INNOVATIVE TOOLS TO ADDRESS DROUGHT RISK IN GRAZING LANDS

KAREN BAEZ Y EVA IGLESIAS

Department of Agricultural Economics, Universidad Politécnica de Madrid, Madrid, Spain

Paper prepared for presentation at the EAAE 2011 Congress
Change and Uncertainty
Challenges for Agriculture,
Food and Natural Resources

August 30 to September 2, 2011
ETH Zurich, Zurich, Switzerland

Introduction

Agricultural production systems are exposed to adverse climatic hazards such as drought. Drought spells can infringe severe impacts in most vulnerable farms. It is well known that uninsured exposure exacerbates income inequality in farming systems (Rosenzweig and Binswager, 1986) and eventually results in welfare losses for rural families (Dercon, 2003). The advantages of farmers who have access to financial tools have been widely acknowledged (Sen, 1966). However, high administrative costs of traditional insurance hinder small farmers' access to risk management tools. The existence of moral hazard and systemic risk prevents the implementation of traditional insurance programs to address the risk of drought in rural areas (Goodwin, 2001).

In particular, the vulnerability of grazing livestock systems with close dependence on silvo-pastoral systems highlights the need for tools to evaluate and mitigate the adverse impacts of drought. Drought risk requires effective management and new technologies may help to overcome the limitations of traditional tools. An example that has attracted considerable interest over the last decade is the development of vegetation indices based on satellite images as an indicator of drought which are being used to provide index insurance in farming activities.

One of the main problems in insurance design relates to obtaining quality data to calculate the risk premium. In rural areas where there are no historical records of production data or adverse events such as drought and its impact on production, remote sensing helps to overcome this problem and generates information from these areas that otherwise would be impossible or too expensive to obtain.

Weather index insurance is an innovative financial instrument that allows policyholders to receive compensation in events triggered by a publicly observable index that is highly correlated with drought impact while traditional insurance is based on observed individual losses.

Index insurance has attracted considerable interest from various governments and organizations as a management tool against large covariate risks that tend to affect a geographical area, such as drought events(World Bank 2008, FAO, 2005, OECD, 2009a). During last decade, an active research agenda has focused on its potential to reduce costs and eliminate some of the barriers of traditional insurance such as moral hazard, adverse selection or lack of individual historical records among others.

Potential limitations have also been explored. Basis risk has been identified in the literature as one of the main problems of indexed insurance (Barnett and Mahul, 2007; Xu et to 2007; Deng et al. 2008; Senholz, 2009; Barnett, 2004, Barrett et al, 2007; among others). Basis risk refers to the imperfect correlation between the index and the losses experienced by the insured and implies that the instrument does not offer adequate protection against adverse events (Barnett, 2004), i.e. the possibility that the insured person experiences a loss and does not receive compensation or, conversely, that the insured does not suffer a drought impact but receive compensation. Gine et al (2007) and

Rowley et (2007) shows that the correlation between the index and actual drought losses increases during severe droughts, reducing basis risk.

Rangeland insurance contract compensates farmers for the increased cost for supplemental feeding due to deficit of pastures when a drought spell sets in. Spain, Canada and the USA are promoting the use of index insurance, particularly for drought risk management in grazing lands (Bielza et al, 2008). Since 2007, USA has started an insurance program for pasture and forage indexed intending to offer drought risk protection in a potential area of 450 million acres (USDA, 2008). Spain has led, since 2001, a pioneering experience for drought insurance in pastures using a vegetation index derived from satellite images (Burgaz, 2008).

The aim of this paper is analyze the potential of index based insurance to address drought risks in grazing lands within the Araucanía Region. We estimate the actuarially fair risk premium and analyze different contract designs. In particular, we analyze risk premium and basis risks for moderate and extreme drought hazards.

Literature review

In 1949, Halcrow already mentioned the potential of index insurance to address systemic risk in vulnerable areas and identified certain areas of research to be developed. Primer works and experiences dealt with yield index insurance where payments are triggered based on the evolution of a regional or area yield index. However, recent interest in index insurance has run parallel to development and advances in meteorological stations and satellite observation techniques. In particular, latest advances have resulted in the development of indices, such as the normalized difference vegetation index (NDVI) and others, with considerably higher resolution and increased frequency and timely data availability.

Index insurance is in this case designed to provide financial compensation when the Normalized Difference Vegetation Index (NDVI) for a certain period of days, is below a threshold that indicates drought impact (e.g. a decrease in the availability of grass for animal feed). Therefore, assessment of damage is done through vegetation indices derived from satellite images by homogeneous geographic areas.

It is important to note the increasing number of experiences that are being implemented in different countries. Barnett and Mahul (2007) and OECD (2009b) cite experiences with index insurance in Mexico, Peru and India and drivers of drought index insurance in Ukraine, Malawi, Ethiopia, China, Tanzania, Nicaragua, Thailand, Kazakhstan, Senegal and Morocco , among others.

The expectations generated by the potential of index insurance to deal with systemic risks have led to an emerging and active body of scientific literature in recent years. Most of these investigations have focused on the potential advantages of index insurance as compared to traditional crop insurance. Skees (2008) points out simple information requirements, eliminating the costs of inspection, reducing traditional problems of moral hazard and adverse selection, low administration costs, standardized and transparent structure, and ease of reinsurance. Similarly, Barnett and Mahul (2007) emphasize that the index insurance does not require classification of the insured individual risk exposure. In the same vein, the OECD (2009a) mentioned among the main advantages of immediate availability of the funds once triggered adverse events and low administration costs if the solution is properly configured.

On the other hand, most authors point out that main limitation for index insurance is related to basis risk (Barnett and Mahul, 2007, Xu et al 2007, Deng et al, 2008; Senholz, 2009, Barnett, 2004, Barrett et al, 2007, among others). OECD (2009b) noted that the successful implementation of index insurance depends on the identification of an appropriate index. This index should be highly correlated with actual loss and provide a reliable and consistent measure.

To minimize basis risk, Deng et al (2008) suggest the development of more sophisticated indices, based on the interaction of different variables. However, Vedenov and Barnett (2004) warn that optimal index insurance may require complicated combinations of weather variables to achieve reasonable accommodation between climate and performance. Other authors point out that index insurance should be offered only in areas where spatially correlated climate variable is the main cause of losses (Barnett and Mahul, 2007).

Evaluation of recent experiences suggest that implementation of index insurance requires an appropriate legal and institutional framework that not only addresses the proper regulation of insurance sales, but also the execution of contracts. Similarly, there must be objectivity, reliability and thoroughness in the measurement of the index (Skees, 2008, Barnett and Mahul, 2007). Similarly, Skees (2008) notes the problems associated with marketing the product and emphasizes the importance of providing training and information assurance system to farmers.

Despite its limitations several authors suggest that, index insurance is the most appropriate risk management tool when there are notorious difficulties in measuring performance, as is the case of grazing lands (Barnett, 2004). In a rangeland insurance program, the use of traditional approaches to the measure grass yield per growing season is a problem also mentioned by other authors such as Rowley (2002) and Zhou (2007).

Methodological Framework

In this section we develop an actuarial model estimate the fair risk premium for an index insurance contract based on satellite vegetation index for both severe and moderate triggering index. Further, we evaluate and analyze basis risk under both selected threshold indexes.

We develop a theoretical framework that extends the methodology proposed by Miranda (1991) for crop yield index insurance to a multi-period model that characterizes extensive livestock systems and evaluates drought risks on grasslands.

We define area vegetation index, $\tilde{y}_{ct}$, as the average of all pixels located within a given zone *c*. In addition, it is assumed that farm pasture growth in period t is perfectly captured by the evolution of the pixel index $\tilde{y}_{it}$ where it is located.

The equation relating drought farm losses and area vegetation index is as follows:

$$\tilde{y}_{it} = \mu_{it} + \beta_{it}(\tilde{y}_{ct} - \mu_{ct}) + \tilde{\varepsilon}_{it} \qquad (1)$$

Where:

$\tilde{y}_{it} = pixel\ vegetation\ \ index$

$\tilde{y}_{ct} = area\ vegetation\ index$

$\beta_{it} = Cov\,(\tilde{y}_{it}, \tilde{y}_{ct}) \,/\, \sigma^2{}_{y\,ct}$

$\mu_{it} = E\,(\tilde{y}_{it}) \qquad with\ \ Var\,(\tilde{y}_{it}) = \ \sigma^2{}_{y_i}$

$\mu_{ct} = E\,(\tilde{y}_{ct}) \qquad with\ \ Var\,(\tilde{y}_{ct}) = \sigma^2{}_{y\,c}$

$E\,\tilde{\varepsilon}_{it} = 0 \qquad with\ \ Var\,(\varepsilon_{it}) = \sigma^2\tilde{\varepsilon}_{it} \quad Cov\,(\tilde{y}_{it}\ , \varepsilon_{it}) = o$

We assume that pastures growth in farm *i* is a random variable influenced both by endogenous and exogenous growing conditions. Therefore, equation (1) establishes that vegetation index in pixel i depends both on systemic and non systemic components. The systemic component $\beta_{it}\,(\tilde{y}_{ct} - \mu_{ct})$ is correlated with the zone vegetation index while non-systemic component $\tilde{\varepsilon}_{it}$ is only dependent on endogenous farm characteristics.

The definition of the index insurance contract provides compensation in terms of daily cost due to feed supplement when drought reduces pasture availability. The compensation is triggered when zone vegetation index $\tilde{y}_{ct}$ falls below the critical threshold $\mu_{ct} - k\sigma_{y_{ct}}$. According to this the farmer receives an annual compensation as stated in equation (2):

$$\tilde{x} = c \sum g\,(\tilde{y}_{ct}\,; \mu_{ct}, \sigma_{ct}, k) \qquad (2)$$

Where $g\,(\tilde{y}_{ct}\ ; \mu_{ct}, \sigma_{ct}, k)$ is defined as a binary random variable

$$g\,(\tilde{y}_{ct}\ ; \mu_{ct}, \sigma_{ct}, k) = 1 \qquad \text{si}\ \ \tilde{y}_{ct} < \mu_{ct} - k\sigma_{ct} \qquad (3a)$$

$$g\,(\tilde{y}_{ct}\ ; \mu_{ct}, \sigma_{ct}, k) = 0 \qquad \text{si}\ \ \tilde{y}_{ct} \geq \mu_{ct} - k\sigma_{ct} \qquad (3b)$$

Substituting equation (1) in equation (3a) and (3b) and arranging terms, the condition that triggers compensation payment can be rewritten as:

$$\frac{1}{\beta_{it}}(\tilde{y}_{it} - \mu_{it}) - \frac{1}{\beta_{it}}\tilde{\varepsilon}_{it} < k\sigma_{ct} \qquad (4)$$

Based on these equations, compensation payment for each farm is determined by the following equations:

$$g\ (\tilde{y}_{ct}\ ; \mu_{ct}, \sigma_{ct}, k) = 1\ ; \qquad \text{si}\ \ \tilde{y}_{it} - \mu_{it} > \beta_{it}\ k\ \sigma_{ct} + \tilde{\varepsilon}_{it} \qquad (5a)$$

$$g\ (\tilde{y}_{ct}\ ; \mu_{ct}, \sigma_{ct}, k) = 0\ ; \qquad \text{si}\ \ \tilde{y}_{it} - \mu_{it} \leq \beta_{it}\ k\ \sigma_{ct} + \tilde{\varepsilon}_{it} \qquad (5b)$$

Finally, the fair risk premium is defined as the expected value of annual compensation as expressed by the following equation:

$$\pi = E\tilde{x} = \sum_{t=1}^{12} g\ (\tilde{y}_{ct}\ ; \mu_{ct}, \sigma_{ct}, k)\ c \qquad (6)$$

Considering the conditions established in equations (5a) and (5b), we can rewrite the fair risk premium as:

$$\pi = \sum_{t=1}^{12} P(\tilde{y}_{it} - \mu_{it} > \beta_{it}\ k\ \sigma_{ct} + \tilde{\varepsilon}_{it}\ ; \mu_{it}, \sigma_{ct}, k))\ c \qquad (7)$$

Equation (7) shows that basis risk or probability of suffering a drought that is not detected by the terms of the contract is determined by systemic and non-systemic component. The systemic component depends on the selected index threshold and the correlation coefficient between area vegetation index and pixel vegetation index.

This framework for designing and setting the premium shows the relevance of certain elements of the contract: the selection of index, the definition of homogeneous areas and the triggering index threshold level.

In particular, we want to analyse the influence of the triggering index threshold in basis risk. This may be a key issue if correlation is not constant but increases for severe drought spells. This is, if correlation is higher at the left tail of the distribution, basic insurance coverage to address severe droughts impacts will exhibit low basis risk.

There is an inherent basis risk in index insurance that is defined as the probability of experiencing losses that may not be detected by the contract. However, basis risk also comprises the possibility of receiving an indemnity without experiencing drought impacts.

This matrix classifies all possible situations in index insurance contracts:

	Drought $\tilde{y}_{it} < \mu_{it} - k\sigma_i$	Non-drought $\tilde{y}_{it} > \mu_{it} - k\sigma_i$
Compensation $\tilde{y}_{ct} < \mu_{ct} - k\sigma_c$	TRUE POSITIVE $P(\tilde{y}_{it} < \mu_{it} - k\sigma i / \tilde{y}_{ct} < \mu_{ct} - k\sigma_c)$	FALSE POSITIVE $P(\tilde{y}_{it} > \mu_{it} - k\sigma i / \tilde{y}_{ct} < \mu_{ct} - k\sigma_c)$
No compensation $\tilde{y}_{ct} > \mu_{ct} - k\sigma_c$	FALSE NEGATIVE $P(\tilde{y}_{it} < \mu_{it} - k\sigma i / \tilde{y}_{ct} > \mu_{ct} - k\sigma_c)$	TRUE NEGATIVE $P(\tilde{y}_{it} > \mu_{it} - k\sigma i / \tilde{y}_{ct} > \mu_{ct} - k\sigma_c)$

According to the above classification we can apply Bayes therorem to measure two types of basis risk. This is what we want to know: (i) which is the probability of not receiving a compensation when the farmer experiences a drought?, and (ii) which is the probability of being compensated when the farmer does not experience a drought?

$$P(\tilde{y}_{ct} > \mu_{ct} - k\sigma_c / \tilde{y}_{it} < \mu_{it} - k\sigma_i) = \frac{P(\tilde{y}_{it} < \mu_{it} - k\sigma_i / \tilde{y}_{ct} > \mu_{ct} - k\sigma c)P(\tilde{y}_{ct} > \mu_{ct} - k\sigma_c)}{P(\tilde{y}_{it} < \mu_{it} - k\sigma_i)} \qquad (8)$$

$$P(\tilde{y}_{ct} < \mu_{ct} - k\sigma_c / \tilde{y}_{it} > \mu_{it} - k\sigma_i) = \frac{P(\tilde{y}_{it} > \mu_{it} - k\sigma_i / \tilde{y}_{ct} < \mu_{ct} - k\sigma_c)P(\tilde{y}_{ct} < \mu_{ct} - k\sigma_c)}{P(\tilde{y}_{it} > \mu_{it} - k\sigma_i)} \qquad (9)$$

In the next section an empirical application is developed to analyze the potential of index insurance in Chilean grazing ecosystems. We estimate the fair risk premium and evaluate basis risk under regional index insurance for both severe and moderate triggering index.

Our hypothesis is that basis risk decreases when a lower triggering index is used. In order to test this hypothesis we estimate the above probability matrix and analyze the two components of basis risk as defined in (8) and (9) for a low and a high triggering indexes.

Empirical application

The empirical application is based on Normalized Differential Vegetation Index (NDVI) time series for the Araucanía Region in Chile. NDVI satellite images were captured by the AVHRR sensor NOAA with a resolution of 0.5 km.

The database[1] contains Monthly Maximum Value Composite NDVI measured from 1981 to 1994 in the Araucanía Region. The STATA software has been used for data statistical analysis.

---

[1] The University of New Hampshire, EOS-WEBSTER Earth Science Information Partner (ESIP), is the data distributor for this dataset

The Araucanía Region concentrates 30% farms in the country and accounts for an important bovine livestock. Most frequent socio-economic farm characteristics are family farms with low incomes and limited access to technology and financial tools.

Table 1. Farming systems in the Araucanía Region

Region	**farms**		**bovine**		**sheep**		**goats**		**grasslands**	
	n°	**%**	**n°**	**%**	**n°**	**%**	**n°**	**%**	**ha**	**%**
La Araucanía	37.641	30,0	668.140	18,0	277.884	7,1	50.810	7,1	614.852,90	5,5
Country	125.421	100,0	3.719.709	100,0	3.889.389	100,0	715.824	100,0	11.115.846	100,0

Source: INE - Chile, 2007

The first step was to select appropriate pixels according to land use, ten pixels where found with relevant grassland uses. The second step was to define the homogeneous area. A regional administrative unit was found too heterogeneous and a pixel correlation matrix was developed in order to identify homogeneous areas.

The third step relates to the definition of the triggering thresholds. Index thresholds were defined following the Spanish insurance design to address drought in grazing lands (see eq. 3a and 3b). The calculation of thresholds considered monthly average vegetation index less k times the standard deviation. Two alternative options are established: k=0,7 offering a moderate drought risk coverage and k= 1,5 that only cover more severe drought risks.

Given that the available time series was not very long, Burn analysis was preferred to Montecarlo method in order to develop the actuarial model and estimate the fair insurance premium. Feed costs are estimated using forage prices in Chile and insurance premium are estimated in €/bovine head.

Results and concluding remarks

The coefficient correlation matrix obtained for the different pixels was used to define two different clusters and improve the correlation of index based insurance as compared to a unique regional index contract ($\rho_{cluster\ 1} = 0{,}79$, $\rho_{cluster\ 2} = 0{,}83$ and $\rho_{region} = 0{,}62$)

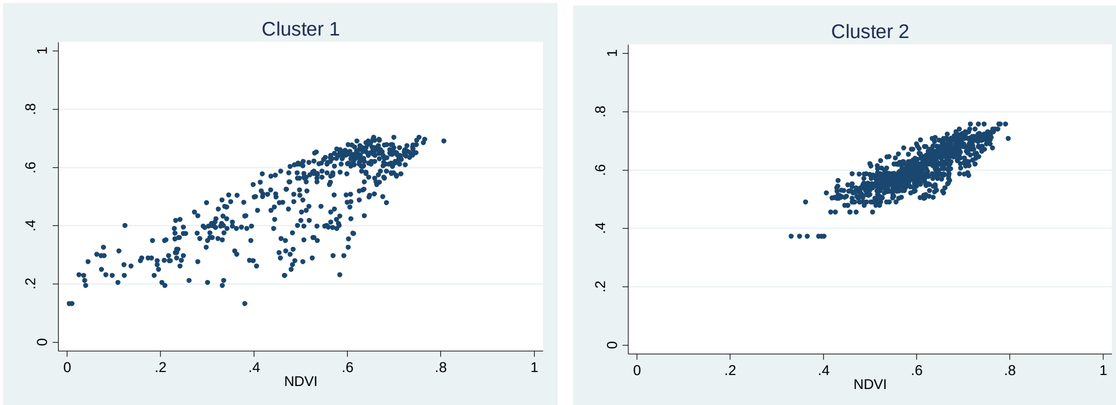

Figure 1. Scatter plots NDVI pixel vs NDVI cluster

Table 2 illustrates that the probability of suffering a drought sharply increases when considering moderate drought coverage (k=0,7) as compared to severe drought coverage (k=1,5).

Probabilities are quite similar at the different locations or pixels for moderate drought coverage. However, more important differences arise for a severe drought coverage (k=1,5). The probability of drought at pixel 4 more than doubles the probability at pixel 7 when a severe drought threshold is considered.

Table 2. Probability of moderate and severe drought at each location

Location or Pixel	**Threshold k= 0,7** **Moderate Drought** $P(\tilde{y}_{it} < \mu_{it} - 0{,}7\sigma_{it})$	**Threshold k= 1,5** **Severe drought** $P(\tilde{y}_{it} < \mu_{it} - 1{,}5\sigma_{it})$
1	37	9
2	35	12
3	38	10
4	31	13
5	34	8
6	35	9
7	36	6
8	34	9
9	36	9

This may be inherent to the triggering index structure. While in some index-based drought programs the index threshold is established as a given percentage of the average value, in this empirical application we have followed the guidelines established in the Spanish insurance contract which is based in *k* deviations from the average. One characteristic of this threshold structure is that if the NDVI follows a normal probability distribution, such a contract design translates into similar risk premiums. In consequence, even at different locations farmers will pay similar risk premiums for the same threshold coverage.

This does not happen when the probability distribution function is asymmetric. It has to be noted in this case that asymmetries are more pronounced at the tail of the index probability distribution function and this explains why significant differences in risk premiums arise between different locations when a severe drought coverage or a more stringent threshold is used.

Table 3 below describes the two components of basis risk under moderate and severe triggering thresholds (k=0,7 and k=1,5). Type I basis risk is defined as the probability of receiving no compensation while type II basis risk refers to the probability of being for compensation when the farmer does not suffer drought losses. When drought coverage is reduced, type II basis risk improves for all locations while type I gets worst in all locations except one.

Our results show that basis risk does not necessarily reduce when only severe drought coverage (k=1,5) is offered. These results may be intuitively confirmed when looking at the scatter plots for both cluster which reveal that contrary to our hypothesis correlation may be lower at the left tail (Figure 1).

Table 3. Basis risk at each location (pixel)

Location of pixel	Probability of no compensation when farmer experiences a drought (eq. 8)		Probability of compensation when there are no droughts impacts in the farm (eq. 9)	
	Threshold k=0,7	Threshold k=1,5	Threshold k=0,7	Threshold k=1,5
1	0,378	0,222	0,093	0,044
2	0,200	0,583	0,064	0,023
3	0,289	0,500	0,075	0,022
4	0,290	0,308	0,097	0,031
5	0,324	0,500	0,091	0,066
6	0,229	0,333	0,073	0,015
7	0,167	0,333	0,046	0,029
8	0,294	0,444	0,100	0,022
9	0,250	0,333	0,074	0,015

Our results are not conclusive and caution has to be taken in the selection of the appropriate index as it has an important impact in basis risk. Further analyses of the relation between contract design and basis risk is a promising area of research that may render an important social utility for most vulnerable farming systems.

References

Barnett, B. y Mahul, O. 2007. Weather Index Insurance For Agriculture And Rural Areas In Lower-Income Countries. American Journal of Agricultural Economics 89(5): 1241-1247.

Barnett. 2004. Agricultural index products: strengths and limitations. Agricultural Outlook Forum

Barrett, C; Barnett, B; Carter, M; Chantarat, S; Hansen J; Mude, A; Osgood, D; Skees, J; Turvey, C y Ward, M. 2007. Working paper: Poverty Traps and Climate Risk: Limitations and Opportunities of Index-Based Risk Financing. International Research Institute for Climate and Society (IRI), Columbia University, New York, USA.

Bielza, M.; Conte, C.; Dittmann C.; Gallego, J. y Stroblmair, J. 2008. Agricultural Insurance Schemes. EUR report

Burgaz, F. 2008. El seguro como herramienta para mitigar los efectos de la sequía en el sector agrario. En: Conferencia Internacional Gestión de la sequía: innovaciones científicas y tecnológicas.

Deng, X.; Barnett, B.; Hoogenboom, G.; Yu, Y. y Garcia, A. 2008. Alternative crop insurance indexes. Journal of Agricultural and Applied Economics 40 (1): 223-237

Dercon, S. 2003. Insurance against poverty. Oxford Scholarship Online Monographs. 465

Gine, X.; Townsend, R. y Vickery, J. 2007. Statistical Analysis of Rainfall Insurance Payouts in Southern India. American Journal Agricultural Economics 89 (5): 1248-1254

Goodwin, B. 2001. Problems with Market insurance in agriculture. American Journal Agricultural Economics 83 (3):643-649

Halcrow, H. 1949. Actuarial structures for crop insurance. Journal of farm economics 31 (3): 418-448

Miranda, M. 1991. Area Yield Crop Insurance Reconsidered. American Journal of Agricultural Economics 73 (2): 233-242

OECD. 2009a. Studies in Risk Management: Innovation in country risk management.

OECD. 2009b. Policy guidance on Integrating climate change adaptation into development co-operation

Rosenzweig, M and Binswanger, H. 1993 Wealth, Weather Risk and the Composition and Profitability of Agricultural Investments. The Economic Journal 103 (January 1993): 56-78

Rowley, R.; Price, K. y Kastens, J. 2007. Remote sensing and rancher: linking rancher perception and remote sensing. Rangeland Ecology and Management, 60 (4): 359-368

Sen, A. 1966. Peasants and dualism with or without surplus labor. Journal of Political Economy. 74 (June):425-50

Sennholz. 2009. Helping farmers weather risks? Assessing the World Bank´s work on index insurance. Briefing Bretton Woods Project

Skees, J. 2008. Innovations in Index Insurance for the Poor in Lower Income Countries. Agricultural and Resource Economics Review, 37 (1): 1–15

USDA. 2008. Risk Management Agency expands pasture, rangeland, forage insurance availability over next two years.

Vedenov, S. y Barnett, B. 2004. Efficiency of weather derivates as primary crop insurance instruments. Journal of Agricultural and Resource Economicas 29 (3): 387-403

World Bank. 2008. Managing risk to increase efficiency and reduce poverty. Background Paper for the World Development Report

Xu, W.; Odening, M. y Mubhoff, O. 2007 Indifference pricing of weather insurance. En: The 101º EAEE Seminar "Management of climate risk in agriculture"

Zhou. 2007. Assessing remote sensing application on rangeland insurance in canadian prairies Thesis Master of Science in the Department of Geography University of Saskatchewan Saskatoon.