Structuring Institutions to Share Local Weather Risk Globally

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Jianqiang Hao and Jerry Skees

Abstract

This paper envisions the national weather index as an efficient instrument to hedge the agricultural risk. The theoretical framework is established based on the partition of risk and the cost minimization. The Morocco case was applied and the result shows that the risk can be reduced to a larger extent.

Key works: risk, weather index, reinsurance.

This article is motivated by the prospects for a more efficient global market for weather risk. Rainfall index insurance contracts are used as the empirical case to illustrate some basic concepts. These risks are first targeted at the local level with province contracts and then aggregated to the national level as a portfolio of regional contracts. A national rainfall index is developed to hedge (or reinsure) the basket of regional indexes. Despite relatively strong correlation among the regions, this aggregation performs as it should for insurance purposes by shifting risk among regions and reducing the total risk level of the pool below the pre-aggregated sum of individual risks. Harrington and Niehaus demonstrate the potential hedging effectiveness of insurance derivatives using the regional estimates of catastrophe losses and the multi-state contracts. This paper applies a similar framework to a bundle of agricultural risk in Morocco. What is important about this contribution is that it provides both an empirical case study and suggested institutional arrangements for what is possible in structuring regional, national, and global risk sharing markets.

Four parts are included in this article. First, the conceptual problem is developed along with a review of the literature. Second, the theoretical framework for a national weather index and the basic institutional model for applying the national index are developed. Third, the empirical analysis is provided using data from rainfall and crop yields in Morocco. Fourth, conclusions and recommendations are developed.

Background and Literature Review

Global climate change poses significant challenges to our society, especially for farmers and those whose livelihoods are often determined by the climate. Extreme events can have a devastating impact on a wide population. Weather Futures & Options Resource Center estimates that nearly twenty percent of the U.S. economy is directly affected by weather, especially agriculture, energy, retailing, travel, leisure and entertainment (CME). It is reasonable to believe that this percentage is even larger for many developing countries since the economies of these countries rely heavily on the agriculture, which highly sensitive to weather conditions.

In the United States and some other developed countries, such as Europe and Canada, the federally subsidized insurance programs, for example the disaster aid program, crop insurance program, and the private catastrophe insurance also provide protection against many weather-related risks. However, these programs are plagued with moral hazard, adverse selection, correlated risks and reinsurance problems (Skees and Reed; Smith and Goodwin; Miranda and Glauber; Skees and Barnett; Skees). Risk sharing markets in developing countries are largely considered as incomplete markets.

Weather markets emerged in the U.S. in 1997 to hedge against weather events that created fluctuations in revenues for energy providers. These markets have expanded to Japan and Europe, from energy markets to agricultural markets. In recent years, actual trading of weather has slowed. However, the concept of writing insurance-like contracts on weather events has been adopted by most of the major reinsurers of the world. The World Bank has been involved in providing significant technical assistance to introduce the index contracts like rainfall insurance contracts in several developing countries (e.g., Morocco, Mexico, Tunisia, Ethiopia, Argentina, Turkey, Romania, Ukraine, and Mongolia [Skees, Varangis, Larson, and Siegel]) .

Prior research has analyzed weather risk and provided the evidences about the potential of weather markets in sharing agricultural risk. Rosenzweig and Binswanger utilize panel data from rural India investments, wealth and rainfall to measure the riskiness of farmers' investment portfolios in terms of their sensitivity to weather variation. Their results supported the hypothesis that the asset portfolios are influenced significantly by the degree of rainfall variability. In particular, farmers in riskier environments select portfolios that are less sensitive to rainfall variation and less profitable. Chichilnisky and Heal address four key issues regarding weather-related risks: 1) difficulty in assessing risks; 2) endogenity of risks, 3) correlation of risks, and 4) irreversibility. They propose that it would be better to allow agents to trade securities contingent on such collective risks, and cover the individual components of risks by mutual insurance contracts.

Weather risks are spatially correlated at levels that are less than 100%, thus Skees and Barnett refer to these risks as "in-between" risk. They provide a conceptual base for understanding why markets for sharing catastrophic risks may be incomplete and suggest auctioning government options on indexes that would facilitate reinsurance for low-frequency, high-consequence events as a more efficient means. Martin, Barnett and Coble develop a unique precipitation derivative to allow the purchaser to specify the parameters of the indemnity function and use a cotton harvest example from Mississippi to present the pricing method. Their results show a potential for weather derivatives to serve niche market within U.S. agriculture.

Skees, Hazell and Miranda introduce negotiable state-contingent contracts settled on area or locally appropriate weather indices, such as regional rainfall insurance contracts, as a good instrument to share the risks. The essential principle of area-based index insurance is that contracts are written against specific perils or events defined and recorded at a regional level. Turvey uses the daily rainfall and temperature data from Ontario, Canada to analyze the relationship of rainfall to the specific event risks that cause economic damage and then designs weather derivatives to hedge these risk. His results suggest that weather derivatives have the properties similar to conventional options and single payoff and multiple event contracts can be written.

The advantage of weather index is obvious: the indemnity depends on the specified weather variable rather than actual losses such as crop failure, thus, moral hazard and adverse selection has been eliminated and the transaction costs have been reduced significantly (Skees, Hazell, and Miranda). In a true market for weather investors outside of agriculture would have a chance to purchase or write the weather index contract. However, the correlated risk across different regions poses a significant pressure for the insurance and reinsurance company to maintain adequate reserves to cover high losses associated with a low probability of occurrence. Turvey, Nayak and Sparling in 1999 showed that the significance or benefits of reinsurance may not rely on indemnities only but rather on liquidity of capital held in reserve funds. Thus, an efficient weather market requires a convergence of insurance and capital markets (Jeffee and Russell). Unfortunately, such a prerequisite is unlikely for most developing countries. Meanwhile, international insurance and reinsurance markets are unlikely to offer affordable insurance for risks that are correlated. The global reinsurance markets are quite cyclical even in developed economies. For example, hurricane insurance was withdrawn by insures after the devastating losses associated with hurricane Andrew in 1992 (Miranda and Glauber). Earthquake insurance coverage availability declined immediately after Northridge earthquake (GAO). And there has been a significant tightening of the reinsurance market in response to the devastation created by the terrorist attacks of 9-11.

An ideal market for reinsurance would have a highly elastic supply curve where price of reinsurance would be insensitive to the actual losses. However, the imperfections in capital markets imply that the marginal cost of providing reinsurance is increasing and the supply curve of reinsurance is upward sloped. The leftward shift in the supply curve (Figure 1) as a result of reinsurer losses leads to the increase in the price of reinsurance. On the other hand, the catastrophe losses may lead to increases in the demand because of the perceived risk. Rightward shift in the demand curve (Figure 1) also can lead to an increase in the reinsurance price. Thus, the new equilibrium in the reinsurance markets after a catastrophe loss is generally a higher price and a lower quantity supplied. Froot and Connell reported that prices on catastrophe-reinsurance more than doubled during 1992-1994 and then began to decline thereafter. Furthermore, they suggest that most of price and quantity shocks stem from shifts in the supply of capital in the reinsurance market due to the incomplete capital market.

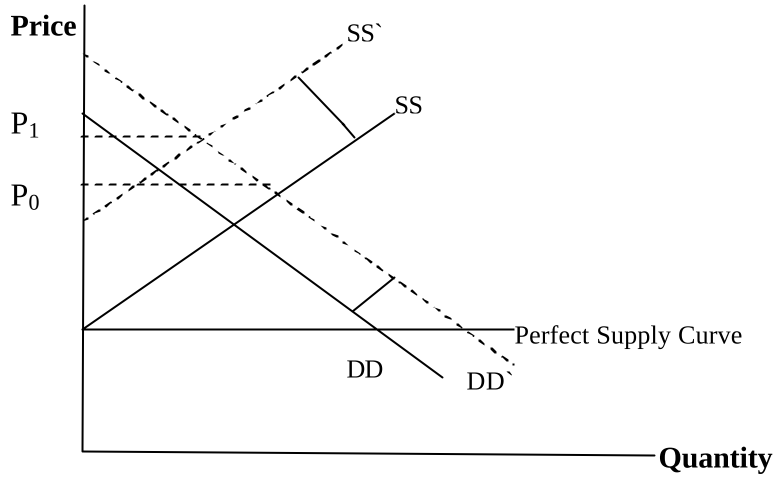


Figure 1. The Effect of Catastrophe Shock on the Reinsurance Market

Theoretically, in the Arrow-Debreu framework, an exogenous "states of nature" exists whose values are random and represent sources of uncertainty. Agents in the economy are allowed to trade "state-contingent commodities." Under a complete set of markets for state-contingent commodities, the first theorem of welfare economics holds for economics under uncertainty, that is, Pareto Optimality can be obtained by a competitive economy with uncertainty about exogenous variables (Arrow).

In the absence of Arrow-Debreu world, there are two primary mechanisms for managing risk: trading of market-based securities and the use of insurance. The securities model needs the public information and counter-party willing to take the opposite position in the specific risk being hedged. For example, in many commodities futures market (e.g. corn) the hedgers can take different positions in futures contracts to diversify the risk of price change.

The use of insurance markets for pooling risks requires a large population and statistically independent risks. The law of large numbers holds and then the frequency of occurrence of an insured event would be asymptotically distributed as its incidence in the whole population (Chichilnisky and Heal; Skees and Barnett). Asymmetric information between the insured and the outside creates the dual problems of adverse selection and moral hazard. Priest argues that there are three principal features that determine the extent to which insurance can effectively share the risk level: the aggregation of risks, the segregation of risks into separate risk pools, and the control of moral hazard and adverse selection through deductibles, coinsurance, and exclusions of coverage.

Furthermore, Chichilnisky and Heal state that Arrow-Debreu approach to risk reduction through state-contingent markets is universally applicable but cumbersome, sometimes extremely complicated and perhaps unrealistic in the case of risks with individual components while insurance markets are more manageable but leave uncovered collective or correlated risks. According to Lewis and Murdock's analysis, the securities model of managing risk is most appropriate when the critical information is public and a market for the trading of the risk exists. The insurance model, on the other hand, is more appropriate for providing protection against a large and independent risk of an individual. Under these conditions, the insurance providers diversify the risk by creating a large portfolio of these independent and identically distributed risks so that the variance of mean risk in the portfolio is significantly lower than the variance of the individual risk.

Concurrently, there are two approaches to pricing the risk. One is the actuarial approach ("Burn Rate") to pricing. This method begins by identifying the weather events that have a significant impact on the revenue stream and developing contracts that effectively shift this risk. Insurance companies are the main source of protection against such weather events. These companies must load the pricing to pay for reinsurance and the reinsurers load their pricing to develop reserves and to cover ambiguity in understanding the catastrophe risk. The burn-rate approach draws from the statistical inference over time, which assumes that history will repeat itself with the same likelihood as the past events described by the data used.

If the weather risk can be efficiently traded, the second pricing method is arbitrage pricing. The market-maker creates a market by allowing parties with opposite positions to trade or swap their risks. Here prices are set by the willingness of counterparties to pay to take a given risk position. Arbitrage plays a role as speculators take advantage on differences between options prices and the price of the underlying tradable commodity using a pricing method such as Black-Scholes.

Unfortunately, weather derivatives do not fall completely in either category of these two pricing methods. On the one hand, weather risks are not independent and identically distributed but are geographically correlated; on the other hand, information on the properties of weather risk is not generally publicly available and is asymmetrically distributed in favor of the insured (Lewis and Murdock). Currently, there is agreement in the literature that pricing of weather derivatives, at this time, more clearly follows the actuarial approach (Lewis and Murdock, Skees and Barnett). According to the Swiss Reinsurance Company, in 2000, risk-linked securities represented less than 0.5 percent of the worldwide catastrophe insurance (GAO). However, as the market develops and counterparty risks are more fully recognized, liquidity and volume could increase making pricing of weather derivatives look more like arbitrage pricing, or at least to add some aspects of arbitrage pricing so that end prices are lower than a pure actuarial approach.

Skees, Hazell and Miranda address a system of insurance that needs the following requirements: 1) It is affordable and accessible to all kinds of people, especially for the rural people and the poor; 2) It compensates for catastrophic income losses to protect consumption and debt repayment capacity; 3) It is practical to implement given the limited kinds of data available; 4) It can be provided by the private sector with little or no government subsidies; 5) It avoids the moral hazard and adverse selection problems to the least extent.

However, the insurance of weather risk is not same as that of the traditional risk, such as automobile, fire, and so on. For most of insurance, the loss ratio is reasonably smooth since the value of loss varies little from year to year. In contrary, the annual losses of weather risk are highly variable. Statistically, the loss might be far from its mean in some bad years so that a large amount of capital is required to cover the huge losses. The variability of different loss is shown in the table 1. The results show that the loss variability (CV) of the Multiple Peril Crop is about as 8 times as that of Private Auto Liability. Thus, some researches recommend loading the premium for the weather risk to cover the varied losses (Borch; Jaffee and Russel; Skees and Barnett).

Table 1. Loss Raito and Variability of Different Risks Between 1991 to 1994

Name	1991 (%)	1992 (%)	1993 (%)	1994 (%)	Variability (CV)
Fire	56.6	77.0	53.0	55.7	18.3
Commercial Auto Liability	69.2	66.4	65.0	66.1	2.7
Private Auto Liability	77.2	73.5	73.4	71.7	3.1
Burglary and theft	23.9	17.1	19.1	21.2	14.3
Multiple Peril Crop	124.2	125.0	167.6	89.5	25.3
Earthquake	12.9	9.7	2.9	852.2	192.2

Source: the loss ratio is from A. M. Best, the CV is calculated by authors.

Therefore, Skees and Barnett propose five basic equations under the actuarial approach. The equations are the guide for us to establish the national rainfall index.

(1) Loss cost = indemnities / protection outstanding

(2) Additional cost = reserve load + cat. Load + administer. Costs + return on equity

(3) Premium rate = expected loss cost + (additional cost / protection outstanding)

(4) Premium = premium rate * protection outstanding

(5) Loss ratio = $\frac{\sum indemnities}{\sum premiums}$

Theoretical Framework and Basic Model

Theoretical Framework

The basic model is examined following the work of Mahul except using the national index as the hedging tool. Since the weather-related risk is partially correlated across the insureds, the aggregate loss L of a national pool can be partitioned into a systemic component s and an idiosyncratic component e. Assume these two components are independent. The loss function can be written as

(1) L = L (s, e)

The insurers can provide two layers of policies in hedging these two components. The first layer is designed to insure the idiosyncratic risk on the realization of the systemic loss, Mahul called it the fully participating policy. It can be described by the set (I(.),P(.)). I is the indemnity function based on the national index.

(2) I = I (?) where ? is the designed national index.

The idiosyncratic risk is assumed to be independent with zero transaction cost and a large risk pool. Then, the law of large numbers holds and the premium is thus equal to the expected indemnity.

(3) P = E I (?)

The second layer (J(.), Q(.)) is designed to hedge the non-diversifiable risk, which is called the non-participating policy by Mahul. The national index is not fully correlated with the weather variable in the individual regions. For example, we can assume $q = a_0 + a_1 R + b$, where R is the regional weather index and b represents the basis risk. The indemnity function based on the loss due to the basis risk can be written as:

(4) J = J (?, R)

Assume insurers are risk averse and the safety loading is a function of the indemnity. The premium Q can be written as

(5) Q = EJ (?, R) + C(J), where C is the loading cost.

For the low frequency but high consequence risk, a convenient rule for making the safety loading is proportional to the standard deviation of the expected loss (Borch).

The decision rule for determining the optimal contract is not unique. The framework of utility maximization might be the traditional method. However, an insurance company that holds the weather index with the catastrophic loss might have priority to reduce the probability of ruin that may jeopardize the position of the company. Thus, we choose the minimization of the cost as the objective for the insurers. It can be expressed as

(6) $\underset{w}{Min}(P + Q)$

Subject to conditions of (2)-(5)

Basic Model

Consider a country where there are n provinces (regions). Let R_{it} be rainfall for the individual province i during the time t. The country index is introduced as

(7) $$q_t = \sum_{i=1}^{n} w_i R_{it}$$

where w_i is the revenue share of the province i, $w_i = \frac{\overline{\text{Re}\, v_i}}{\sum_{i=1}^{n} \overline{\text{Re}\, v_i}}$ and $\overline{\text{Re}\, v_i}$ is the average revenue for the province i during this period and $\sum_i w_i = 1$.

A number of researches have made contribution to the form of indemnity function for the weather market (Skees and Zeuli; Turvey; Martin, Barnett and Coble). We follow the European precipitation options proposed by Skees and Zeuli and developed by Martin, Barnett and Coble, but it is in the form of puts since our emphasis is the rain deficiency rather than excessive rain:

$$\text{Indemnity} = \left| \begin{array}{ll} 0 & \text{if x>strike} \\ \frac{strike - x}{strike - \lim it} & \text{if strike} \geq \text{x} > \text{limit,} \\ 1 & \text{if x} < \text{limit} \end{array} \right| \times \text{liability,}$$

Where strike, limit and liability are three choice variables to define the indemnity function and the pure premium rate is the average of the percentage shortfalls below the strike. The indemnity function is pictorially sketched in the figure 2.

Based on the indemnity function, the regional rainfall index is defined as

(9) $$I(R_{it}, Strike_i) = Max((Strike_i - R_{it}) \times Tick_i, 0)$$

where $Tick_i = \frac{\overline{\text{Re}\, v_i}}{Strike_i - \lim it_i}$

Indemnity varies over years and the underwriter would like to load the pricing to cover a set amount of average loss over time. A proportion of the standard deviation is chosen to reflect the likelihood of having a catastrophic year. Here we define the pure premium (PP) and the loaded premium (LP) for the regional index as:

(10) $$PP_i = Mean_i = E(I(R_{it}, strike_i)$$

$$LP_i = Mean_i + load \times SD_i \,.$$

Where $Mean_i = E(I(R_{it}, Strike_i))$, $SD_i = \sqrt{Var(I(R_{it,} Strike_i))}$.

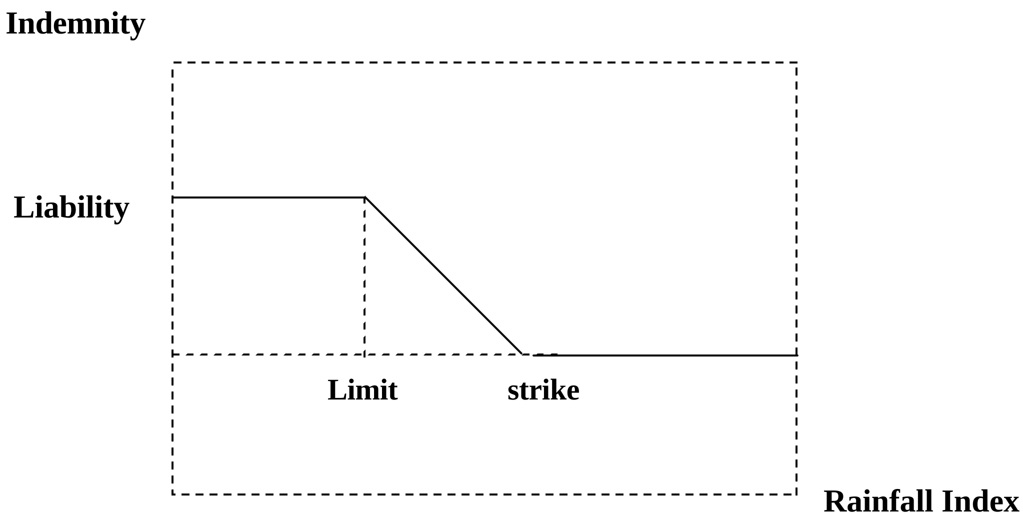


Figure 2: Indemnity Payment for the Rainfall Index

The distribution of rainfall can be estimated by using either nonparametric methods (e.g. kernel smoothing, empirical distribution) or parametric methods. Nonparametric density estimation techniques do not assume a particular functional form for the rainfall distribution but allow the observed data to select the most appropriate form of the rainfall distributions. The simplest nonparametric method available for making the inference is to use the empirical rate. Parametric techniques fit the observed data to one of the standard distribution (e.g. normal distribution, gamma distribution etc) by some statistical methods (e.g. by the maximum likelihood method). Martin, Barnett and Coble have suggested a gamma distribution to characterize the distribution of climatological variables (such as cumulative rainfall) because it is non-negative, skewness and sufficiently flexible to adequately characterize cumulative precipitation over time periods of varying length.

Assume we known the probability density function of R_{it} is f(R), we can redefine the pure premium rate (PPR) as

(11) $$PPR_i = \frac{Mean_i}{\sum_i \overline{\mathrm{Re}\, v_i}} = \int_{\lim it_i}^{strike_i} \left(\frac{strike_i - R}{Strike_i - Limit_i}\right) \times f(R) dR$$

Under the framework of risk partition and cost minimization for the national index, we can provide the first layer (I(.), P(.)) for the national index as

(12) $$I(q_t, Strike) = Max((Strike - q_t) \times Tick, 0)$$

where $Tick = \frac{\sum_i \overline{\mathrm{Re}\, v_i}}{Strike - \lim it}$, for country index.

(13) $$P(q, strike) = E(I(q_t, strike))$$

where $f(q)$ is the probability density function of the national rainfall index.

The second layer (J(.), Q(.)) for the national index is designed as

(14) $$J(R,q) = TI_t - Min(I(q_t, strike), TI_t)$$

where $TI_t = \sum_{i=1}^{n} I(R_{it}, Strike_i)$, reflecting the total indemnity for period t using the regional index.

(15) Q = $E(J(R,q)) + SD(J(R,q))$

Optimally national rainfall index should be designed to minimize the cost under the two layers of contract, that is,

(16) $$\underset{strike}{Min}\ \mathrm{P} + \mathrm{Q} = E(I(q_t, strike)) + E(J(R,q)) + SD(J(R,q))$$

Subject to the conditions of (12)-(15)

The optimal premium rate for the national index can defined as

(17) $$TPR = \frac{E(I(q_t, strike)) + E(J(R,q)) + SD(J(R,q))}{\sum_i \overline{\mathrm{Re}\, v_i}}$$, strike is set at the optimal level.

The reduction in the cost can be attributed to two factors: first, systematic risks have been reduced to some extent because of pooling the regional risk to the national level; second, because of the potential for lowering the national loading via the loading rules.

Data and Empirical Results

The following empirical analysis focuses on Morocco's three primary cereal crops in seventeen provinces: hard wheat, soft wheat, and barley, maize is added in some parts. These crops are planted in the fall and subject to basically the same weather events. In Morocco, agriculture represents nearly 20% of the GDP but suffers from cyclical droughts of variable amplitudes. Kumado has showed that the country's GDP is highly related to agricultural production, which is in turn highly correlated to rainfall. The primary source of information used in this analysis is data supplied by the Ministry of Agriculture in Morocco. These data include the rainfall information, the annual production and plantings from the 1978-79 campaign to the 1998-99 campaign for 17 provinces which exist in the zones of B.FAVORABLE, D.SUD and INTERMED. Since maize data were also supplied, maize is added to some of the analysis.

Following the work of Skees, Gober, Varangis, Lester and Kalavakonda, an average of the previous three years of plantings is used to estimate the current crop revenue by location. Current prices for each commodity are also used in all provinces: 190 MAD/quintal for maize; 190 MAD/quintal for barley; 250 MAD/quintal for soft wheat; and 280 MAD/quintal for hard wheat. The series of adjusted yields is then used to develop a matrix of revenues for the specific events in today's term:

(18) $\text{Revenue}_{tpc} = \text{Adjusted yield}_{tpc} \times \text{Hectares}_{tpc} \times \text{Price}_{c}$

Where t = year, 1979-1999; p = province; and c = crop

Yields are adjusted for the heteroscedasticity, that is, the variances in the yields around trend are increasing through time.

(19) Adjusted $Yield_t$ = (Actual $yield_t$ / Trend $yield_t$)×Forecasted 1999 Yield

The national rainfall index was set up based on the rainfall weighted on the each province's revenue. The summary statistics for rainfall in each province and the national index are presented in table 2. The national index appears to have a small variance comparing with the rainfall in most of individual provinces.

Table 2 Summary Statistics of Rainfall and National Rainfall Index from 1979-1999

Variable	N	Mean	Std Dev	Minimum	Maximum
AGADIR	21	234.19524	128.87361	69	602
BEN_SLIMANE	21	344.94635	133.09045	127.18333	633.7
CASABLANCA	21	306.47143	135.56426	110	612.8
EL_JADIDA	21	334.97619	133.71756	112.8	676.5
EL_KELAA	21	255.33333	114.52345	105.73333	576.03333
ESSAOUIRA	21	268.19762	139.7987	94	597.4
FES	21	270.51429	106.77171	94.8	466
KENITRA	21	404.27143	179.48568	117.2	822.4
KHEMISSET	21	344.94635	133.09045	127.18333	633.7
KHOURIBGA	21	290.2381	112.41536	103.4	564.2
MARRAKECH	21	170.17143	68.95513	76.7	314
MEKNES	21	329.72857	110.558	102.2	553
RABAT	21	361.04762	155.82895	121	763.6
SAFI	21	314.21429	161.06353	133	804.7
SETTAT	21	315.77222	126.41831	120.06667	629.36667
TAOUNATE	21	344.94635	133.09045	127.18333	633.7
TAZA	21	365.40952	154.88978	100.4	639.9
National Index	21	311.19499	119.24126	123.85938	624.94222

CV is a good measure of relative risk as long as the risks are normally distributed. Skees, Gober, Varangis, Lester and Kalavakonda test the assumption of normality and fail to reject for the Moroccan revenue data. Pearson correlations are used to evaluate the relationship between rainfall and revenue among provinces. The estimate s of relative risk (CV) for revenue and Pearson correlation between rainfall and revenue during two periods: 1979-1999 and 1990-1999 are presented as the table 3. The results show that there are rather great differences in the relative risk across Morocco; the average of CV for revenue across the seventeen provinces is 48% during this period. Correlation for these three zones average 69 percent over the full 21-year period. They increase to an average of 77 percent over the last decade. The change indicates a higher exposure to rainfall risk. Skees, et al attributed it to increased cultivation of marginal areas that are more susceptible to weather risks and because of the downward trend in average rainfall.

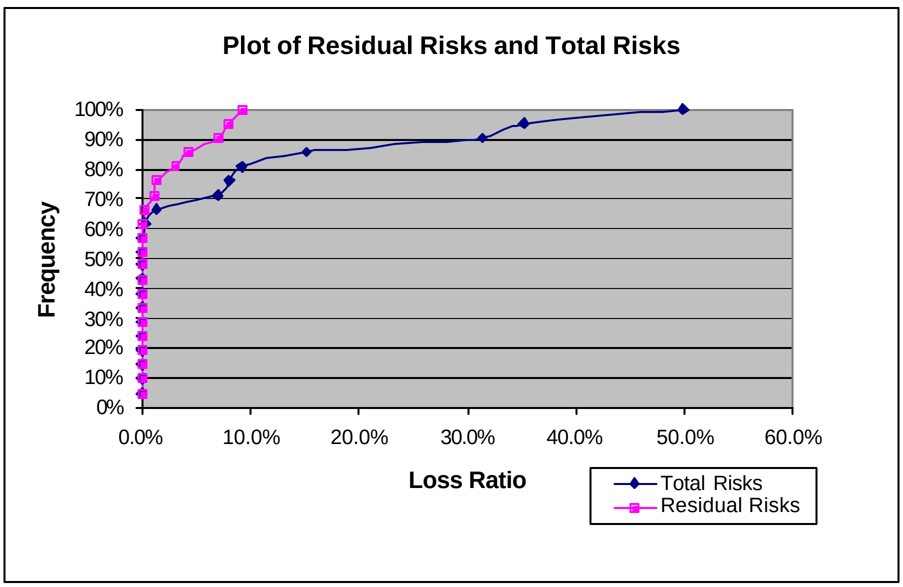
Pearson correlations are also used to check the spatial correlation risk among the provinces. The full matrix of Pearson correlation coefficients is listed in table 4. Probability values associated with tests that the Pearson correlations are zero are computed by treating $\frac{(n-2)^{1/2} r}{(1-r^2)^{1/2}}$ as coming from a student t distribution with n-2 degrees of freedom, where r is the appropriate correlation. As expected, the results show that the correlated risk of rainfall among the province is significant, suggesting that the use of national rainfall index might be applicable for the Morocco's case.

The indemnity function for the regional index is constructed based on our model. First, we set the limit as 50 since it is a relatively low number. Next, we choose the burn rates (pure premium rates) as 5%, 7.5% and 10% respectively for all 17 states, then the corresponding strikes for each province can be determined based on the (11). The loading factor is chosen as 33% of the standard deviation of the indemnity to cover the likelihood of a real blow out.

Finally, we establish the national rainfall index as the weighted index and provide two policies (fair and loading) for different risks. The contract is optimized so that the total cost is minimized. The optimal strike and premium rate for the country index can be solved numerically. The empirical results under the 5% burn rate, 7.5% burn rate and 10% burn rate are provided in table 5-7.

Under the 5% burn rate, the optimal strike was set to be 180 to minimize the cost for the national index. The pure premium rate drops to 3.86% from 5% and the total premium rate drops by 39.7% from 9.58% to 5.78%.

Under the 7.5% burn rate for the regional index, the strike was set to be 203 to minimize the cost. The pure premium rate drops to about 5.96% from 7.5% and the loaded premium rate drop by 35% from 13.17% to 8.55%. The empirical distribution of loss ratio for the residual risk and the total risk is plotted as the follow. The efficacy of the national index in hedging the risk is shown by the difference of these two empirical CDF.



Under the 10% burn rate, the pure premium rate drop from 10% to 7.94% and the loaded premium rate drop by 31.1% from 16.56% to 11.41%.

The about one-third reduction in the premium rate for each of these three cases demonstrates the efficacy of the national index in hedging the risk.

Conclusion

Weather market is emerging as an innovative mechanism to share the climate risks and it has wide applications in both nonagricultural industries and agricultural production. However, the traditional weather index might be difficult in application to the developing country because of the correlated risk across different regions and imperfect capital market imperfections.

In this article, we propose the national rainfall index under the actuarial approach as a more efficient instrument in hedging the weather-related risk. The efficacy of national rainfall index lies on its spread on the correlation risk, reduce the loaded premium rate and increase the potential interest of international re-insures and capital markets in investing in this program. Empirically, the over one-third reduction in the loaded premium in the Morocco case demonstrates its effectiveness and the principles of layering the risk and organizing the institutions to do so. Since rainfall index can be undermined by El nino Southern Oscillations for example and that may change the probability of the insurance events. In such case, an adjustment of index policies may be necessary (Skees, Hazzll and Miranda).

Further research could consider the reinsurance market in this model and address the potential for reducing country basis risk by trading the national index within several countries in the global market, a general equilibrium model can be applied for the further analysis.

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Table 3. Estimates of Relative Risk (CV) for Revenue and Pearson Correlation Between Rainfall and Revenue

Provinces	Zone	CV for Revenues	Pearson Correlation 1979-1999		Pearson Correlation 1990-1999	
AGADIR	D.SUD	48%	Nov-Mar	77%	Nov-Mar	89%
BEN_SLIMANE	B.FAVORABLE	46%	Oct-Mar	77%	Oct-Mar	73%
CASABLANCA	INTERMED	47%	Oct-Mar	60%	Oct-Mar	60%
EL_JADIDA	INTERMED	50%	Oct-Mar	63%	Nov-Mar	64%
EL_KELAA	D.SUD	54%	Oct-Mar	66%	Oct-Mar	72%
ESSAOUIRA	D.SUD	54%	Nov-Mar	69%	Oct-Mar	82%
FES	B.FAVORABLE	46%	Nov-Mar	76%	Nov-Mar	85%
KENITRA	B.FAVORABLE	35%	Oct-Mar	59%	Oct-Mar	65%
KHEMISSET	B.FAVORABLE	37%	Oct-Mar	77%	Oct-Mar	84%
KHOURIBGA	D.SUD	62%	Oct-Mar	57%	Oct-Mar	90%
MARRAKECH	D.SUD	54%	Oct-Mar	75%	Oct-Mar	78%
MEKNES	B.FAVORABLE	37%	Nov-Mar	81%	Nov-Mar	85%
RABAT	B.FAVORABLE	39%	Nov-Mar	48%	Nov-Mar	59%
SAFI	D.SUD	52%	Oct-Mar	73%	Oct-Mar	71%
SETTAT	INTERMED	70%	Oct-Mar	70%	Oct-Mar	69%
TAOUNATE	B.FAVORABLE	44%	Nov-Mar	69%	Oct-Mar	84%
TAZA	B.FAVORABLE	42%	Nov-Mar	62%	Nov-Mar	91%
Average		48%		69%		71%

Source: Skees, Gober, Varangis, Lester and Kalavakonda

Table 4: Pearson Correlation of Rainfall among 17 Provinces and the Test of Significance

Prob > |r| under H0: Rho=0

Province	AGADIR	BEN_ SLIMANE	CASABLANCA	EL_JADIDA	EL_KELAA	ESSAOUIRA	FES	KENITRA	KHEMISSET
AGADIR	1	0.69598	0.79062	0.78862	0.95045	0.90985	0.56842	0.71554	0.69598
		0.0005	<.0001	<.0001	<.0001	<.0001	0.0072	0.0003	0.0005
BEN_SLIMANE	0.69598	1	0.84229	0.83809	0.7306	0.64524	0.93005	0.94849	1
	0.0005		<.0001	<.0001	0.0002	0.0016	<.0001	<.0001	<.0001
CASABLANCA	0.79062	0.84229	1	0.8954	0.84884	0.81817	0.76164	0.86244	0.84229
	<.0001	<.0001		<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
EL_JADIDA	0.78862	0.83809	0.8954	1	0.88414	0.84347	0.70082	0.84563	0.83809
	<.0001	<.0001	<.0001		<.0001	<.0001	0.0004	<.0001	<.0001
EL_KELAA	0.95045	0.7306	0.84884	0.88414	1	0.96914	0.61177	0.7418	0.7306
	<.0001	0.0002	<.0001	<.0001		<.0001	0.0032	0.0001	0.0002
ESSAOUIRA	0.90985	0.64524	0.81817	0.84347	0.96914	1	0.50936	0.68539	0.64524
	<.0001	0.0016	<.0001	<.0001	<.0001		0.0183	0.0006	0.0016
FES	0.56842	0.93005	0.76164	0.70082	0.61177	0.50936	1	0.81407	0.93005
	0.0072	<.0001	<.0001	0.0004	0.0032	0.0183		<.0001	<.0001
KENITRA	0.71554	0.94849	0.86244	0.84563	0.7418	0.68539	0.81407	1	0.94849
	0.0003	<.0001	<.0001	<.0001	0.0001	0.0006	<.0001		<.0001
KHEMISSET	0.69598	1	0.84229	0.83809	0.7306	0.64524	0.93005	0.94849	1
	0.0005	<.0001	<.0001	<.0001	0.0002	0.0016	<.0001	<.0001	
KHOURIBGA	0.76153	0.73435	0.78362	0.89484	0.89532	0.85805	0.63661	0.70001	0.73435
	<.0001	0.0002	<.0001	<.0001	<.0001	<.0001	0.0019	0.0004	0.0002
MARRAKECH	0.77293	0.60134	0.73036	0.69057	0.82264	0.7222	0.54476	0.59521	0.60134
	<.0001	0.0039	0.0002	0.0005	<.0001	0.0002	0.0107	0.0044	0.0039
MEKNES	0.64243	0.94417	0.79395	0.80941	0.69659	0.59886	0.93937	0.84181	0.94417
	0.0017	<.0001	<.0001	<.0001	0.0005	0.0041	<.0001	<.0001	<.0001
RABAT	0.78275	0.95389	0.86773	0.89401	0.81788	0.7558	0.8352	0.92317	0.95389
	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
SAFI	0.92935	0.71298	0.81793	0.86177	0.97918	0.94287	0.60419	0.72839	0.71298
	<.0001	0.0003	<.0001	<.0001	<.0001	<.0001	0.0037	0.0002	0.0003

SETTAT	0.81318	0.8663	0.97188	0.9736	0.89445	0.85477	0.76039	0.872	0.8663
	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
TAOUNATE	0.69598	1	0.84229	0.83809	0.7306	0.64524	0.93005	0.94849	1
	0.0005	<.0001	<.0001	<.0001	0.0002	0.0016	<.0001	<.0001	<.0001
TAZA	0.52233	0.92624	0.6573	0.6602	0.53599	0.43796	0.85034	0.83522	0.92624
	0.0151	<.0001	0.0012	0.0011	0.0123	0.0471	<.0001	<.0001	<.0001
National	0.85587	0.93226	0.9358	0.95578	0.91555	0.8564	0.8245	0.92228	0.93226
	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001

Province	KHOURIBGA	MARRAKECH	MEKNES	RABAT	SAFI	SETTAT	TAOUNATE	TAZA	National
AGADIR	0.76153	0.77293	0.64243	0.78275	0.92935	0.81318	0.69598	0.52233	0.85587
	<.0001	<.0001	0.0017	<.0001	<.0001	<.0001	0.0005	0.0151	<.0001
BEN_SLIMANE	0.73435	0.60134	0.94417	0.95389	0.71298	0.8663	1	0.92624	0.93226
	0.0002	0.0039	<.0001	<.0001	0.0003	<.0001	<.0001	<.0001	<.0001
CASABLANCA	0.78362	0.73036	0.79395	0.86773	0.81793	0.97188	0.84229	0.6573	0.9358
	<.0001	0.0002	<.0001	<.0001	<.0001	<.0001	<.0001	0.0012	<.0001
EL_JADIDA	0.89484	0.69057	0.80941	0.89401	0.86177	0.9736	0.83809	0.6602	0.95578
	<.0001	0.0005	<.0001	<.0001	<.0001	<.0001	<.0001	0.0011	<.0001
EL_KELAA	0.89532	0.82264	0.69659	0.81788	0.97918	0.89445	0.7306	0.53599	0.91555
	<.0001	<.0001	0.0005	<.0001	<.0001	<.0001	0.0002	0.0123	<.0001
ESSAOUIRA	0.85805	0.7222	0.59886	0.7558	0.94287	0.85477	0.64524	0.43796	0.8564
	<.0001	0.0002	0.0041	<.0001	<.0001	<.0001	0.0016	0.0471	<.0001
FES	0.63661	0.54476	0.93937	0.8352	0.60419	0.76039	0.93005	0.85034	0.8245
	0.0019	0.0107	<.0001	<.0001	0.0037	<.0001	<.0001	<.0001	<.0001
KENITRA	0.70001	0.59521	0.84181	0.92317	0.72839	0.872	0.94849	0.83522	0.92228
	0.0004	0.0044	<.0001	<.0001	0.0002	<.0001	<.0001	<.0001	<.0001
KHEMISSET	0.73435	0.60134	0.94417	0.95389	0.71298	0.8663	1	0.92624	0.93226
	0.0002	0.0039	<.0001	<.0001	0.0003	<.0001	<.0001	<.0001	<.0001
KHOURIBGA	1	0.67995	0.77427	0.79298	0.84208	0.87346	0.73435	0.54308	0.87709
		0.0007	<.0001	<.0001	<.0001	<.0001	0.0002	0.011	<.0001
MARRAKECH	0.67995	1	0.55491	0.64267	0.7812	0.73495	0.60134	0.47959	0.75323
	0.0007		0.009	0.0017	<.0001	0.0001	0.0039	0.0278	<.0001
MEKNES	0.77427	0.55491	1	0.86743	0.6674	0.83317	0.94417	0.84122	0.88414
	<.0001	0.009		<.0001	0.0009	<.0001	<.0001	<.0001	<.0001

RABAT	0.79298	0.64267	0.86743	1	0.79909	0.90778	0.95389	0.83001	0.95357
	<.0001	0.0017	<.0001		<.0001	<.0001	<.0001	<.0001	<.0001
SAFI	0.84208	0.7812	0.6674	0.79909	1	0.86547	0.71298	0.52452	0.89481
	<.0001	<.0001	0.0009	<.0001		<.0001	0.0003	0.0146	<.0001
SETTAT	0.87346	0.73495	0.83317	0.90778	0.86547	1	0.8663	0.67917	0.9738
	<.0001	0.0001	<.0001	<.0001	<.0001		<.0001	0.0007	<.0001
TAOUNATE	0.73435	0.60134	0.94417	0.95389	0.71298	0.8663	1	0.92624	0.93226
	0.0002	0.0039	<.0001	<.0001	0.0003	<.0001		<.0001	<.0001
TAZA	0.54308	0.47959	0.84122	0.83001	0.52452	0.67917	0.92624	1	0.77963
	0.011	0.0278	<.0001	<.0001	0.0146	0.0007	<.0001		<.0001
National	0.87709	0.75323	0.88414	0.95357	0.89481	0.9738	0.93226	0.77963	1
	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	

Table 5 Risk Hedging Under the 5% Case

	Strike	Tick	Loaded Prem	Pure Prem
AGADIR	97.3	4688769	10.3%	5.00%
BEN_SLIMANE	212.4	2327772	9.5%	5.00%
CASABLANCA	160	1481759	9.3%	5.00%
EL_JADIDA	188.7	7168546	9.6%	5.00%
EL_KELAA	158.05	8486939	9.0%	5.00%
ESSAOUIRA	142.1	2286664	10.0%	5.00%
FES	170.9	2476632	9.9%	5.00%
KENITRA	181.4	4685096	9.4%	5.00%
KHEMISSET	212.4	3505251	9.5%	5.00%
KHOURIBGA	182.2	2534956	10.0%	5.00%
MARRAKECH	94.44	10065705	8.8%	5.00%
MEKNES	235.2	1209456	10.4%	5.00%
RABAT	218.7	283838	9.3%	5.00%
SAFI	178.15	4418802	8.5%	5.00%
SETTAT	191.9	10080210	9.8%	5.00%
TAOUNATE	212.3	2356478	9.5%	5.00%
TAZA	209.9	2283307	10.2%	5.00%
Average			**9.58%**	
National Hedge				
First Policy	180.00	62827068		3.86%
Second Policy			1.92%	
Total Premium Rate			**5.78%**	

Table 6 Risk Hedging Under the 7.5% Case

	Strike	Tick	Loaded Prem	Pure Prem
AGADIR	121.08	3120129	14.3%	7.50%
BEN_SLIMANE	241	1979215	13.0%	7.50%
CASABLANCA	191.7	1150272	13.4%	7.50%
EL_JADIDA	223.6	5727404	13.4%	7.50%
EL_KELAA	170.9	7584895	12.3%	7.50%
ESSAOUIRA	158.3	1944615	13.3%	7.50%
FES	194.2	2076455	13.3%	7.50%
KENITRA	224	3538055	13.6%	7.50%
KHEMISSET	241	2980381	13.0%	7.50%
KHOURIBGA	215.9	2020019	13.6%	7.50%
MARRAKECH	101.24	8729897	12.5%	7.50%
MEKNES	263.15	1050862	13.4%	7.50%
RABAT	244.6	246061	12.8%	7.50%
SAFI	197.8	3831322	12.3%	7.50%
SETTAT	222.6	8287264	13.4%	7.50%
TAOUNATE	241	2002390	13.0%	7.50%
TAZA	238.8	1933796	13.5%	7.50%
Average			**13.17%**	
National Hedge				
First Policy	203.00	53382476	5.96%	5.96%
Second Policy			2.6%	
Total Premium Rate			**8.55%**	

Table 7 Risk Hedging Under the 10% Case

	Strike	Tick	Loaded Prem	Pure Prem
AGADIR	140.7	2445191	17.8%	10.00%
BEN_SLIMANE	267.6	1737271	16.3%	10.00%
CASABLANCA	217.3	974259	16.8%	10.00%
EL_JADIDA	265.4	4615958	17.1%	10.00%
EL_KELAA	187.15	6686211	15.9%	10.00%
ESSAOUIRA	172.85	1714300	16.5%	10.00%
FES	209.4	1878450	16.3%	10.00%
KENITRA	267.9	2825248	17.3%	10.00%
KHEMISSET	267.6	2616052	16.3%	10.00%
KHOURIBGA	236.55	1796415	16.6%	10.00%
MARRAKECH	110.5	7393718	16.3%	10.00%
MEKNES	284.35	955798	16.3%	10.00%
RABAT	276.2	211686	16.3%	10.00%
SAFI	221.05	3310549	16.0%	10.00%
SETTAT	252.7	7056644	16.7%	10.00%
TAOUNATE	267.6	1757612	16.3%	10.00%
TAZA	269.6	1662572	16.8%	10.00%
Average			**16.56%**	
National Hedge				
First Policy	228.00	45884937	7.94%	7.94%
Second Policy			3.5%	
Total Premium Rate			**11.41%**	