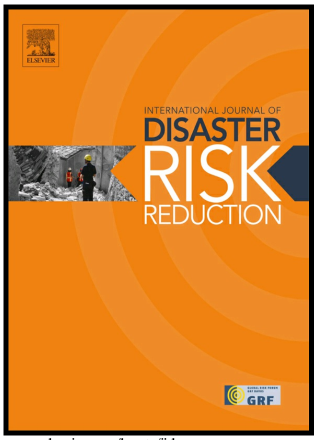
Author's Accepted Manuscript



www.elsevier.com/locate/ijdr

A global review of the impact of basis risk on the functioning of and demand for index insurance

Kristina Yuzva, W.J. Wouter Botzen, Jeroen Aerts, Roy Brouwer

PII: S2212-4209(18)30004-9
DOI: https://doi.org/10.1016/j.ijdrr.2018.01.001
Reference: IJDRR745

To appear in: *International Journal of Disaster Risk Reduction*

Received date: 3 April 2017
Revised date: 20 December 2017
Accepted date: 2 January 2018

Cite this article as: Kristina Yuzva, W.J. Wouter Botzen, Jeroen Aerts and Roy Brouwer, A global review of the impact of basis risk on the functioning of and demand for index insurance, *International Journal of Disaster Risk Reduction,* https://doi.org/10.1016/j.ijdrr.2018.01.001

A global review of the impact of basis risk on the functioning of and demand for index insurance

Kristina Yuzva Clement[a], Dr. W.J. Wouter Botzen[b], Prof. Dr. Jeroen[c], Prof. Dr. Roy Brouwer[d]
[a]Department of Environmental Economics Institute of Environmental Studies VU University Amsterdam
[b]Professor of Economics of Climate Change and Natural Disasters at the Department of Environmental Economics, Institute for Environmental Studies (IVM), Vrije Universiteit Amsterdam, Deputy Head of the Department of Environmental Economics, Professor of Economics of Global Environmental Change at the Utrecht University School of Economics, Utrecht University.
[c]Director of the Institute for Environmental Studies (IVM), Vrije Universiteit Amsterdam
[d]Professor Department of Economics at the University of Waterloo

***Corresponding Author Contact Information:** Kristina Yuzva Clement, Tentenstr. 5 53225 Bonn, Germany, (C) +49 (0) 159 06022072 (E) yuzvakri@gmail.com

Abstract

Climate change is increasing the risks of weather-related disasters in many regions around the world. This has an adverse socio-economic impact on households, farmers and small businesses. Some strategies for effectively managing climate related disasters include index based insurance products, which are increasingly offered as alternatives to traditional insurance, particularly in low-income countries. However, the uptake of index insurance remains low, which can be partially attributed to the inherent problem of basis risk. This review assesses the problem of basis risk that occurs when insurance payouts depend on an index that is imperfectly related with actual losses experienced by the insurance policyholder. Special attention is paid to the design of the index, quality and sampling data, the estimation of basis risk and its influence on insurance demand, and index-insurance supply. The paper concludes with several policy recommendations including the need for a systematic approach to quantify the magnitude of basis risk, to inform index design with participatory approaches, to offer index insurance through existing risk sharing networks. Moreover, we recommend to improve policyholders access to information about their risk and measures they can take to limit risk, create an enabling environment for a well-functioning insurance market, and lastly to have an integrated approach that incorporates insurance with other mechanisms that reduce basis risk.

Keywords: basis risk, climate change, index insurance, insurance demand, natural disaster risk

1. Introduction

Climate change can have major impacts on human society through increasing the magnitude and frequency of extreme weather events that can trigger a natural disaster or emergency (IPCC 2012). The economic losses resulting from natural disasters have already increased worldwide and are expected to increase further in the future (IPCC 2014). For instance, the economic costs of natural disasters have increased from $25 billion per year in the 1980s to $ 175 billion in 2016 (Munich Re 2017). These trends in natural disaster risks highlight the need to develop policies that limit, and help society cope with, the impacts of future natural disasters. It has been suggested that multi-sector partnerships can be effective to encourage adaptation to climate change risks, which consist of collaborations between different private or public agents and institutions (e.g. Bowen and Ebi, 2015). Establishing such partnerships in financial compensation arrangements for climate risks, such as insurance, is important since these can aid in managing natural disaster risks and can decrease the immediate and long-term financial impacts associated with natural disasters (Kunreuther, 2015). Recent research has shown that climate risk insurance is a priority area for many countries with at least 38 countries mentioning climate risk insurance approaches in their Nationally Determined Contributions (NDCs). In addition, another four countries feature the topic in their more elaborated National Adaptation Plans (NAPs). These countries represent some 4 billion people including some of the world's extreme poor (Kreft et al. 2017).

Index-based insurance products were first proposed as alternatives to traditional claim-based insurance starting in the 1950s when the U.S. started to experiment with area-yield index insurance (Barnett et al. 2005). Approximately fifty years later, weather and satellite based index insurance products are increasingly being piloted in both developed and developing countries. Index-based insurance products are primarily used as financial instruments to mitigate agricultural and livestock mortality risks resulting from natural disasters. Managing risks to agriculture is particularly important in developing countries where, for example, social unrest is often associated with low agricultural production and incomes (Clarke and Dercon 2009). Livestock mortality risk is also cumbersome for pastoralist communities in, for example, semi-arid lands in the Horn of Africa (Jensen, Mude and Barrett, 2014 a). Developing countries are particularly interested in alternative risk management interventions that are affordable and easy to administer, such as index insurance products, which can stimulate economic growth and reduce poverty (Akter et al. 2009). The combination of climate and socio-economic change will likely increase weather-related risks and can result in even greater demand for insurance coverage to limit the socio-economic impacts of climate change (Botzen and van den Bergh 2009).

Index-based insurance products rely on an external signal to provide coverage for covariate risks[1] and are attractive to developing countries for several reasons. The index used by these products on which payouts are based, are designed using either direct measures such as area-yield index insurance contracts in the U.S using the average annual crop yields, or the indexes are based on external measurement from e.g. weather or satellite information. This is

[1] This paper distinguishes between idiosyncratic risk as household level shocks unrelated to one's neighbor versus covariate risk as community shock whereby households suffer similar shocks as their neighbor (adapted from Jensen et al., 2014 and Barrette, 2011).

clear from Table 1, which shows the indexes used in the studies that we reviewed. The index reduces the moral hazard problem likely with traditional insurance products. This is because individuals cannot influence the amount of the insurance compensation as the payout of claims is based on an external index. Moreover, linking indemnity payments to external indicators rather than the policyholder's actual losses can reduce transaction costs since there is no need for lengthy verification processes, which are difficult to conduct in remote areas (Miranda and Gonzalez-Vega 2011). Moreover, the financial coverage provided by an index-based insurance can stimulate investments. For example, in the anticipation of a payout in the case of a bad year, index insurance policyholders can choose to invest in high risk and high-return activities, such as investing in higher revenue producing but risker crops (Chetty and Looney 2005).

Despite efforts by governments in both developed and developing countries to expand index insurance coverage, the demand for these products is low, particularly for low-income groups (Cole et al. 2013). One of the underlying issues for such low demand is basis risk. Basis risk is inherent to index insurance products, and occurs when insurance payouts depend on an index that is not perfectly correlated with the actual losses experienced by the insurance policyholders. In other words, basis risk can result in insurance payouts that are higher or lower than actual losses, and the payouts may deviate from policyholder expectations about coverage.

Basis risk can result in low index insurance demand and have the effect that households resort to undesirable mechanisms to deal with downside risks, like reducing consumption or selling their valuables (Clarke and Dercon 2009). Moreover, many existing studies lack empirical evidence on the magnitude of basis risk under various index insurance products, which makes it difficult to assess how effectively these products reduce risk.

This paper provides an overview of the different approaches used to measure basis risk and the impact of basis risk on insurance demand. This paper aims to analyze the current status of index insurance products and the link between the negative impacts of basis risk on the functionality and demand for index insurance products. It provides insights for countries that are considering to implement index insurance products that enhance resilience-building capacities towards climate-related impacts, such as extreme weather events and disasters. The policy recommendations that follow from the synthesis of key papers on index insurance can inform various climate risk insurance initiatives (e.g., Global Partnership for Climate and Disaster Risk Finance and Insurance Solutions; UNFCCC's institutions and policies, including the set-up of the Clearing House for Risk Transfer, etc.,).

We conducted a systematic review of the available literature consisting of peer-reviewed published and unpublished articles about basis risk and index- based insurance[2] by searching 3 main databases with varying combinations of keywords.[3] We include study sites from both developed and developing countries. General discussion papers and those that did not focus on the empirical relationship between index insurance and basis risk were not included. A qualitative instead of a quantitative review was conducted, because only a handful of studies have comparable basis risk variables.

The remainder of this article is structured as follows. Section 2 presents the different types of basis risk considered in the existing literature. Section 3 describes the methods used to create the index insurance contracts. Section 4 discussed the quantification of basis risk. Section 5 examines the effects of basis risk on index insurance demand. Section 6 lists and describes other mechanisms to facilitate the development of index-based insurance markets. Section 6 concludes and proposes avenues for future research.

2. Types of basis risk

[2] Index-based insurance included: area-yield index insurance, satellite-based index insurance and weather index insurance products.

[3] The following search terms were used in Google Scholar, Science Direct and Web of Science: basis risk AND index insurance AND insurance AND agricultural insurance; basis risk AND product design basis risk AND spatial basis risk AND temporal basis risk AND geographic basis risk AND local basis risk; area yield index insurance AND basis risk; weather index insurance AND basis risk, index insurance AND insurance demand. The search was conducted in the period June 2014 until December 2017.

In order to be able to determine the magnitude of basis risk, it is important to come up with a unified definition of basis risk. Such a definition is lacking in the current literature as is clear from Table 2 which shows that a variety of definitions has been used in the studies that we reviewed. This is because the majority of these studies do not have unified methods to quantify basis risk. Basis risk is measured either *ex ante* using a correlation analysis of hypothetical simulated index values and insurance payouts or *ex post* by comparing the actual frequency of payouts versus the amount that would be predicted by the original policy conditions. Additionally, basis risk has a variety of causes and the lack of a systematic approach to weighting the different types of basis risk makes it difficult to have a single definition.

In light of these challenges, we define basis risk as the weak correlation between the selected insurance index and the individual loss outcomes. [4] Traditional indemnity based insurance covers both idiosyncratic risk[5] and covariate risk. By construction, index insurance is only appropriate to address covariate risk because it allows the insurer to predict losses and determine indemnity

[4] For households, the correlation between the index insurance payout and the individual loss outcomes will be important. The focus on payout would require an analysis of the insurance coverage and deductibles, which is not included in the basis risk literature.

[5] Idiosyncratic risk refers to risk posed to the individual and not experienced by all the households in the area, such as animal damage to crops and localized pests and diseases.

payments for a larger number of policyholders and for a wide geographical zone. Inherently this leads to basis risk in two ways, as is also apparent from Table 1 which demonstrates the key factors influencing basis risk for both actual insurance products and for simulated hypothetical insurance products for 19 studies. First, by constructing index insurance only against covariate shocks, idiosyncratic shocks are left uninsured. The larger the area and the more heterogeneous the individual risks faced by the policyholders, the larger the idiosyncratic variance and the poorer the index will be in predicting individual outcomes. Second, basis risk can also arise from design error, which is a portion of the potentially insurable covariate risk. This takes place when, for example, the reference weather station is too far away from the individual farms and the index insurance does not account for the important variability in weather conditions. Design error can also occur when the insurance contract fails to account for the sensitivity of losses to weather conditions at different times in a year, such as the sensitivity of yield to rainfall variation during each stage of the crop growing cycle. This implies that measuring the rainfall sum during only one stage of the crop growing cycle can result in poor estimation of the actual losses (Lin et al. 2009).

3. Methods to design the index insurance contract

In order to understand how index insurance programs will be affected by basis risk in practice, it is important to compare the methods used to both design the index insurance contract and to quantify the level of basis risk as shown per study in Table 3.

In order to design an index insurance contract in a way that minimizes basis risk and to price the risk *ex ante* the introduction of the product, it is important to properly estimate the probability distribution of the index and have good quality longitudinal data of the variables that determine the index, such as weather records. Moreover, properly designing the index insurance contracts also requires data on expected losses. This data is often difficult to obtain because it is expensive to collect especially in developing countries and its availability is also dependent on the different types of index insurance contracts. Not having the proper data in place leads to a misrepresentation of the true probability distribution of the index and can result in a poor correlation between the index and individual loss outcomes.

Historical weather data are the primary pre-requisite for pricing and designing a weather-based index insurance products (Bryla 2009). In order to fully understand the historical weather patterns, historical data should ideally be of high quality, uninterrupted and range from at least 20-30 years (Warner et al. 2013). There is some indication from the current studies that historical rainfall data are available in some of the countries ranging from 15 to 31 years (see Table 4).

However, some countries have incomplete rainfall datasets, which means that proxy data are required to fill the years where no data are available (Castillo et al. 2012; Skees et al. 2001). This problem is acute to low-income countries with a limited number of weather stations and poor documentation of historical weather patterns (Morduch 2006). Indeed, the three studies in the U.S. and Germany have some of the more extensive datasets and weather stations distributed across the country (see Table 4). High basis risk can be expected when deploying a proxy for missing weather data and when relying on only a single variable (i.e., rainfall) in determining , for example, crop yield growth (Kellner and Musshoff 2011).

The data used to design area-yield index insurance are often aggregated at the country level or use few farm-level observations, which makes it difficult to account for the spatial and temporal heterogeneity and can lead to either upward or downward biased yield estimates compared to the farm-level situation (Claasen and Just 2011). Additionally, unlike rainfall data, area-yield insurance requires estimates of area yields that generally require costly local data collection and are more difficult to obtain especially in developing countries (Miranda and Farrin 2012). To account for spatial and temporal heterogeneity and decrease the problem of basis risk, Awondo et al. (2013) used pseudo-simulated country yields and expected losses using farm geospatial climatic data. Barnett et al. (2005) and Deng, Barnett and Vedenov (2007) used on-the-ground farm level yield data estimates from a risk management agency and complemented this with country-level yield data. Despite efforts to improve the collection of area-yield data, further efforts are needed to meet the necessary data requirements to effectively design the area-yield index insurance contracts.

The index-based livelihood insurance programs calculate the indemnity, by combining household level herd data with satellite-based vegetation data that indicates the amount and vigor of vegetation based on photosynthetic activity at a high spatial resolution (Normalized Difference Vegetation Index, NDVI). Aside from obtaining a high spatial resolution, combining satellite data with on the ground household-level data is one way to reduce design risk and improve the performance of the index (Chantarat et al. 2013). Generally long records (minimum of 25 years) of index data is needed to correctly estimate livestock mortality risk and to accurately calculate the related insurance premiums. Vrieling et al. (2014) observe that data from current operational satellites used for NDVI span a maximum of 15 years in places such as Kenya. The uncertainty around index probability estimates can result in the insurance companies charging higher premiums which subsequently decreases insurance demand.

Skees et al. (2001), Gine et al. (2008) and Elabed et al. (2013) have stressed the importance of including feedback from community members and farm groups in the design phase of the index *ex ante* the introduction of the product in order to design indices that better predict individual losses. This helps to create more sophisticated contracts that closely mirror actual losses and, therefore, can reduce the problem of basis risk. For example, Elabed et al. (2013) showed how cotton cooperatives leaders in Mali helped to design multi-scale index insurance pilots that scaled down the index to the village cooperative level as opposed to only the district level. Yields were measured at the village cooperative level in order to account for the spatial variability of rainfall in the region and, hence, to reduce geographic basis risk. The second trigger level set at the district level limits the moral hazard problem by verifying that the rainfall reporting at the village level reflects the actual insurance coverage required by those villages. In particular, the district level trigger is used to assess the accuracy of the loss reporting at the village level.

4. Quantifying basis risk

Most studies have approximated the impact of basis risk on index insurance payouts and crop revenue fluctuations ex post the introduction of the insurance product. In particular, studies examining the rainfall index insurance conducted a correlation analysis. This includes determining the strength of the correlation between weather indices measured at different weather stations using statistical analysis (see Table 3). The analysis consists of selecting pairs of weather stations such as a general weather station and a weather station that is 100 km away.

The results from the correlation coefficients allow to determine the area up to where the index is still representative for the individual losses. The correlation coefficient is then later used to determine the impact of basis risk on revenue production and to analyze whether the farmers are better or worse off using index insurance products. However, the weakness with using the correlation analysis is that it assumes a homogenous environment and does not account, for example, for topographical differences that can potentially influence a local weather event.

Most of the reviewed studies evaluated the risk reduction potential of insurance by applying a simulation analysis (see column 4 in Table 3). Risk reduction refers to insurance payouts that compensate revenue deviations resulting from extreme weather events. A simulation analysis is used in most cases to compare insurance payouts for different altitude and geographic coordinates (Norton et al. 2013). In a second stage, studies used a simulation analysis to determine the risk reduction potential of insurance by comparing crop revenues over an observed period of time with insurance and without insurance (Skees et al. 2001; Lin et al. 2009; Musshoff et al. 2011; Heimfarth and Musshoff 2011). The advantage of using simulations is that it allows flexibility to construct more complex insurance policies and to determine whether basis risk distorts the insurance payoffs. Despite this advantage, there are still some notable limitations with this approach. For example, the studies did not account for access to other risk management tools such as diversification of agricultural activities or asset accumulation, nor did they simulate the impact of future climate change on the risk reduction potential of index insurance products.

The simulation analysis showed that basis risk has an impact on insurance payouts and the level of revenue risk that can be reduced using insurance payouts. The reviewed studies demonstrate that index insurance payouts do not equal incurred losses as a result of basis risk. Norton et al. (2013) found that if insurance contracts do not account for key geographic variables that can impact index insurance performance, individual farmers can get stuck with non-compensated losses. The study found that as the distance between the insured farms and reference weather station increases, the difference in pay-offs also increases, and the index insurance payouts will be less accurate. Despite these findings, Castillo et al. (2012) found that area yield index insurance resulted in significantly greater payouts ($202.77) than traditional insurance ($161.56), but only during the rainy season. However, it is difficult to compare this study to the rest as it focuses on area-yield index insurance, which, in theory, is subject to lower levels of basis risk as compared to rainfall index insurance.

Aside from unpredictable insurance payouts, three studies found that index insurance products with severe basis risk could not sufficiently protect farmers from crop revenue fluctuations (Lin et al. 2009; Musshoff et al. 2011; Heimfarth and Musshoff 2011). For instance, two studies we reviewed demonstrated how index insurance products offer greater protection from revenue fluctuations under low basis risk compared to a scenario with high basis risk.[6] For instance, insurance contracts with a strong correlation between the rainfall index and crop yields varying between 57 and 85 percent, and hence a low basis risk, resulted in a weighted average relative overall risk of 42% without insurance compared to an overall relative risk of 36% and 30% with a 5 % and 10% insurance cover respectively (Skees et al., 2001). In contrast, insurance contracts with higher levels of spatial basis risk led to a reduction in the guaranteed return that farmers would accept from an index insurance under zero basis risk (Lin et al. 2009). This is exactly what the two studies below demonstrate.

Musshoff et al. (2011) showed that excluding basis risk translated into zero revenue risk fluctuations for the farmer. However, under both geographical and local basis risk the reduction of the standard deviation of the revenue payout was smaller than under no basis risk. Furthermore, Heimfarth and Musshoff (2011) found that the extent to which precipitation-based index insurance increases the risk reduction potential not only depends on basis risk, but also on the insured crop and on the location of the weather stations. For instance, the standard deviation of corn revenue is reduced by 24.4 percent under index-based insurance compared to a reduction of the standard deviation of less than 1% for wheat index insurance. In other words, the

[6] Low basis risk refers to a scenario in which there is a strong correlation between the index and individual loss outcomes, while high basis risk refers to a scenario where there is a weak correlation between the index and individual loss outcomes.

deviations of grain revenues were better compensated by insurance payouts for corn than for wheat. Moreover, insurance payouts were more accurate when weather stations were placed on the mainland as opposed to coastal or mountainous regions.

Area-yield index insurance contracts performed either equally as well, or better compared to traditional insurance contracts in certain states in the U.S. and for particular crops. However, the area-yield index insurance performed worse than traditional contracts when the problem of basis risk was included in the analysis, especially when the area-yield fails to account for localized changes in crop yield (Awondo et al. 2013; Deng, Barnett and Vedenov 2007; Barnett et al. 2005). Index based livelihood insurance products were proven to work best for covariate losses and have smaller design risk, but by construction they do not account for idiosyncratic risk (Chantarat et al. 2013; Jensen, Barrett and Mude 2014a; Jensen, Barrett and Mude 2014b). Moreover, if the index insurance contract is designed to capture covariate losses the population can also fair better than the index in the short run. Only Elabed et al. (2013) find evidence of this in their simulation analysis and define this as a false positive payout where a policyholder does not experience a loss, but the insurance product triggers a payout anyway, so the policyholder profits.

A study by Jensen et al., (2015) on index-based livestock insurance (IBLI) in Kenya and Ethiopia found that the insurance products improved the situation of the policyholder even when indemnity payouts did not occur. Particularly, the authors stated that IBLI products "improved peace of mind about drought exposure" (Jensent et al., 2015). Moreover, households with IBLI coverage increased their investments in livestock veterinary and vaccination services, and reduced their herd size. These changes to production strategies led to an increase in milk productivity of livestock and the total value of milk produced (Jensen et al., 2015).

4.1 Challenges of analyzing the magnitude of basis risk for index insurance contracts

Although the section above demonstrates that basis risk can result in index insurance payouts that do not correlate well with individual losses and insufficient protection to farmers from crop revenue fluctuations, the magnitude of basis risk for the different index products is difficult to quantify. This makes it hard to conclude whether index insurance products are indeed risk reducing. This is partially because of the lack of data available to both design index insurance contracts and to subsequently analyze the level of basis risk. Another key factor is that basis risk arises due to a variety of factors – design error, idiosyncratic risks, etc., - and the current studies have not yet established a systematic approach on how to weigh the types of basis risk by level of impact. Lastly, the three index insurance contracts use different units. Area-yield index insurance are policies explicitly tied to yields by transforming raw yield data into an index scale that reflect the levels of yield. In contrast, weather-based and satellite-based index insurance are implicitly tied to yield (in case of weather index) or livestock (in case of IBLI products) because there is an indirect relationship between the index and actual yield outcomes.

5. The impact of basis risk on index insurance demand

All of the demand studies showed that index insurance participation is higher when basis risk is low, but only a few studies analyzed how the magnitude of basis risk influences demand by using actual household level data. Gine et al. (2008) examined demand for an index insurance product in Andhra Pradesh, India. A regression analysis of insurance demand of 752 people showed that a decrease in basis risk resulted in an increase in weather index insurance demand. The study was based on the assumption that those growing the two cash crops castor and groundnut, for which the weather index was designed, will subsequently have less basis risk and hence results in higher insurance demand. This assumption ignores the possibility that growing the top cash crop might not be a measure farmers choose to reduce the problem of basis risk, but rather an issue of crop choice made by more trained and well-informed farmers to maximize their profits. The results showed that the probability of purchasing insurance indeed increases by 59% for groundnut crop insurance and 34% for castor crop insurance due to lower basis risk. The authors supported this by a survey that showed that 24% of the respondents stated that basis risk was one of the reasons for not buying index insurance.

Elabed et al. (2013) conducted a demand study with a sample size of 331 people. The study simulated the impact of basis risk on Malian cotton farmers under conventional and a two-scale trigger index. The two-scale trigger insurance was employed to reduce geographical basis risk by designing an insurance contract with one trigger at the district level and one at a lower geographical scale, which is more relevant to the farmer such as the village he/she lives in. The results suggested that the two-scale trigger index had different statistical properties than the conventional insurance. In particular, the former decreased the incidence of false negative payout from 70 to 35% and completely eliminated the problem of a false positive payout. The study found that demand for the two-scale contract is higher than an equally priced conventional contract. The authors supported their results by empirical findings from a one-year multi-scale pilot whereby 30% of the target group agreed to purchase the product. Although these results do not directly indicate that basis risk results in lower index insurance demand, it does signify that contracts with a trigger level closer to those of the policyholder result in greater demand.

Similar findings were also reported by Hill et al. (2013) in a willingness to pay (WTP) study that showed that geographical basis risk resulted in a significant decrease in index insurance demand. Using a sample size of 1400 households and the distance from the weather station squared as a proxy for basis risk, the double-bounded dichotomous choice contingent valuation model showed that basis risk affected WTP significantly and negatively. These findings were supported by another survey conducted by these authors, which revealed that 30% of the respondents indicated that basis risk prevents them from continuing to purchase the index insurance product.

Other studies measured demand indirectly using willingness to pay studies with strong assumptions on the relationship between basis risk and index insurance demand, while others used randomized experiments as coarse proxies for idiosyncratic risk in order to understand the impact of basis risk on insurance uptake (see column 5 in Table 3). For example, Mobarak and Rosenzweig (2012) and Dercon et al. (2014) hypothesized that informal risk sharing, such as purchasing index insurance as a group, decreases basis risk because it offers mutual protection against idiosyncratic losses under the condition that not all basis risk is perfectly correlated among its members. Mobarak and Rosenzweig (2012) randomly assigned the sample participants to be placed at different distances from the automated rainfall stations to determine what impact basis risk would have on index insurance demand. All the participants were informed about the nearest located weather station and hence, the study included the perceived and actual basis risk variation. The study showed that a higher level of informal risk sharing for idiosyncratic risk increased index insurance demand with basis risk. Assuming that the perceived distance to the weather station is a proxy for basis risk, for every kilometer increase in distance, the demand decreased by 6.4 percent.

Dercon et al. (2014) study randomized the effect of insurance training on demand whereby one group received training on how risk sharing can reduce the problem of basis risk and the other only received training on the individual benefits of insurance. This study examined how insurance demand was framed and how people perceive the problem of basis risk. The study similarly found that framing index insurance as beneficial for groups through a decrease in basis risk resulted in an increase in the probability of purchasing insurance by 29 percent compared with the group which received no training related to the benefits of informal risk sharing.

The limitation of both of these studies is that they examined groups who are already pre-disposed to manage and share their risks. Mobarak and Rosenzweig (2012) only examined people belonging to a caste system, the jati, which play a large role in business, investments and risk sharing in major parts of India (Munshi 2011; Munshi and Rosenzweig 2006). Dercon et al. (2014) sampled people who are members of funeral societies that pay a premium for funeral insurance and other forms of insurance to some or all the members called 'iddirs'. Members of the iddirs tend to better understand the insurance and how it functions than those not belonging to the group (Dercon et al. 2006). A challenge with both studies is that it can be difficult to disentangle the impacts of belonging to the risk-sharing group that resulted in greater insurance demand or the impact of the insurance product itself on demand.

With the exception of one study by Jensen, Barrett and Mude (2014 b), the majority of the demand studies did not have access to actual household level data to identify which factors better estimate index insurance demand by separating the two components of basis risk – idiosyncratic and design risk. This was the only study that distinguished between the magnitude of basis risk on insurance demand. The authors found that households with greater average idiosyncratic risk were less likely to purchase insurance and that design risk played a much smaller role in index insurance demand. Consequently, it can be concluded that reducing design risk will not completely overcome the basis risk problem on influencing insurance demand.

Price and non-price factors can also negatively affect demand for index insurance products (see Table 5). Basis risk had a greater negative impact on insurance demand when the price of the contract was high, which suggests that the impact of basis risk on demand will be smaller for a product that is cheaply priced (Hill et al. 2013; Mobarak and Rosenweig 2012). Risk aversion was also associated with low insurance take-up because basis risk causes uncertain damage reimbursements which makes the insurance less attractive for risk averse individuals. Jensen, Barrett and Mude (2014 b) found that a better knowledge of index insurance products and basis risk had no impact on insurance uptake, while Dercon et al. (2014) found a positive relationship between knowledge and index insurance demand. Overall, the impact of basis risk on index insurance should not be studied in isolation to other influencing factors on demand.

6. Index insurance approaches and other mechanisms to facilitate the development of index-based insurance markets and limit basis risk

The problem of basis risk not only influences index insurance demand, but can also influence the supply of index insurance products. For instance, in Ethiopia researchers are examining the impact of incorporating so-called “gap insurance” into the design of an index insurance product in order to cover the risks not covered by the index. This verification process has been shown to increase the number of insurance policies sold, but the project still requires designing a market strategy, capacity building and reinsurance engagement to scale-it-up (Index Insurance Innovation Initiative, 2013). There are other examples of risk management initiatives that have developed mechanisms to offset or reduce the impacts of potential basis risk associated with index insurance. For example, some insurance companies retain the basis risk component rather than passing it on to the clients such as the MiCRO programme in Haiti. Another example is Mexico’s FONDEN which provides other financial resources in situations where basis risk prevents a pay-out (Quesne et al., 2017).

Other studies have looked at the impact of the risk-layering approach that looks at index insurance in combination with other risk financing instruments (Quesne et al., 2017; Carter et al., 2015; Miller and Keipi 2005). This approach includes “identifying the various layers of disaster risk, who bears each level of risk, and the possible risk transfer instruments available to each layer" (Miller and Keipi, 2005). In order for index insurance to be effective, these products need to be better integrated with other mechanisms to reduce basis risk. For example, in Mongolia's Index-Based Livestock Insurance Project (IBLIP) herders take out commercial insurance to cover themselves against small losses, while larger losses are covered by a social safety net funded by the government which transfers risk to private insurance and reinsurance markets.

Bundling insurance with financial and non-financial services, such as training, is a potential means of increasing its perceived value among potential customers and more effectively meeting their needs (ACT, 2016). Cole et al., (2013) compare the levels of education of farmers enrolling in rainfall insurance in India, and find that literate farmers were 15 percentage points more likely to take up rainfall insurance and use it to plant cash crops. In a previous pilot, Cole et al. (2011) had found that participation in education programmes on rainfall insurance more than doubled the uptake of rainfall insurance. Providing readily available information to insurance policyholders about their risks and mechanisms to avoid those risks is another key obstacle. For instance, insurers often charge a fee for accessing the information that they generate and maintain as part of their business model. In addition to this, governments can also restrict the information they disclose for reasons of sensitivity or because information-sharing channels are simply not there (Quesne et al., 2017). The most vulnerable population is the least likely to pay for access to information. In turn, governments should provide an enabling environment to ensure information reaches the most vulnerable. The weather index insurance initiative by PepsiCo in India is one such example, which combines capacity-building and information exchange with the insurance products. Policyholders are offered technical advice on production practices and weather information and advisories through text messaging (Hazell et al., 2010).

Subsidies can help with creating an enabling environment to get a market for index based insurance started, and appear to be commonly used for this purpose. Rates of insurance premium subsidization vary greatly between different types of insurance products as well as between different countries and sectors, but tend to be higher for index-based schemes. Mahul and Stutley (2010) reviewed agricultural insurance schemes in 65 countries (developed and developing), and found that almost two-thirds provide substantial premium subsidies. In their review of 39 agricultural insurance schemes operating in developing countries, Hess and Hazell (2016) show that of the index-based options, subsidization is lowest in contract farming and input supplier schemes, and highest in credit-linked, direct and safety-net insurance schemes. Subsidization rates in the latter scheme are 80 per cent on average. The few large-scale agricultural index-based schemes in middle- and low-income countries are heavily subsidized (Quesne et al., 2017). In India, nearly one quarter of agricultural households participate in index insurance markets, and government subsidies account for 60-75 per cent of premium costs (Isakson, 2015). Two of the largest index insurance schemes in the world are the Chinese Agricultural Scheme and India's National Agricultural Insurance Scheme, which cover around 160 million and 15.9 million policyholders respectively (Hess and Hazell, 2016). Additional research can examine whether subsidies are an effective way to increase demand for index insurance products that have a high level of basis risk.

7. Conclusion and recommendations

Index-based insurance products are primarily used to mitigate the negative impacts of agriculture and livestock mortality risks and are especially attractive for developing countries because of its lower costs than traditional claim based insurance. Providing index-based insurance often depends on a risk sharing partnership between an insurance company and insurance customers, like farmers, sometimes supported by a governments or NGOs with start-up capital. Despite their advantages, the demand for index insurance products is lower than expected and there is limited empirical evidence to suggest that index insurance products are indeed risk reducing. Our literature review demonstrates that basis risk hampers the functioning of index insurance products and lowers insurance demand. However, while there are empirical studies that try to quantify the impact of basis risk on risk reduction and insurance demand, there are few systematic and complete analyses of these impacts. This can be attributed to a number of gaps in the current literature such as a lack of a clear definition of basis risk. To ameliorate this challenge, the review proposed that basis risk is defined as the weak correlation between the selected insurance index and the individual loss outcomes. The other gap in the current literature is that most studies only analyze a portion of basis risk, but basis risk is a multi-faceted problem with a variety of causes and the impacts of basis risk can be quite large if all these aspects are considered. To further complicate the analysis, there are many ways to design the index insurance contracts – area-yield index insurance, weather based index insurance, satellite based index insurance – and each approach has its advantage and disadvantage as discussed above. However, to the authors' knowledge, there is not yet one study that provides an empirical comparison on the variation of basis risk across the different types of contracts.

Furthermore, despite the call for a more rigorous empirical analysis of basis risk dating back in the literature as far as 10 years ago, only 18 studies have been identified in the review that focus on the empirical relationship between index insurance and basis risk. Moreover, the impact of basis risk on risk reduction and insurance demand is difficult to estimate, primarily due to the fact that the data used to design the contracts and to analyze the level of basis risk are often incomplete. They are either too costly to obtain such as when countries have a limited number of weather stations, or the documentation of historical data patterns is poor. Moreover, rather than using actual household level data of the target group to estimate the impact of basis risk on insurance demand and the actual performance of index insurance products, the literature often uses proxies for basis risk or simulation analysis. This makes it challenging to properly estimate the level of basis risk inherent in the index insurance contract design.

This review has identified key areas to improve future research on basis risk and index insurance products. Suggestions for enhancing the data quality include not relying on proxy data or single variables to determine individual losses for weather-based contracts and to complement data aggregated at the country-level with farm level observations for area-yield index insurance. Farmers can be the ultimate source of information to limit basis risk. Participatory approaches that involve community groups and farmers in the index design phase can result in products with low basis risk. Additionally, designing more sophisticated contracts that closely mirror actual losses and, therefore, can reduce the problem of basis risk can result in greater demand. Moreover, basis risk depends on various factors and future research should develop a systematic approach that weighs the impacts of the various types of basis risk for the range of index insurance products. Additional studies are also needed to determine whether index insurance products can effectively manage risks in real-life as most of the evidence comes from hypothetical insurance products or short-term pilots. Moreover, index insurance products should not be examined in isolation to other risk management tools.

There are different pathways to foster index insurance markets at the national level, especially in relation to the agriculture sector and food-security objectives. This can include climate literacy campaigns to national insurance stakeholders, or generally increasing government capacities to promote climate risk management and insurance. Countries implementing index insurance approaches also need to have the proper enabling environment including data provision, regulatory and supervisory frameworks, capacity development of key institutions. Providing readily available information to insurance policyholders about their risks and mechanisms to avoid those risks is another recommendation. Furthermore, the insurance industry can contribute to the standardization of available data, which further supports analysis and action.

References

Akter, S., Brouwer, R., Choudhury, S., Aziz, S. (2009) Is there a commercially viable market for crop insurance in rural Bangladesh? Mitigation and Adaptation Strategies for Global Change. 14:215–229.

Awondo,S.N., Datta, G.S., Ramirez,O. and Fonsah,E.G. (2013) Small Area Estimation of Insurance Premiums and Basis Risk. 2013 Annual Meeting, February 2-5, 2013, Orlando, Florida from Southern Agricultural Economics Association. Accessed on May 205. Available from: http://ageconsearch.umn.edu/bitstream/143109/2/manus_SAEA_2013.pdf

Barnett, B.J., Black, J.R., Hu,Y., and Skees, J.R. (2005) Is Area Yield Insurance Competitive with Farm Yield Insurance? Journal of Agricultural and Resource Economics 30(2):285-301.

Barrett,C . (2011). Covariate Catastrophic Risk Management in the Developing World. *American Journal of Agricultural Economics*, Volume 93, Issue 2, 1 January 2011, Pages 512–513, https://doi.org/10.1093/ajae/aaq134

Botzen, W.J.W. and van den Bergh, J.C.J.M. (2009) Managing natural disaster risk in a changing climate. Environmental Hazards, 8(3): 209-225.

Bryla, E. (2009) Weather risk management: An Ethiopian pilot. Experiential briefing note. Washington DC ; World Bank. Accessed on September 2014, available at: http://documents.worldbank.org/curated/en/2009/01/17694673/weather-risk-management-ethiopian-pilot.

Carter M., de Janvry A., Sadoulet E. et Sarris A. (2015). “Index based weather insurance for developing countries: A review of evidence and a set of propositions for up scaling”, Fondation pour les Etudes et Recherches sur le Developpement International (FERDI), Working paper No 112, September 2014

Castillo, M.J., Boucher, S., Carter, M.R. (2012) Will I be paid after a loss? Evaluating conventional versus index insurance contracts in Ecuadorean Agriculture, working paper. UC Davis Working paper. Accessed September 2012, available at http://agecon.ucdavis.edu/people/faculty/ michael-carter/docs/CastilloBoucherCarterNov2012.pdf.

Chantarat, S., Mude,A.G., Barrett,C.B., Carter,M.R. (2013) Designing index-based livestock insurance for managing asset risk in Northern Kenya. The Journal of Risk and Insurance 80 (1): 205-237.

Chetty, R. and Looney, A. (2005) Consumption smoothing and the welfare consequences of social insurance in developing economies. NBER Working Paper No. 11709.

Claassen, R., and R. E. Just. (2011) “Heterogeneity and Distributional Form of Farm- Level Yields,” American Journal of Agricultural Economics, 93(1), 144–160.

Clarke,D.J. and Dercon, S. (2009) "Insurance, Credit and Safety Nets for the Poor in a World of Risk," Working Papers 81, United Nations, Department of Economics and Social Affairs.

Cole, S., Giné, X., Tobacman,J.,Topalova, P.,Townsend,R., and Vickery,J. (2013) Barriers to Household Risk Management: Evidence from India. American Economic Journal: Applied Economics 5(1): 104-35.

Cole, S., et al. (2013, b). Dynamics of Demand for Index Insurance: Evidence from a Long-Run Field Experiment. American Economic Review 104 (5), 284-90

Deng, X, Barnett, B.J., and Vedenov, D.V. (2007) Is There a Viable Market for Area-Based Crop Insurance?. American Journal of Agricultural Economics 89 (2): 508-519.

Dercon, S., Weerdt, J.D., Bold, T., Pankhurst, A. (2006) Group-based funeral insurance in Ethiopia and Tanzania. World Dev. 34 (4):685–703.

Dercon, S.,Vargas-Hill, R.,Clarke,D., Outes-Leon, I., and Taffesse,A.S. (2014) Offering rainfall insurance to informal insurance groups: Evidence from a field experiment in Ethiopia. Journal of Development Economics 106(C): 132-143.

Elabed, G, Bellemare, M., Carter, M., and Guirkinger. C. (2013) Managing basis risk with multiscale index insurance. Agricultural Economics 44(4-5): 419-31.

Giné ,X., Townsend, R., Vickery, J. (2008) Patterns of rainfall insurance participation in rural India. World Bank Economic Review 22(3): 539–566.

Hazell, P., et al.,. The potential for scale and sustainability in weather index insurance for agriculture and rural livelihoods. Rome: WFP/International Fund for Agricultural Development, 2010. Available from https://www.ifad.org/documents/10180/32647150-6e8a-41f3-8642-404768cfc99f

Heimfarth, L.E., and Musshoff, O. (2011) Weather index-based insurances for farmers in the North China Plain An analysis of risk reduction potential and basis risk. Agricultural Finance 71 (2):218-239.

Hess, U., and P. Hazell. (2016). Innovations and Emerging Trends in Agricultural Insurance. How can we transfer natural risks out of rural livelihoods to empower and protect people? Bonn/Eschborn: Deutsche Gesellschaft fu□r Internationale Zusammenarbeit,

Hill, R.V., Hoddinott,J., Kumar, N. (2013) Adoption of weather-index insurance: learning from willingness to pay among a panel of households in rural Ethiopia. Agricultural Economics 44: 385–398.

Isakson, S.R. 2015. Derivatives for Development? Small Farmer Vulnerability and the Financialization of Climate Risk Management. Journal of Agrarian Change, vol. 15, No. 4, pp. 569-580.

IPCC. (2012) Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, UK, and New York, NY, USA, 582 pp.

IPCC. (201). Climate Change 2014:Synthesis Report. Contribution of Work Groups I, II, III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change {core writing team, R.K. Pachauri and L.A. Meyer (eds.)}. IPCC, Geneva, Switzerland, 151 pp. in IPCC AR5 Synthesis report website.

I4 Update. 2013. "Insuring Against the Weather: Addressing the Challenges of Basis Risk in Index Insurance using Gap Insurance in Ethiopia." http://basis.ucdavis.edu/wp-content/uploads/2014/08/I4-Update-Gap-Insurance-in-Ethiopia.pdf

Jensen, N.D., Barrett, C., B., and Mude, A. (2014) (a). Basis Risk and the Welfare Gains from Index Insurance: Evidence from Northern Kenya. Accessed on May 2015. Available at: http://ssrn.com/abstract=2505764.

Jensen, N.D., Barrett, C., B., and Mude, A. (2014) (b). How Basis Risk and Spatiotemporal

Adverse Selection Influence Demand for Index Insurance: Evidence from Northern Kenya (December 10, 2014). Accessed on May 2015. Available at: http://ssrn.com/abstract=2475187.

Jensen, Nathaniel D., Christopher B. Barrett, and Andrew Mude (2015). The favorable impacts of Index-Based Livestock Insurance: Evaluation results from Ethiopia and Kenya. ILRI Research Brief 52, May. Available from https://cgspace.cgiar.org/bitstream/handle/10568/66652/ResearchBrief52.pdf?sequence=1.

Karlan,D., Osei,R., Osei-Akoto,I., Udry, C. (2014) Agricultural Decisions after Relaxing Credit and Risk Constraints. The Quarterly Journal of Economics: 597–652.

Karnieli, A., Agam, N., Pinker, R.T., Anderson, M., Imhoff, M., Gutman, G.G., Panov, N., Goldberg, A. (2010) Use of NDVI and Land Surface Temperature for Drought Assessment: Merits and Limitations. Journal of Climate 23: 618- 633.

Kreft, S.,Schaefer, L., Behre, E., and Matias,D. 2017 Climate risk insurance for resilience: Assessing Countries Implementation Plans. Report No. 23. Bonn: United Nations University Institute for Environment and Human Security (UNU-EHS)

Kunreuther, H. (2015). The role of insurance in reducing losses from extreme events: The need for public-private partnerships. The Geneva Papers on Risk and Insurance, 40: 741

Lin, S., Mullen, J.D., and Hoogenboom, G. (2009) Spatial and Temporal On-Farm Risk Management - Crop Production Scheduling and Index Insurance Strategies. Selected Paper prepared for presentation at the Agricultural & Applied Economics Association 2009 AAEA & ACCI Joint Annual Meeting, Milwaukee, Wisconsin, July 26-29, 2009.

Mahul, O., and C. Stutley. Government Support to Agricultural Insurance: Challenges and Options for Developing Countries. Washington DC: International Bank for Reconstruction and Development/World Bank, 2010. Available from https://openknowledge.worldbank.org/bitstream/handle/10986/2432/538810PUB0Gove101Official0Use0Only1.pdf?sequence=1&isAllowed=y

Miller, S., and K. Keipi. Strategies and Financial Instruments for Disaster Risk Management in Latin America and the Caribbean. Inter-American Development Bank, 2005. Available from https://publications.iadb.org/bitstream/handle/11319/4835/Strategies%20and%20Financial%20Instruments%20for%20Disaster%20Risk%20Management%20in%20Latin%20America%20and%20the%20Caribbean.pdf?sequence=1

Miranda, M.J., and Gonzalez-Vega,C. (2011) Systemic Risk, Index Insurance, and Optimal Management of Agricultural Loan Portfolios in Developing Countries. American Journal of Agricultural Economics 93(2): 399–4.

Miranda,M.J., and Farrin. (2012) Index Insurance for Developing Countries. Applied Economic

Perspectives and Policy: 1–37.

Mobarak, A.M., and Rosenzweig, M.R. (2012) Selling Formal Insurance to the Informally Insured. Yale Economics Department Working Paper No. 97; Yale University Economic Growth Center Discussion Paper No. 1007. Accessed on September 2014,available at SSRN: http://ssrn.com/abstract=2009528 or http://dx.doi.org/10.2139/ssrn.2009528.

Morduch, J. (2006) "Micro-insurance: the next revolution?", in Abhijit, B., Roland, B. and Dilip, M. (Eds), What Have We Learned About Poverty?, Oxford University Press, Oxford.

Munich Re. Natural catastrophe losses at their highest for four years, 2017. Press release. Available from https:// www.munichre.com/en/media-relations/publications/pressreleases/2017/2017-01-04-press-release/index.html

Munshi, K., and Rosenzweig,M. (2009) "Why is Mobility in India so Low? Social Insurance, Inequality, and Growth." NBER Working Paper No. 14850. Accessed on May 2015. Available from: http://www.nber.org/papers/w14850

Munshi, K. (2011) "Strength in Numbers: Networks as a Solution to Occupational Traps," Review of Economic Studies 78: 1069–1101.

Musshoff, O., Odening, M., Xu, W. (2011) Management of climate risks in agriculture - will weather derivatives permeate? Applied Economics, 43(9):1067-1077.

Norton,T.M., Turvey,C., Osgood, D. (2013) Quantifying spatial basis risk for weather index insurance. The Journal of Risk Finance, 14(1): 20-34.

Quesne, F., Tollmann, J., Range, M., Balogun, K., Zissener, M., Bohl, D., Souvignet, M., Schuster, S., Zwick, S., Phillips, J., Branko Wehnert and Soenke Kreft. 2017. The role of insurance in integrated disaster and climate risk management: Evidence and lessons learned. Report No. 20. Bonn: United Nations University Institute for Environment and Human Security (UNU-EHS)

Skees, J.R, Gober S., Varangis P., Lester R., Kalavakonda, V. (2001) Developing rainfall based index insurance in Morocco. Policy, Research working paper. WPS 2577. Washington: The World Bank. Accessed on September 2014, available: http://wdsbeta. worldbank.org/external/default/WDSContentServer/IW3P/IB/2001/04/27/ 0000949.

Vrielinga, A., Meronib, M., Sheec, A., Mudec, A.G., Woodardd, J., de Biea, C.A.J.M. , Rembold,K. (2014) Historical extension of operational NDVI products for livestock insurance in Kenya. International Journal of Applied Earth Observation and Geoinformation 28: 238-251.

Warner, K., Yuzva, K., Zissener, M., Gille, S., Voss, J. and S. Wanczeck. (2013) Innovative Insurance Solutions for Climate Change: How to integrate climate risk insurance into a comprehensive climate risk management approach. Report No. 12. Bonn: United Nations University Institute for Environment and Human Security (UNU-EHS).

United Nations Office for Disaster Risk Reduction. Making Development Sustainable: The Future of Disaster Risk Management. Global Assessment Report on Disaster Risk Reduction. Geneva, Switzerland: United Nations Office for Disaster Risk Reduction, 2015. Available from http://www.preventionweb.net/english/hyogo/gar/2015/en/gar-pdf/GAR2015_EN.pdf

Biographies of authors:

Kristina Yuzva, is currently working for the Munich Climate Insurance Initiative with a special focus on designing comprehensive climate risk management approaches for developing countries that include insurance. She is also a PhD candidate at the Department of Environmental Economics, Institute for Environmental Studies at the VU University Amsterdam examining weather index insurance products and incentives for risk reduction behavior in the Caribbean.

Dr. **Wouter Botzen** is a Professor of Economics of Climate Change and Natural Disasters at the Department of Environmental Economics, Institute for Environmental Studies (IVM), VU

University Amsterdam. He is Deputy Head of the Department of Environmental Economics. Moreover, he is full Professor of Economics of Global Environmental Change at the Utrecht University School of Economics, Utrecht University. He is a visiting scholar at the Risk Management and Decision Processes Center at the Wharton School of the University of Pennsylvania.

Prof. Dr. **Roy Brouwer** the Executive Director of the Water Institute at the University of Waterloo. Before joining the department of Economics at the University of Waterloo, he was head of the department Environmental Economics at the Vrije Universiteit Amsterdam (2009-2015). His main research interests are in water economics and environmental risk. He is visiting professor at the Swiss Federal Institute for Aquatic Science and Technology and chief editor of the journal Water Resources and Economics.

Prof. Dr. **Jeroen Aerts** is director of the Institute for Environmental Studies (IVM).Within IVM, Jeroen is also head of the department 'Water and Climate Risk'. Jeroen has an established an internationally- recognized leading position in the field of water and climate risk management.

Table 1: Studies included in the review focusing on index insurance for agricultural and livestock mortality risk

Study	**Country**	**Type of index**	**Type of insurance product**	**Risk covered**	**Factors influencing basis risk**
Skees et al. (2001)	Morocco	Rainfall	Hypothetical	Crop yield (wheat, barley, maize)	Design error
World Bank (2001)	Nicaragua	Rainfall	Hypothetical	Crop yield (various)	Design error
Gine et al. (2008)	India	Rainfall	Actual	Crop yield (groundnut and castor)	Design error
Lin et al. (2009)	US	Rainfall	Hypothetical	Crop yield (cotton)	Design error
Musshoff et al. (2011)	Germany	Rainfall	Hypothetical	Crop yield (wheat)	Design error and idiosyncratic variance
Heimfarth and Musshoff (2011)	China	Rainfall	Hypothetical	Crop yield (corn, wheat)	Design error
Castillo et al. (2012)	Ecuador	Rainfall	Actual and hypothetical	Crop yield (maize, rice)	Design error
Mobarak and Rosenzweig (2012)	India	Rainfall	Actual	Not crop specific	Design error
Elabed et al. (2013)	Mali	Area-yield	Hypothetical and actual	Crop yield (cotton)	Design error
Hill et al. (2013)	Ethiopia	Rainfall	Hypothetical	Crop yield (various)	Design error

Norton et al. (2013)	US	Rainfall and heat	Hypothetical	Crop yield	Design error
Dercon et al. (2014)	Ethiopia	Rainfall	Actual	Crop yield	n.d.
Awondo et al. (2013)	US	Area-yield	Actual	Crop yield	Design error
Deng , Barnett and Vedenov (2007)	US	Area-yield	Actual	Crop yield	Design error
Barnett et al. (2005)	US	Area-yield	Actual	Crop yield	Design error
Chantarat et al. (2013)	Kenya	Normalized Difference Vegetation Index	Actual	Livestock	Idiosyncratic variance and design error
Jensen, Barrett and Mude (2014) a	Kenya	NDVI	Actual	Livestock	Idiosyncratic variance and design error
Jensen, Barrett and Mude (2014) b	Kenya	NDVI	Actual	Livestock	Idiosyncratic variance and design error

Karlan et al. (2014)	Ghana	Rainfall	Actual	Agricultural	Idiosyncratic variance

Table 2. Basis risk definition

Study	**Basis risk definition**
Skees et al. (2001)	Not specified
Gine et al. (2008)	Correlation between insurance payout and risk to be insured/household consumption risk.
World Bank (2001); Barnett et al. (2005); Deng, Barnett and Vedenov (2007); Lin et al. (2009); Heimfarth and Musshoff (2011); Musshoff et al. (2011); Mobarak and Rosenzweig (2012); Awondo et al. (2013);	Correlation between index and individual losses/outcome.
Castillo et al. (2012)	Basis risk arises due to idiosyncratic risk, large geographical area, and from design error. The risk of being insured and having a loss but receiving no payment.
Elabed et al. (2013)	A probability that the farmer will not be indemnified even when losses occur.
Hill et al. (2013); Karlan et al. (2014)	The probability that the index records a good state of the world, when the individual experiences a bad state of the world.
Norton et al. (2013)	The risk that payoffs do not correspond to the underlying exposures.
Chantarat et al. (2013); Dercon et al. (2014);	Basis risk is the difference between the losses actually incurred and the losses insured.
Jensen, Barrett and Mude (2014) a; Jensen, Barrett and Mude (2014)	Remaining uninsured risk or residual risk due to imperfect association between experienced losses and indemnification based index values.

b

Table 3: Methods used to design the index insurance contract and quantify the impact of basis risk on index insurance

Study	Method to design an index	Method to quantify basis risk	Method to determine potential risk reduction	Method to determine insurance demand
Skees et al. (2001)	Community feedback	Not specified	Simulation	Not applicable
World Bank (2001)	Not specified	Statistical analysis	Not specified	Not applicable
Gine et al. (2008)	Community feedback and statistical analysis	Not specified	Not specified	Willingness to pay study
Lin et al. (2009)	Index value simulation	Not specified	Simulation	Not applicable
Musshoff et al. (2011)	Index value simulation	Statistical analysis	Simulation	Not applicable
Heimfarth and Musshoff (2011)	Index value simulation and burn analysis	Statistical analysis	Simulation	Not applicable
Castillo et al. (2012)	Index value simulation	Comparison of actual to theoretical payout	Comparison analysis of index insurance versus traditional insurance	Not applicable
Mobarak and Rosenzweig (2012)	Statistical analysis	Not specified	Survey	Randomized experiment
Elabed et al. (2013)	Index value simulation and community feedback	Comparison of actual to theoretical payout	Simulation	Simulation and survey
Hill et al. (2013)	Not specified	Not specified	Not applicable	Willingness to pay

				study
Norton et al. (2013)	Burn rate analysis[7]	Statistical analysis	Simulation	Not applicable
Dercon et al. (2014)	Statistical analysis	Not specified	Not applicable	Randomized experiment
Awondo et al. 2013	Statistical analysis	Simulation	Comparison analysis of index insurance versus traditional insurance	NA
Deng, Barnett and Vedenov 2007	Statistical analysis	Statistical analysis	Comparison analysis of index insurance versus traditional insurance	NA
Barnett et al. 2005	Simulation	Not specified	Comparison analysis of index insurance versus traditional insurance	NA
Chantarat et al. (2013)	Statistical analysis	Comparison of actual to theoretical payouts.	NA	NA
Jensen, Barrett and Mude (2014) a	Statistical analysis	Statistical analysis	NA	NA
Jensen, Barrett and Mude (2014) b	Statistical analysis	Statistical analysis	NA	Randomized experiment
Karlan et al. 2014	NS	NS	NA	Randomized experiment

[7] The burn analysis predicts the insurance payoffs by examining how the contract would have performed in the previous years (Spicka and Hnilica 2013).

Table 4. **Study characteristics related to the design of the index insurance contract**

Study	**Time series of rain data**	**Time series of yield or livestock mortality data**
Skees et al. (2001)	Proxy and actual data for 21 years	21 years
World Bank (2001)	15 years	9 years
Gine et al. (2008)	25 years	NS

Lin et al. (2009)	10 years	10 years
Musshoff et al. (2011)	20 years	13 years
Heimfarth and Musshoff (2011)	31 years	31 years
Castillo et al. (2012)	Not specified	10 years
Mobarak and Rosenzweig (2012)	Not specified	NS
Elabed et al. (2013)	Not specified	10 years
Hill et al. (2013)	Not specified	NS
Norton et al. (2013)	Approx. 75 years of data available.[8]	NS
Awondo et al. 2013	NS	NS
Deng, Barnett and Vedenov 2007	NS	30 years of country level area yield data and 4-10 farm level yield data
Barnett et al. 2005	NS	10 years
Chantarat et al. (2013)	NDVI data in real-time every 10 days and dates to 1981.	17 years
Jensen, Barrett and Mude (2014) a	NDVI data	4 years
Jensen, Barrett and Mude (2014) b	NDVI data	8 years
Karlan et al. 2014	Approx.50 years of rainfall data. [9]	NS

[8] Although most weather stations date back to after 1945, some have as little as one or two years of data for the entire 75 year data period.

[9] For second year of experiment, used 33 years of data (though not every year offered complete data).

Table 5: Other factors influencing index insurance demand

Explanatory factor	Direction of influence on demand	Statistically Significant	Studies
Index insurance price	Negative	Yes	Hill et al. (2013); Mobarak and Rosenzweig (2012); Karlan et al. (2014)
Risk aversion	Negative	Yes	Gine et al. (2008); Elabed et al. (2013)
Basis risk	Negative	Yes	Gine et al. (2008); Mobarak and Rosenzweig (2012); Elabed et al. (2013); Hill et al. (2013); Dercon et al. (2014); Jensen, Barrett and Mude (2014) b[10]
Wealth	Positive	Yes	Gine et al. (2008); Hill et al. (2013)
Access to informal risk sharing network and basis risk	Positive	Yes	Gine et al., (2008); Dercon et al. (2014); Mobarak and Rosenzweig (2012); Jensen, Barrett and Mude (2014) b
Intertemporal adverse selection	Negative	Yes	Jensen, Barrett and Mude (2014) b
Knowledge of index insurance	Positive/ Neutral	Yes	Jensen, Barrett and Mude (2014) b (0) ; Dercon et al. 2014 (+)

[10] Note this is the only study that separate between the type of basis risk (design or individual) and that determines which is more important for demand.