooding) for affected member states (ARC 2014a). This is an important institutional response from the African Union Commission to manage agricultural risks in Africa and ARC has recently provided weather index based payouts in Senegal, Mauritania and Niger (ARC 2014b). When it is widely implemented, this will be an important macro-level drought risk management system that allows African countries reduce the high social and humanitarian costs from delayed responses to drought and related risks by providing predictable and timely responses to food insecure populations affected by extreme weather events based on a measurable index to trigger payouts to member states.[2]

Review

Weather index insurance

Conceptual issues

Weather index insurance principles were initiated by Halcrow (1948) and further developed by Dandekar (1977). Skees et al. (1999) theoretically proposed these principles for developing countries and later on empirically tested in Moroco (Skees et al. 2001). Mahul (2001) provided a more formal framework for weather index insurance in agriculture. Using historical rainfall and temperature data, Turvey (2001) illustrated how weather index insurance could be used to address specific-event risks measured at the local level and how rainfall and heat insurance could be priced in practice.

Weather index insurance provides protection for vulnerable households against specific weather shocks (e.g. rainfall shortage or flooding) by using historical rainfall, yield and related agronomic and weather data (Osgood et al. 2007; Barnett et al. 2008).[3] A contract is signed between an insurer and a policy holder in advance. Payment is made based on the observable intensity of a weather index closely correlated to yield rather than to the non-observable specific impact on yield (Mahul 2001). The policy holder will get a payout when, for instance, rainfall is below an agreed amount (trigger point) based on automated weather station records. Weather insurance thereby needs evidence of the statistical relationship between the specific weather event being measured and volumetric risk (e.g. crop loss) at the farm level.

The challenge is how to make weather index insurance functional and attractive to both insurers and policy holders. This calls inter alia for a reliable index,[4] appropriate compensation of the policy holders in the event of loss, and affordability to the bulk of farm households in the risky environments. Several questions however remain whether index insurance would become a game-changing innovation for managing agricultural risks in low income regions where other options have often failed due to high costs and low returns to insurance providers. Will poor households use their limited savings and other resources (including labor) to participate in weather insurance markets? How does weather index insurance compare to traditional risk management arrangements (Binswanger-Mkhize 2012)?

The scientific and development community (including politicians) are somewhat polarized whether weather index insurance really works – particularly in terms of performance so far, and the inherent problems related to the accuracy of indices used. The advocates can be further divided into those eager to learn more about the 'index' and proposing ideas for further analysis (testing of weather index insurance); and those who trust the current indices and advocate scaling up and promotion. Critics argue that weather index insurance is costly to administer and suggest developing better insurance products such as using an area-yield approach (Herbold 2013). They further argue that since the current indices are far from representing the situation on the ground and are affected by basis risk, an insurance product (e.g. area-yield index contract) based on proper sampling of individual farm yields is far more realistic. This idea may be reasonable considering the large number of area-yield index based Indian crop insurance programs compared to the small number of weather based crop insurance contracts (Mahul and Stutley 2010; Rao 2010). However, the Indian programs that focus on area-yield indices are not free from basis risk[5] and the high administrative costs including the need for better infrastructure and manpower to undertake yield samples across remotely located farms (Rao 2010). In fact, an insurance company would have to undertake such studies in order to prove that there is, in fact, an insurable covariate risk between a proposed weather insurance product and a targeted loss. However, in less developed economies with limited historical yield data with which to measure covariate risks, taking random samples for yield estimation is expensive and may not provide a true yield distribution that can be generalized to the farming community, nor is random sampling robust enough to capture and price specific event risks. This is most important in capturing the extreme tails of the weather index insurance that is coupled with extreme losses in farm production. Unfortunately, there have been no empirical studies comparing the administrative costs of traditional crop insurance, versus weather index insurance schemes.

Mainstreaming weather index insurance mechanisms is already challenging with the current weather variability in low income countries. This is aggravated by climate change, with worrying trends and increasing variability in temperature and rainfall in many developing regions (IPCC 2007). With climate change, both informal insurance and market-based risk management strategies would be less effective unless equipped with innovations that will allow incorporating the changing likelihood of future uncertainty in temperature and rainfall (Mills 2007). A weather index insurance contract needs to account for such changes to avoid any biases and mismatches in payout calculations relative to the loss incurred at local level. Insurers may need to pool risks across larger locations (population) to reduce the variance of income and look for re-insurance (Skees et al. 1999; Meze-Hausken et al. 2009). However, pooling risks over extended locations (spatial variability) may increase basis risk, unless methods for minimizing it are applied. Any future success of weather index insurance rests on minimizing the above polarized/contested views and developing indices that truly identify and capture extreme weather risks.

Developing insurance instruments

The relevance of long term yield and weather data One of the key challenges in designing weather index insurance in developing countries is the lack of long term yield and weather data (Osgood et al. 2007; Kapphan 2011). In some cases, the level of aggregation of yield data is also a problem. Some researchers argue that it is more accurate to include yield or input use data (for calibrating indices) derived from plot level information/surveys than taking regional or national average yield or input use. For instance, Laajaj and Carter (2009) find that basis risk could be minimized using the village level area-yield index derived from plot and household level survey data. Morduch (2006) shows the relevance of long-term data on the same households through randomized location decisions to see the benefits of weather index insurance for the poor. However, care should be taken in any form of calibrating weather index insurance to non-weather variables since this will alter natural covariate relationships between weather and loss. Instead, the more practical approach is to allow a suite of products with different triggers that can be offered to farm households with different risk requirements and needs (Turvey and McLaurin 2012).

The availability of long term time series data for 25 to 30 years containing daily rainfall and temperature observations is another challenge for many low income countries. In many cases, weather data are incomplete or missing for several seasons and weather stations do not often represent heterogeneity in agro-climatic conditions. Although the current indices consider households within a 20 to 25 km radius from a weather station (Osgood et al. 2007), these indices do not often work in mountainous or heterogeneous farming systems where local variability in weather conditions is high (Gommes and Gobel 2013). Rainfall can vary across short distances as influenced by certain microclimatic factors. This is another type of basis risk negatively influencing the adoption of weather index insurance in many developing countries (Clarke 2011; Hill et al. 2010). In this regard, the establishment of automatic rainfall stations that are not subject to manipulation are expected to reduce basis risk. However, new stations lack historical data to write contracts unless insurers simulate data based on nearby station records (Kapphan 2011).

In case of serious droughts, basis risk may be less of a problem since the whole region could be affected more or less uniformly (serious drought as covariate risk). However, the magnitude of the problem depends on how the index is structured

(Barnett et al. 2008). Designing the contracts only for big shocks is another solution to reduce basis risk (Turvey 2008; Hazell and Hess 2010; OECD 2011). This allows smallholders to utilize their traditional risk management schemes for smaller and more frequent risks.

Rainfall indices and satellite imagery data Some researchers argue that rainfall may not be a good indicator since rain water may easily disappear as run-off or percolate into subsoil with no benefit to the plants (Rosema et al. 2010). Light rain may evaporate easily before it reaches plant roots and heavy rains beyond the limit of rain gauges are inaccurately measured (Leblois and Quirion 2011). At present, there are reasonable methods to fill in missing rainfall data (Gommes and Gobel 2013), and to calibrate new modern weather stations with older data. However, more research is needed to improve the effectiveness of these methods considering the capacity of poor nations. As an alternative to rainfall indices, the use of relative[6] evapo-transpiration (RE) was suggested by some service providers as an accurate measure of crop water use (Rosema et al. 2010; FESA 2014). RE relies on the use of satellite remote sensing and is being tested in some parts of Africa. For instance, in early 2010, using RE data supported by satellite images as an index, a maize insurance pilot was launched in Burkina Faso and Mali (Rosema et al. 2010; FESA 2014). (Also see Section 4 for Malawi).

Using satellite imagery, the Normalized Difference Vegetation Index (NDVI) is an important advancement to reduce basis risk. NDVI is capable of reporting a vegetation index at various resolutions and time intervals (Laajaj and Carter 2009). However, NDVI rarely differentiates pastures from cultivated land and availability of estimated indices can be delayed due to clouds (Leblois and Quirion 2011). Turvey and Mclaurin (2012) found that NDVI should not be widely applied unless calibrated using location specific data (Turvey and Mclaurin 2012). However, some of the current imperfections in satellite imagery can be improved in the near future. Hence, there could be alternative ways of addressing or minimizing the problem of basis risk in weather index insurance contracts through remote sensed relevant climate data or crop simulation models which estimate yield responses to climate shocks at the local level. This will require multi-disciplinary approaches and effective communication among different actors (crop modelers, climate scientists, underwriters, insurers, re-insurers and end users).

Implementation challenges

A key constraint of weather index insurance for small-scale farmers in low income countries is basis risk – often aggravated by poor data quality in calibrating indices (e.g. for drought, soil moisture or vegetation cover) in a given area (Barnett et al. 2008; Osgood et al. 2007; Clarke 2011; Hill et al. 2010; Cole et al. 2013). Poor correlation between yield at farm level and rainfall records at the nearby weather station results in spatial basis risk. A farmer with more experience and/or investments in soil and water conservation practices is less likely affected by flood compared to others with little or no experience/investments. The former may require insurance only if the extreme rainfall causes damage and when premiums are adjusted to take into account the precautionary measures already in place. In such instances, low-cost weather index insurance could be useful to backstop existing mitigation strategies. In order to capture the local context and reduce basis risk, a weather insurance product should be flexible enough to consider heterogeneity in location and household land management practices, long-term location-specific yield and input use data, historical rainfall information, flexible for regular updating and risk modification from contemporaneous seasonal weather forecasts. Incorporating such detailed variations will however lead to higher monitoring and insurance administrative costs that eventually make insurance more expensive. Subsidies have been variously used to make agricultural insurance including weather index insurance more attractive to farmers (Mahul and Stutley 2010; Mahul et al. 2012). The challenge would be to find a balance which will make the insurance product attractive to risk-prone smallholder farmers by lowering basis risk without unsustainable subsidies and a micro-level delivery mechanism that will be profitable to the insurance providers.

Case studies of market-based pilots in Africa

In this section, we summarize weather index insurance pilot projects from selected sub-Saharan countries in Africa: Ethiopia, Kenya and Malawi.[7] Without claiming to be complete or exhaustive, these case studies highlight experiences and challenges in testing and scaling weather index instruments in the sub-Saharan Africa region and complement an increasing body of literature on weather index insurance across different regions (Mahul and Stutley 2010; Fuchs and Wolf 2012; Mahul et al. 2012). Particularly, the results from recent pilot projects in Ethiopia that integrate weather index insurance with safety nets are important additions (Brans et al. 2010; OA 2010, 2013). Similarly, the cases from Kenya and Malawi are important in the on-going discourse regarding scaling up of weather index insurance and will inform the discussion on interlinking weather index insurance with credit. The examples from these three countries also represent the biggest initial efforts in terms of testing innovative pilot insurance products in sub-Saharan Africa.[8] Each case looks into the evidence, current debates and insights relevant for scaling up innovations and enhancing the demand for weather index insurance products. Although our review focuses on micro- and meso-level applications and implementation challenges, we also touch on some macro-level applications of weather index insurance such as integrating with safety net programs supported by governments and humanitarian organizations (see OA 2010; IFAD and WFP 2010; ARC 2014a; and it is further explored in Section 5.2).

Ethiopia Ethiopia is one of the largest food aid recipients in sub-Saharan Africa, largely due to drought-induced production shocks. Donor agencies and international organizations including national and regional governments are, therefore, looking for new ways of mitigating the effects of weather variability, including application of weather index insurance principles for disaster prevention (see Skees et al. 1999; World Bank 2005, 2011). In 2005/2006, the World Bank and World Food Program (WFP) tested the relevance of weather index insurance schemes for disaster relief in Ethiopia. During this period, WFP purchased drought insurance from Axa Re-insurance of about US$1 million (with a maximum payout of US$7.1 million) to finance weather insurance derivatives for Ethiopian farmers. Similarly, the World Bank provided a loan of US$180 million which included a pilot project for disaster relief (US$2.3 million). However, none of the pilot projects were viable (e.g. drought was not a problem in that particular period and those who paid a premium wanted to claim it back) and it was later discontinued. This does not mean the risk has disappeared. Farmers need insurance to transfer this risk although payouts may not have occurred. Because weather index insurance for famine prevention (drought mitigation) was in its infancy, farmers, local governments and policy makers were not in favor of supporting this pilot project in Ethiopia when they faced the real trade off in this particular year with good rainfall. This indicates that farmers and policymakers were not sufficiently educated on how weather index insurance principles operate and become hesitant after a good harvest to pay for the insurance coverage in the following season. The good year seems to create a short-lived euphoria that undermines the demand for insurance. It is important to design such pilot projects with full information on the principles and in close consultation with the end users and local officials. In some places, the lack of safety nets to integrate with weather index insurance is considered a challenge rather than conceptualizing its benefit.

In 2009, the Horn of Africa Risk Transfer and Adaptation project (HARITA) of Oxfam America (OA) along with local and international organizations such as the International Climate Research Institute (IRI) at Columbia University, Swiss Re and Nyala Insurance (a private company in Ethiopia) were able to develop a more participatory weather index insurance product in Northern Ethiopia. The HARITA project tried to integrate the Productive Safety Nets Program (PSNP) activities of the Ethiopian government with the so-called insurance-for-work (IFW) model (Brans et al. 2010). Farmers overwhelmingly supported the idea of insurance-for-work and suggested several creative ways of participation (Brans et al. 2010; OA 2010; also see section 5.2). This pilot insurance scheme initially covers 200 *teff*-producing farmers in the Kola Tenben districts of Northern Ethiopia (Brans et al. 2010; OA 2010). Later this pilot was scaled up from 200 farmers in one village to 13,000 in 43 villages (OA 2010). Supported by WFP, the International Fund for Agricultural Development (IFAD) and Oxfam America, the program was rolled out to additional regions in Ethiopia and Senegal (OA 2013; Greatrex et al. 2015). For instance, in 2012 about 19, 000 farmers were insured over 76 villages in northern parts of Ethiopia (OA 2013). However, the pilot project still faces the challenge of developing a viable and flexible index that could predict losses. More innovation (to minimize the problem of basis risk and behavioral problems affecting adoption of weather index insurance) and analysis will be needed to see the sustainability of this model.

Several other studies have been conducted in various parts of Ethiopia. For instance, Dercon et al. (2014) find that the uptake of weather index insurance is higher when insurance is channeled through group-based informal insurance schemes *iddir* (a funeral society) with appropriate training for group leaders. Hill and Viceisza (2011) found some evidence on the positive role of weather index insurance on fertilizer adoption. Other economic studies in Ethiopia on household willingness to pay for weather index insurance also found several factors, such as basis risk, education and trust as an important determinant for insurance uptake (Hill et al. 2010; Clarke 2011; Sarris 2013b).

Many rural households in Ethiopia have a limited understanding of crop insurance. For instance, in Tadesse et al. (2013) 64 % of households reported that they perceived insurance as something designed for rich people who can afford to pay insurance premium as is the case of motor insurance (many people in the survey areas are aware of motor insurance). A few others (5 %) thought drought was too infrequent. Other reasons include the lack of trust in insurance providers. Thus, focusing only on bigger, but infrequent, shocks may allow households to buy time and save a little money year after year.

Kenya Kenya is one of the countries where both index-based crop insurance (IBCI) and Index-based Livestock Insurance (IBLI) pilots have been tested. A recent review of the Financial Sector Deepening (FSD) supported by several donors in Kenya provided important lessons and recommendations based on the performance of weather index insurance pilots in the country (FSD 2014). The FSD review recommends that FSD scale down the retail pilots and take a longer-term view by concentrating on meso- and macro- level cover, such as an agricultural lending portfolio or area drought cover for government agencies and others responsible for drought response (FSD 2014) which is quite interesting and pragmatic given the challenges of micro-level commercialization of the product using the existing delivery mechanisms and weather data for computing locally relevant indices to trigger payout.

In 2010/11, an innovative index-based livestock insurance (IBLI) was introduced in Northern Kenya through the joint effort of the International Livestock Research Center (ILRI), Cornell University in USA, a private insurance company in Ethiopia and Swiss Re. Initial results from this initiative indicate that high premium, basis risk and risk preferences have strong effects on the uptake of insurance, similar to earlier findings (Mude and Barrett 2012). Using the NDVI index for vegetative cover on rangeland, Chantarat et al. (2012) found that risk preference, perceived basis risk and the subjective expectation of loss were important factors affecting Northern Kenyan pastoralists' willingness to pay for index-based livestock insurance. Besides index-based livestock insurance pilots, index-based crop insurance schemes (*Kilimo Salama*, meaning safe farming) are being tested. In an effort to reduce delivery costs, mobile phones are in use to pay premiums, receive payouts and weather information (see Syngenta 2012). The delivery mechanism is based on linking insurance with input marketing. When farmers buy seeds, fertilizer or other agricultural inputs, they can also buy insurance for their inputs by paying 5 % of the input cost. Covered farmers need to register in one of the weather stations close to their farm.

By the end of 2011, these innovations covered 23,000 households in five regions of Kenya and expansion to the remaining regions and other countries in Africa is expected (Syngenta 2012; ASN 2012). By the end of 2013, the program reached over 185,000 farmers in Kenya and Rwanda (Syngenta 2014). However, part of the success/expansion may be related with the 50 % premium subsidy[9] offered by this scheme although the program plans to achieve operational sustainability by the end of 2016 (Syngenta 2014). Timely delivery of agricultural inputs (fertilizer and improved seeds) interlinked with insurance services through mobile banking could bring a major breakthrough in transforming the rural economy in Kenya. If the index is properly developed, this approach has the potential to further reduce administrative costs in reaching the clients with specific information and effecting payouts in the event of shocks. Use of automated weather stations also overcomes the problem of manipulation of weather records. Syngenta claims that insured farmers earned 16 % more income compared to their uninsured neighbors (Syngenta 2014).

Malawi The weather index insurance programs in Malawi often bundled credit with mandatory weather index insurance to assure worried lenders (Suarez and Linnerooth-Bayer 2010; also see section 5.1). With technical support from the World Bank, weather index insurance was offered in 2005 by the Opportunity International Bank of Malawi (OIBM) and the Malawi Rural Finance Corporation (MRFC) to 892 groundnut and maize farmers (Hess and Syroka 2005). A total of a US$40,000 payout was made based on nearby weather station records. In 2006, the World Bank provided insurance for the purchase of improved seeds covering a total of 1700 households. For this pilot, farmers were required to pay 4.9 Euros per hectare premium to get a 25 Euro payout for their input cost if drought occurred. In 2010/11, program participation expanded and a total of 10,500 households were covered for their cash crop, tobacco. Besides tobacco and groundnuts, maize is an important staple crop being piloted by various programs in Malawi. For instance, in 2012/2013 a Dutch-based re-insurance company called COIN-Re along with local insurance companies insured 1282 maize growers in Central and Northern parts of Malawi using relative evapotranspiration (RE) as an index instead of using the rainfall index (FESA 2014). Similar pilot projects are on-going in other African countries such as Mozambique, Tanzania and Burkina Faso using RE as index (FESA 2014).

Since 2008, the government of Malawi and the World Bank along with Swiss-Re actively engaged in a weather derivative market to price drought risk (Syroka and Nucifora 2010). This is a typical macro-level application of weather index insurance similar to the WFP/World Bank and Ethiopian government pilot program in 2005/2006. With the establishment of the African Risk Capacity program, the Government of Malawi became one of the African member states which established a common risk management strategy (ARC 2014a).This may imply African countries are in a better position to manage disaster risks (e.g. drought, flood and related catastrophic events) without having to look for significant financial support from the World Bank and other donor agencies.

Approaches to enhance weather index insurance uptake

Given the numerous challenges associated with introducing and scaling weather index insurance in low income countries, we discuss below two innovative approaches: interlinking weather index insurance with credit or with safety nets. Although these approaches have been looked into in the academic literature and World Bank studies (Linnerooth-Bayer et al. 2005; Hess and Syroka 2005), new insights are emerging on opportunities and challenges for enhancing the uptake of weather index insurance in rural economies (Carter 2009; Shee and Turvey 2012; McIntosh et al. 2013; Tadesse et al. 2013).

Interlinking weather index insurance with credit

In low income countries farmers are often cash constrained and would benefit from accessing micro-credit – but uninsured loans may increase risk (Dercon and Christiaensen 2011; Karlan et al. 2014). For instance, farmers in rural Ethiopia equate taking loans as falling into an abyss where escape is not possible (Tadesse 2014). Moving towards insured loans (via interlinking credit with insurance such as demonstrated in *Kilimo Salama*, Kenya case study) may thereby provide improved access to modern agricultural technologies in risk-prone regions as long as insurance providers manage the relevant risks (Clarke and Dercon 2009; Carter 2009).

Beyond reducing lenders' fears, linking insurance with credit will also allow service providers to use one distribution channel (reduce administration costs such as through the use of innovative tools - e.g. mobile phone discussed earlier) that may also help to further reduce interest rates and insurance premiums. If credit is insured (either by directly paying part of the input cost as insurance premium or insuring agricultural output through weather index insurance), lenders will be less reluctant to enter into the rural financial markets (Shee and Turvey 2012; Carter 2009; Churchill 2002; Mahul 2001; Barnett et al. 2008). The findings from Shee and Turvey (2012) specifically showed the benefits of adding insurance risk premiums to base loan interest rates, thus avoiding the need to purchase the insurance up front, which is one of the key problems of cash constrained farmers. McIntosh et al. (2013) show that Ethiopian households that participate in interlinked index based weather insurance schemes are more likely to use chemical fertilizer compared to those with standalone insurance schemes.

Interlinking weather index insurance with credit holds particular promise (Shee and Turvey 2012; Carter 2009; Hess and Syroka 2005; McIntosh et al. 2013). Giné and Yang (2009) is an exception: they found demand for uninsured loans to be higher than for insured loans in Malawi. A possible explanation may be that taking a loan along with additional fees for insurance cover may be too expensive for some households with little or no money to pay up front. Although interlinking weather index insurance with credit may encourage rural financial institutions to provide credit to smallholder farmers (Carter 2009), it is important to develop products that could easily be interlinked with insurance (see Swiss Re 2010) and ease supply side constraints such as providing timely credit with the required amount (McIntosh et al. 2013). In addition, despite the theoretical justifications for interlinking insurance with credit (Farrin and Miranda 2015), there is lack of empirical evidence illustrating reductions in loan interest rates or insurance premiums due to the interlinkage. For instance, the study by McIntosh et al. (2013), though a good example of actual implementation of interlinked products, is still a pilot project with both supply and demand side problems. The authors indicate that one important supply side constraint is the lack of timely provision of credit in the required amount for households looking for interlinked products (McIntosh et al. 2013). Thus, future research may need to investigate whether or not such interlinkage will help reduce insurance administrative costs in practice. This may include the reduction in potential risks insurers may face while providing interlinked products to households who may be cash constrained to pay part of the upfront cost of insurance and increased demand for input credit that will reduce the need for input subsidies or reduce the cost of providing input loans when credit is insured.

Interlinking weather index insurance with safety nets

One recent innovative approach[10] in agricultural risk management is through the creation of employment opportunities for resource-poor farmers to pay insurance premiums in kind – e.g. through labor invested in natural resource management such as tree planting (Brans et al. 2010; OA 2010) or other public goods. Those who participate in insurance-for-work programs will receive an insurance certificate to guarantee payouts in the event of drought affecting crop production (Brans et al. 2010; OA 2010). This approach has been tested in northern Ethiopia by Oxfam America, private insurers, cooperative unions/micro-financial institutions, farmers and government agencies that run the current Productive Safety Net Programs (PSNP) in the country. About 60 % of the households chose to participate in the insurance-for-work program to get coverage for their most important staple cereal crop, *teff.* The remaining households participated by paying premiums in cash (Brans et al. 2010; OA 2010). This approach resolves the cash constraints of the poor to invest in risk transfer instruments and could contribute to enhancing wider uptake if the index is appropriate. Alternatively, it can be used to provide consumption smoothing to affected households in the event of catastrophic climate shocks which will allow them avoid famine or asset disinvestments. It opens new opportunities to combine safety nets with insurance provision, using the seasonally abundant family labor resources, and without denying the food or cash to those who need it most to smooth their consumption.

Building on these initial results from this pilot project in Northern Ethiopia, a more quantitative econometric analysis on this innovative approach was conducted in Southern and Oromia regions of Ethiopia in order to verify its scalability (Tadesse et al. 2013). Households were provided with three payment options: cash, labor and a combination of cash and labor – the wage rate for this study was set at16 Ethiopian Birr (the Ethiopian currency) per day (close to US$1 during the survey period) similar to the wage rate for food-for-work or cash-for-work programs in Ethiopia. Results from this study indicate that the majority of households (83 %, $N = 576$) would like to participate in the insurance-for-work program (labor option) even at a lower wage rate than the wage rate under food-for-work or cash-for-work programs in Ethiopia. Those with better assets (cash, livestock, and stored grain) prefer to use their cash rather than investing their labor in low wage insurance-for-work programs. This suggests cash-constrained farmers are more willing to use their labor to get insurance cover rather than use their scarce cash when wage-earning options are limited (Tadesse et al. 2013). However, the insurance-for-work option needs someone to provide employment (e.g. productive safety nets programs to build local public goods) for the small-scale farmers to pay their premium through their seasonal labor. This does not mean their premium is paid by someone else but an interlocutor is needed to facilitate the employment option, for example in the form of existing food-for-work or cash-for-work programs to help them pay their premium through their labor. This may indicate that interlinking safety net programs that provide income and employment functions such as PSNP with insurance may provide a win-win outcome which will provide insurance to vulnerable families and enhance local public goods for long-term resilience. Insurance providers/governments may also expand their services using a more flexible approach which will allow even the very poor households to participate in insurance markets and pay their premium. This enables donors and government agencies to help focus on ex-ante risk financing instruments (see Hess and Syroka 2005; Chantarat et al. 2007; Linnerooth-Bayer et al. 2005; ARC 2014a) delivered through trusted and functional local employment schemes which use family labor as the most available resource of the poor rather than rely on ex-post disaster risk management strategies that are often costly.

Because this innovative approach is in its early stage (OA 2013), further research is needed by testing its validity across agro-ecologies and socio-economic groups, especially in areas where safety net programs are operational. The approach is promising for wider piloting and scaling up because it overcomes a key cash constraint that weather index insurance typically faces through the use of surplus labor during the slack season when the opportunity cost of labor is low. The credibility of the program was enhanced by its linkage with a reliable program. However, it still faces the problem of basis risk to make reliable payouts based on objective assessment of individual losses from climate shocks.

Design features for weather index insurance

The studies reviewed in this article show varying potential for the use of weather index insurance in smallholder agriculture at different levels (macro-, meso- and micro). Lack of trust in the product, the delivery mechanisms and the mismatch between the calculated index and realities on the ground (actual yield loss) have particularly affected local level retailing of weather index insurance for agricultural risk management. The classic problems of contracting and contract enforcement (Barrett et al. 2012) prevent service providers from retailing weather index insurance products directly to the producers. This is particularly the case when the premium is included as part of the interest payment on the input credit (Shee and Turvey 2012). Problems of contract enforcement and the risk of securing sufficient payouts in the event of drought also push smallholders to shy away from signing on to available insurance schemes. In order to overcome problems of trust and moral hazard, some authors have advocated collective contracting of index insurance (Trærup 2012) but this is unlikely to solve the inherent problem of high basis risk which underlines computation of payouts. Because of these challenges, the various pilots suggest that weather index insurance should not at this stage press for retailing of the product to individual farmers (FSD 2014). For instance, the modified national agricultural insurance scheme in India still primarily relies on area yield index despite the costs and short-comings (Mahul and Stutley 2010; Mahul et al. 2012). However, the meso- and macro-applications of weather index insurance may still be compelling (IFAD and WFP 2010).

- Meso-level where lenders, input providers, farmer organizations, or NGO purchase portfolio or group cover policies in order to retail to members, particularly against default, without requiring measurement of individual losses.
- Macro level, in which a government or NGO insures a particular region or country in order to ensure that timely payouts are available for disaster assistance.

Several examples of weather index insurance reviewed provide examples of meso- and macro-level applications. Agencies involved in disaster risk management (e.g. governments, NGOs, WFP) could buy weather index insurance to cover vulnerable communities/regions or households with the objective of accessing timely funds to provide assistance before hunger and malnutrition sets in and forces households to sell their productive assets needed for long-term resilience and poverty reduction. Along the same lines, the potential of weather index insurance for famine prevention is widely recognized (Linnerooth-Bayer et al. 2005; World Bank 2011; ARC 2014a). Chantarat et al. (2007) using data from Kenya show the positive benefit of linking weather index insurance contracts for famine prevention as it allows timely response to shocks and reduces humanitarian costs through the pre-financing ability of insurance. In some cases, vulnerable households may be able to pay the premiums through employment in public works and productive safety nets (as in the Ethiopia case). In other cases, governments and NGOs may be able to buy such insurance as famine prevention strategies without retailing to individual households. The recent initiative by African Union member states (African Rick Capacity) is an example of macro and regional risk pooling that may solve the challenges related to securing funds before disaster hits a given region or population (ARC 2014a).

Conclusions

Despite the increasing popularity of weather index insurance principles among the scientific and insurance/re-insurance community, its uptake remains limited and challenging in smallholder agriculture. For many, the actual benefits (relative to costs) in reducing household vulnerability to production risks and poverty remains to be proven – especially in the context of extreme climate variability and change. However, refining rainfall-based insurance indices, using multiple weather stations instead of one station to represent a particular target area (Gommes and Gobel 2013), and investing in automatic rainfall stations (infrastructure) for developing countries, possibly through external support (Leftley 2009; Sarris 2013a), are some of the issues that need policy attention and public-private partnerships (Mills 2007), to mitigate the impact of weather-based agricultural risks in the low income world. It is necessary to acknowledge that weather index insurance should be considered a promising addition to the portfolio of risk management options in developing countries, instead of considering it *the* only solution for all weather-based risks faced by resource-poor producers (Churchill 2002). Furthermore, weather risk is just one – albeit a major – risk that confronts smallholders in developing countries. Approaches that link weather index insurance with crop yield or revenue indices may help address the multiple shocks that affect smallholder producers.

Social scientists can contribute to developing better methods and tools that increase the demand for weather-index insurance through demand analysis and the understanding of farmer decision-making behavior and the effect of imperfect and asymmetric information. Hence, collaboration among social scientists, economists, remote sensing experts, agro-climatologists, crop modelers, climate scientists and development practitioners, including end-users, is essential to streamline the weather-index insurance approach for agricultural risk management.

Our review identified two innovative approaches. First, in drought-affected areas (e.g. the Horn of Africa regions and many parts of sub-Saharan Africa), agricultural input credit schemes may be interlinked with insurance to enhance access to credit services and improve adoption of improved agricultural technologies (Carter 2009). This offers the dual benefit of reducing the lenders' and borrowers' risk which has been the major obstacle for provision of input credit and for farmer adoption of complementary inputs such as fertilizer and improved seeds. It will enhance the uptake of weather index insurance when it is linked to a trusted delivery mechanism (or supplier) and bundled with the supply of key inputs. The complementary use of insurance and credit may in the long term facilitate poverty reduction through technical change, asset building and resilience to diverse shocks. In order to leverage these gains, mandatory insurance may be required (e.g. India) for farmers borrowing to finance inputs. Second, case studies from Ethiopia showed the attractiveness of linking weather index insurance with productive safety net programs (food-for-work or cash-for-work). This allows cash-constrained households to use their seasonal surplus labor to buy insurance against drought while building public goods local infrastructure or assets, which will enhance resilience or access to markets. Even in this case, payouts cannot be directly linked to farm level losses rather than payments for consumption smoothing to avoid famine situations. However, robust indices are still needed before the large-scale popularization of the insurance-for-work model. Future success in commercializing the product at the micro-level would depend on to what extent weather index insurance will be attractive to smallholder producers in risk-prone regions, who often prefer informal systems and tighten their belts, diversify crops, borrow from friends or neighbors rather than invest in formal insurance mechanisms or productive assets that may be risky but provide a higher return.

There is a need for innovation and further research in minimizing basis risk (indices improvement) and in educating smallholders and building trust, both in the indices and in the providers of index insurance. Statistical indices constructed based on weak and unreliable agro-climatic data for linking rainfall with agricultural productivity are distinctly inadequate. A more reliable predictor of smallholders' yield and consumption risks and losses due to weather changes is needed to operationalize the approach. In this regard, more flexible geospatial crop modeling tools that take into account location specific agro-climatic soil and agronomic conditions to properly predict the effects of weather deviations on crop yield[11] may be relevant. In the short run, weather index insurance schemes seem to be more attractive at the macro- and meso-levels to allow risk pooling and transfers across regions in preparation for a timely and effective response to catastrophic climatic shocks. We call for more research on ways to reduce the basis risk, combining the best data and decision tools available, and develop indexes that adequately predict the risks faced by smallholders. This will be a major contribution to making weather index insurance more functional and attractive to both insurers and policy holders and thereby enable it to realize its full potential and generate widespread uptake. Finally, the review acknowledges that, despite the promising conceptual justifications, the suggested solutions for interlinking insurance with credit markets still require ground level applications and empirical evidence on the benefits in terms of lowering insurance costs or reducing the cost of borrowing and making credit more accessible to smallholder farmers in low income countries.

Endnotes

[1]In some cases, it is also possible to design index based insurance contracts based on remote sensing information without relying on weather station records.

[2]The creation of the Caribbean Catastrophe Risk Insurance Facility (CCRIF) established in 2007 to provide member states with immediate liquidity after natural disasters

is a good example for such regional risk pooling and transfer systems. While CCRIF is designed to support governments in providing enhanced assistance to affected populations, ARC may in addition need to consider contingency plans and national delivery mechanisms to ensure timely response and effective assistance for the needy (ARC 2014a).

[3]In principle, it may work for broader agro-climatic shocks that affect production such as heat waves, frost and other extreme events as long as these are independently observable and verifiable at low cost.

[4]A good correlation between actual yield loss and the weather index.

[5]Area-yield index does not directly rely on a weather parameter for crop insurance contract design but it depends on crop yield index across a representative target area or individual farm historical yield. However, it requires monitoring crop yield at individual or sample farmers' field condition that may still be costly.

[6]This method uses visual and thermal infrared satellite data in mapping temperature, radiation, evapotranspiration and precipitation from space (Rosema et al. 2010).

[7]Considering the large number of pilot projects and interest in weather index insurance, the current case study countries may not be representative.

[8]The experience of Ghana and Senegal is also interesting and will require additional reviews.

[9]We thank one of the anonymous referees for the subsidy information on Kenyan pilots.

[10]Our review shows that even standard approaches in the design and application of weather index insurance can be challenging for roll out to smallholder farmers (e.g. in terms of skills, resources, and infrastructure). Thus, it may not be possible to develop one standard approach in product design and delivery and new approaches are needed to enhance product uptake.

[11]For example, the Agricultural Insurance Simulation Model (AISM) was developed to model the relationship between weather conditions and crop yields in Mexico. The model consists of a system of equations representing the crop-soil-weather relationship taking into account the specifics of each agronomic climate region and determines the critical threshold values of the index below which the indemnity payments are triggered (Fuchs and Wolf 2012).

Competing interests
The authors declare that they have no competing interests.

Authors' contributions
MT carried out a systematic review and development of key concepts and produce a draft manuscript. MT also contributed towards improving sections and subsections of this article. BS contributed by expanding the initial concepts, provided further insights and improved many of the sections and subsections of the article. OE carried out structuring the draft manuscript and contributed improving many of the sections and subsections. All authors read and approved the final manuscript.

Acknowledgments
The first author gratefully acknowledges financial support from the Research Council of Norway project (# 208540). The first author also gratefully acknowledges the Norwegian University of Life Sciences, School of Economics and Business, Ås Norway and CIMMYT for providing the necessary supports during his post-doctoral research fellowship period (2011-2013) when the first draft of this paper was completed. The views expressed in this review are those of the authors and do not necessarily reflect the views of the authors' institutions. We are grateful to the anonymous reviewers for their valuable comments. We also thank Clare Stirling, and Calum G. Turvey for helpful comments on earlier versions ofthis paper. The usual disclaimer applies.

Author details
[1]Department of Statistics and Actuarial Science, University of Waterloo, 200 University Avenue West, N2L3G1, Waterloo, Ontario, Canada. [2]Partnership for Economics Policy, Nairobi, Kenya. [3]International Maize and Wheat Improvement Center (CIMMYT), Texcoco, Mexico.

Received: 18 May 2014 Accepted: 13 November 2015
Published online: 30 November 2015

References

ARC (2014a) African Risk Capacity. Sovereign Disaster Risk Solution. A specialized agency of the African Union. Building Resilience to Climate Change in Africa., Available at: http://www.africanriskcapacity.org/documents/350251/371565/ARC_Climate_Change_in_Africa_2014.pdf. Accessed 22 October 2014

ARC (2014b) African Risk Capacity. Sovereign Disaster Risk Solution. A specialized agency of the African Union. Risk pool., Available at: http://www.africanriskcapacity.org/countries/risk-pool-1

ASN (2012) African Science News. Kenya's innovative agricultural program wins award. http://www.kacekenya.co.ke/news.asp?ID=293. Accessed on 18 Nov 2015.

Barnett BJ, Barrett CB, Skees JR (2008) Poverty traps and index-based risk transfer products. World Dev 36(10):1766–1785

Barr R, Fankhauser S, Hamilton K (2010) Adaptation investments: A resource allocation framework. Mitig Adapt Strat Glob Chan 15(8):843–858

Barrett CB, Bachke ME, Bellemare MF, Michelson HC, Narayanan S, Walker TF (2012) Smallholder participation in contract farming: comparative evidence from five countries. World Dev 40(4):715–730

Battamishra R, Barrett CB (2010) Community-based risk management arrangement: A review. World Dev 38(7):923–932

Binswanger-Mkhize HP (2012) Is there too much hype about index-based agricultural insurance? J Dev Stud 48(2):187–200

Brans MV, Tadesse M, Takama T (2010) Community-based solutions to the climate crisis in Ethiopia. In: Fujikura R, Kawanishi M (eds) Climate Change Adaptation and International Development. Making Development Cooperation More Effective. Earthscan, UK

Burke M, de Janvry A, Quintero J (2010) Providing index based agricultural insurance to smallholders: Recent progress and future promise. Available at: http://siteresources.worldbank.org/EXTABCDE/Resources/7455676-1292528456380/7626791-1303141641402/7878676-1306270833789/Parallel-Session-5-Alain_de_Janvry.pdf. Accessed 18 Nov 2015.

Carter MR (2009) Intelligent design of index insurance for smallholder farmers and pastoralists. In: Hill RV, Torero M (eds) Innovations in insuring the poor. Focus 17, Brief No 6. 2020 Vision for Food, Agriculture and Environment. IFPRI, Washington, DC

Chantarat S, Barrett CB, Mude AG, Turvey CG (2007) Using weather index insurance to improve drought response for famine prevention. Am J Agri Econ 89(5):1262–1268

Chantarat S, Mude A, Barrett CB, Carter M (2012) Designing index based livestock insurance for managing asset risk in Northern Kenya. J Risk Insurance 80(1):205–237

Churchill C (2002) Trying to understand the demand for micro-insurance. J Inter Dev 14(3):381–387

Clarke D (2011) Insurance design for developing countries: A theory of rational demand for index insurance. Discussion paper series. Department of Economics. University of Oxford. Available at: http://core.ac.uk/download/pdf/6330307.pdf. Accessed on 18 Nov 2015.

Clarke D, Dercon S (2009) Insurance, credit and safety nets for the poor in a world of risk. UN/ DESA Working Paper No. 81. Economic and Social Affairs, USA, Available at: http://www.un.org/esa/desa/papers/2009/wp81_2009.pdf. Accessed on 18 Nov 2015.

Cole S, Giné X, Tobacman J, Topalova P, Townsend R, Vickery J (2013) Barriers to household risk management: Evidence from India. Am Econ J 5(1):104–35

Dandekar VM (1977) Crop insurance for developing countries. Teaching and Research Forum Paper No. 10. Agricultural Development Council, New York, Accessed 12 January 2013

Dercon S, Christiaensen L (2011) Consumption risk, technology adoption, and poverty traps: Evidence from Ethiopia. J Dev Econ 96(2):159–173

Dercon S, Hill RV, Clarke D, Outes-Leon I, Seyoum TA (2014) Offering rainfall insurance to informal insurance groups: Evidence from a field experiment in Ethiopia. J Dev Econ 106(C):132–143

Farrin K (2015) Miranda MJ (2015) A heterogeneous agent model of credit-linked index insurance and farm technology adoption. J Dev Econ 116:199–211

FESA (2014) Food Early Solution for Africa (FESA) FESA micro-insurance. Crop insurance reaching every farmer in Africa. January 2014 Final report. Available at: http://www.ears.nl/user_files/FESA%20Micro-insurance%20-%20reaching%20every%20farmer%20in%20Africa.pdf. Accessed 15 December 2014

FSD (2014) Review of FSD's index based weather insurance initiatives. Financial Sector Deepening (FSD) Kenya. Available at: http://fsdkenya.org/publication/review-of-fsds-index-based-weather-insurance-initiatives-issue-03/. Accessed on 18 Nov 2015.

Fuchs A, Wolf H (2012) Concept and unintended consequences of weather index insurance: The case of Mexico. Am J Agri Econ 93(2):505–511

Gautam M, Hazell PBR, Alderman H (1994) Rural demand for drought insurance. Policy Research Working Paper 1383. World Bank, Washington DC

Giné X, Yang D (2009) Insurance, credit, and technology adoption: Field experimental evidence from Malawi. J Dev Econ 89(1):1–11

Gommes R, Gobel W (2013) Beyond simple, one station indices. In: Gommes R, Kayitakire F (eds) Proceedings of the challenges of weather index insurance for food security in developing countries. Organized by the EC Joint Research

Centre (JRC) and the International Research Institute for Climate and Society (IRI, Earth Institute, Columbia University), Milan, 2013
Greatrex H, Hansen J, Garvin S, Diro R, Le Guen M, Blakeley S, (2015) Scaling up index insurance for smallholder farmers: Recent evidence and insights. Report No 14. CCAFS, Copenhagen. Available at: https://cgspace.cgiar.org/bitstream/handle/10568/53101/CCAFS_Report14.pdf. Accessed 30 January 2015
Halcrow HG (1948) The theory of crop insurance. Unpublished doctoral dissertation, University of Chicago. Department of Economics, Chicago
Hazell PBR, Hess U (2010) Drought insurance for agricultural development and food security in dryland areas. F Security 2(4):395–405
Hazell P, Bassoco LM, Arcia G (1986) A model for evaluating farmers' demand for insurance: Applications in Mexico and Panama. In: Hazell PBR, Pomareda C, Valdés A (eds) Crop insurance for agricultural development: issues and experience. Johns Hopkins University Press, Baltimore
Herbold J (2013) Index insurance in agriculture-the (re) insurer's perspective. Agricultural department, Munich Re. In: Gommes R and Kayitakire F (Eds.) Proceedings of the challenges of weather index insurance for food security in developing countries. Organized by the EC Joint Research Centre (JRC) and the International Research Institute for Climate and Society (IRI, Earth Institute, Columbia University), Milan, 2013
Hess U, Syroka J (2005) Weather-based Insurance in Southern Africa. The Case of Malawi. Agriculture and Rural Development Discussion Paper 13. The World Bank. Available at: http://siteresources.worldbank.org/EXTCOMRISMAN/Resources/weathermalawi.pdf. Accessed on 18 Nov 2015.
Hill RV, Kumar N, Hoddinott J (2010) Adoption of weather-index insurance: Learning from willingness to pay among a panel of households in rural Ethiopia. Mimeo, International Food Policy Research Institute (IFPRI). Available at: http://www.ifpri.org/sites/default/files/publications/ifpridp01088.pdf. Accessed 20 November 2012
Hill RV, Viceisza A (2011) A field experiment on the impacts of weather shocks and insurance on risky investment. Exp Econ 15(2):341–371
FAD, WFP (2010) International Fund for Agricultural Development (IFAD) and World Food program (WFP). Potential for scale and sustainability in weather index insurance for agriculture and rural livelihoods. Rome.
IPCC (2007) Intergovernmental Panel for Climate Change. Working group II. Fourth Assessment report. Available at: https://www.ipcc.ch/publications_and_data/publications_ipcc_fourth_assessment_report_wg2_report_impacts_adaptation_and_vulnerability.htm. Accessed on 18 Nov 2015.
Kapphan I (2011) Optimal weather insurance design- a quantitative exploration. Paper presented at modeling and simulation society of Australia and New Zealand, MSSANZ. Perth, May 2011
Karlan D, Kutsoati E, Osei-Akoto I, Udry C (2014) Agricultural decisions after relaxing credit and risk constraints. QJEcon 129(2):597–652
Laajaj R, Carter MR (2009) Using satellite imagery as the basis for index insurance contracts in West Africa. University of Wisconsin-Madison, Department of agricultural and applied economics. BASIS letter dated on March 7, 2009. Accessed 20 December 2012
Leblois A, Quirion P (2011) Agricultural insurances based on meteorological indices: realizations, methods and research challenges. Mete Applic. doi:10.1002/met.303
Leftley R (2009) Micro-insurance for health and agricultural risks. In: Hill RV, Torero M (eds) Innovations in insuring the poor. Focus 17, Brief No. 4. 2020 Vision for Food, Agriculture and Environment. IFPRI, Washington DC
Linnerooth-Bayer J, Mechler R, Pflug G (2005) Refocusing disaster aid. Science 309:1044–1046
Mahul O (2001) Optimal insurance against climatic experience. Am J Agri Econ 83(3):593–604
Mahul O, Verma N, Clarke D (2012) Improving farmers' access to agricultural insurance in India. World Bank Policy Research Working Paper 5987. Available at: http://elibrary.worldbank.org/doi/abs/10.1596/1813-9450-5987. Accessed on 18 Nov 2015.
Mahul O, Stutley JC (2010) Government support for agricultural insurance. Challenges and options for developing countries. World Bank, Washington DC, Available at https://openknowledge.worldbank.org/bitstream/handle/10986/2432/538810PUB0Gove101Official0Use0Only1.pdf?sequence=1. Accessed 15 December 2014
McIntosh C, Sarris A, Papandopoluos F (2013) Productivity, credit, risk, and the demand for weather index insurance in smallholder agriculture in Ethiopia. Agri Econ 44(4-5):399–417
Meze-Hausken E, Patt A, Fritz A (2009) Reducing climate risk for micro insurance providers in Africa. A case study of Ethiopia. Glob Envi Chan 19(1):66–73
Mills E (2007) Synergisms between climate change mitigation and adaptation: an insurance perspective. Mitig and Adapt Strat Glob Chan 12(5):809–842
Miranda MJ, Farrin K (2012) Index insurance for developing countries. Appl Econ Presp and Policy 34(3):391–427
Morduch J (1995) Income smoothing and consumption smoothing. J Econ Persp 9(3):103–114
Morduch, J. (2006) Microinsurance: the next revolution? Understanding Poverty. In: A. Banerjee, R. Benabou, and D. Mookherjee (eds.), Oxford University Press, New York, NY.
Mude AG, Barrett CB (2012) Index-based livestock insurance in northern Kenya: An analysis of the patterns and determinants of purchase. Paper presented at I4 meetings, Rome, Italy. June 14, 2012. Cited 10 Jan 2013.
OA (2010) Oxfam America. Horn of Africa Risk Transfer for Adaptation, (HARITA). HARITA progress report: January-June, 2010. Available at: http://www.oxfamamerica.org/publications/harita-progress-report-jan-jun-2010. Accessed 20 October 2013
OA (2013) Oxfam America. R4 Rural Resilience Initiative. 2013 Annual report, Available at: http://www.oxfamamerica.org/static/media/files/r4-quarterly-report-jan_mar2013.pdf-2.pdf. Accessed 02 December 2014
OECD (2011) Organization for Economic Co-operation and Development. Risk management in agriculture. What roles for governments?, Available at: http://www.oecd.org/agriculture/agricultural-policies/49003833.pdf. Accessed on 18 Nov 2015.
Osgood DE, McLaurin M, Carriquiry M, Mishra A, Fiondella F, Hansen J, et al. (2007) Designing weather insurance contracts for farmers in Malawi, Tanzania and Kenya. International Research Institute for Climate and Society, Earth

Institute, Columbia University Pallisades, New York., Available at: http://iri.columbia.edu/~deo/IRI-CRMG-Africa-Insurance-Report-6-2007/IRI-CRMG-Kenya-Tanzania-Malawi-Insurance-Report-6-2007.pdf. Accessed on 18 Nov 2015.
Otsuka K, Hayami Y (1993) The economics of contract choice: An agrarian perspective. Clarendon, Oxford
Rao KN (2010) Index based crop insurance. International conference on agricultural risk and food security. Agriculture and agricultural science procedia 1(2010):1993–203
Rosema A, DeWeirdt M, Foppes S, Wilczok C (2010) FESA Micro-insurance: methodology, validation, contract design. Millennium project no 38, DG International Cooperation, Ministry of Foreign Affairs, the Netherlands. Publication EARS Earth Environment Monitoring BV, Delft, the Netherlands
Rosenzweig M, Binswanger HP (1993) Wealth, weather risk and the composition and profitability of agricultural investments. Econ J 103(416):56–78
Sakurai T, Reardon T (1997) Potential demand for drought insurance in Burkina Faso and its determinants. Am J Agri Econ 79(4):1193–1207
Sarris A (2013 a) Demand for index based insurance by smallholders in light of existing rural institutions in Africa. In: Gommes R and Kayitakire F (Eds.) Proceedings of the challenges of weather index insurance for food security in developing countries. Organized by the EC Joint Research Centre (JRC) and the International Research Institute for Climate and Society (IRI, Earth Institute, Columbia University), Milan, 2013
Sarris A (2013b) Weather index insurance for agricultural development: Introduction and overview. Agri Econ 44(4-5): 381–384
Shee A, Turvey CG (2012) Collateral-free lending with risk-contingent credit for agricultural development: indemnifying loans against pulse price risk in India. Agri Econ 43(5):561–574
Skees JR, Hazell PBR, Miranda M (1999) New approaches to crop yield insurance in developing countries. International Food Policy Research Institute, Environment and Production Technology Division. EPTD discussion paper No.55. Washington, DC. Available at: http://www.worldcat.org/title/new-approaches-to-crop-yield-insurance-in-developing-countries-jerry-skees-peter-hazell-and-mario-miranda/oclc/44644350. Accessed on 18 Nov 2015
Skees J, Gober S, Varangis P, Lester R, Kalavakonda V (2001) Developing Rainfall-Based Index Insurance in Morocco, Working Paper No. 2577. The World Bank, Policy Research: Washington, DC. Available at http://documents.worldbank.org/curated/en/2001/04/1089479/developing-rainfall-based-index-insurance-morocco. Accessed 17 July 2015
Suarez P, Linnerooth-Bayer J (2010) Micro insurance for local adaptation. WIREs Clim Chan Focus Article 1:271–278
Swiss Re (2010) Micro insurance-risk protection for 4 billion people. Sigma. N0 6/2010. Switzerland. Available at: http://www.globalmicrocreditsummit2011.org/
Syngenta (2012) Foundation for Sustainable Agriculture. Skeptical farmers change their views. http://www.syngentafoundation.org/index.cfm?pageID=562. Accessed 19 July 2012
Syngenta (2014) Foundation for Sustainable Agriculture. Kilimo Salama.Available at: http://www.syngentafoundation.org/index.cfm?pageID=758. Accessed on 18 Nov 2015.
Syroka J, and Nucifora A (2010) National Drought Insurance for Malawi. World Bank Policy Research Working Papers, No. 5169. Available at: http://elibrary.worldbank.org/doi/book/10.1596/1813-9450-5169. Accessed 8 December 2014
Tadesse M, Alfnes F, Holden ST, Erenstein O (2013) Demand for innovative drought insurance schemes in Ethiopia. In: Gommes R, Kayitakire F (eds) Proceedings of the challenges of weather index insurance for food security in developing countries. Organized by the EC Joint Research Centre (JRC) and the International Research Institute for Climate and Society (IRI, Earth Institute, Columbia University), Milan
Tadesse M (2014) Fertilizer adoption, credit access and safety nets in rural Ethiopia. Agri Finance Rev 73(3):290–310
Trærup SLM (2012) Informal networks and resilience to climate change impacts: A collective approach to index insurance. Global Env Chan 22:255–267
Turvey CG (2001) Weather derivatives for specific event risks in agriculture. Rev Agri Econ 23(2):333–351
Turvey CG (2008) The pricing, structure, and function of weather-linked bonds, mortgages, and operating credit. Agri Finance Rev 68(1):135–150
Turvey CG, McLaurin MK (2012) Applicability of the Normalized Difference Vegetation Index (NDVI) in index- based crop insurance design. Wea Climate Soc 4(4):271–284
Walker TS, Jodha NS (1986) How small households adapt to risk. In: Hazell P, Pomareda C, Valdés A (eds) Crop insurance for agricultural development, issues and experience. Johns Hopkins University Press, Baltimore
Wang W, Vinocur B, Altman A (2003) Plant responses to drought, salinity and extreme temperatures towards genetic engineering for stress tolerance. Planta 218(1):1–14
World Bank (2005) Managing agricultural production risk: Innovations in developing countries. Agriculture and Rural Development Department, The World Bank, Washington DC, Available at: http://siteresources.worldbank.org/INTARD/Resources/Managing_Ag_Risk_FINAL.pdf. Accessed 23 November 2014
World Bank (2011) Weather index insurance for agriculture: Guidance for development practitioners. Agriculture and Rural Development Discussion paper 50. The World Bank, Washington, DC, Available at: http://documents.worldbank.org/curated/en/2011/11/15643352/weather-index-insurance-agriculture-guidance-development-practitioners. Accessed 23 December 2014