Meso-level weather index insurance

Overcoming low risk reduction potential of micro-level approaches

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Abstract

Purpose – Using cotton yield, and rainfall data from Tajikistan, the purpose of this paper is to investigate the magnitude of weather induced revenue losses in cotton production. Hereby the authors look at different risk aggregation levels across political regions (meso-level). The authors then design weather index insurance products able to compensate revenue losses identified and analyze their risk reduction potential.

Design/methodology/approach – The authors design different weather insurance products based on put-options on a cumulated precipitation index. The insurance products are modeled for different inter-regional and intra-regional risk aggregation and risk coverage scenarios. In this attempt the authors deal with the common problem of developing countries in which yield data is often only available on an aggregate level, and weather data is only accessible for a low number of weather stations.

Findings – The authors find that it is feasible to design index-based weather insurance products on the meso-level with a considerable risk reduction potential against weather-induced revenue losses in cotton production. Furthermore, the authors find that risk reduction potential increases on the national level the more subregions are considered for the insurance product design. Moreover, risk reduction potential increases if the index insurance product applied is designed to compensate extreme weather events.

Practical implications – The findings suggest that index-based weather insurance products bear a large risk mitigation potential on an aggregate level. Hence, meso-level insurance should be recognized by institutions with a regional exposure to cost-related weather risks as part of their risk-management strategy.

Originality/value – The authors are the first to investigate the potential of weather index insurance for different risk aggregation levels in developing countries.

Keywords Insurance, Index insurance, Risk aggregation, Tajikistan

Paper type Research paper

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1. Introduction

Despite the potential of (agricultural) insurance for investment stimulation (Karlan *et al.*, 2014), there is evidence that insurance uptake in developing countries is low (Cole *et al.*, 2013a; Dercon *et al.*, 2014; Giné *et al.*, 2008; Giné and Yang, 2009; Janvry *et al.*, 2014). There is research arguing that non-price aspects, such as trust or salience, are important (Cole *et al.*, 2013a; Giné and Yang, 2009) and others that focus on price effects. They consider high costs of traditional, i.e. indemnity based, insurance to be of most relevance for the low insurance uptake in developing countries and try to overcome cost impediments with alternative insurance solutions. In this context, weather index-based insurance solutions and their attributes in particular are widely discussed in the literature (e.g. Miranda and Gonzalez-Vega, 2011; Turvey, 2001; Vedenov and Barnett, 2004; Woodard and Garcia, 2008).

However, these attempts have not led to a significant increase of insurance uptake rates in developing countries, especially for micro-insurance products (i.e. individual insurance products for low income groups). Micro-insurance products require, in relation to contract sizes, relatively high product design, and marketing costs for the insurer (Miranda and Farrin, 2012). These costs cannot completely be passed on to clients because this would diminish product attractiveness. Furthermore, technical innovations which have proven to be cost-reducing for large contract sizes do not seem to work sufficiently well when contract sizes decline. Here, especially index-based insurance products for farmers seem less suited for micro-insurance purposes due to high basis risks.

In contrast to indemnity-based insurance products, which measure the actual loss after an insurance event and compensate losses accordingly, index-based weather insurance products start to pay out indemnities when *ex-ante* defined trigger values of weather variables (e.g. rainfall) are reached. Hence, index-based weather insurance products are more objective and have lower transaction costs than indemnity-based insurance products. However, they are subject to basis risk. Basis risk is the risk that: yields realized by farmers are affected by more factors than weather (idiosyncratic basis risk); and weather data measured at the reference weather station differs from the weather realized on the individual farms (geographical basis risk) (Woodard and Garcia, 2008). Importantly, geographical basis risk increases disproportionately with declining farm sizes (Clarke, 2011; Dercon *et al.*, 2014; Janvry *et al.*, 2014). Neither the application of better quality weather data (Binswanger-Mkhize, 2012) nor a more accurate index-based insurance product through the application of more complex weather indices (Vedenov and Barnett, 2004) can reduce the geographical basis risk of index-based weather insurance.

In order to overcome these obstacles, some consideration has been given to meso- or macro-level insurance, especially for insuring agricultural weather risks (Binswanger-Mkhize, 2012; Miranda and Farrin, 2012). Meso- or macro-level insurance focusses on insuring agricultural intermediaries (Collier and Skees, 2012). In this context, agricultural intermediaries can be any institution along the agricultural value chain that is exposed to agricultural risks, such as agricultural input suppliers, financial institutions, producer organizations, or agricultural traders (Miranda and Gonzalez-Vega, 2011). Depending on the contract design, meso- or macro-level insurance is flexible. If the insurance intends to have an indirect effect, e.g., increasing agricultural lending of financial institutions, indemnity payments can be structured to compensate losses from agricultural loans under negative weather events. Alternatively, should the insurance be targeted toward providing indemnity coverage for individual farmers against negative weather effects (direct effect), then indemnity payments (which can be used to pay back loans) can be channeled by the agricultural intermediary to individual farmers. In either case, the intermediary is well informed about the consequences of weather events on primary agricultural production and payout structures can be designed effectively (Binswanger-Mkhize, 2012; Miranda and Farrin, 2012; Miranda and Gonzalez-Vega, 2011).

Surprisingly, meso- or macro-level insurance solutions have not received much attention in the insurance-related literature. This might be because in developed countries the insurance market for the micro-level is well established and, hence, there is only little risk aggregated by intermediaries. Also, the majority of projects from development institutions (e.g. World Bank) in the past mainly focussed on the development and the design of micro-level insurance schemes.

To help fill this gap the purpose of this paper is to investigate the risk reduction potential of meso-level index-based weather insurance for the cotton sector in Tajikistan. In Tajikistan, 69 percent of the population is employed in agriculture, and the cotton sector contributes 60 percent of the gross agricultural output (GAO). Thus, the government budget, the return of agricultural intermediaries, and the income of farmers all depend directly on cotton yields, and indirectly on weather events (PlaNet Guarantee, 2011). In contrast, the insurance market for agricultural insurance in Tajikistan is largely underdeveloped and, hence, unable to insure the agricultural sector against weather risks. Our analysis contributes to the development of this agricultural insurance sector by investigating the potential of a new insurance instrument (meso-level insurance).

The remainder of this paper is structured as follows: In the second part, we provide an overview of the current discussion on meso- and macro-level insurance solutions, which leads us to our research hypotheses. In the third part, the data applied to investigate our hypotheses is presented, followed by a description of our empirical approach. The results are discussed in the fourth section, and the fifth section summarizes our research and ends with suggestions for further research.

2. Literature review and hypotheses

In a randomized field experiment with maize farmers in Ghana, Karlan *et al.* (2014) investigate the provision of cash grants and grants for buying index-based weather insurance (insurance grants) on investment. They find that overall both grants applied independently lead to higher investment in terms of input use and to more risky investment projects; the combination of both grants increases these effects. They attribute their findings for insurance grants to the effect that farmers are able (or willing) to mobilize investment capital when they have insurance coverage. However, there seems to be a gap between insurance potential and insurance demand in developing countries as literature frequently reveals low uptake rates for micro-level insurance products (Cole *et al.*, 2013a; Dercon *et al.*, 2014; Giné *et al.*, 2008; Giné and Yang, 2009; Karlan *et al.*, 2014). In their study Karlan *et al.* (2014) also conduct a demand analysis for the insurance product which they provided with varying prices above the actuarial fair price[1]. Their results, which confirm the findings of similar studies (e.g. Cole *et al.*, 2013b), reveals a steep elasticity of insurance prices above the actuarial fair price. By applying the market price, demand diminishes to 11 percent of the demand where the product is offered as a grant. In addition, Karlan *et al.* (2014) find that demand for insurance decreases with increasing basis risk. Taking this into account, it seems plausible why index-based insurance products for small coverage levels either only work due to heavy premium subsidies or because governments pressure insurance companies to develop and offer (mandatory) insurance products for lower income groups (Miranda and Gonzalez-Vega, 2011; World Bank Group, 2012).

Increasing contract sizes might overcome price-related uptake impediments. This is because transaction costs can be reduced relatively, and cost saving, technical innovations such as index-based weather insurance work more effectively. In terms of agricultural insurance, this could, e.g., mean targeting large farms with weather index-based insurance products. For developing countries, where most agricultural production takes place on small-scale farms, this seems a bit counterintuitive. Moreover, it is typically the small-scale farms for which the insurance market (and the credit market) is imperfect while large farms do not face the same difficulties in getting access to insurance or credit.

By hypothetically relaxing the assumption that larger contract sizes are connected to larger farm sizes, insurance uptake might be increased. Increasing contract sizes without increasing individual farm sizes would be feasible if a group of farmers insures its aggregated land against weather hazards. Contract size would, therefore, increase while (individual) farm sizes remain the same (Janvry *et al.*, 2014). This form of risk pooling (Dercon *et al.*, 2014; Janvry *et al.*, 2014) also helps to connect informal insurance (e.g. community insurance) and formal insurance (Janvry *et al.*, 2014; Mobarak and Rosenzweig, 2013).

The risk-pooling idea of group insurance is, however, not limited to primary agricultural producers but also applies to central or local governments when they have to compensate the farming sector in case of severe weather events. Agricultural input suppliers and processors are also affected as they depend on the demand or the supply from farmers exposed to weather risks. Here, insurance for financial intermediaries have received the most attention (Collier *et al.*, 2011; Collier and Skees, 2012; Miranda and Farrin, 2012; Miranda and Gonzalez-Vega, 2011; Pelka *et al.*, 2015). Pelka *et al.* (2015) provide evidence that severe weather events can negatively affect repayment quality of agricultural microfinance borrowers. In their analysis, Pelka *et al.* (2015) investigate agricultural loans disbursed by a microfinance institution to wet rice farmers on the central plateau of Madagascar. They find that excessive rain during the harvesting season can increase credit risk up to 35 times, depending on the three credit risk indicators (i.e. loans overdue by at least 1, 15, and 90 days, respectively), applied. These findings show that agricultural production risk is neither limited to primary agricultural production nor that risk aggregation especially within a certain region (e.g. the central plateau of Madagascar) necessarily evens out risks. This might be the case for idiosyncratic aspects of individual farms, such as variation of skills or capital endowment but not for covariate aspects such as negative weather events which reduce yields for all farmers (Woodard and Garcia, 2008).

Surprisingly, the issue of weather risk aggregation has not received much attention in the insurance-related literature. This might be because in developed countries the insurance market for primary producers is well established and, hence, there is only little risk aggregated, e.g., by traders or processors. The only research paper explicitly dealing with the effects of risk aggregation in the context of weather index-based insurance is Woodard and Garcia (2008), who illustrate how idiosyncratic and weather-related (temperature) yield effects in the agricultural sector interrelate with increasing risk aggregation. This interrelation is based on the following conceptual model:

$$Y_{t,k} = \alpha_k + f_k(\boldsymbol{W}_{t,k}) + \varepsilon_{t,k} \tag{1}$$

In Equation (1), $Y_{t,k}$ represents the yield which is composed of two effects, a systemic weather component $f_k(\boldsymbol{W}_{t,k})$ with $\boldsymbol{W}_{t,k}$ being a vector of weather variables and $\varepsilon_{t,k}$ representing the idiosyncratic risk component. Furthermore, α_k is a constant, k being a location index, and t being a time index. The expected value $E[\varepsilon_{t,k}]=0$. Summing the yield across k locations leads to:

$$E\left[\sum_k Y_{t,k}\right] = \sum_k \alpha_k + E\left[\sum_k f_k(\mathbf{W}_{t,k})\right] + E\left[\sum_k \varepsilon_{t,k}\right] \quad (2)$$

The yield variance across k locations is:

$$Var\left[\sum_k Y_{t,k}\right] = Var\left[\sum_k f_k(\mathbf{W}_{t,k})\right] + Var\left[\sum_k \varepsilon_{t,k}\right] + Cov\left[\sum_k f_k(\mathbf{W}_{t,k}), \sum_k \varepsilon_{t,k}\right] \quad (3)$$

From (3) it follows that the aggregated variance depends on the variance of the idiosyncratic and the weather component. In the simple case of two locations, perfectly opposite idiosyncratic effects, similar weather effects, and no dependency of idiosyncratic and weather effects, the aggregated variance would solely consist of the sum of weather variance of both locations (and vice versa). This would be the case when the variance of precipitation is above average in one region and below average in the other. Woodard and Garcia (2008) assume that with an increasing spatial yield aggregation level, the idiosyncratic risk might self-diversify while weather risk aggregates. Despite the simple assumption of weather being the only systemic component (there might be others, e.g. market prices), the model illustrates that the likelihood that yield variance increases on an aggregate level is higher when yield is determined by systemic effects, rather than by idiosyncratic effects. As a result, the risk reduction potential of weather insurance should increase with increasing risk aggregation. Woodard and Garcia (2008) show that this is the case for corn yield risks in Illinois, USA.

This aggregation of risks across space supports a focus on meso-level insurance (e.g. small farmer groups, financial institutions, producer organizations, traders of agricultural commodities, non-financial input suppliers), or macro-level insurance (e.g. central or local government insurance) instead of micro-level insurance. This also addresses the problem of poor data availability faced by many developing countries.

Only recently has meso- and macro-level insurance received more attention. Prominent in this context is the African Risk Capacity (ARC), an institution enabling African countries to insure each other against drought events (IFPRI, 2013). The ARC pays indemnities to participating countries when a certain threshold of a precipitation index is reached.

Taking the aforementioned into account, our first hypothesis is the following:

H1. "Accumulation effect": risk reduction potential of meso-level index-insurance increases with increasing risk aggregation levels.

The way individuals benefit from meso- or macro-level (weather) insurance solutions depends on whether the insurance product is intended to have an indirect or a direct effect. In the case of an indirect effect for individuals, the indemnity payment will stay with the intermediary covering (fully or partly) weather-related business losses. For a financial intermediary, the indemnity payment could, e.g., be used to compensate weather-related default costs of agricultural loans. This might allow the financial institution to accept a higher exposure in the agricultural sector, leading to a higher number of loans disbursed to farmers. In the case of a direct effect for individuals, the insurance contract would be designed to transfer the indemnity payments to individuals affected by weather-related business losses, e.g., yield of farmers. This is the case for the ARC, where insured countries have to *ex-ante* provide a schedule how, in the case of a drought, indemnity payments are channeled to affected individuals.

The ability of risk aggregators to bear weather-related risks themselves or if they should transfer risks on the insurance market depends also on the absolute costs related. Under different cost regimes it might be plausible to transfer only parts of the weather-related risk instead of seeking for full loss compensation. However, there is evidence for micro-level insurance products that a lower frequency of insurance payouts negatively affects insurance uptake (Karlan *et al.*, 2014). The focus on less frequent but more severe covariate weather events (e.g. droughts, typhoons) might also affect hedging effectivity of weather index-based insurance. Taking this into account, our second hypothesis is the following:

> *H2.* "Compensation effect": risk reduction potential of meso-level weather index-based insurance changes with the severity of weather events covered.

3. Data and methods

Data

Tajikistan is located in Central Asia, bordering Afghanistan, Uzbekistan, Kyrgyzstan, and China. The national territory covers 142,000 sq km of which almost the half lies at altitudes of higher than 3,000 meters. The arable land is estimated at less than 900,000 ha (7 percent of the national territory) (FAO, 2011). The agricultural sector plays a vital role in the Tajik economy and accounted for 18.7 percent of the gross domestic product (GDP) in 2010. The majority of the population (70 percent) lives in rural areas, and 67 percent are employed in the agricultural sector (mainly engaged in the cotton sector). The non-farm economy in the rural areas is only developed to a limited extent. Tajikistan is zoned into four different political regions: Sogd in the north, the Regions of Republican Subordination (RRS) with the capital Dushanbe, Kathlon in the southwest, and Gorno-Badakhshan Autonomous Oblast (GBAO) in the east (Government of Tajikistan, 2007).

Sogd covers about 18 percent of the country's area (32 percent of the national arable land) and accounts for about 30 percent of the population (75 percent rural). The RRS occupy about 20 percent of the country's area (18 percent of the national arable land) and account for around 25 percent of the population (90 percent rural). Kathlon accounts for around 17 percent of the country's area (49 percent of the national arable land) and about 35 percent of the population (83 percent rural). The GBAO accounts for 45 percent of the country's area (1 percent of the national arable land) and only 3 percent of the total population (Government of Tajikistan, 2007).

Agriculture is dominated by the production of cotton, accounting for 60 percent of the GAO (FAO, 2011). Cotton and wheat are together the two major crops in Tajikistan. Of the roughly 900,000 ha arable land, cotton covers 32 percent, wheat 36 percent, and other cereals 9 percent (Government of Tajikistan, 2007). Other planted crops are potatoes, vegetables, fruits, and nuts. There are obvious differences in the importance of agriculture between the different regions as Table I reveals. Cotton is primarily produced in Kathlon, Sogd, and the RRS with 59, 30, and 11 percent of the national harvest, respectively. The mountainous GBAO is not suitable for cotton production and contains primary areas of pasture and livestock production.

Although climatic conditions of Tajikistan (typical continental climate with hot and dry summers and cold winters) allow for growing a wide range of crops, precipitation is the limiting factor. Thus, only RRS is suitable for pure rain-fed agricultural production.

Table I. Agricultural production in Tajikistan in 2007

Product	Sogd (%)	Region RRS (%)	Kathlon (%)	GBAO (%)
Cotton	30	11	59	0
Cereals	21	18	59	1
Rice	44	19	36	0
Flax	5	36	51	1
Tobacco	93	1	5	0
Potatoes	35	35	24	6
Vegetables	36	29	34	2
Fruits	42	24	28	5
Grapes	32	24	43	0
Milk	26	22	40	2
Meat	25	23	46	6
Share of national GAO	25	26	45	4

Source: PlaNet Guarantee (2011)

About 67 percent of the agricultural production depends on irrigation. However, effective and efficient water allocation is limited by administrative problems (e.g. weakness of water user associations) or malfunctioning irrigation systems (e.g. limited water pumping due to power shortages or leaks in the systems). Given that 89 percent of the country's cotton production originates from Kathlon and Sogd (both with annual precipitation below 300 mm), the importance of timely and adequate water supply is obvious. The cotton season in Tajikistan starts with sowing between April and May and ends with the harvest between September and December. Most water-sensitive periods which limit yield (potential) of cotton plants are the germination phase shortly after seeding (water shortage lags/suppresses sprouting and limits the strength of the plants) and the flowering period (water shortages limit the number of flowers, and hence, the number of cotton balls). Thus, spring and summer droughts are most yield relevant (National Cotton Council, The Cotton Foundation, 2007).

The basis of our analysis is cotton yield data provided in detail for all subregions by the Government of Tajikistan, covering the time period 2000-2010. The data include all cotton producing regions (Kathlon, Sogd, RRS) with their 34 subregions. The cultivation of cotton in Tajikistan is split up as follows: 100,595 ha in Kathlon, 53,977 ha in Sogd, and 7,812 ha in RRS (Government of Tajikistan, 2007). The average yield differs significantly between regions. While the average yield/ha in Kathlon is 16.78 decitonnes (dt), it is 17.08 dt in Sogd and 20.58 dt in RRS (PlaNet Guarantee, 2011).

The weather data used for our analysis is recorded by three weather stations located in Kathlon, Sogd, and RRS and is also provided by the Government of Tajikistan. The entire time period covered is from 1985 to 2010, but only for the period 2000-2010 is the data consistent and will, hence, be used for our analysis. The average precipitation per year shows regional variations. Kathlon has an average precipitation of 243 mm, while Sogd only has 204 mm, and RRS has 645 mm. The dry summer is much shorter in RRS (July-October) and Sogd (June-September) than in Kathlon (June-November).

Methods

Our analysis is based on five consecutive steps. First, a suitable weather index reflecting the dependency between weather variables and cotton yield needs to be identified. Here we focus our analysis on precipitation, as water scarcity during the vegetation period is considered to be most yield limiting in cotton production. Therefore, we identify the most yield-critical time period, based on a correlation analysis between the cumulated precipitation for different time periods and cotton yield. Based on these results, and in a second step, we structure an index-based weather insurance product able to compensate precipitation-induced yield variations. In a third step, we analyze the risk reduction potential (hedging effectivity) of such a weather insurance product by comparing the hypothetical returns from cotton production for the 34 subregions of the regions Kathlon, Sogd, and RRS with and without insurance. In a fourth step, we consider different risk aggregation levels by aggregating yield data of different subregions. Based on this, we are able to investigate our first hypothesis. In a fifth step, we introduce two strike-level modifications to investigate our second hypothesis.

Weather index. Due to the fact that water is one of the most important production factors in cotton production, we focus on a precipitation index. In order to build a precipitation-based weather index, we use an accumulation index similar to that of Stoppa and Hess (2003) or Berg *et al.* (2005). We generate a weather index I_t based on the precipitation sum inherent in a one-month accumulation period x of a year t:

$$I_t = \sum_{d=1}^{x} R_d \tag{4}$$

where R_d denotes the precipitation at day d. The precipitation is added up over all days d belonging to the accumulation period x in year t. Due to the best correlation between precipitation sum and cotton yield (0.33), May is the relevant accumulation period for Kathlon, while August is relevant for Sogd (0.22) and RRS (0.54). Moreover, May and August are the most water-sensitive periods for cotton yield (National Cotton Council, The Cotton Foundation, 2007).

Index insurance. We develop a precipitation-based weather index insurance product which is able to compensate precipitation-induced cotton yield losses of different (sub) regions. This can be achieved by a payout from the insurance product when predefined precipitation thresholds (strike level) are achieved. Put options are the dominating instrument for precipitation indices (Berg *et al.*, 2005). A positive payout n_t^{put} is made when the precipitation sum I_t is below the strike level S:

$$n_t^{put} = max(S - I_t; 0) \cdot a \tag{5}$$

The tick size (a) determines the payout per mm lower deviation. For our analysis, the strike level S equals the historical average of the precipitation index, which is different for Kathlon (24.07 mm), Sogd (1.56 mm), and RRS (2.09 mm). With a precipitation above the strike level the payout is zero. Moreover, the insurance payout cannot be negative. This is why the expected value of the insurance product is always positive. We define the price of the insurance as "fair premium" r (Turvey, 2001, 2005). The fair premium equals the mean value of all payouts for the considered time period in our analysis (2000-2010). By modifying the tick size a, which has to be greater or equal to zero, we maximize the payout. This maximization method is applied for each subregion.

Hedging effectivity. In order to calculate the expected value of the returns from cotton production without insurance $E_t^{without}$ for a specific (sub) region, we multiply the cotton yield (dt/ha) Y_t by the cotton price (USD/dt) p_t:

$$E_t^{without} = Y_t \cdot p_t \tag{6}$$

The cotton price is assumed to be fixed at USD150/dt due to price hedging via the futures market for the time period considered. In order to calculate the expected value for without insurance E_t^{with} we add the payout from the insurance product and subtract the (fair) premium from $E_t^{without}$:

$$E_t^{with} = E_t^{without} + n_t^{put} - r \tag{7}$$

We then calculate the reduction of the standard deviation of the returns SD achieved through the insurance payouts and calculate the hedging effectiveness HE as follows:

$$HE = \frac{\left(SD^{with} - SD^{without}\right)}{SD^{without}} \cdot 100 \tag{8}$$

The hedging effectivities are calculated for each of the 34 subregions of Kathlon, Sogd, and RRS.

Aggregation levels. In our analysis we consider five different yield aggregation levels (AL 1, AL 2, AL 3, AL 4, AL 5). For AL 1, the hedging effectivity of the three riskiest subregions (the subregions with the highest yield standard deviation) are considered. For AL 2/AL 3/AL 4, the AL 5/AL 7/AL 10 most risky subregions are considered. The yields are aggregated for each region and the national level (represented by Kathlon, Sogd, and RRS only). For AL 5 yield data is considered of all subregions of Kathlon, Sogd, and RRS, respectively (regional level), and for all 34 subregions for Tajikistan as a whole (national level). For the calculation of the hedging effectivities, yields of all subregions considered on each aggregation level are pooled, and their mean value is used for the calculation of the expected values. In contrast to the regional level, strike level, and tick size for AL 2, AL 3, AL 4, and AL 5 might differ on the national level. This is because subregions considered for the calculations on the national level might belong to different regions where weather index periods are different.

Variation of strike level

In order to focus on extreme weather events in our insurance design, we set for the national level (including all 34 subregions of Kathlon, Sogd, and RRS) different strike levels for 0 percent (SL 0), 30 percent (SL 30), and 50 percent (SL 50) below the average precipitation sum in the time period considered in our analysis.

4. Results

Table II depicts cotton yield characteristics, attributes, and hedging effectivities of the weather index-based insurance product applied for: the national level, the regional level, different yield aggregation levels (AL 1, AL 2, AL 3, AL 4, AL 5) as well as for, and different strike-levels (SL 0, SL 30, SL 50). Table III shows cotton yield characteristics, attributes, and hedging effectivities of the weather index-based insurance product applied for all 34 subregions. Furthermore, regional mean hedging effectivities are depicted in Table III.

Table II shows that on the regional level (AL 5), index-based weather insurance has the potential to reduce the standard deviation of returns from cotton production between 11.92 and 20.16 percent. On the national level (AL 5), the hedging effectivity is

Table II. Yield and index insurance characteristics at national, regional, and different risk aggregation levels

Region	Aggregation level (AL)	Cotton yield in dt/ha	Cotton yield SD	Cotton yield maximum in dt/ha	Cotton yield minimum in dt/ha	Index month	Mean precipitation in mm/month	Tick size	Hedging effectivity (%)[a]
Kathlon	AL 1	16.08	3.59	20.73	11.03	May	24.07	26.02	−14.22
	AL 2	15.71	3.43	20.31	13.12	May	24.07	31.34	−23.78
	AL 3	16.74	3.14	20.59	11.1	May	24.07	25.95	−18.92
	AL 4	16.32	2.85	19.52	10.61	May	24.07	26.27	−24.42
	AL 5	16.78	2.37	19.17	11.99	May	24.07	20.13	−20.16
Sogd	AL 1	18.78	2.30	22.77	14.42	August	1.7	279.36	−24.93
	AL 2	17.81	1.98	20.34	13.52	August	1.7	210.69	−18.43%
	AL 3	17.08	1.48	19.27	13.91	August	1.7	130.72	−12.29
	AL 4	na	na	na	na	na	na	na	na
	AL 5	17.08	1.48	19.27	13.91	August	1.56	141.11	−12.22
RSS	AL 1	20.00	3.63	23.61	12.74	August	2.09	262.28	−13.91
	AL 2	20.58	3.05	24.08	14.41	August	2.09	205.26	−11.92
	AL 3	na	na	na	na	na	na	na	na
	AL 4	na	na	na	na	na	na	na	na
	AL 5	20.58	3.05	54.08	14.41	August	2.09	205.26	−11.92
Tajikistan	AL 1	16.08	3.59	20.73	11.03	May/August	na	na	−13.43
	AL 2	16.51	3.03	20.60	12.24	May/August	na	na	−17.15
	AL 3	16.94	2.96	20.48	11.53	May/August	na	na	−18.38
	AL 4	17.86	2.21	20.65	13.93	May/August	na	na	−18.71
	AL 5 (SL 0[b])	18.15	1.67	20.24	15.47	May/August	na	na	−14.69
	SL 30[b]	18.15	1.67	20.24	15.47	May/August	na	na	−14.22
	SL 50[b]	18.15	1.67	20.24	15.47	May/August	na	na	−15.38

Notes: [a]The hedging effectivity indicates the potential of the index-based weather insurance product to reduce the SD of cotton returns. Hence, the lower the hedging effectivity, the higher is the potential of the index-based weather insurance product for reducing the SD of cotton returns; [b]SL 0/30/50 indicate strike levels equal to average/30 percent below average/50 percent below average precipitation, respectively

Table III.
Yield and index insurance characteristics for the sub-regions

Sub-region		Cotton yield in dt/ha	Cotton yield SD	Cotton yield maximum in dt/ha	Cotton yield minimum in dt/ha	Index month	Mean precipitation in mm/month	Tick size	Strike level	Hedging effectivity[a]
Kathlon	1	16.48	4.15	21.22	7.8	May	24.07	36.86	24.10	−22.39
	2	19.36	3.18	22.92	13.10	May	24.07	22.69	24.10	−13.79
	3	18.58	2.55	21.45	14.00	May	24.07	25.73	24.10	−30.11
	4	17.82	4.54	22.66	10.60	May	24.07	31.75	24.10	−13.14
	5	12.63	3.32	18.45	6.70	May	24.07	26.42	24.10	−17.49
	6	13.99	3.04	18.24	7.80	May	24.07	13.04	24.10	−4.74
	7	19.12	3.36	23.39	11.88	May	24.07	12.67	24.10	−3.64
	8	17.22	2.93	21.33	12.38	May	24.07	0	24.10	0.00
	9	21.92	2.60	25.45	17.10	May	24.07	1.66	24.10	−0.10
	10	14.01	3.18	19.36	8.60	May	24.07	32	24.10	−29.88
	11	13.76	4.81	19.96	7.55	May	24.07	3.54	24.10	−0.14
	12	12.95	3.02	17.20	8.30	May	24.07	9.31	24.10	−2.42
	13	13.82	4.47	21.86	8.55	May	24.07	41.77	24.10	−25.08
	14	21.71	3.03	24.63	14.11	May	24.07	16.11	24.10	−7.36
	15	14.19	3.04	20.81	10.20	May	24.07	15.66	24.10	−6.93
	16	16.66	4.82	21.97	6.40	May	24.07	42.78	24.10	−22.26
	17	19.54	4.05	23.55	11.70	May	24.07	12.26	24.10	−2.33
	18	18.36	2.54	22.03	14.90	May	24.07	19.25	24.10	−15.68
										−12.08[b]
Sogd	1	11.00	1.15	12.53	8.58	August	1.56	14.34	1.60	−0.20
	4	18.90	3.21	24.7	13.87	August	1.56	380.75	1.60	−19.81
	5	17.45	2.66	20.61	11.84	August	1.56	297.99	1.60	−17.46
	6	16.02	2.36	20.03	11.90	August	1.56	52.63	1.60	−0.63
	9	19.98	2.62	25.7	17.56	August	1.56	215.55	1.60	−8.95
	10	19.49	2.17	22.5	15.56	August	1.56	0	1.60	0.00
	11	16.72	2.34	19.65	12.44	August	1.56	183.41	1.60	−8.08
										−7.88[b]
RRS	1	22.32	2.35	25.50	18.20	August	2.09	24.15	2.10	−0.26
	2	20.54	3.44	25.1	12.80	August	2.09	215.29	2.10	−10.20
	3	19.01	3.52	24.35	13.38	August	2.09	266.13	2.10	−15.32
	4	20.47	4.41	26.87	13.09	August	2.09	295.13	2.10	−11.75
	5	20.53	3.69	24.07	11.31	August	2.09	225.59	2.10	−9.72
										−9.45[b]
Tajikistan										−9.41[b]

Notes: [a]Mean of the hedging effectivities of the respective sub-regions (corresponding mean value); [b]the hedging effectivity indicates the potential of the index-based weather insurance product to reduce the SD of cotton returns. Hence, the lower the hedging effectivity, the higher is the potential of the index-based weather insurance product for reducing the SD of cotton returns

14.69 percent. Comparing these results with the hedging effectivities of the three regions and Tajikistan as a whole based on the mean hedging effectivities of the respective subregions (corresponding mean values), our results (cf. Table III) show that the respective aggregated hedging effectivities (AL 5) are much lower[2] than the corresponding mean values. In fact, the aggregated hedging effectivities on the regional level are between 0.8 and 1.6 times as high as the corresponding mean values. On the national level, the aggregated hedging effectivity equals about 1.5 times the corresponding mean value of all 34 subregions considered.

In order to investigate our *H1* "Accumulation effect," stipulating that the risk reduction potential of meso-level index-insurance increases with increasing risk aggregation levels, we take into account the riskiness of the respective subregions, which is reflected by the different risk aggregation levels (AL 1, AL 2, AL 3, AL 4). Here our results differ between the regional and the national level. They reveal that the aggregation of yield data from subregions with successively decreasing weather risk leads to a successively increase of the hedging effectivities (and vice versa) on the national level, while this is not the case for the regional level. Hence, we have to reject our first hypothesis.

For the national level, our results confirm the findings of Pelka and Musshoff (2015) and Woodard and Garcia (2008), both finding higher hedging effectivities when index-based weather insurance is based on aggregate yield data instead of individual farm yields or, as in our case, yields from subregions. Moreover, we find that risk is accumulated on an aggregate level despite that weather risk (measured by yield standard deviation) is successively decreasing for each additional subregion considered for the calculation of the hedging effectivities. Including more subregions, hence, can improve hedging effectivity. Moreover, the more subregions are considered the higher the chance will be that the insurance product will pay out indemnities. Considering findings in the literature on insurance uptake (Cole *et al.*, 2013b), this might increase insurance attractiveness for the party insured.

Why results for the national level cannot be confirmed for the regional level is surprising, at least at first glance, especially as Kathlon in comparison to Sogd and RRS shows a relatively large number of subregions. But it needs to be considered that our analysis for the different aggregation levels considers politically determined regions and does not take into account the geographical situation of the subregions. We do not account for the effect that weather-related yield risks of subregions are likely correlated beyond regional borders (two neighboring subregions might belong to different political regions). But following (Woodard and Garcia, 2008), the aggregation of weather risk on the regional level depends on the covariance of the weather effect for different subregions. Our results for the regional level suggest that weather risk between the subregions of one region is not necessarily positively correlated, while on the national level the hedging effectivity is constantly increasing from AL 1 to AL 4. On the regional level, fluctuating hedging effectivities over the different aggregation levels even suggest negative covariance of weather risk between subregions. Nevertheless, the hedging effectivities above the corresponding mean values on the different risk aggregation levels suggest a higher hedging effectivity for insurance products offered on an aggregate instead of a sub-regional level. If meso-level insurance is to be developed commercially, it would, however, be prudent to reconsider the common use of regional, political, or economic boundaries in favor of climatic, meteorological, or ecological boundaries.

In order to investigate our *H2* "Compensation effect," stipulating that risk reduction potential of meso-level weather index-based insurance changes with the severity of weather events covered, we set different strike levels below the average precipitation sum in the time period considered. Our results reveal that focussing on the compensation of less frequent weather events changes the hedging effectivity of weather index-based insurance. In fact, we find a decreasing hedging effectivity from SL 0 to SL 30 and an increasing hedging effectivity from SL 0/SL 30 to SL 50. We, therefore, can accept our second hypothesis. These results suggest that looking *ex-ante* on the risk compensation needs of the party insured is crucial for designing products with optimal hedging effectivity. Such needs also depend on alternative risk management instruments in place with the party insured. Here, agricultural cotton processors might want to avoid bankruptcy in case of a severe national drought but might be able to cover regionally focussed droughts by themselves; while (regional) governments might prefer a full loss coverage for being able to provide compensation payments to drought-affected farmers. On this latter point, the assurance that indemnities from meso-level insurance actually extend to farmers and primary producers may require additional contract specifications, regulation, and/or oversight.

5. Summary and conclusions

Despite a high-risk exposure (especially against weather risk) of (agricultural) individuals and small businesses in developing countries, insurance uptake rates in these countries are low. By this means, the potential of insurance for investment stimulation in particular remains unexplored. Here, research is focussed on micro-level insurance, i.e., insurance products for individuals. This includes innovative insurance approaches, such as index-based weather insurance, which suffer from significant basis risk when applied on the micro-level with small contract sizes. Meso-level approaches, i.e., insurance products for risk aggregators, bear a large risk reduction potential at relatively low administrative costs but seem to be overlooked by most researchers.

This paper contributes to filling this research gap by investigating the risk reduction potential of meso-level index-based weather insurance for cotton production in the three most important cotton producing regions of the Republic of Tajikistan. In Tajikistan, 69 percent of the population is employed in agriculture, and the cotton sector contributes 60 percent of the GAO. We design different weather insurance products based on put options on a cumulated precipitation index. The insurance products are modeled for different inter-regional and intra-regional risk aggregation and risk coverage scenarios, and their risk reduction potential is investigated.

We find that it is feasible to design index-based weather insurance products for the meso-level with a considerable risk reduction potential against weather-induced revenue losses in cotton production. Furthermore, we find that the risk reduction potential of index-based weather insurance products increases the more subregions are considered for the insurance product design. Moreover, we find that risk reduction increases if weather index-based insurance is designed to compensate extreme weather events (SL 50) instead of compensating negative deviations from long-term precipitation averages.

The design and, hence, the risk reduction potential of weather index-based insurance depends also on the party insured and the level to which the party insured wants to be compensated. Here, meso-level insurance can have direct and indirect effects. The direct effect is the most plausible; the indemnity payment remains with the party insured, e.g., a regional cotton processor is compensated for under-capacities of his cotton mill when yields are low due to a drought. The indemnity payments might prevent him from bankruptcy. Similarly, a financial institution can use indemnity payments for directly covering drought-induced losses (given drought-induced loan default). The indirect effect might be that the indemnity payments help to make the processor stay with his business strategy, e.g., despite high-income risk exposition when focussing on a specific region, the processor will not change his regional focus due to expected compensations from the insurance contract in case of a severe drought. His presence might be an indirect benefit for the regional cotton farmers due to higher competition or shorter distances for marketing their cotton. For the financial institution, the indirect effect might be that indemnity payments expected in case of a severe drought gives the financial institution confidence to continue banking with farmers in the cotton sector. Combining both direct and indirect insurance effects in agricultural lending is the idea of insurance-backed credit or risk-contingent credit (Giné and Yang, 2009; Miranda and Gonzalez-Vega, 2011; Shee and Turvey, 2012) which is currently discussed in research and practice as an innovative instrument for increasing financial inclusion of agricultural firms in developing countries without jeopardizing loan portfolio quality of agricultural lenders.

However, even if we can show that there is a large potential for meso-level index insurance, transferring risks to the insurance market is only one option for yield risk management. For the specific case of Tajikistan we discussed earlier that about 60 percent of the cotton production depends on irrigation and that for different reasons the Tajik irrigation system is currently not functioning well. The potential of meso-level insurance might decrease (in the long run) when the irrigation system works at its full capacity. Nevertheless, especially when severe national droughts occur, irrigation water reservoirs might be affected as well, despite fully functioning irrigation systems. Here, meso-level insurance could complement water risk management measures in Tajikistan, e.g., by focussing on extreme weather events also affecting irrigation water reservoirs. Area yield insurance might be an alternative to meso-level weather index-based insurance. Area yield insurance has the advantage that besides rainfall also other (weather) risk variables are implicitly covered. Furthermore, the weather index applied in our analysis could be extended by additional weather variables (e.g. temperature), instead of focussing solely on precipitation. This increases complexity but might also increase the hedging effectivity of the meso-level insurance product applied. Our results might also change if the selection of the weather station for designing the weather index-based insurance product would be explicitly designed for the sub-regional level. Here, each subregion could be linked to the weather station showing the highest correlation of yield and precipitation (e.g. subregions on the edges of regions might be closer to the weather station of the neighboring region). However, there might be downside effects due to the adaptation of aggregation procedures. Alternative aggregation approaches, including a completely randomized selection or following geographical patterns such as distance from the weather station should be investigated. Furthermore, we assume different potential buyers of meso-level insurance products might have different insurance needs and different risk management measures in place to complement each other. Further research should, hence, focus on potential risk accumulators and consider their needs for insurance design. In this context, particularly the potential of insurance for (regional) governments should be investigated.

Notes

1. At the actuarial fair price the average insurance payout is equal to the indemnity payments over a given time period, i.e., the insurance coverage costs as much as it returns.

2. The hedging effectivity indicates the potential of the index-based weather insurance product to reduce the standard deviation of cotton returns. Hence, the lower the hedging effectivity, the higher is the potential of the index-based weather insurance product for reducing the standard deviation of cotton returns.

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