

Using Remotely-Sensed Vegetation Condition Index to investigate the feasibility of  
Drought Insurance for Smallholder Farmers in Zimbabwe

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## Abstract

This paper assesses the feasibility of area-yield drought insurance based on a remotely sensed vegetation condition index (VCI) and targeted for poor smallholder farmers in Zimbabwe and, more generally, Southern Africa. The objective is to develop insurance contracts that maximize the correlation between yield losses and indemnities, subject to possessing premiums cheap enough to attract participation of poor smallholder farmers. Using historical crop yields from nine selected districts and satellite data obtained from SADC Remote Sensing unit, we show that for most districts VCIs show correlations with crop yields that range from 0.60-0.90. Further, for most districts, premium rates within the desirable range (5-10%) are recoverable. In addition, for most districts VCIs were able to consistently trace extreme drought events but tended to miss on events of lesser intensity..

## Background

Drought is the most common climate-related hazard in Zimbabwe and in Southern Africa. More than 60% of population in Zimbabwe consists of smallholder farmers that practice rain-fed subsistence and semi-subsistence agriculture. Unlike their large-scale counterparts, smallholder farmers have limited access to insurance and credit markets. Less than 1% of the total cultivated area in Zimbabwe's smallholder agricultural sector is under irrigation. Thus, the livelihood and food security of millions of smallholder farmers are exposed to profound drought risk.

Like most countries in Southern Africa, food-aid remains the most common approach to combating drought risk in Zimbabwe. Frequently, food-aid programs are instituted on an ad-hoc emergency basis to avert a looming famine. However government-administered food-aid programs are often riddled with numerous problems. First, the costs of food acquisition, distribution and administration can be exorbitant, sometimes reaching 5-10% of GDP following an extreme drought event. Second, publicly administered food-aid programs are often subject to political abuse. Third, food-aid programs are vulnerable to logistical failures if they involve large-scale operations. And, fourth, and most importantly, food-aid programs tend to nurture a culture of dependency that discourages recipients from implementing risk-mitigation measures.

The main purpose of food-aid programs across Southern Africa is to provide relief to the starving population as fast as possible. While food-aid partly addresses the problem of transitory household food insecurity, it is not in itself a sustainable solution. A solution to the problem of food insecurity does not lie in the mere provision of free food to affected households. Food-aid programs tend to overshadow the need to develop sustainable solutions to the problem of household food insecurity and chronic poverty. In Sen's words (1986) food-aid "*conjures up the picture of a battle already half lost and focuses the attention on emergency operations narrowly aimed at containing large-scale mortality*". Effective pro-poor policies call for much more than simply rushing food to the victims when they start dying of starvation. Perhaps it's time government stops treating drought as a natural calamity warranting emergency declaration, but rather integrate the inevitability of drought into its national food policy and prioritization program.

Missing in Zimbabwe are agricultural policies that promote the evolution of formal risk-sharing institutions. Risk-sharing institutions could play a crucial role in reducing the vulnerability of smallholders to climate risk, particularly drought, while reducing dependence on expensive and often ineffective food-aid measures. As argued by Zeller and Sharma (2000), the myth that the poor smallholders are unable to insure or save has led to the implementation of non-supportive and non-facilitative policies that have neglected the savings and insurance services that are essential to the poor. One plausible avenue to reducing the vulnerability of households to drought lies in the way smallholder farmers can protect themselves against drought risk. Instead of relying on ad-hoc food-aid programs, smallholder farmers could be encouraged to seek more formal risk-sharing tools, such as drought insurance.

The idea of drought insurance is not new. It was first suggested by Chakravarti (India, 1920) when he made the observation that *'no insurance authority could ever maintain a supervising agency which would be able to watch and enforce that every insured field receives the required amount of care and attention at the hands of its cultivator. Unless some method can be devised by which this great difficulty is eliminated, a system of crop insurance would indeed be impossible'*, (in Mishra, page 309). Chakravarti observes that although crop insurance is desirable for smallholder farmers in India, it may not be feasible. Instead Chakravarti argues that given the dependence on Indian agriculture on rainfall, *'it is not only possible but also practicable'* to introduce drought insurance. He concludes that an effective agricultural insurance program that hedges the peasantry against serious pecuniary losses in respect of their agricultural activities will render the country less vulnerable to the ravages of famine.

The benefits of crop insurance are well known: crop insurance has the potential to stabilize farmers' income and save farmers from financial disasters that arise from crop failure; crop insurance could encourage risk-averse farmers to adopt improved technologies that lead to increased production; crop insurance can reduce the risk for credit agencies and hence help farmers secure better loan terms or reduce the need for collateral (Binswanger, 1986).

Public crop insurance covering multiple risks has been in existence in most developed countries for over a century (Mishra, 1996). In Asia, crop insurance has recently been adopted as a major risk management tool, especially for smallholder farmers. In Southern Africa, crop insurance programs targeting smallholder farmers are none existent.

But why have insurance markets failed to develop in Southern Africa? The experience with private multiple-peril crop insurance (MPCI) schemes across most countries has unfortunately has been an expensive failure (Hazell, 1992, Roberts and Dick, 1991, Gudger 1991). A number of reasons have been given for the actuarial failure of MCPI schemes.. Second, due to catastrophic/systemic risk crops of insured farmers within and/or across regions may fail simultaneously. This requires insurers at any given to have large cash reserves to meet the huge indemnity payments associated with widespread natural catastrophes such as droughts. Third, the administration costs of monitoring crop yield and loss assessment of individual farmers are often exorbitant. As concluded by Binswanger (1986), crop insurance is plagued with numerous problems, such that it is the costs and not the absence of farmers' demand that constrain the provision of privately-driven crop insurance.

### **Innovative Approaches to Crop insurance**

In light of the inherent limitations of traditional MPCI programs, some innovations in the design and delivery of crop insurance contracts have recently emerged. The innovations include area-yield and index-based insurance programs, various exchange-traded area-yield contracts, catastrophe options and catastrophe bonds (Vedenov & Miranda, 2001; Skees, Hazell & Miranda, 1999). In particular, catastrophe options and catastrophe bonds allow insurers to securitize systemic risks and hence circumvent the limitations of traditional insurance markets (Vedenov and Miranda, 2001). However, the drawback is that in most developing countries financial markets are not fully developed

to include innovations of this nature. Makaudze (2005) also add another new dimension by suggesting the usage of remote sensing techniques for crop insurance contracts intended for smallholder farmers. Weather derivatives insurance contracts are other new developments in the insurance markets.

Area-yield and index-based insurance possess a number of attractive features. First, farmers in a same region pay the same premium and receive the same indemnity per unit, it reduces the problems of adverse selection. In addition, because there is virtually nothing an insured farmer can do to influence the outcome of an index (e.g. remotely sensed), this eliminates the problem of moral hazard. Second, such insurance schemes could be inexpensive to administer since there are no individual contracts to write, no on-farm inspections and no individual field-loss assessments. Third such insurance scheme could provide an entry point for private insurers to develop other types of insurance products necessary for rural people..

However, index-based insurance has its own problems. For example, an individual can suffer losses and not get any indemnity payment because the major event triggering the payment has not occurred. It is also possible for an individual to be paid when he/she had suffered no loss. This type of risk is referred to as basis risk and index-based insurance would not be attractive, if the basis risk becomes too high.

### Technological innovations

Recent advances in satellite remote sensing technology permit evaluation of drought from a new perspective. Remote sensing technology provides repeated measurements at particular spatial scales and spectral bandwidths that allow dynamic environmental conditions, such as vegetation cover, to be monitored with considerable accuracy. Remote sensing has proven a powerful tool for evaluating the temporal and spatial aspects of crop growing conditions and drought (Johnson 1993, Peters *et al*, 2002). Interest in satellite observation and subsequent evaluation of drought stems mainly from ability of remote sensing to provide a cost-effective synoptic view, a permanent record or data archive and also extra visual information .

In recent years, many organizations and national governments have shown growing interest in using satellite data for drought early warning and crop yield assessment (Johnson *et al*). Remotely sensed data, especially from the Advanced Very High Resolution Radiometer (AVHRR) sensor aboard the National Oceanic and Atmospheric Administration (NOAA) series of polar-orbiting satellites of the USA, has been used for drought early warning and food security purposes (Johnson *et al*, Kogan, 1998).

Today several remotely sensed indices such as normalized difference vegetation index (NDVI) and vegetation condition index (VCI) suggested by Kogan (1998) are used extensively for agronomic monitoring, especially vegetation stress and crop yield assessments. Due to their large area and frequent coverage, these satellite-based indices have the advantage over ground-based measurements in monitoring spatial and temporal variation of drought-related vegetation stress at regional, continental and even global scales.

The VCI is an indicator of the vigor of the vegetation cover as a function of NDVI minima and maxima for a given land are. It normalizes NDVI according to its average over many years and results in a consistent index for different land cover types (Vogt et al, 2000). It is an attempt to separate the short-term weather signal from the long-term signal, as reflected by the vegetation, making it a better indicator of water stress conditions than NDVI (Kogan and Sullivan, 1993). If data are recorded over long periods during which, where extremes in climate are experienced, the VCI indicates potential crop yields (McVicar and Jupp, 1998).

## Study objectives

The main objective of this study is explore whether an area-yield drought insurance based on remotely sensed VCI intended for smallholder farmers would be feasible. If vegetation indices, such as VCI are correlated with crop yield, easy to observe, cheap to obtain and measure on a regular basis via satellites sensors, not subject to manipulation by individual farmers, is an area-yield drought-index insurance feasible?

Skees, Hazell & Miranda (1999) suggest that an insurance scheme intended for smallholder farmers ought to meet the following minimum conditions: (i) the scheme must be affordable and accessible to the majority of the farmers including the poor; (ii) the scheme should compensate for the catastrophic income losses so as protect consumption; (iii) the scheme should be practical to implement; (iv) the scheme ought to be provided by the private sector with little or no government subsidies and (v) the scheme must avoid moral hazards and adverse selection.

## Designing an Index-Based Insurance Contract

When designing an index-based insurance contract, Vedenov et al (2001) suggests that one needs to decide on three important questions: (i) what variable to use as an index for measuring the crop yield losses (ii) how correlated the variable is with yield losses and (iii) how to structure the indemnity schedule in order to provide the optimum risk protection at a reasonable fair premium?

In our case, the VCI is considered the ideal candidate for an index because it is highly correlated with crop yields and hence able to accurately track yield losses. In addition, the VCI is easy to measure on a regular basis and not subject to manipulation by individual farmers or insurers. VCI sequential crop profiles show the progression of canopy emergence, maturation, and senescence during the growing season. Using these crop profiles, crop yields can be assessed with considerable accuracy.

### *Designing and Pricing an Index-based Contract*

This section presents a methodology for designing and pricing an index insurance contract for crop production, based on the setup developed by Vedenov and Miranda (2001). We adapt this setup to compute empirical premium rates for a VCI insurance contract . Mathematically VCI is computed as

$$VCI = \left( \frac{NDVI_{current} - NDVI_{min}}{NDVI_{max} - NDVI_{min}} \right) \quad (1)$$

Suppose, as shown in Figure 1, an elementary contract pays an indemnity  $f(\tau)$  conditional on realization of the index  $\tau$  according to the following schedule

$$f(\tau) = \begin{cases} x & \text{if } [\tau \leq \lambda i^*] \dots \dots \dots (i) \\ x \frac{i^* - \tau}{(1-\lambda)i^*} & \text{if } [\lambda i^* \leq \tau < i^*] \dots \dots \dots (ii) \\ 0 & \text{if } [\tau > i^*] \dots \dots \dots (iii) \end{cases} \quad (2)$$

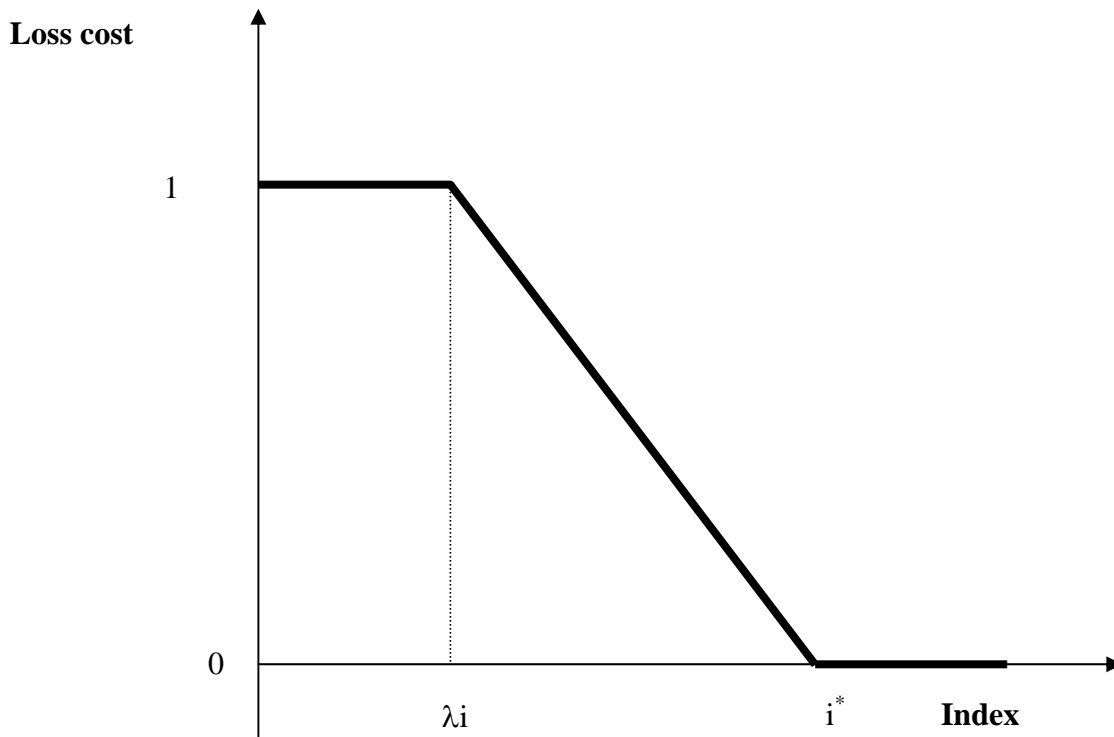
This means that the contract pays whenever the index  $\tau$  falls below a pre-defined trigger  $i^*$ . From Figure 1, the three cases above illustrate that: for case (i) a maximum indemnity \$ $x$  is paid since the index falls below critical value  $\lambda i^*$ . For case (ii), an indemnity proportional to the difference between the index and trigger is paid for  $\lambda i^* \leq \tau < i^*$ , and for case (iii) no indemnity is paid, if the realized index  $\tau$  is above the trigger  $i^*$ . The parameter  $0 \leq \lambda < 1$  is interpreted as the probability of ruin<sup>3</sup> and signifies a catastrophe if its value is closer to 1 and non-catastrophe otherwise. For extreme catastrophe,  $\lambda = 1$  and the contract pays the maximum indemnity, if the index falls below the trigger level  $i^*$ , but pays nothing otherwise.

To derive a particular contract we need to two steps: first we must specify *primal* contract parameters  $[i, \lambda, x]$  and second use primal parameters to search for the *optimal* contract parameters  $[\pi^*, \rho^*, N^*]$  where the  $N^*$  is optimal number of standard unit contracts an individual farmer can buy;  $\rho$  maximum correlation between yield losses and indemnities, maximum pure premium rate,  $\pi$  which ideally should lie between 5-10%. The task boils down to how to determine these parameters.

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<sup>3</sup>  $\lambda$  can be trivially computed by setting  $\lambda i^* = \tau$

Figure 1: VCI-based Indemnity Schedule for a Standard unit contract



### Data Requirements

Historical maize and cotton production data are collected across 9 districts<sup>4</sup> from the department of Agricultural Research and Extension Services (AREX) for the period 1980 to 2001. Maize, the main staple, is grown by over 80% of smallholders and accounts for about 60% of cultivated land each year. Cotton, the main cash crop, is grown predominantly by smallholder farmers and accounts for about 18% of cultivated land each year. Inter-annual crop yield variation in smallholder sector is directly related to the amount of rainfall received each season since crops are largely grown under rain-fed conditions.

NDVI data are obtained from SADC's Regional Remote Sensing unit based in Harare. The data are received at decadal intervals and geo-referenced to 9 selected districts. In turn we use NDVI to compute weekly VCI. The VCI values were computed pixel by pixel for each week and then averaged to determine a district value. In line with area-yield insurance discussed above, the mean value is taken to represent a designated crop area upon which insurance contract is based. Because the satellite data comes geo-referenced, geometrically and radiometrically corrected these are considered ideal for our purpose.

<sup>4</sup> Districts: Chiweshe(1); Gutu(2); Sanyati(3); Chivi(4); Mt Darwin(5); Wedza(6); Hurungwe(7); Shamva(8); Beitbridge(9)

Meteorological data such as rainfall data are obtained from Drought Monitoring Center, Harare. These data are available by different weather stations dotted throughout the country. Other ancillary data collected include SST-anomalies denoted as nino34 surrogate variables for measuring El Nino influence. These data are obtained online from International Research Institute ([www.iriinc.org](http://www.iriinc.org)).

## Discussion of Results

### *Correlation between Crop Yield vs. VCI and Rainfall*

The results in Table 1 show the correlation of maize and cotton yield versus monthly VCI and Nino34. With respect to VCI at the beginning of the farm season during the month of December, correlation is very weak and even negative at -0.02 and -0.03 for maize and cotton respectively. This weak relation is expected since during the early season most crops are still in their early stages of growth and hence manifest little *greenness vigor*. However, as the season progresses, correlation improves remarkably and attains a maximum at 0.64 and 0.73 for maize and cotton, respectively during the months of February and March. By the month of April, most crops would have attained full maturation and senescence sets in. The latter stage is marked by significant diminishing of the *greenness vigor* resulting in a gradual decline in correlation.

The highest correlation occurs during the flowering and grain filling stages (i.e., February/March). This growth phase is the most crucial yield-determining stage. With VCI significantly correlated with crop yield then it follows VCI can be used to model yield losses with satisfactory precision. High correlation is desirable since it underlies the ability of index to trace yield losses and thus minimizing basis risk.

Table 1: Correlation of Crop yield vs. VCI and Nino34 variables

	National Maize yield	National Cotton yield	Smallholder maize yield	Smallholder Cotton yield
a) VC_variables				
vcDec	0.12	0.04	-0.2	-0.03
vcJan	*0.47	0.36	*0.45	0.20
vcFeb	*0.62	0.35	*0.63	*0.55
vcMar	*0.58	0.36	*0.64	*0.73
vcApr	0.26	0.31	0.33	0.53
b) Nino34_variables				
n34Dec	*-0.60	-0.25	*-0.56	-0.31
n34Jan	*-0.61	-0.28	*-0.59	-0.33
n34Feb	*-0.68	-0.28	*-0.64	*-0.35
n34Mar	*-0.66	-0.30	*-0.62	-0.31
n34Apr	*-0.58	*-0.37	*-0.56	-0.34
n34May	*-0.50	*-0.40	*-0.53	-0.29

\*Indicates statistical significance at  $\alpha=0.10$  or smaller level

### Using VCI to rate Drought Insurance across Districts

To rate drought insurance contracts using VCI, we need to determine appropriate values for the *primal* parameters  $[x, \lambda i^*, i^*]$  shown in Figure 1. From Figure 1, because we are assuming a standard contract with a unit liability, parameter  $x$  equals 1.

Parameter  $\lambda i^*$  defines the critical value level below which full compensation is guaranteed. For VCI, this value is set at 0.36 and the value underlies an extreme drought year (McVicar and Jupp, 1998). The parameter  $i^*$  is generally set as the maximum VCI value (Table 2) obtained during the critical crop growth period, such as the month of February. Hence in sum, unit liability contract is fully specified by the two critical *primal* values: 0.36 for  $\lambda i^*$  and 0.71 for  $i^*$ . These parameters shall be referred to as *deficit min* and *deficit max*, respectively. We allow the value of the *deficit max*  $i^*$  to vary depending on region, while fixing the value of *deficit min*.

To assess the feasibility of our insurance scheme, we seek a contract that maximizes the correlation,  $\rho^*$  between yield losses and indemnities, while simultaneously possessing reasonable pure premium rate,  $\pi^*$  which ideally should lie between 5-10%. A higher pure premium rate could prove too expensive especially to the rural poor, who in essence are the target for the insurance scheme.

Table 2: Summary Statistics for VCI by Districts (1980-2000)

District	Descriptive Statistic	VCI			
		Jan	Feb	Mar	Apr
1	Min	.55	.55	.62	.49
	Max	.78	.83	.81	.79
	Mean	.69	.76	.75	.67
	Stdev	.068	.074	.057	.068
2	Min	.42	.43	.49	.42
	Max	.68	.68	.64	.62
	Mean	.54	.57	.56	.52
	Stdev	.068	.074	.057	.068
3	Min	.57	.58	.64	.51
	Max	.89	.89	.87	.81
	Mean	.77	.80	.78	.70
	Stdev	.078	.083	.070	.085
4	Min	.43	.45	.47	.42
	Max	.77	.74	.79	.70
	Mean	.60	.64	.63	.59
	Stdev	.086	.086	.090	.082
5	Min	.57	.57	.55	.49
	Max	.77	.79	.81	.77
	Mean	.66	.73	.73	.64
	Stdev	.063	.054	.055	.072

6	Min	.49	.53	.57	.43
	Max	.74	.74	.70	.66
	Mean	.61	.65	.64	.59
	Stdev	.062	.060	.043	.058
7	Min	.53	.58	.62	.55
	Max	.85	.87	.87	.83
	Mean	.75	.80	.78	.69
	Stdev	.077	.068	.065	.082
8	Min	.57	.60	.57	.57
	Max	.77	.81	.79	.77
	Mean	.67	.73	.74	.66
	Stdev	.058	.062	.049	.057
9	Min	.34	.36	.36	.26
	Max	.81	.74	.77	.68
	Mean	.54	.56	.54	.50
	Stdev	.134	.121	.124	.113

While numerous approaches could be used to determine the optimal contract parameters, here we use an excel spreadsheet to search for the desired optimal parameters at a specified loss criterion rate<sup>5</sup>. Once we specify the *primal* parameters (i.e., *deficit min* and *deficit max*) the program will: (a) computationally search the corresponding premium rate, b) computationally search the maximum correlation between portfolio losses and the optimal number of unit contracts, and c) graph portfolio losses versus the indemnity provided by the optimal number of contracts. This procedure allows us to search for a feasible contract defined as one that maximizes the correlation between losses and indemnities, while possessing a reasonable pure premium rate of 5-10%. Thus, the results generated by the program include: (i) the graph of losses versus indemnities paid when the optimal number of contracts is purchased and (ii) three important variables: the correlation  $\rho^*$  between the contract indemnity and portfolio losses, the optimal number of contracts to be purchased,  $N^*$ , and pure premium rate for the contract,  $\pi^*$ .

Table 3 shows the rating of area-yield insurance contracts based on remotely sensed VCI. Different loss criterion rates of 0.65, 0.75 and 0.90 are used across all districts. The *primal* parameters used to search for the optimal contract are shown in the last three columns. The districts 2, 4 and 9 showed the highest correlation greater than 0.80. The districts 1, 3 and 6 show appreciable correlation ranging from 0.51-0.70. The remaining districts of 5, 7 and 8 showed low correlation ranging between 1-40%. With respect to the premium rates, most districts recorded acceptable rates within a reasonable range of 5-10% except district 9. The premium rate tends to be higher in drier regions (III, IV and V) than in the wettest

<sup>5</sup> Loss criterion defines a proportion at which an insured farmer is presumed to suffer a loss. For example, for a loss criterion rate of 0.75, the insured suffers a loss if he realizes a yield of 0.75 of normal yield.

regions (II) except a few districts. The least number of contracts N (9,000) were recorded in the district 9 where premium rates were highest at 19.2% and hence too expensive for most households. In contrast, largest number of contracts (600,000) was recorded in district 6 with lower premium rate of 2.50. This signifies the fact that as the premium rate decreases, insurance becomes cheaper and hence more contracts are bought.

Table 3: Rating Area-yield Insurance Using VCI

District	NR	Contract Parameters						Primal parameters			
		$\pi$	$\rho$ at different loss rates			# of contracts ('000) at different loss rates			Lambda ( $\lambda$ )	Min Deficit	Max Deficit
			.65	.75	.90	.65	.75	.90			
1	II	4.79	0.58	0.58	0.60	114.4	138.5	174.6	0.54	0.36	0.72
2	IV	2.68	0.90	0.91	0.90	113.1	131.3	158.9	0.51	0.36	0.53
3	III	6.41	0.51	0.53	0.56	155.8	196.7	258.3	0.46	0.36	0.79
4	V	7.85	0.80	0.80	0.78	79.2	93.3	114.3	0.61	0.36	0.59
5	IV	5.30	0.29	0.32	0.30	31.7	38.9	49.5	0.51	0.36	0.71
6	III	2.50	0.66	0.62	0.59	371.1	463.6	601.7	0.60	0.36	0.60
7	II	6.32	0.09	0.09	0.12	85.1	108.9	166.1	0.46	0.36	0.79
8	II	2.22	0.30	0.32	0.32	49.1	58.1	71.5	0.53	0.36	0.68
9	V	19.18	0.84	0.86	0.88	8.8	10.2	12.3	0.71	0.36	0.51

Let's classify drought into three categories: *extreme*, *bad* and *moderate*. This simple classification is based on average precipitation recorded during the growing seasons of 1980-2000. If rainfall is lower than 350 mm, the season is classified as *extreme*, if rainfall is in the range 351-400mm it is classified as *bad* and if in the range of 401-450mm is classified as *moderate*. Using this rather simple approach, we are able to classify some seasons as extreme (marked red), bad (marked blue) or moderate (marked pink) based on rainfall outcome as shown in Table 4).

While it would be desirable to hedge against all forms of drought, practically this is difficult given drought is a catastrophic risk. The objective however is to offer insurance protection against *extreme* and possibly *bad* drought events. Therefore, in Figures 2-10 we are interested in an index which principally traces the *extreme* (1982/83, 1991/92), *bad* (1983/84, 1986/87, 1994/95) and *moderate* (1981/82, 1988/89, 1993/94, 1997/98) drought events. A look at these figures indicates that VCI is able to consistently trace the *extreme* drought events of 1982/83 and 1991/92 across all districts. However, it misses some drought events classified as *moderate* and *bad*. In fact the index is able to trace the *bad* events almost accurately in seven out of nine districts. In addition VCI is also able to pick *moderate* events in four out of nine districts. Hence, if the VCI is to be used to hedge against *extreme* drought events only, basis risk is reduced to zero. Basis risk becomes an issue of grave concern, if index contract covers drought events of high to moderate (*moderate-bad*) intensity.

Table 4: Crop Yield, Rainfall distribution and Drought classification

Season	Maize yield (MT)	Cotton yield (MT)	National Ave. Rainfall(mm)	Classification
198081	1000	45	731	
198182	595	27	402	moderate
198283	285	33	310	extreme
198384	670	70	370	bad
198485	1558	110	607	
198586	1348	98	598	
198687	628	83	333	bad
198788	1609	137	607	
198889	1188	123	412	moderate
198990	1262	103	538	
199091	1019	138	450	moderate
199192	115	36	262	Extreme
199293	1134	135	642	
199394	1313	111	448	moderate
199495	399	56	372	Bad
199596	1687	158	609	
199697	1453	198	643	
199798	723	183	435	Moderate
199899	845	188	681	

Figure 2: Portfolio loss vs. Optimal Indemnity for District #1 using VCI

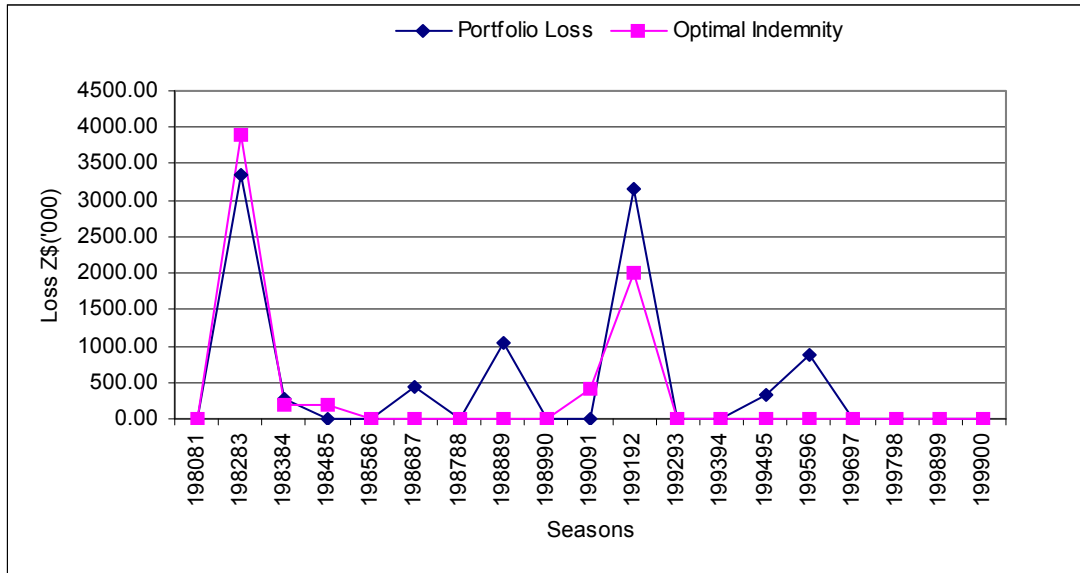
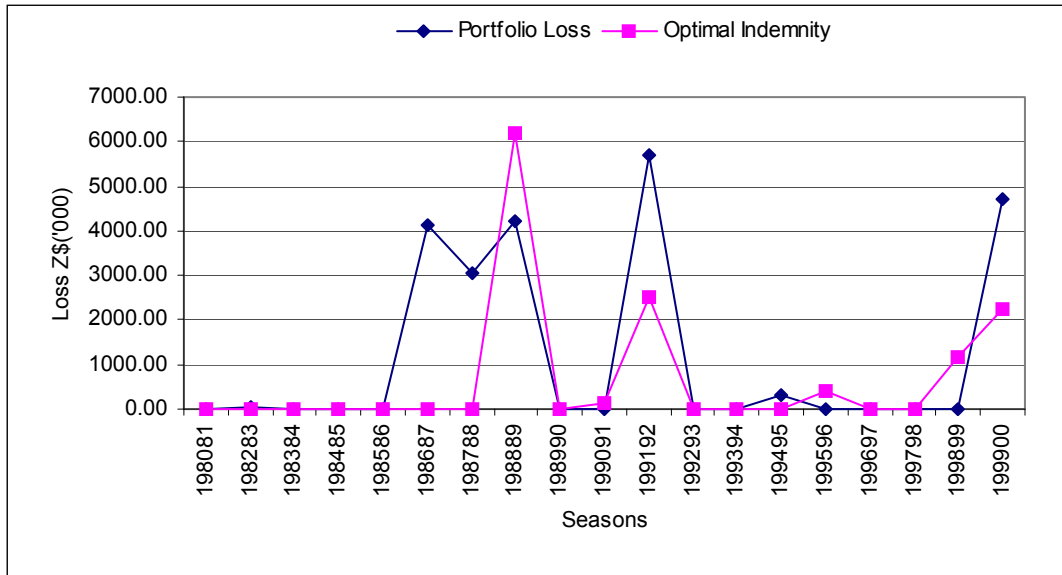


Figure 3: Portfolio loss vs. Optimal Indemnity for District # 2 using VCI

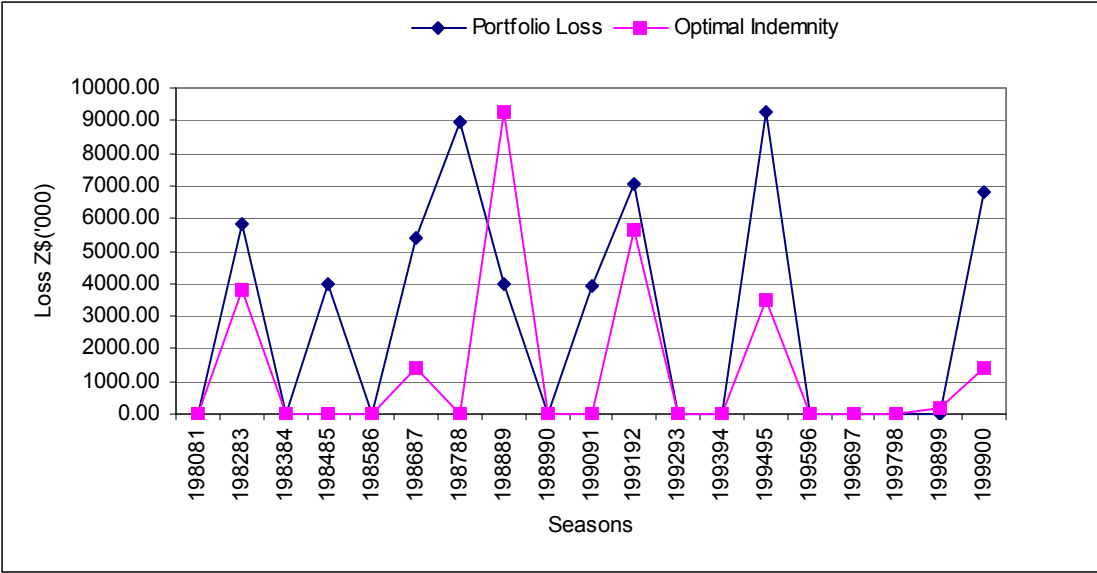


Figure 4: Portfolio loss vs. Optimal Indemnity for District # 3 using VCI

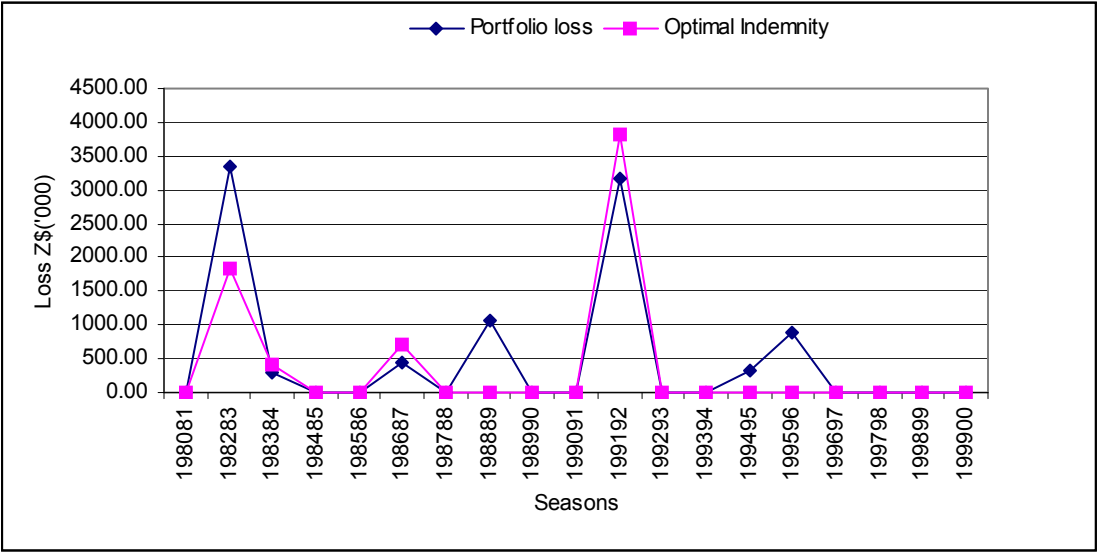


Figure 5: Portfolio loss vs. Optimal Indemnity for District # 4 using VCI

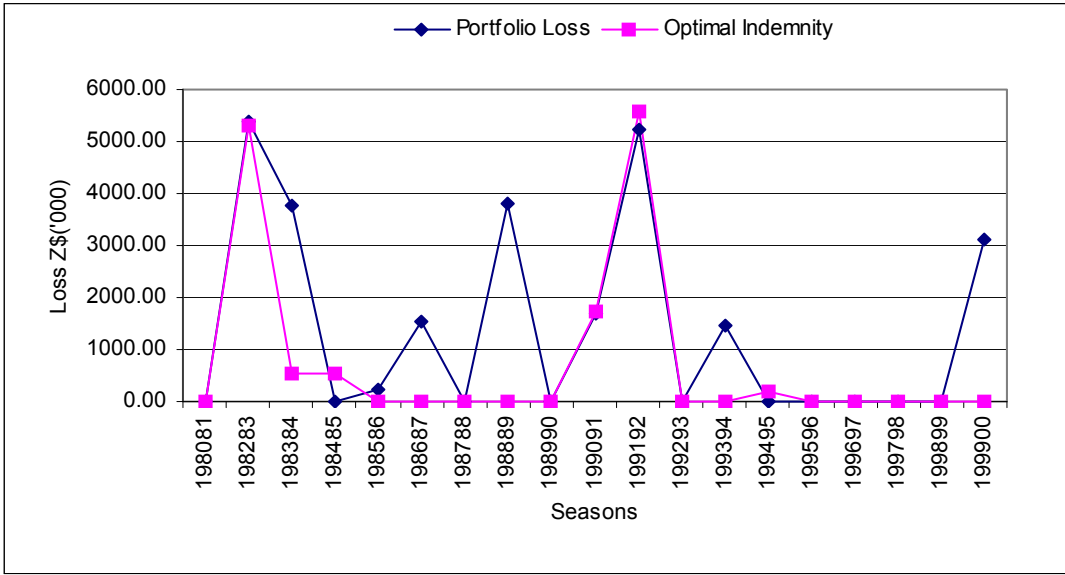


Figure 6: Portfolio loss vs. Optimal Indemnity for District # 5 using VCI

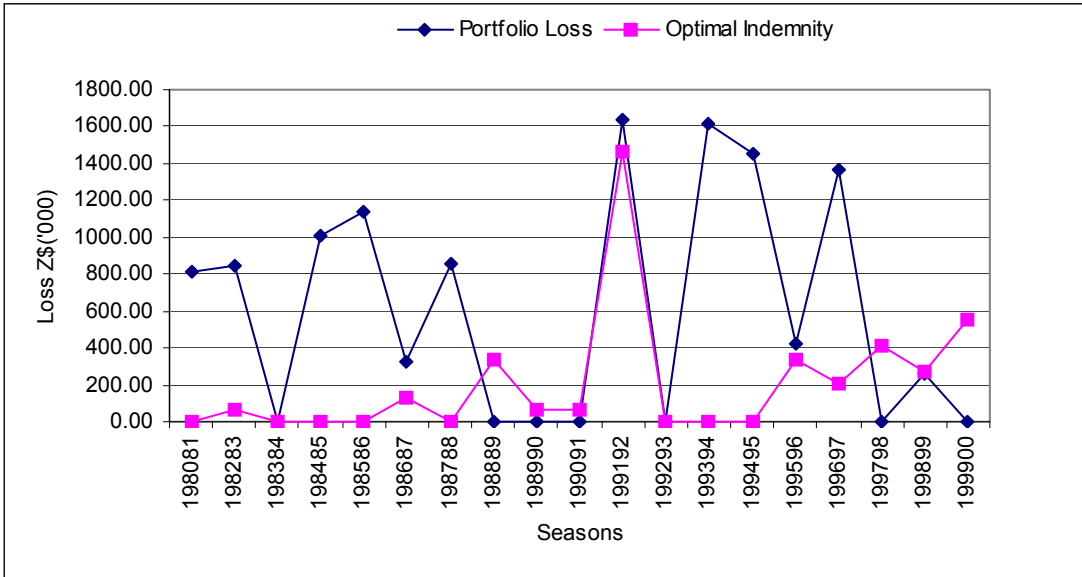


Figure 7: Portfolio loss vs. Optimal Indemnity for District # 6 using VCI

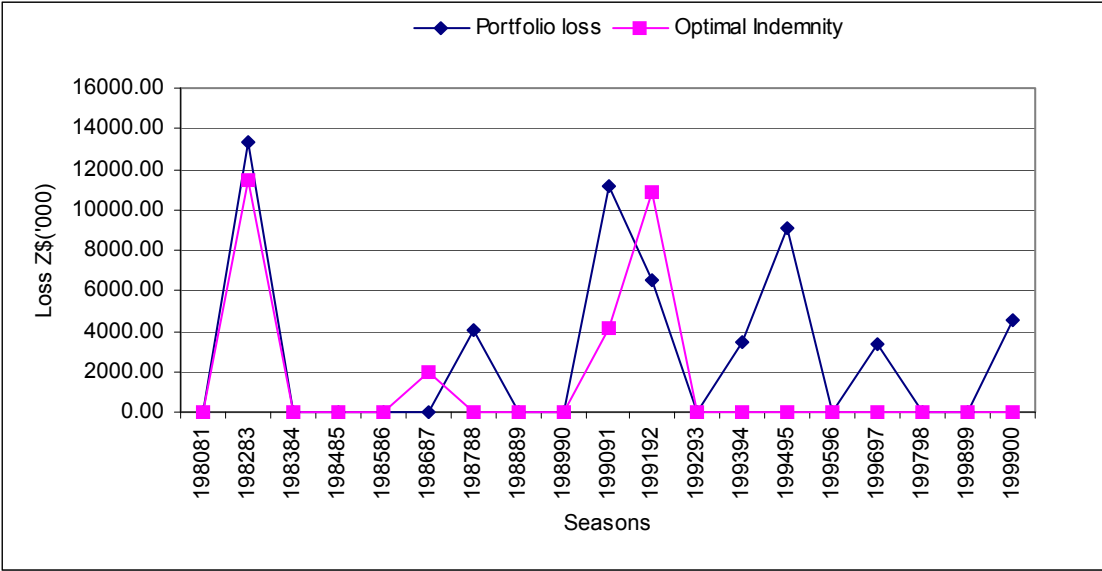
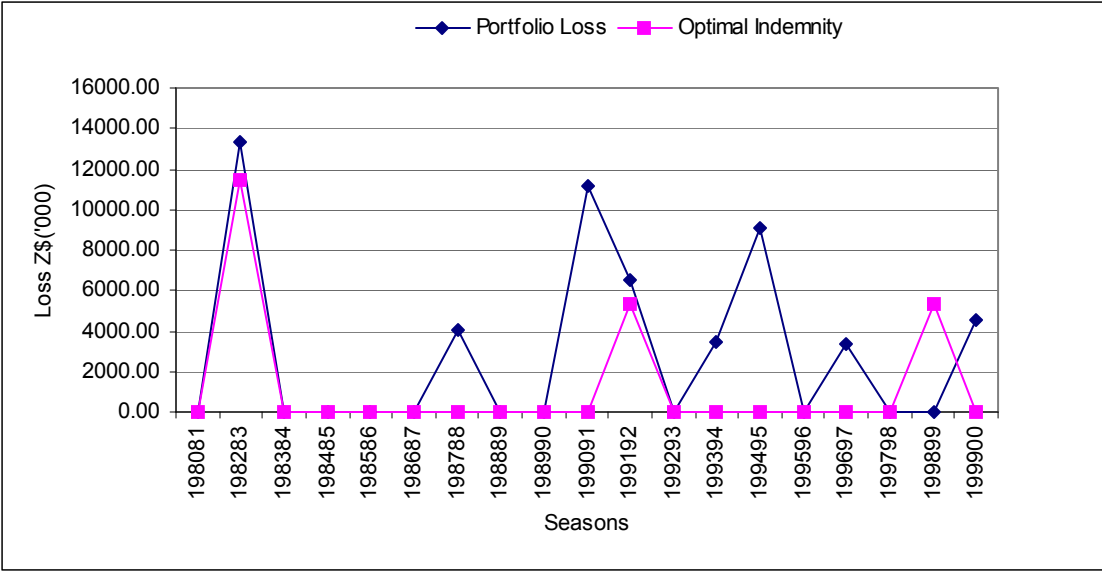


Figure 8: Portfolio Loss vs. Optimal Indemnity for District # 7 using VCI

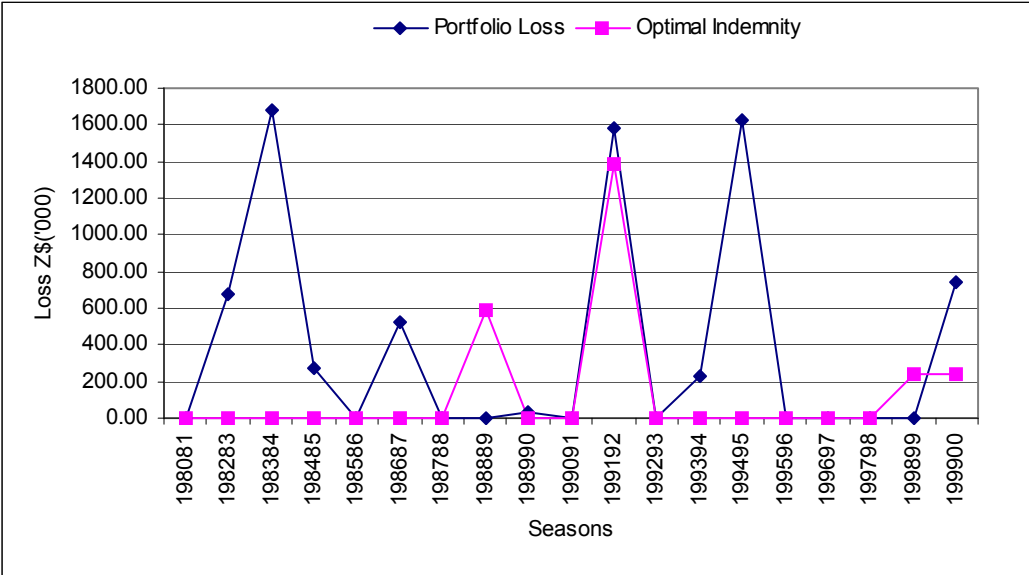
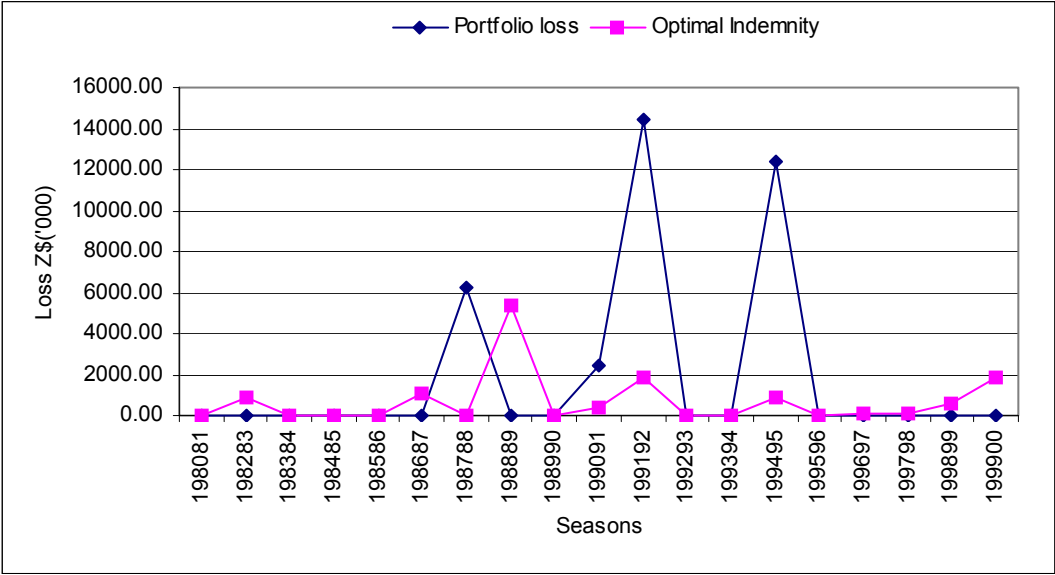
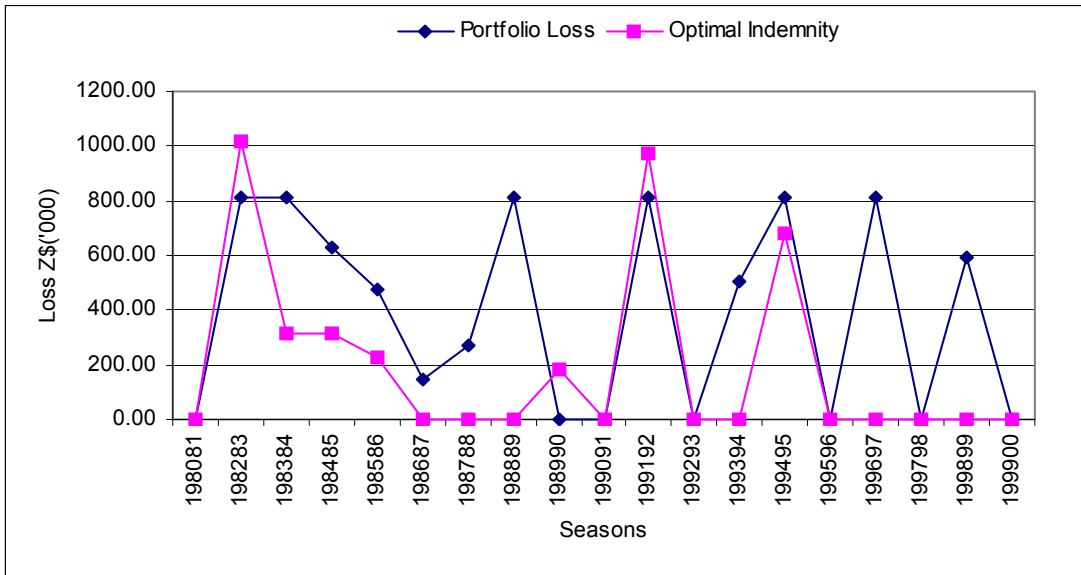


Figure 9: Portfolio Loss vs. Optimal Indemnity for District # 8 using (a) VCI

Figure 10: Portfolio Loss vs. Optimal Indemnity for District # 9 using VCI



### CONCLUSION

Except for a few districts, a VCI shows appreciably high correlation that ranged from 0.60-0.90. Further, most districts had premium rates within the desired range of 5-10% except one district (9). The VCI was able to satisfactorily trace *extreme* drought events but tended to miss on events of lesser intensity. In as far as protecting against extreme drought events, VCI-based contract could be sufficient. However for drought events of *bad-moderate* intensity the index tend to miss and hence basis risk becomes a concern.

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