Theory and application of weather index-based insurance in agriculture

-To pitfalls of aggregation biases and the insurability of farmers in the North China Plain-

Dissertation

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Content

Preface

"Everybody talks about the weather, but nobody does anything about it"

(Charles Dudley Warner)

To what extent the effects of weather can be managed, is certainly a question of interpretation and the parties involved. Hence, it is debatable – or it is rather out of question – that Charles D. Warner intended to advert weather index-based insurance with this quote. In agricultural production, weather represents the most important and least controllable source of risk. At this, bad weather is not only an environmental issue but rather a key economic factor. Weather risk introduces the questions to manage its negative economic consequences for farmers, or, in other words, how to do something about it. To that effect, this dissertation is concerned with the construction, design and evaluation of weather index-based insurance to manage weather risk in agriculture.

Introduction

Weather is an essential production factor but, at the same time, the most important and least controllable source of risk in agriculture (Musshoff et al., 2008). There is scarcely a year without adverse weather events leading to losses in agricultural production in most diverse regions of the world (IPCC, 2008; Lobell et al., 2008). In addition, climate change will likely reinforce weather-related risk by rising temperature, erratic rainfall as well as the occurrence and severity of droughts or floods (Carter et al., 2007; Morton, 2007). The producers involved face the task either to bear or to manage the associated perils (Berg and Schmitz, 2008). Thus, insurance plays an important role when hedging these risks. However, the capabilities to set up risk management instruments vary substantially between industrialized countries and low-income countries. In this context, innovative weather index-based insurance has gained more and more attention in the last decades (Barrett, et al., 2007; Odening et al., 2007; Skees, et al, 2001; Turvey, 2001). This newer type of insurance, in which indemnity payments are based on objectively measurable weather indices rather than actual losses, can challenge the basic requirements of insurable interest and avoid most endemic problems of classic agricultural (indemnity-based) insurances (e.g. Goodwin, 2001). Nevertheless, long-term sustainability of weather index-based insurance offers prevalent debatable claims including their hedging effectiveness as well as some complications if an empirical application is envisaged.

For the evaluation of hedging effectiveness of weather index-based insurance Breustedt et al. (2008) note, for instance, that in recent literature (e.g. Karuaihe et al., 2006; Skees et al., 2001; Vedenov and Barnett, 2004), the analyses are often based on aggregated crop yields rather than on individual farm yields. However, the latter are frequently not available for risk analysis (Coble et al., 2007; Kimura and Le Thi, 2011) and the design of weather index-based insurance and it, therefore, became clear that the use of aggregated time series is sometimes unavoidable. But experience with agricultural yield insurance applications (e.g. area yield insurance) has shown that the aggregation of crop yields causes errors in the risk assessment for farm-level analysis (Cooper et al., 2009; Rudstrom et al., 2002). More specifically, this is due to the fact that crop yield variability is usually significantly smaller if data from more aggregated levels is analyzed (e.g. Finger, 2012). The evaluation of what kind and magnitude of error results from aggregated yield data used for evaluating the hedging effectiveness is thereby important for insurance suppliers as well as for farmers. However, currently there is no literature that explicitly investigates how the interrelationship between data aggregation and yield variability affects the hedging effectiveness of weather index-based insurance. Here, a central question is which hedging effectiveness remains on the individual farm-level if the insurance contract would have been designed on the basis of aggregated yield data. Thus, a relevant contribution of this dissertation is to examine claims of aggregation biases with regard to the level of yield data aggregation in the underlying risk exposure under specific consideration of the hedging effectiveness of weather index-based insurance.

However, a wider set of investigations is needed to reveal optimal insurance design as well as to address the high spatial heterogeneity of weather if application of weather index-based insurance is envisaged. Using the contemporary example of China, it matters that farmers are exposed in particular to weather risk in crop production (Kogan et al., 2005; Turvey and Kong, 2010). The production risk does not affect Chinese agricultural production at large, but especially affects the livelihood of small-scale farmers whose possibility to cope with risk is generally limited. The insurance market in China is still in its infancy (Xu et al., 2010), and recently the Chinese government authorized an investigation into the potential for agricultural insurances (Turvey et al., 2009). In this regard, the World Bank (2007) notes that traditional insurance schemes are still too expensive for Chinese farmers. The question if weather index-based insurances can contribute to risk reduction in Chinas agricultural sector and in particular in the major area of crop production (North China Plain, NCP) has not been studied extensively yet (Turvey and Kong, 2010). The NCP is thereby a strike example for millions of scatter small-scale farms, where the common absence of farm-level yield data prevents the individual evaluation of the risk reduction potential of insurances. However, aggregated yield data of different Chinese provinces can be derived from national statistics and allows evaluating the risk reduction of insurance for an average farm of a specific area. A further relevant contribution of this dissertation is the explicit evaluation of the risk reduction potential of weather index-based insurances developed on the aggregated provincial level of yield data under the consideration of different weather stations in the NCP.

The present dissertation is twofold and takes up the aforementioned issues in two separate and independent articles. In chapter II, the hedging effectiveness of weather index-based insurance with regard to aggregation biases in the underlying risk exposure of aggregated yield time series is presented. The set of problems that arouse during the evaluation of the risk reduction potential for the application of weather index-based insurance in the NCP is discussed in chapter III. Before the specific objectives of both chapters are listed, weather risk in agriculture is reconsidered and the scope of risk management instruments focusing on insurance is briefly reviewed. The dissertation concludes with a summary of the results and their contextual discussion.

Weather risk in agriculture

Eimern and Haeckel (1984) define weather as shape and proceeding of parameters such as temperature, precipitation, humidity or wind speed etc., at a certain time and a specific location. Local weather patterns alternate short-termed and periodically and have positive and negative effects of multiple scopes in agriculture (Hardaker et al., 2004). By way of contrast, Barth (2002) defines climate as weighted weather parameters over a period of at least 30 years. The local evidence of climate change cannot be predicted in general (Collier et al., 2009) but its long-term consequences are mainly cited in the literature to cause adverse weather in agriculture as more frequent and serve for most diverse regions (cf. Lobell et al, 2008).

The occurrence of adverse weather in agriculture can be differentiated into catastrophic (low frequency – high severity) weather events such as hail or flood and non-catastrophic (high frequency – low severity) events which imply variance of the mean of a weather pattern such as drought. Mahul (2001) defines the resulting weather risk as combination of a systemic component which stems from the unpredictability of weather and an idiosyncratic component depending on individual characteristics. It is a matter of course that weather gets in line with a variety of different risks that can threat farmers output, income and ultimately their consumption (cf. Tab. 1). Musshoff and Hirschhauer (2011) divide the types of risks into financial risk and business risks (price-, volume-, behavior risk, risk of policy changes). With focus on weather, systemic risks affect a large number of producers at the same time (e.g. drought) and idiosyncratic risks affect farmers independently (e.g. hail). Joint economic consequence endangers farmers as exogenous business risk (Musshoff et al., 2008).

Apparently, rain feed crop production is most sensitive to weather conditions (Isik and Devadoss, 2006), but weather risk is not limited to the production on field. Livestock farms, the turnover of processors, the demand for many food products and thus large parts of the agribusiness depend on the weather (Hardaker et al., 2004). In addition, agriculture represents a critical source of livelihood for farmers in low-income countries (Skees, 2008).

Table 1: Classification of risk in agricultural production

Type of risk	**Idiosyncratic**	←――――→	**Systemic**
Weather	Hail	Flood, Pest infestation	Drougth
Diseases and Pests			Contagious animal disease
Price			Commodity, inputs, Exchange rates
Financial			Interest rates
Operational		Availability of inputs	Technological progress
Environmental		Pollution, Deforestiation	
Policy			Public subsidies, Agricultural policy
Health	Illnes, Injury	Epidemic diseases	
Property	Fire, Theft		Earthquake, floods

Source: Mahul and Stutley (2010)

Capabilities to cope with weather risk in agricultural enterprises

The adaptation to adverse weather is nothing new for farmers (cf. OECD, 2005; OECD, 2008), who have developed risk management strategies to cope with weather risk. Berg and Schmitz (2008) group farmer’s risk management capabilities into on-farm management and market-based instruments. On-farm risk management includes the adjustment of production technologies, production and labor diversification or the holding of overcapacities (cf. Hardaker et al., 2007). Furthermore, it is not least connected with incurred expenses. For farmers in low-income countries, the investments in assets like seed varieties, irrigation or self-insurance such as financial savings have often been required at very high transaction costs in form of forgone consumption (Carter et al., 2007; Stern, 2006).

The comprehensive approach of on-farm management is frequently combined with market-based risk management instruments which pool various types of insurance and which are predominantly associated with substantial support of national governments. With few exceptions (agricultural revenue insurance in the USA), agricultural insurance does not cover price volatility (cf. Barnett et al., 2005). When exclusively focusing on production risk in agriculture caused by adverse weather, the common forms of traditional indemnity-based insurance schemes as well as newer index-based insurance schemes complement the risk management process.

Indemnity-based insurances are established in many industrialized countries, but are also increasingly integrated by governments in low-income countries (Mahul and Stutley, 2010; World Bank, 2008). Renowned examples of indemnity-based insurance are, e.g., hail insurance in Germany or yield insurance such as multi-peril crop insurance in the USA. Attributed to the need of individual estimation of damage on-farm, the insurance scheme typically causes high transaction costs (Berg and Schmitz, 2008; Ker and Ergun, 2007). Thus, indemnity-based insurances are predominantly provided by the support of national governments in form of subsidized premiums. The governmental support underlays certain national configurations (cf. World Bank, 2008). Even indemnity-based insurances are an established instrument to hedge risks, e.g., Mahul and Stutley (2010) point out general disadvantages: a limited insurance penetration, consistent underestimation of catastrophic risk, poor financial performance, claims and administrative costs exceeding premiums, inappropriate pricing, uncontrolled moral hazard, and adverse selection, apart from further key endemic problems of indemnity-based insurance.

Index-based insurance is the broader term for insurance instruments which couple the indemnity payment on an objectively measurable index, namely cumulated output indices (such as yield) and indices based on the source of losses (such as precipitation). Common insurance based on cumulated damage indices are, e.g., area yield insurance in the USA (Barnett et al., 2005; Miranda, 1991), where participating farmers receive indemnity if the regional average yield of a specific crop falls under a certain level. The same applies to livestock insurance in Mongolia (Mahul and Skees, 2007) and in Kenya (Chantarat et al., 2009), where insurance is based on an index of regional livestock mortality and temperature. In Canada, Spain and the USA, e.g., satellite imagery and vegetation are used as underlying for index insurance of pasture (cf. Mahul and Studley, 2010). In general, the underlying index of weather index insurance can be based on one or more weather variables. Hence, insurance based on weather indices offers advantages over indemnity-based insurance in particular and gains increasing attention especially regarding systemic risk in agriculture (e.g. Odening et al., 2007; Skees, et al., 2001; Turvey, 2001).

Weather index-based insurance

Weather index-based insurance presents a promising alternative to indemnity-based insurance schemes. The pay-offs (indemnity payments) of weather index-based insurance are coupled as mentioned before to an objectively measurable weather index which is measured over a specific period of time at a specific weather station. Its primary advantage over indemnity-based insurance results from the objective nature of the index, which mitigates key problems of information asymmetries and moral hazard (e.g. Berg and Schmitz, 2008; Goodwin, 2001; Ker and Ergun, 2007). In addition, the underlying index removes an expensive damage on-farm which results in increased transparency and comparatively lower transaction costs.

Among industrialized countries, an example of weather index-based instruments is the greenhouse horticulture in the Netherlands stocked with temperature-based indices (Garrido and Bielza, 2008). In Germany, index-based instruments are available to hedge against excessive rain, drought, heat and frost in agriculture (CelsiusPro, 2012). In low-income countries, pilot applications of weather index-based insurance, have been launched in, e.g., Malawi, India and Ethiopia (Hess and Syroka, 2005; Stoppa and Hess, 2003) which are primary based on the amount of precipitation. In addition, there are index-based insurance products which are linked to other services such as micro credits (Skees et al., 2007; Barnett and Mahul, 2007). However, even though the structure of weather index-based insurance has an edge over indemnity-based insurance, the current application in agriculture remains limited.

Constraints of the application of weather index-based insurances are, for example, their complexity, which may cause difficulties in the communication with farmers (e.g. Skees et al., 2001). Also, the provision of insurance to scattered small-scale farms can be very expensive and governments, cooperatives, rural banks or microfinance institutions play an important role in delivering the insurance product. Cost-effective alternatives in the form of community-based organizations, (known from health insurance or mutual insurance), which operate at very low overhead costs compared with commercial insurance, have received only little attention by policy makers yet (Mahul and Stutley, 2010). The primary disadvantage of weather index-based insurance is the so-called basis risk corresponding to the fact that the insurance pay-offs do not fully correlate with the losses in the underlying risk exposure (e.g. to the gross margin of the insured crop) (Woodard and Garcia, 2007). At this, the basis risk represents a non-insurable risk and has two sources. First, a geographical basis risk results from the spatial difference between weather patterns at the reference weather station and at a specific farm location. Second, for the farmers, the basis risk of production always remains because individual yields are often correlated imperfectly with the underlying index or, more specifically, weather is not the only factor which influences crop yields. Still index-based insurance implies that no individual damage estimation occurs on farm, the farmers must bear the basis risk. Thus, in one year, an individual farm may have yield losses but does not obtain any compensation from the insurance. Conversely, a farm may obtain compensation without having any yield losses (Skees, 2008).

Design and construction of weather index-based insurance contracts is complex and requires technical expertise for both, developing and operational phase. Mahul and Stutley (2010), World Bank (2008) or Swiss Re (2009) provide a brought overview about administrative and operational requirements. The technical aspects are discussed in detail in the chapters II and III. To reveal detailed research questions of this dissertation, some key requirements for the design and evaluation of weather index-based insurance are explained in the following.

Requirements and obstacles for the empirical implementation of weather index-based insurance

From the methodological point of view, structuring weather index-based insurance requires: (1) the statistical modeling of weather variables, (2) the quantification of the interrelationship between weather variables and production, (3) the design of the insurance, (4) insurance pricing and, (5) evaluation of the risk reduction potential. As a matter of course, these interrelated components comprise specific sub problems.

A weather index can be modeled diversely using single weather variables such as precipitation or temperature during a certain period of time (Barrett et al., 2007; Cao et al., 2004; Garrido and Bielza, 2008; Stoppa and Hess, 2003). Combined or mixed indices such as growing-degree days which are based on several weather variables can also be found in the literature (e.g. Breustedt et al., 2008; Turvey, 2001; Vedenov and Barnett, 2004). During this process, e.g., either the surplus of a weather variable, a deficit, daily minima or maxima, averages or the cumulated amount of the underlying weather variable can be statistically modeled to image the performance of weather. An irreplaceable precondition is the advisedly collection of weather data. In most industrialized countries, dense networks of weather stations provide an extensive record over long time horizons but this is frequently constrained in many developing countries (Hess, 2003). Furthermore, e.g., low destiny of weather stations amplifies the geographical basis risk at the development of weather index-based insurance (Norton et al., 2010; Odening et al., 2007). To attain hedging effectiveness, the challenge is here to transfer the information from an established weather station to locations where local weather patterns are unknown.

Another essential step for the development of weather index-based insurance is the estimation of the interrelationship between the weather index and the variable of agricultural production. With regard to realization, Xu et al. (2008) note that frequently constant production prices are assumed, so that the interrelation can be estimated between the weather index and, e.g., the physical crop yields. To do so, either correlation analysis can be applied or a production function can be estimated including weather as production factor (cf. e.g. Barrett et al., 2007; Skees et al., 2001; Stoppa and Hess, 2003, Turvey, 2001; Vedenov and Barnett, 2004). For analysis, it becomes apparent that obtaining individual farm-level yield data is sometimes much more difficult than weather data. Moreover, a lack of farm-level time series limits the risk assessment of insurance on individual farms. National statistical services of many countries often provide, e.g., crop time series on an aggregated regional or provincial level that are frequently used for the development and analysis of weather index-based insurance to hedge weather risk on the individual farm-level (cf. Breustedt et al., 2008). However, Finger (2012) and Rudstorm et al. (2002) reveal that crop yield variability usually is significantly smaller if data from more aggregated levels is analyzed and, e.g., Cooper et al. (2009) demonstrate for the example of agricultural yield insurance that the aggregation of crop yields causes errors in the risk assessment for farm-level analysis. As already mentioned in the introduction, for weather index-based insurance, there currently is no revealing literature which analyzes the questions of whether the interrelationship between data aggregation and yield variability affects the hedging effectiveness. Furthermore, additional questions arises if insurance designed to hedge weather risk on aggregated level also produces its estimated hedging effectiveness on the individual farm-level.

To control insurance pay-offs out of a weather index, commonly call- or put-options are used, but also swaps, futures or the combination of different options can be found in the literature (Xu et al., 2008). With regard to this, the distribution of the weather index influences the return of pay-offs, which can be investigated either nonparametrically by using the empirical distribution of weather data or by estimation using stochastic methods such as index-value simulation and daily simulation (e.g. Jewson et al., 2005; Turvey and Norton, 2008; Odening et al., 2007). The distributional form of the weather indices also affects the insurance premium which is critically discussed in the literature by, e.g., Odening et al., 2007; Richards et al., 2004; Turvey and Norton, 2008. The ongoing debate about insurance pricing includes actuarial methods, capital asset pricing models (Turvey, 2002), or indifference pricing models (Xu, et al., 2008) but so far, no standard method has been established.

The evaluation of the hedging effectiveness of the insurance involves at least measuring the risk reduction potential, e.g., by comparing the risk profiles with and without insurance on farm (e.g. Miranda, 1991; Skees et al., 2001; Smith et al., 1994). For this, nonparametric approaches, such as historical simulation, can be applied (cf. Xu et al., 2008), especially if crop time series are containing a sufficient amount of consistent observations. Another option are parametric approaches where the yield distributions are replaced by estimated crop- and region-specific production functions (Vedenov and Barnett, 2004; Zhang et al., 2003). For both approaches, risk assessment implies, e.g., the quantification of the individual farm damage, for instance, as percentage loss. The profiles with and without insurance on farm can be compared at least quantitatively by applying statistical risk measures, such as standard deviation, or the value at risk of crop revenues (e.g. Breustedt et al., 2008; Manfredo and Leuthold, 1998; Odening and Hinrichs, 2003; Torriani et al., 2008).

Objectives

This dissertation investigates constitutive parts of risk assessment and the possible application of weather index-based insurance resulting from the aforementioned problems. Chapter II and III feature two independent articles with specific objectives:

The first article "*Hedging weather risk on aggregated and individual farm-level – Pitfalls of aggregation biases on the evaluation of weather index-based insurance –*" addresses the fundamental problem that frequently no historical data on the individual farm-level is available for the design of weather index-based insurance. One specific objective is the theoretical investigation of the magnitude of bias which occurs if the hedging effectiveness of weather index-based insurance is estimated either on individual farm-level or on aggregated level of yield data. The issue is carried out for the example of wheat producing farms in Central Germany. The following questions will be answered:

1. How does the interrelationship between data aggregation and yield variability affect the hedging effectiveness of weather index-based insurance?
2. Does insurance designed to hedge weather risk on aggregated yield data produce the estimated hedging effectiveness also on the farm-level?
3. Are there significant differences between the hedging effectiveness of insurance designed to hedge weather risk for farmers on aggregated and individual farm-level?

The second article: *"Weather index-based insurances for farmers in the North China Plain: An analysis of risk reduction potential and basis risk"* addresses the extent to which weather index-based insurances can contribute to the reduction of shortfall risks in revenues of small scale farmers in the North China Plain. Another specific objective is the development of weather index-based insurance under the consideration of different weather stations and the evaluation of the risk reduction potential on the aggregated provincial level of yield data. In addition, the geographical basis risk is quantified to give insight in which area around a weather station an insurance can be expanded to reach hedging effectiveness at community level. The following questions will be answered:

4. Can weather index-based insurance contribute to the reduction of shortfall risks in grain production in the North China Plain?

5. What is the extent of potential risk reduction of insurance designed for an average farm by using different weather stations in the North China Plain?
6. Up to which size of an area around a certain weather station can insurance be expanded at community level in the North China Plain?

The common purpose of this dissertation is to close existing research gaps in the agricultural economic literature and to derive recommendations regarding the empirical application of weather index-based insurance in both industrialized and low-income countries. The results are therefore important for policy makers and potential insurance providers as well as for farmers.

References

Barnett, B., Black, R., Hu, Y., and Skees J. (2005), “Is area yield insurance competitive with farm insurance?”, *Journal of Agricultural and Resource Economics* Vol. 30, pp. 285-301.

Barnett, B. and Mahul, O. (2007), “Weather index insurance for agricultural and rural areas in lower income countries”, American *Journal of Agricultural Economics*, Vol. 30, No, 2, pp. 285-301.

Barrett, C.B., Barnett, B.J., Carter, M.R., Chantarat, S., Hansen, J.W., Mude, A.G., Osgood, D.E., Skees, J.R., Turvey, C.G. and Ward, M.N. (2007), “Poverty traps and climate risk: limitations and opportunities of index-based risk financing”, IRI Technical Report No. 07-02, September.

Barth, H.J. (2002), “*Klima – Eine Einführung in die Dynamik der Atmosphäre*“, University Press, Paderborn.

Berg, E. and Schmitz, B. (2008), “Weather-based instruments in the context of whole-farm risk management”, *Agricultural Finance Review*, Vol. 68, pp. 119-33.

Breustedt, G., Bokusheva R. and Heidelbach O. (2008), “The potential of index insurance schemes to reduce farmers` yield risk in an arid region”, *Journal of Agricultural Economics*, Vol. 59 No. 2, pp. 312-328.

Cao, M., Li, A. and Wei, J. (2004), “Precipitation modeling and contract valuation: A frontier in weather derivatives“, *The Journal of Alternative Investments*. Vol. 2004, pp. 93-99.

Carter, T.R., Jones, R.N., Lu, X., Bhadwal, S., Conde, C., Mearns, L.O., O’Neill, B.C., Rounsevell, M.D.A., and Zurek M.B. (2007), “New assessment methods and the characterization of future conditions”. *Climate Change 2007*, Impacts, adaptation and vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Parry, M.L., Canziani, O.F., Palutikof, J.P., van der Linden, P.J. and Hanson C.E. (Eds.), Cambridge University Press, Cambridge, UK, pp. 133-171.

CelsiusPro, Professional weather protection (2012). Product information. http://www.celsiuspro.com/Products/tabid/482/language/de-DE/Default.aspx.

Chantarat, S., Mude, A.G. and Barrett C.B. (2009), “Willingness to pay for index based livestock insurance: Results from a field experiment in North Kenya”, Research Paper.

Coble, K.H., Zuniga, M. and Heifner, R. (2003), “Evaluation of the interaction of risk management tools for cotton and soybeans”, *Agricultural Systems*, Vol. 75 No. 2-3, pp. 323-340.

Collier, B., Skees J. and. Barnett, B. (2009), “Weather index insurance and climate change: opportunities and challenges in lower income countries”, *The Geneva Papers*, Vol. 34, pp. 401-421.

Cooper, J., Langemeier M., Schnitkey G. and Zulauf C. (2009), „Constructing farm-level yield densities from aggregated data: analysis and comparison of approaches”, paper presented at the Agricultural and Applied Economics Association Annual Meeting, 26-28 July, Milwaukee, WI.

Finger, R. (2010), “Revisiting the evaluation of robust regression techniques for crop yield data detrending”, *American Journal of Agricultural Economics,* Vol. 92 No. 1, pp. 205-211.

Finger, R. (2012), “Biases in farm-level yield risk analysis due to data aggregation”, *German Journal of Agricultural Economics,* in press.

Eimern, v.J. and Häckel, H. (1984), “*Wetter- und Klimakunde*“, Stuttgart.

Garrido, A. and Bielza, M. (2008), “Income stabilization in a changing agricultural world: policy and tools”, European Association of Agricultural Economists (EAAE), 108th Seminar, Warsaw.

Goodwin, B.K. (2001), “Problems with market insurance in agriculture”, *American Journal of Agricultural Economics*, Vol. 83, pp. 643-9.

Hardaker, J.B., Huirne, R.B.M., Anderson J.R. and Lien C. (2004), “*Coping with risk in agriculture*”, Second Edition. CABI Publishing, Cambridge.

Hess, U. (2003), “Innovative financial services for rural India: Monsoon-indexed lending and insurance for smallholders”, Working paper no. 9, Agriculture and Rural Development Department, The World Bank, Washington, DC.

Hess U. and Syroka, J. (2005), ” Weather-based insurance in Southern Africa: The case of Malawi”, World Bank, ARD, Discussion Paper Vol. 13.

Intergovernmental Panel on Climate Change (IPCC) (2006), “Climate change and water” – IPCC Technical Paper, Vol. 6. www.ipcc.ch/pdf/technical-papers/climatechange-water-en.pdf.

Isik, M. and Devadoss, S. (2006), “An analysis of the impact of climate change on crop yields and yield variability”, *Applied Economics,* Vol. 38, pp. 835 - 844.

Jewson, S. and Brix, A. (2005), “*Weather Derivative Valuation: The Meteorological, Statistical, Financial and Mathematical Foundations”*, Cambridge University Press, Cambridge.

Karuaihe, R.N., Wang, H.W. and Young, D.L. (2006), “Weather-based crop insurance contracts for African countries”, paper presented at the International Association of Agricultural Economists Conference, 12-18 August, Gold Coast, Australia.

Ker, A. and Ergun, A.T. (2007), “On the revelation of private information in the US crop insurance program”, *The Journal of Risk and Insurance,* Vol. 74, pp. 761-76.

Kimura, S. and Le Thi, C. (2011), “Farm level analysis of risk and risk management strategies and policies: technical note” OECD Food, Agriculture and Fisheries Working Papers, No. 48, OECD Publishing, Paris.

Lobell, D.B., Ortiz-Monasterio, J.I. and Falcon, W.P. (2007), “Yield uncertainty at the field scale evaluated with multi-year satellite data”, *Agricultural Systems* Vol. 92 No. 1-3, pp. 76-90.

Norton, M., Osgood, D.E. and Turvey, C.G. (2010), ”Weather index insurance and the pricing of spatial basis risk”, paper presented at the Agricultural & Applied Economics Association’s 2010 AAEA, CAES & WAEA Joint Annual Meeting, 25-27 July, Denver, CO.

Mahul, O. (2001), “Managing catastrophic risk trough insurance and securitization”, *American Journal of Agricultural Economics,* Vol. 83 No. 3, pp. 656-661.

Mahul, O. and Stutley C.J. (2010), “Government support to agricultural insurance: Challenges and options for developing countries”, *World Bank Publications,* http://siteresources.worldbank.org/FINANCIALSECTOR/Resources/CountryOverviewMasterPiece_final_ANNEX_E.pdf.

Mahul, O. and Skees J.R. (2007), “Managing agricultural risk at the country level: The case of index-based livestock insurance in Mongolia”, World Bank Policy Research Working Paper No. 4325.

Manfredo, M.R. and Leuthold, R.M. (1998), “Agricultural applications of value-at-risk analysis: a perspective”, University of Illinois at Urbana-Champaign, Office for Futures and Options Research Working Paper No. 98/04.

Miranda, M.J. (1991), “Area-yield crop insurance reconsidered”, *American Journal of Agricultural Economics,* Vol. 73 No. 2, pp. 233-242.

Morton, J.F. (2007), “The impact of climate change on smallholder and subsistence agriculture’, *Proceedings of the National Academies of Sciences,* Vol. 104, pp. 19680-19685.

Mußhoff, O. und Hirschauer, N. (2011), “*Modernes Agrarmanagement – betriebswirtschaftliche Analyse- und Planungsverfahren*“, 2 Auflage, Franz Vahlen, München.

Musshoff, O., Hirschauer, N. and Odening, M. (2008), “Portfolio effects and the willingness to pay for weather insurance”, *Agricultural Finance Review,* Vol. 68 No. 1, pp. 83-98.

Kogan, F., Yang, B., Wei, G., Zhiyuan, P. and Xianfeng, J. (2005), “Modelling corn production in China using AVHRR-based vegetation health indices”, *International Journal of Remote Sensing,* Vol. 26, pp. 2325-36.

Odening, M. and Hinrichs, J. (2003), ”Using extreme value theory to estimate value-at-risk”, *Agricultural Finance Review,* Vol. 63 No. 1, pp. 55-73.

Odening, M., Musshoff, O. and Xu, W. (2007), “Analysis of rainfall derivatives using daily precipitation models: opportunities and pitfalls”, *Agricultural Finance Review,* Vol. 67 No. 1, pp. 135-156.

OECD (2005), “Agriculture and development: The case for policy coherence”. OECD, Paris.

OECD (2008), ”Economic aspects of adaptation to climate change”. OECD, Paris.

Richards, T.J., Manfredo, M.R. and Sanders, D.R. (2004), “Pricing weather derivatives”, *American Journal of Agricultural Economics,* Vol. 86, pp. 1005-17.

Rudstrom, M., Popp, M., Manning, P. and Gbur, E. (2002), “Data aggregation issues for crop yield risk analysis”, *Canadian Journal of Agricultural Economics,* Vol. 50 No. 2, pp. 185-200.

Skees, J. R., Gober, S., Varangis, P., Lester, R. and Kalavakonda, V. (2001), ”Developing rainfall-based index insurance in Morocco”, Policy Research Working Paper 2577, World Bank, Washington D.C.

Skees, J.R. (2008), “Challenges for use of index-based weather insurance in lower income countries”, *Agricultural Finance Review,* Vol. 68, pp. 197-217.

Skees, J., Hartell., J., Murphey, A. (2007), "Using index-based risk transfer products to facilitate micro lending in Peru and Vietnam", *American Journal of Agricultural Economics*, Vol. 89, No. 5, pp. 1255-1261.

Smith, V.H., Chouinard, H.H. and Baquet, A.E. (1994), "Almost ideal area yield crop insurance contracts", *Agricultural and Resource Economics Review*, Vol. 23 No. 1, pp. 75-83.

Stern, N. (2006), "*Review report on the economics of climate change*". Cambridge.

Stoppa, A. and Hess, U. (2003), "Design and use of weather derivatives in agricultural policies: the case of rainfall index insurance in Morocco", paper presented at the International Conference "Agricultural Policy Reform and the WTO: Where are We Heading", Capri.

Swiss Re. (2007), "*Insurance in Emerging Markets*". Sigma, Zurich.

Torriani, D.S., Calanca, P. and Beniston, M. (2008), "Hedging with weather derivatives to cope with climate variability and change in grain maize production", *Agricultural Finance Review*, Vol. 68, pp. 67-81.

Turvey, C.G. (2001), "Weather derivatives for specific event risks in agriculture", *Review of Agricultural Economics*, Vol. 23, pp. 333-51.

Turvey, C.G. (2002), "Insuring heat related risks in agriculture with degree day weather derivatives", paper presented at the American Agricultural Economics Association (AAEA) Annual Conference, Long Beach, CA.

Turvey, C.G. and Kong, R. (2010), "Weather risk and the viability of weather insurance in China's Gansu, Shaanxi, and Henan provinces", *China Agricultural Economic Review*, Vol. 2, pp. 5-24.

Turvey, C.G., Kong, R. and Belltawn, B. (2009), "Weather risk and the viability of weather insurance in Western China", Agricultural and Applied Economics Association. Annual Meeting, Milwaukee, Wisconsin.

Turvey, C.G. and Norton, M. (2008), "An internet-based tool for weather risk management", *Agricultural and Resource Economics Review*, Vol. 37, pp. 63-78.

Vedenov, D.V. and Barnett, B.J. (2004), "Efficiency of weather derivatives as primary crop insurance instruments", *Journal of Agricultural and Resource Economics*, Vol. 29, pp. 387-403.

World Bank (2005), "Managing agricultural production risks: Innovations in developing countries", World Bank report.

World Bank (2007), "China: Innovations in agricultural insurance – Promoting access to agricultural insurance for small farmers, World Bank report.

Woodard, J.D. and Garcia, P. (2008), ''Basis risk and weather hedging effectiveness'', *Agricultural Finance Review*, Vol. 68 No. 1, pp. 99-117.

Xu, W., Odening, M. and Musshoff, O. (2008), "Indifference pricing of weather derivatives", *American Journal of Agricultural Economics*, Vol. 90 No. 4, pp. 979-993.

Xu, W., Okhrin, O., Odening, M. and Cao, J. (2010), "Systemic weather risk and crop insurance": The case of China", SFB 649 Discussion Paper, pp. 2010-053.

Zhang, H. (2003), "Improving water productivity through deficit irrigation: Examples from Syria, the North China Plain and Oregon, USA", *Water Productivity in*

Agriculture: Limits and Opportunities for Improvement, (Eds), Kijne, W.R., Barker and D. Molden, Wallingford, UK and Cambridge, pp. 30.

I. Hedging weather risk on aggregated and individual farm-level

–Pitfalls of aggregation biases on the evaluation of weather index-based insurance–

Authors: Leif Erec Heimfarth, Robert Finger and Oliver Musshoff

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Abstract

Purpose – Since the 1990s, there has been a discussion about the use of weather index-based insurance, also called weather derivatives, as a new instrument to hedge against volumetric risks in agriculture. It particularly differs from other insurance schemes by pay-offs being related to objectively measurable weather variables. Due to the absence of individual farm yield time series, the hedging effectiveness of weather index-based insurance is often estimated on the basis of aggregated farm data. We expect that there are differences in the hedging effectiveness of insurance on the aggregated level and on the individual farm-level. The purpose of this paper is to estimate the magnitude of bias which occurs if the hedging effectiveness of weather index-based insurance is estimated on aggregated yield data.

Design/methodology/approach – The study is based on yield time series from individual farms in central Germany and weather data provided by the German Meteorological Service. Insurance is structured as put-option on a cumulated precipitation index. The analysis includes the estimation of the hedging effectiveness of insurance on aggregated level and on individual farm-level. The hedging effectiveness is measured non-parametrically regarding the relative reduction of the standard deviation and the value at risk of wheat revenues.

Findings – Findings indicate that the hedging effectiveness of a weather index-based insurance estimated on aggregated level is considerably higher than the realizable hedging effectiveness on the individual farm-level. This refers to (i) hedging effectiveness estimated on the aggregated level is higher than the mean of realized hedging effectiveness on the individual farm-level and (ii) almost every evaluated individual farm in our analysis realizes a lower hedging effectiveness than estimated on the aggregated level of the study area. Nevertheless, weather index-based insurance designed on the aggregated level can lead to a notable risk reduction for individual farms.

Research limitations/implications – We focused on farms in central Germany and found a pronounced bias when the hedging effectiveness of weather index-based insurance is estimated on aggregated data and assigned to individual farms. To confirm that the indicated magnitude of this bias is also applicable to other geographic regions, further research is required.

Practical implications – The results reconfirm that weather index-based insurance can be attractive for farmers. The fact that the hedging effectiveness estimated on aggregated level is higher than that estimated on individual farm-level reveals that (potential) suppliers of insurance may overestimate the market potential if their analysis is only based on aggregated data.

Originality/value – To our knowledge, this paper is the first that analyzes the influence of crop yield aggregation with regard to the hedging effectiveness of weather index-based insurance.

Keywords: Weather index-based insurance, wheat production, hedging effectiveness, aggregation bias.

Paper type: Research paper

II. Weather index-based insurances for farmers in the North China Plain

– An analysis of risk reduction potential and basis risk –

Authors: Leif Erec Heimfarth and Oliver Musshoff

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Abstract

Purpose – The purpose of this paper is to analyze the extent to which weather index-based insurances can contribute to reducing shortfall risks of revenues of a representative average farm that produces corn or wheat in the North China Plain. The geographical basis risk is quantified to analyze the spatial dependency of weather patterns between established weather stations in the area and locations where the local weather patterns are unknown.

Design/methodology/approach – Data are based on the Statistical Yearbook of China and the Chinese Meteorological Administration. Methods of insurance valuation are burn analysis and index value simulation. Risk reduction is measured non-parametrically and parametrically by the change of the standard deviation and the Value at Risk of revenues. The geographical basis risk is quantified by setting up a decorrelation function.

Findings – Results suggest significant differences in the potential risk reduction between corn and wheat when using insurance based on a precipitation index. The spatial analysis suggests a potential to expand the insurance around a reference weather station up to community level.

Research limitations/implications – Findings are limited by a weak database in China and, in particular, by the unavailability of individual farm data. Moreover, the low density of weather stations currently limits the examination of the approach in a broader context.

Practical implications – The risk reduction potential of the proposed insurance is encouraging. From a policy point of view the approach used here can support the adjustment of insurers towards different crops.

Originality/value – To our knowledge this paper is the first that investigates a weather index-based insurance designed for an average farm in the North China Plain and the quantification of geographical basis risk.

Keywords: China, weather risk, grain production, weather index-based insurance, basis risk

Summary and contextual discussion

Weather is an essential production factor, but at the same time, it is a major factor of uncertainty in agricultural production. Moreover, the effects of the global climate change are likely to reinforce the occurrence and severity of adverse weather events in the future. In this context, innovative weather index-based insurance has gained more and more attention in the last decades to challenge the basic requirements of insurable interest for farmers in both industrialized and low-income countries. Nevertheless, the long-term sustainability of weather index-based insurance still offers some debatable claims. In this respect, the present dissertation examines constitutive parts concerning the risk assessment and the possible empirical application of weather index-based insurance.

The present dissertation is twofold and based on two separate and independent articles. In the first article, it is investigated which kind and magnitude of bias occurs if the hedging effectiveness of weather index-based insurance is estimated either on individual farm-level or on aggregated level of yield data. In the second article, it is investigated to which extent weather index-based insurances can contribute to the reduction of shortfall risks in revenues of small-scale farmers in NCP. The specific research questions mentioned in the introduction will be recapitulated and consolidated as well as contextually discussed.

1. How does the interrelationship between data aggregation and yield variability affect the hedging effectiveness of weather index-based insurance?
2. Does insurance designed to hedge weather risk on aggregated yield data produce the estimated hedging effectiveness also on the farm-level?
3. Are there significant differences between the hedging effectiveness of insurance designed to hedge weather risk for farmers on aggregated and individual farm-level?

The evaluation of what kind and magnitude of error is made by comparing the hedging effectiveness of weather index-based insurance on aggregated and individual farm-level is carried out in the present dissertation by considering yield data of individual farms in Central Germany. Insurance is structured to mitigate the risk of low precipitation in spring, where the underlying cumulated precipitation-based index is modeled for different weather stations. The results clearly indicate that potential reductions of weather-related losses in wheat production revenues found at the aggregated level overestimates the actual risk reduction potential at the individual farm-level. Nevertheless, in many cases it is still possible to achieve risk reduction for individual farms if insurance contracts that are designed to hedge revenue losses on the aggregated level of a specific area are applied. Furthermore, the results show that the optimum number of insurance contracts determined on the aggregated level shows a slightly higher hedging effectiveness on individual farm-level compared to the case if all individual farms purchase only one insurance contract based on data from the same weather station. For farmers, it might be attractive to purchase insurance designed on aggregated level of yield data because of the reduced transaction costs (i.e. it is expected that this insurance would be offered at lower costs). Nevertheless, the hedging effectiveness of insurance designed on the aggregated level is significantly inferior to the hedging effectiveness on the individual farm-level if the reference weather station to modeling the index is selected and optimized separately for each individual farm.

4. Can weather index-based insurance contribute to the reduction of shortfall risks in grain production in the North China Plain?
5. What is the extent of potential risk reduction of insurance designed for an average farm by using different weather stations in the North China Plain?

In the absence of long-term yield data on individual farm-level in the NCP, this dissertation focuses on an average farm and uses aggregated yield data on a provincial scale as well as data from reference weather stations on different locations. Precipitation data are used to model a cumulated index to insure the risk of low precipitation during the cropping seasons of corn and wheat. The results clearly indicate the insurance's potential to reduce the risk of weather-related shortfalls of grain revenues of an average farm. The extent to which the weather index-based insurance contributes to the risk reduction heavily depends on the type of crop insured and on the location of the reference weather station. The risk reduction potential for corn production in the NCP exceeds those of wheat production.

6. Up to which size of an area around a certain weather station, insurance can be expanded on community level in the North China Plain?

The geographical basis risk, which is inherent to the index insurance, is quantified for the study area by using a decorrelation function. The results reveal that for provision of insurance on the community level, the area around a reference weather station cannot be unbounded if a high hedging effectiveness will be realized on the individual farm-level in that area. In this regard, the spatial analysis indicates a significant correlation between the weather indices within a range of up to 100 km around a weather station for selected weather stations of a nearly homogeneous area in the NCP and suggests a potential to expand the insurance around a reference weather station up to community level.

The contextual findings entail various implications for the design and the evaluation as well as the empirical application of weather index-based insurance. A pronounced bias is found when the hedging effectiveness of weather index-based insurance is estimated on aggregated data and assigned to individual farms. However, the results reveal that it might be attractive for farmers to purchase weather index-based insurance contracts which are designed on the aggregated level of a specific area. The fact that the hedging effectiveness estimated on aggregated level is higher than estimated on the individual farm-level implicates that (potential) insurance providers might overestimate the market potential if their analysis is only based on aggregated data. This is of special importance because the research focus of index-based insurances is often laid on regions where it is difficult to gather farm-level data over large time horizons. For the contemporary example of the NCP, the findings reveal that there is a potential for a successful introduction of a weather index-based insurance on individual-farm level and encourage the use of aggregated data for the insurance design and the application of weather index-based insurance for a sizable area around a reference weather station. From a policymakers' point of view, the findings can support the adjustment of insurers towards different crops in the NCP. Nevertheless, the results confirm that the hedging effectiveness of insurance designed on the aggregated level is significantly inferior to the hedging effectiveness on the individual farm-level if the reference weather station to model the index is selected separately for the individual farms.

There are still some research questions left regarding both, theory and application of weather index-based insurance. To contextually confirm that the magnitude of bias found in hedging effectiveness of weather index-based insurance estimated on aggregated data and assigned to individual farms in Central Germany is also applicable to other geographic regions, the results have to be replicated for corresponding research areas. In addition, some effort is required to determine willingness to pay for weather index-based insurance and the ratio of hedging effectiveness to the price of weather index-based insurance designed on aggregated level. If an empirical application of weather index-based insurance is envisaged such as in the aforementioned example of the NCP, it would be in addition important to answer the questions of whether an (and which) administrative unit could purchase this instrument. Finally, it might be interesting to compare the put-option on cumulated precipitation index, primarily used in this dissertation, to other pay-off structures as well as to different possibilities of modeling indices.