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Viability of Weather Index Insurance in Managing Drought Risk in Australia

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Abstract

In this paper, we look into the risk management strategies adopted by farmers to manage revenue shortfall resulting from drought-induced yield losses. We survey literature on traditional indemnity–based insurance and weather index insurance. Some challenges facing the indemnity-based insurance were discussed and the prospects of resolving these challenges by using an index based risk transfer product called weather index insurance was analysed. The particular weather variable of interest was rainfall. Basis risk and methodological challenges were recognized as some of the major challenges to the uptake of weather index insurance. We showed the relationship between yield and cumulative precipitation indices using regression analyses. The hedging efficiency of the product was analysed using the Mean Root Square Loss (MRSL) and Conditional Tail Expectation (CTE) while the systemic nature of the risk was captured with Loss Ratios. We concluded that a strong relationship between the rainfall index and yield does not necessarily lead to high hedging efficiency and other variables would have to be taken into consideration in order to make the design of weather index insurance more robust. We found that the MRSL is more resistant to strike levels of the contracts than the CTE. The results from the Loss Ratio Analysis showed that spatial and temporal pooling of insurance contracts reduce the risk to the insurer.

Keywords: Weather index insurance, hedging efficiency, burns analysis, conditional tail expectations, mean root square loss, loss ratio, quantile regression analysis, drought.

Please, refer to these abbreviations for quick reference although they are explicit within the text

CSPI - Cumulative Standardized Precipitation Index	PReg – Panel Data Regression Analysis
CTE – Conditional Tail Expectation	QLD - Queensland
CV – Coefficient of Variation	QReg – Quantile Regression
FE – Fixed Effect	RE – Random Effect
LR – Loss Ratio	SD – Standard Deviation
MRSL – Mean Root Square Loss	SPI – Standardized Precipitation Index
OReg – Ordinary Least Square Regression	WA – Western Australia

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1. 1 Introduction

The insurance system is getting over stretched given the frequency and intensity of extreme weather events in recent years (Keenan & Cleugh 2011; Parry et al. 2007). Although, extreme weather events like drought affect most sectors in the economy at least indirectly, some sectors are more vulnerable than others. The agricultural sector is among those sectors most vulnerable because rainfall deficit has grave implications on dry land crop yields and livestock grazing (Bardsley, Abey & Davenport 1984; Chantarat et al. 2007; Ghiulnara & Viegas 2010; Kimura & Antón 2011). Previous efforts to insure against the covariate nature of drought risk have been considered inefficient (Miranda & Glauber 1997).

Recently, Kimura and Antón (2011) recommended the exploration of insurance markets to manage drought risk in Australia. This suggestion by Kimura and Antón (2011) is in tandem with that of Bardsley (1986) that the viability of rainfall insurance is contingent on the relationship between yield losses and the index used as proxy for payout for the insurance contracts and the behaviour of a portfolio of the contracts when aggregated over time and space. The case of weather index insurance is different from certain existing insurance contracts like household fire insurance in that drought risk is usually systemic and therefore less diversifiable.

Literature on the use of weather index insurance as a means of hedging climate related risk is growing, but there has been a focus on temperature related risks in the energy industry without much consideration given to rainfall insurance as a means of hedging shortfalls in agricultural productions (Bokusheva 2011; Sharma & Vashishtha 2007; Vedenov & Barnett 2004; Yang, Brockett & Wen 2009). Researchers have related crop yields to weather indices but concluded that there is need for an in-depth analysis of crop and region specific studies (Bardsley, Abey & Davenport 1984; Turvey 2001; Vedenov and Barnett 2004). This region-specific analysis of rainfall insurance focusing on wheat was conducted by Bardsley, Abey and Davenport (1984) for some shires in New South Wales (NSW) in Australia, however, the data used was from 1945 to 1969 and interstate risk pooling was not modelled. Although the authors agreed that pooling risk beyond NSW will lower the risk to the insurer. Given that the data covered only a 25 year period and the climatic realities observed within the period may be different from what obtains at the moment in light of climate change, there is need for a re-examination of the topic with a longer and more recent data.

The conclusions in Bardsley (1986) suggest that weather index insurance is a possible tool for managing drought risk but Binswanger-Mkhize (2012) is of the view that there is too much hype about weather index insurance. The major challenge facing the prospects of weather hedging in the agricultural sector is the empirical estimation of

necessary parameters involved including prices and the dependence structure of the risk among others (Jewson & Brix 2005).

The general objective of this study was to determine the viability of weather index insurance. More specifically, we determined the relationship between weather index and yield. Also, the hedging efficiency of weather index insurance was determined and finally, we determined the extent to which a portfolio of weather index insurance is diversifiable. We discussed the literature surrounding weather index insurance and the methodology adopted after which the analysis follows the sequence of the specific objectives. The paper ended with discussion of the findings and conclusion.

2. Weather and Climate Risk Management in Australian Agriculture

The Australian agricultural system is susceptible to extreme weather particularly drought risk that has become an integral part of the system. This has lead to a paradigmatic shift in the perception of drought as a disaster to a risk that requires self-sufficiency on the part of the farmer as stated in the Australian Drought Policy (Kokic et al. 2007; Lindesay 2005; Wilhite 2005). Consequently, there is a re-assessment of the role of weather index insurance in the context of agricultural risk management particularly in Australia given its susceptibility to drought. This susceptibility and the consequent paradigm shift have lead to a re-examination of the role of weather index insurance in Australian agriculture as noted in Kimura and Anton (2011) although the debate on its viability remains inconclusive as observed in the work of Quiggin (1994):

> *While the debate did not reach a settled conclusion, there was a consensus that a rainfall insurance scheme would not have a major impact in the absence of some subsidy at least on administrative costs. On the other hand, if subsidies were to be paid to farmers suffering from adverse climatic conditions, rainfall insurance would be one of the most cost-effective alternatives. (p. 123).*

Nevertheless, Quiggin (1986) are of the view that we can achieve reduction in the cost of risk if government's policies do not deter the design of insurance schemes. Similarly, Zeuli and Skees (2005) opined that some benefits may be possible with weather index insurance and that as little as the benefits may be, it could mean much to farmers who are exposed and have no other cover.

Weather risk, like every other risk, involves the probability and intensity of loss (Bodie & Merton 1998; Cuevas 2011). The economists' position is that risk is the variance in the outcome that results from an action. This economist's view is implied in Adam Smith's perception of insurance as a trade that gives security to individuals

in that these individuals could trade their risks for a portion of their utility (Zweifel & Eisen 2012, p. v). This trade is primarily a trade-off between the expectation of the outcome and its variance (Hayman & Cox 2005, p. 119). The etymological history of risk emphasises choice and opportunities rather than loss and fate and the ability to manage variability remains a major source of entrepreneurial competitiveness (Bernstein 1996). Managing risks therefore involves making choices among a range of competing alternatives through adequate consideration of costs and benefits (Harwood et al 1999). There are several sources of risk in agriculture including drought and given that weather could no longer be treated as a force majeure, hedging it has become an issue of paramount importance (Kimura & Antón 2011).

Enterprise diversification, crop insurance and government welfare supports are among alternatives that have been traditionally available to farmers to manage revenue fluctuations resulting from the impacts of exogenous variables on yield (Harwood et al. 1999). There are three layers of risk as noted in OECD work on risk management in agriculture (OECD 2011). The first layer is normal risk which is frequent but not too damaging. At the intermediate layer is the marketable risk which is more frequent but more damaging but not to a catastrophic extent. The third layer is catastrophic risk which is least frequent but most destructive. Generally, enterprise diversification is useful in managing the first layer of risk in that though the probability of occurrence of risk at this level is high; its impact is very low. At the second layer, the frequency of the risk is lower than the first but has a higher impact while the third layer has the lowest frequency but maximum impact because of its systemic nature. The second layer could be readily managed using market-based instruments to promote self-reliance. This layer of risk coincides with the level of risk that farmers are willing to insure unlike events that have low probability with more disastrous consequences which are hardly given considerations in risk planning (Wright & Hewitt 1994).

Given the covariate nature of drought risk at the extreme tail, drought may be uninsurable in the domestic market and governments have often acted as risk bearer of last resort (O'Meagher 2005; Quiggin, Karagiannis & Stanton 1994). Reinsurance has been suggested as an alternative to manage the covariance of drought risk at the extreme tail in that pooling the risk in a larger portfolio of risk makes it bearable for the reinsurer unlike a local insurance firm (Chantarat 2009). The reinsurer has the capacity to pool the risk over space and risk pooling over time could also provide additional diversification opportunities (Hoeppe & Gurenko 2006). This alternative makes response swift and takes the declaration of exceptional circumstances beyond political advocacy that has characterised government response in Australia and other parts of the world (Kimura & Antón 2011).

Besides drought relief, governments have traditionally used multi-peril crop insurance to manage drought risk but the work of Wright and Hewitt (1994) described the objective function of multi-peril crop insurance and its basic assumptions as untenable

(p. 85). They noted that the main reason for the failure of all-risk insurance was that it is based on a theoretical model that overstates its potential value. Drought relief is one method the government uses to assist farmers and is not without its own criticism as well (Meuwissen, Van Asseldonk & Huirne 2008). The major argument is that drought assistance is subjective and politicised besides the equity issues it raises (Kimura & Antón 2011). Drought is considered as a part of agricultural endeavours especially in a country like Australia and government intervention has been left to exceptional circumstances the declaration of which is flawed (Keenan & Cleugh 2011; Kimura & Antón 2011; Meuwissen, Van Asseldonk & Huirne 2008; Quiggin 1994). The work of (Botterill & Wilhite 2005) shows that farmers are expected to manage the first and second layer of drought risk but they are yet to be empowered with the necessary mechanism to manage the second layer. The third layer of risk has been called an exceptional circumstance but its benchmarking as a once in 20 to 25 year event is questionable given recent trends in the frequency of drought (Kimura & Antón 2011). The once in 20 year drought corresponds to the Bureau of Meteorology's 5^{th} percentile rainfall (BoM 2012). Since the multi-peril crop insurance is highly cost prohibitive given its loss ratios (Quiggin 1994; Wright & Hewitt 1994) and governments' efforts are subjective, Index Based Risk Transfer Products (IBRTPs) have been considered as useful alternatives to managing agricultural production risks (Kimura & Antón 2011). A particular type of IBRTP is weather index insurance, an agro-insurance to prevent risk avoidance on the part of farmers.

Recent experiences have shown that without significant subsidies, the agro-insurance market will be thin (Smith & Glauber 2012). However, Skees and Collier (2012) found that premium subsidies can undermine the essence of weather market. Helping farmers to manage their risks curtails risk avoidance that could culminate in the redeployment of factors of production invested in agriculture. Hence, the government of Australia has taken several initiatives to assist farmers but these initiatives are not without their accompanying inefficiencies particularly slow response, politicization and inequity (Kimura & Anton 2011).

Generally, public agencies tend to be associated with inefficiencies and a private alternative is often considered as the solution which unfortunately is not always the case (Niskanen 1971). Subsidizing the contracts and outsourcing it to private firms could lead to rent seeking behaviours, besides, Smith and Glauber (1971) are of the view that insurance subsidy is a form of wealth transfer to farmers. This wealth transfer is an incentive for farmers to make sub-optimal decisions as few farmers are willing to pay the full price of insurance. Therefore, if individuals expect compensation, in whatever form, from government to offset natural disaster losses, they will take on additional risks. If producers do not bear the consequences of risky decisions, they will continue to do the things that expose them to the risk.

3. Weather Index Insurance and Traditional Indemnity-Based Insurance

Two major types of insurance products exist namely; traditional indemnity-based insurance and index–based insurance. Under the traditional category are the named peril, multiple peril and mutual insurance products. The index-based products include yield and weather insurance. The payouts from traditional indemnity-based insurance products are based on the actual losses farmers experienced whereas some proxies are used as the basis for payouts under the index based products (Turvey 2001; Chantarat 2009).

The most commonly cited advantages of index-based insurance are that it prevents moral hazards and adverse selections. Moral hazard is any behaviour of the insured that makes him not to protect himself against losses in anticipation of indemnity payment. Since, weather index insurance is based on exogenous variables beyond the control of both counterparties to the insurance contracts the asymmetric information leading to the problem of moral hazard plaguing the traditional indemnity insurance will be resolved. The cost of monitoring moral hazards increases the cost of traditional insurance. It is expected that index-based proxies like precipitation and temperature would eliminate this cost thereby making weather index insurance cheaper. However, the problem of basis risk reduces this cost benefit (Yang, Brockett & Wen 2009).

Basis risk could be geographic or structural. Geographic basis risk creates a gap between the station where the weather readings are made and the farm land insured. Structural basis risk refers to creating weather index insurance that is not suited for the particular crop. Using the currently traded precipitation derivatives used by the energy industry will create structural basis risk for farmers in that the product is not suitable for them. If the farm is located in Clifton, about 150 kilometres west of Brisbane (Clifton 2012), then, there will be geographic basis risk if the weather station in Brisbane is used for precipitation reading. To resolve the problem of basis risk, the contracts may have to be localized thereby reducing the expected cost savings of weather index insurance.

Adverse selection is also said to be characteristic of the traditional indemnity insurance (Ahsan, Ali & Kurian 1982; Just, Calvin & Quiggin 1999). This is because those who are the most affected by the peril of interest will tend to take the insurance thereby creating a pool of risky contracts. Since the trade of insurance is supposed to *divide among a great many that loss which could ruin an individual* (Adams Smith in Zweifel & Eisen 2012, p.v), adverse selection makes this impossible as only those individuals who are risky are in the insurer's pool. If farmers are able to predict the weather to a reasonable extent, then, adverse selection could still be possible with weather index insurance in that farmers would only take cover in those years when they are most at risk. Similarly, some locations could be at risk of droughts than the

others (Agnew 2011; Hicks 2011). The implication is that farmers who are farming in locations at risk of drought will take drought insurance thereby creating a risky portfolio of insurance contracts. The adverse selection resulting from this geographical diversity could be aggravated if the pricing of the contracts does not reflect the relative susceptibility of these locations to drought. Hence, if location A is at higher risk than B, then the pricing should reflect this relative risk for the insured to feel fairly treated. Hence the need for pareto-efficiency in the pricing of weather index insurance contracts.

Since the insurance market operates like the capital market in that it enhances the production capacity of farmers, it is better than non-market alternatives to managing their risk exposures (Quiggin & Chambers 2004). The availability of these insurance options raises some questions. These questions include; what insurance products are most suitable to cater to the needs of primary producers and what are the legal implications of these options?

4. Legal Treatment of Weather Derivatives and Insurance

Weather hedges could be purchased as derivatives or insurance and they have certain similarities and differences (Raspe 2002; Skees & Collier 2012). In terms of similarities, weather insurance and derivatives require the forfeiture of a premium to be entitled to receive payouts should a contingent event occur. There are regulatory, tax and accounting standard differences between the two products as noted by (Raspe 2002). The insurance market is highly regulated while derivatives are excluded from too much regulatory scrutiny as long as it conforms to certain conditions (Raspe 2002).

In Kelly and Ball (1991), insurance contract was defined in the context of Australia and it was noted that three essential requirements are needed for a contract to be an insurance contract. The first is premium and benefit, the second being uncertainty of the event and finally an interest besides that created by the insurance contract itself. The premium paid obligates the insurer to confer value on the insured should the fortuitous event occur as noted in Raspe (2002). Kelly and Ball (1991) argued that these three requirements are also present in other contracts like warranties and acknowledged the difficulties involved in defining insurance contract. Kimball-Stanley (2008) identified two basic theories in articulating the difference between insurance contracts and other contracts; they are legal interest test and the factual expectancy test. Kelly and Ball (1991) recommended an approach that focuses on the intention of the parties as being helpful. In particular, the intention of the assured who has more information peculiar to the risk, to transfer possible losses to the insurer confers on him (the assured) a duty of care in the form of disclosure of necessary information. The duty of care by both parties in the risk assessment remains a major distinguishing factor between insurance and other contracts.

Translating this definition into the context of weather hedging, we can say that since meteorological information is publicly available, there is no private information to disclose by the assured and the insurer has limited opportunities to engage in malpractices. Premiums and benefits are evidently part of the contracts but the uncertainty is not on whether or not drought will occur, rather, when it will occur. Given recent advances in meteorological sciences, it may be possible to predict occurrence of droughts to a reasonable degree of confidence. The implication is that although weather information is publicly available, farmers may have enough information to decide on when to purchase a cover in such a way to maximize their own benefits at the expense of the insurer. The consequent adverse selection will lead to weak temporal risk pooling as farmers will not take insurance in years they are least likely to be drought stricken. Also, those in less drought prone areas will not take insurance. The implication is that as insurers tend to factor in this form of adverse selection into their pricing, the price of insurance will be driven upwards.

Following the thoughts of Raspe (2002, p. 225), 'An entity executing a weather derivative trade does not need to show an insurable interest. This interest is a major distinguishing characteristic between insurance contract and a wager. An insurance contract definition based on Section 1101(a)(1) of New York's Insurance Laws given in Raspe (2002, p. 226) is as follows:

[A]ny agreement or other transaction whereby one party, the "insurer", is obligated to confer benefit of pecuniary value upon another party, the "insured" or "beneficiary", dependent upon the happening of a fortuitous event in which the insured or beneficiary has, or is expected to have at the time of such happening, a material interest which will be adversely affected by the happening of such event.

The insured imposes the obligation to the insurer through the premium paid and the occurrence of weather event remains one of the most fortuitous of all and therefore helps to contain moral hazard which is typical of the traditional indemnity-based insurance that requires proof of losses. However, the relationship between yield losses and the weather index on which payout is based is not in absolute tandem with the payout. This disparity results from structural and geographical basis risk characteristic of weather index insurance. Hence, there could be years when there are losses without payouts and years with payouts but no losses. At best, should all the years of payouts match with years when losses are experienced, the payouts may not be commensurate with the losses.

In essence, value is conferred on the insurer on the basis of the weather index but the material insurable interest is the observed yield which translates into utility in the form of revenue. The case of weather index insurance is similar to the amphibious nature of preferred stock that stands between equity and debt with its unique legal standards.

Recent studies seem to implicitly suggest that the structure of insurance contracts follow the same structure as that of derivatives without any proof of loss but an insurable interest exists (Chantarat 2009; Kapphan, Calanca & Holzkaemper 2012). It seems that the function of weather index insurance may not be different from weather derivatives but they require a well-articulated legal distinction to prevent abuse of the classification and regulatory frameworks guiding derivatives and insurance. Failure to regulate the products may create new risks (Kimball-Stanley 2008). Some authors (Chantarat 2009; Kapphan 2012) in their reports interchangeably used insurance and derivatives because of the functional convergence between the two products.

The possible mismatch in the payout and yield loss suggests that weather index insurance may not completely satisfy the conditions of insurance like the traditional indemnity-based insurance. Hence, in defining what constitutes insurance, there is need to differentiate between indemnity-based insurance and index-based insurance. A major similarity between the two insurance types is that they both require insurable interests but there is no need for proof of loss in the case of index-based insurance. The index-based insurance is also different from weather derivatives in that derivatives do not necessarily require an insurable interest.

Skees and Collier (2012) noted that weather hedges could be purchased as over-the-counter weather index products which are tailored to individual needs of the clientele or as actively traded standardized exchange traded derivatives. Given the nature of the response of different crops in different regions to weather variables, exchange traded weather derivatives may not be practical in the context of agriculture because the patronage for standardized contracts will be limited. Vortex (2012) effectively summarized these differences in terms of eligibility to purchase the hedging product, accounting treatment, liquidity, flexibility and regulatory control.

5. Weather Index Insurance and Climate Change

It is a well-established fact that weather variability is the major source of yield fluctuations (Dai, Trenberth & Qian 2004; Kapphan, Calanca & Holzkaemper 2012) and that weather variability will be exacerbated by Climate Change with a consequent effect on yield (Keenan & Cleugh 2011). The old saying that; '*however big floods get, there will always be a bigger one coming …',* is therefore true in relation to climate change and drought (President's water Comm. in Gumbel (1958). However, Kapphan, Calanca and Holzkaemper (2011, p. 33) concluded that increase in weather risk, particularly exacerbated by climate change, generates a huge potential for the insurance industry. They showed that when hedging with contracts adjusted for future climate scenarios, benefits almost triple for the insured while profits increase by 240% for the insurer. The implication is that weather index insurance would become more profitable for both counterparties if it is updated to capture latest weather

information. In the study, it was further noted that insurers could suffer losses if future contracts do not capture changes in weather distributions over the coming years.

Skees and Collier (2012) noted that the price of weather hedging will increase as climate change increases weather risk. Consequently, the capacity of those at risk could be impeded by the exorbitant prices that could prohibit the insured from taking the insurance leading to insufficient demand. The low demand could have resulted in economy of scale for the insurer offering the product. They noted that the price of the insurance will increase for three reasons namely; increases in pure risk, the potential size of losses and ambiguity of the risk. The link between climate change and the price of weather insurance is due to the fact that the pricing is of the contract is done using Historical Burns Analysis. Burns analysis involves the use of historical data to estimate the fair premium of insurance. Hence, as there is a change in the data trend, there will be a corresponding shift in the statistical parameters used in the estimation of the prices. This model assumes that the insurer's profit over the years is zero as the premium is assumed to cover all indemnities only (Chantarat 2009; Jewson & Brix 2005; Kapphan, Calanca & Holzkaemper 2011).

6. Global Experience in the use of Weather Index Insurance

Weather index insurance has been successfully used in some countries while it is been pilot tested in others and further researches are being undertaken in this area (Gurenko 2006; Sharma & Vashishtha 2007). The case of Mongolia was emphasized by Skees (2008) as a model for Low Income Countries (LICs). The Mongolian case is a typical example of how index insurance could be used to hedge livestock losses. The drought and harsh winter in the early 2000s in Mongolia lead to losses of about a third of the country's cattle. The disaster was financed through a loan agreement with the World Bank to finance a tranche of index–based livestock insurance. In Honduras, the use of weather index insurance has been found to be effective among smallholder farmers (Nieto et al. 2012). The study by Bardsley, Abey and Davenport (1984) focused on European agriculture. In the study, it was noted that perception of risk by scientists and farmers are not necessarily in congruence and that a theoretically promising risk management instrument may not necessarily work well for farmers. This divergence in risk perception could partly explain the friction in the uptake of weather index insurance by farmers. The study concluded that risk perception varies considerably across EU member states. Another important conclusion of the study was that risk management solutions need to be 'tailor-made' to cater to the diversity in risk perception and exposure among the EU states.

7. Methodological framework

7.1: Data and data processing: The rainfall data used is based on the available data from the Bureau of Meteorology of Australia (BoM 2012) and the yield data from the Department of Primary Industry and Fisheries (Potgieter, Hammer & Doherty 2012). The actual yield data is not available for a sufficiently reasonable period of time so the simulated data was used. Although the simulated yield data is available from 1900 till 2011, the precipitation data is not sufficiently available over the same period in many shires. Hence, a 40–year period was used from 1971 till 2010. There were missing data in this period as well but experts were of the view that such missing data are better taken as zero readings rather than using average values to substitute the missing data.

There are different types of indices that could be used in the design of weather index insurance (Chantarat et al. 2012; Dai, Trenberth & Qian 2004; Kapphan, Calanca & Holzkaemper 2011; Turvey 2001). However, the Standardized Precipitation Index (SPI) was used because it is relatively simplistic in comparison to the likes of Palmer Drought Severity Index, Reconaissance Drought Index and others. The SPI is calculated using the standardized values of rainfall. The season was divided into dekads (ten day periods) and the SPI for each dekad was summed up to form the Cumulative SPI (CSPI) which was used for benchmarking. The benchmarking was done at percentile levels. For example, the 5^{th} percentile benchmark will imply that the contracts will pay out twice in the 40–year period, the 10th percentile pays out four years with the lowest SPI in the period while the 30th percentile pays out 12 years of the 40 years. The analysis was done with equal weightage of the dekads in the season and then with optimized weightage. However, the emphasis was on the optimized weightage because the optimized weights lead to a stronger relationship between yield and the index. The equal weighting implies that each 10–day period in the season equally influences crop yield whereas the optimized weightage implies that some dekads have more impact than the others. The GRG nonlinear algorithm in Microsoft Excel package was used to allocate weights that maximize the yield-index relationship. In all cases the relationship was stronger when weights were optimized. The commencement of the season for Queensland shires is around 1^{st} of June while it is approximately 1^{st} of April in Western Australia, depending on the shire. The periods covered by the contracts were from sowing to the commencement of maturity over an approximately 180–day period from the commencement of the season. The rainfall (in millimetres) was accumulated in dekads. We assumed a soil maximum water retention capacity of 60mm for all the shires. This is because rainfall above this amount may not contribute to plant growth (Stoppa & Hess 2003).

The following optimization problem was adopted to obtain the weights for the dekads:

$$r_i \equiv \max\left[r^*_i, CAP_i\right]$$

Where r_i is the actual rainfall in period i, and CAP_i is the amount of rainfall in the particular dekad or period i above which additional rainfall will not increase wheat yield.*

$$R_{cz_t} = \sum\nolimits_i^n \omega_i r_{it}$$

Where n is the total number of 10-day periods in the growing season which in our case is 18 ten-day periods, ω_i, is the weight assigned to the period i of the growing season, r_{it} is the effective rainfall in period i of year t and R_{cz_t} = Cumulative Standardized Precipitation Index for each year (t),

The weights, ω_i, were chosen to maximize the sample correlation between the rainfall index and yield based on the yield data from 1971 to 2010.

$$\max_{\omega_i} corr(R_{cz}, Y) = \frac{\sum_{t=1971}^{2010} (R_{cz_t} - \bar{R}_{cz})(Y_{z_t} - \bar{Y}_z)}{\left[\sum_{t=1971}^{2010} (R_{cz_t} - \bar{R}_{cz})^2\right]^{1/2} \left[\sum_{t=1971}^{2010} (Y_{z_t} - \bar{Y}_z)^2\right]^{1/2}}$$

Subject to the constraint; $0 \le \omega_i, \forall_i$

Where: Y_t is the yield in year t, $\bar{Y}$ = average yield. These values vary from shire to shire across both states.

7.2: Payout procedure: The contract design follows a put option design as described in Turvey (2001), however, we follow the indemnity structure in Stoppa and Hess (2003) for simplicity. The rainfall index derivative based on the Cumulative Standardized Precipitation Index (R_{cz_t}) must be below an alpha (5^{th}, 10^{th} and 30^{th}) percentile threshold ($T_\propto$) for payout to occur. The payment was designed to be proportional to the extent to which the index is below the threshold. The value of R_{cz_t} is the sum of the values obtained by multiplying the rainfall index in each period *(i)* of a particular year *(t)* by the specific weight *(ω_i)* assigned to the period i.

$$Indemnity = \left| \begin{matrix} 0 \text{ if } R_{cz_t} \geq T_\alpha \\ \dfrac{T_\alpha - R_{cz_t}}{T_\alpha} if R_{cz_t} \leq T_\alpha \end{matrix} \right| * Liability$$

Where: $R_{cz_t} = Cumulative\ Standardized\ Precipitation\ Index\ for\ each\ year\ (t)$;

$T_\alpha =$ percentile threshold, $\alpha =$ 5^{th}, 10^{th} and 30^{th} percentiles

The liability is the insurable interest or the value of a hectare of wheat which was estimated using the average yield and the average monetary value of wheat. The price is assumed to be the same for all shires because the national export price was used but average yield differs from shire to shire. Hence, we are analysing the effect of weather index insurance on the revenue of a representative wheat farmer in each shire who took the average national price of $183.71 per hectare of wheat harvested (ABS 2012) over the 40-year period. Since the price is constant across the shires over the period under consideration, our analyses basically focus on the effect of weather derivatives or insurance on the hedgibility of the representative farmer's revenue resulting from the stochastic nature of wheat yield.

7.3: Data Analyses:

7.3.1: Objective 1: To determine the relationship between the weather index and yield.

To achieve the first objective, the Ordinary Least Square Regression (OReg) was adopted in an attempt to find the relationship between the weather index and yield. However, since the OReg assumes uniform slope across the yield-index continuum, the Quantile Regression (QReg) was utilized to study the strength of the relationship at different quantiles on the continuum (Adeyinka & Kaino 2012; Koenker 2005) The PReg (Panel Regression) analysis was used to determine the effect of location on the analysis. In essence, we sought to know whether or not different indices are required for different locations (Panel effect) (Chantarat 2009).

7.3.2: Objective 2: *To determine the hedging efficiency of weather index insurance*

The Standard Deviation (SD) may not be an appropriate measure of risk since we are interested in the downside risk. Value at Risk (VaR) also has its short coming because it is considered incoherent and does not satisfy the required axioms of an appropriate risk measure (Acerbi & Tasche 2001). Therefore, the Conditional Tail Expectation (CTE) and Mean Root Square Loss (MRSL), otherwise called Root Mean Square Loss (RMSL), were used to measure the hedging efficiency of the insurance at different strike levels (Vedenov & Barnett 2004). The CTE analysis in this study is

measured at the 5th, 10th and 30th percentiles. That is, we analyse the expected revenue in the worst 2, 4 and 12 years in the 40–year period. The purpose of this analysis is to know whether or not insurance will increase the revenue of farmers in the worst two years of rainfall, the worst four years of rainfall and the worst 12 years of rainfall in the 40-year period. If the contract is efficient, then, the utility of the farmer, measured in terms of revenue, should increase in years when droughts are experienced.

The Mean Root Square Loss (MRSL) is another measure of risk and is appropriate in this context because the minimization of the semi-variance rather than the full variance is of relevance since farmers are mainly interested in managing their downside losses (Vedenov & Barnett 2004). Given the different contracts (5th, 10th and 30th percentile contracts), the MRSL was calculated in an attempt to observe the extent to which the downside risk is minimized. Hence, if the MRSL reduces with insurance, then the contract is efficient at that strike level or contract.

The revenue without contract is given by: $I_t = pY_t$ and with contract is: $I_{t\alpha} = pY_t + \beta - \theta$

Where; I_t = revenue at time t without insurance, p= wheat price, $I_{t\alpha}$ = revenue at time t with alpha percentile level of insurance, Y_t = yield at time t, $\beta_{\alpha t}$ = insurance payout for that level of insurance in that year and $\theta\alpha$ = the yearly premium for that level of insurance and is constant throughout the years in question so it is written as θ, MRSL is the Mean Root Square Loss without insurance and MRSLα is the Mean Root Square Loss with an alpha level of insurance. These values differ by location but a location subscript is not included in the formula for simplicity.

$$\text{MRSL} = \sqrt{\frac{1}{T}\sum_{t=1}^{T}[\max(p\bar{Y} - I_t, 0)]^2}$$

$$\text{MRSL}\alpha = \sqrt{\frac{1}{T}\sum_{t=1}^{T}[\max(p\bar{Y} - I_{t\alpha}, 0)]^2}$$

7.3.3: Objective 3: *To determine the diversifiability of a portfolio of weather index insurance*

The Loss Ratio *(L_t)* is the ratio of the indemnity paid to premiums collected. Pooling the premiums and indemnities across different shires and over time helps to examine the spatial and temporal covariate structure of the risk. The L_t is calculated as follows:

$$L_t = \frac{\sum_{l \in L} \Pi_{lt}}{\sum_{l \in L} P_{lt}}$$

and when pooled over time, it becomes;

$$L_t = \frac{\sum_{t \in \tau} \sum_{l \in L} \Pi_{lt}}{\sum_{t \in \tau} \sum_{l \in L} P_{lt}}$$

Π=Indemnities, P = Premium, L=locations (18 shires, 8 from Queensland and 10 from Western Australia), *τ=time* (the pooling was based on 1, 2, 5 and 10 years).

If L_t is lower than 1 (L_t<1) , it indicates that the premium collected is more than the indemnities paid and therefore the insurer makes a profit, when it is 1 (L_t = 1), it implies a breakeven in that the indemnities paid is exactly equal to the premium and when it is above 1 (L_t >1), it means that the insurer experienced a loss for that period in that indemnities paid is more than the premium collected (See Chantarat2009 pp. 108 – 110).

8. Summary of Results

8.1: Descriptive statistics

Seasonal capped rainfall (in millimetres –mm) was higher in Western Australia (WA) than in Queensland (QLD) with Boddington having as much as 430.80mm of rainfall and Kondinin with 179.19mm. In Queensland, Clifton experienced an average of 266.69mm of rainfall and the lowest was in Balonne with 183.30mm. The standard deviations (SDs) and Coefficients of Variation (CV) were higher in Queensland than in Western Australia. The CV is the ratio of the standard deviation to the mean. The standard deviation and CV for yield show the same trend implying that farmers assume more risk per unit of production in Queensland than in Western Australia. In terms of skewness in the distribution of rainfall, Ravensthorpe is the most negatively skewed with a value of -1.33 while Katanning with 0.85 skewness is the most positively skewed. This implies that Ravensthorpe obtains frequent modest rainfall and few droughts but Katanning experiences more frequent mild rainfall deficits but few flooding. Positive skewness in yield is highest for Booringa with the value of 1.43 and negative skewness for Katanning was -3.14 to be the most negatively skewed location in terms of yield. It could be intuitively concluded that a portfolio of weather index insurance would be more volatile in Western Australia than in Queensland given the skewness of the data although Queensland farmers tend to bear more risk per unit of wheat production as shown by the yield coefficient of variation.

The pricing of the insurance contract was done using the actuarial burns analysis to reflect the historical nature of the risk. The Black-Scholes pricing model was inappropriate because the underlying index is not traded. It was noted that the pricing of the products rises with strike levels (See Appendix 1). For example, Balonne was 4.67%, 5.55% and 15.90% at the 5th, 10th and 30th percentiles respectively. Boyup Brook was the cheapest for the 10th and 30th percentile contracts in terms of the percentage of the insurable interest paid as premium (3.44% and 6.83% respectively). However, both CTE and MRSL revealed that the Boyup Brook contract hedged revenue losses at all percentile strikes whereas more expensive contracts did not necessarily provide any hedging advantage. The 5th percentile strike paid as much as 4.73% of the insurable interest as premium annually in Millmerran to be the second most expensive for this strike level without adding value to the revenue of the farmer under both MRSL and CTE. It seems that the actuarial burns analysis does not capture the relative efficiency of the contracts.

Table 0.1: Descriptive Statistics of yield and 60mm cap dekadal rainfall for all locations

		Rainfall				Yield			
Station numbers	**Queensland**	**Mean (mm)**	**SD**	**CV**	**Skewness**	**Mean (t/ha)**	**SD**	**CV**	**Skewness**
048020	**Balonne**	183.30	81.80	0.45	0.09	1.18	0.49	0.42	-0.54
043060	**Booringa**	202.10	84.25	0.42	0.61	1.29	0.59	0.46	1.43
043043	**Bendemere**	225.69	96.39	0.43	0.31	1.59	0.56	0.35	0.21
043093	**Bungil**	205.93	82.54	0.40	0.66	1.67	0.65	0.39	0.40
035070	**Taroom**	218.48	96.02	0.44	-0.03	1.27	0.56	0.44	-0.32
052020	**Waggamba**	198.91	83.82	0.42	0.42	1.41	0.51	0.36	-0.12
041018	**Clifton**	266.69	86.98	0.33	-0.17	2.66	0.44	0.17	-0.72
041069	**Millmerran**	252.74	89.00	0.35	0.18	2.24	0.36	0.16	-0.42
	Western Australia								
009575	**Boddington**	430.80	82.21	0.19	0.1	2.70	0.25	0.09	-3.03
009504	**Boyup Brook**	388.95	72.40	0.19	0.14	3.04	0.47	0.15	-3.13
010526	**Broomehill**	203.37	51.05	0.25	0.45	2.83	0.40	0.14	-2.77
010006	**Bruce Rock**	182.22	50.93	0.28	0.13	1.97	0.27	0.14	-1.33
010536	**Corrigin**	235.63	50.80	0.22	0.36	2.08	0.30	0.14	-0.94
010579	**Katanning**	294.92	63.58	0.22	0.85	2.74	0.32	0.12	-3.14
010513	**Kondinin**	179.19	52.32	0.29	0.72	2.09	0.21	0.10	-0.24
010121	**Tammin**	229.66	60.64	0.26	0.54	2.53	0.22	0.09	-1.47
010626	**Pingelly**	267.46	59.06	0.22	0.59	2.46	0.07	0.03	-0.77
010019	**Ravensthorpe**	235.35	61.02	0.26	-1.33	2.25	0.12	0.05	0.64

**CV=Coefficient of variation; mm = millimetres; (t/ha) = tonnes per hectare; SD = Standard deviation*

8.2: Objective 1: Relationship between weather index and yield

As could be seen in Figures 1.1 and 1.2, when the season is divided into dekads and they are optimized, the match between yield losses and payouts tend to increase. The extent to which these matches are improved is the extent to which optimizing the weights of the contracts increases the correlations between yield and the weather index. In Figure 1.1, the highest yield loss was experienced in 1995 and it would have been expected that the three contracts will pay out this year, only the 30th percentile contract paid a meagre 6.56% of the insurable interest. With optimization (Figure 1.2) the situation improved as the 5th percentile contract paid out 86.93% while the 10th and 30th percentile contracts paid 91.08% and 96.20% respectively. In the optimized model, the 100% pay outs also corresponded to year 2002 when 83.79% of the highest historical yield losses were experienced in contrast to the year 1991 when only 28.74% of the loss was experienced in the equally weighted contracts. This analysis shows the importance of considering the susceptibility of yield to water stress at the various phases of the crop growth cycle.

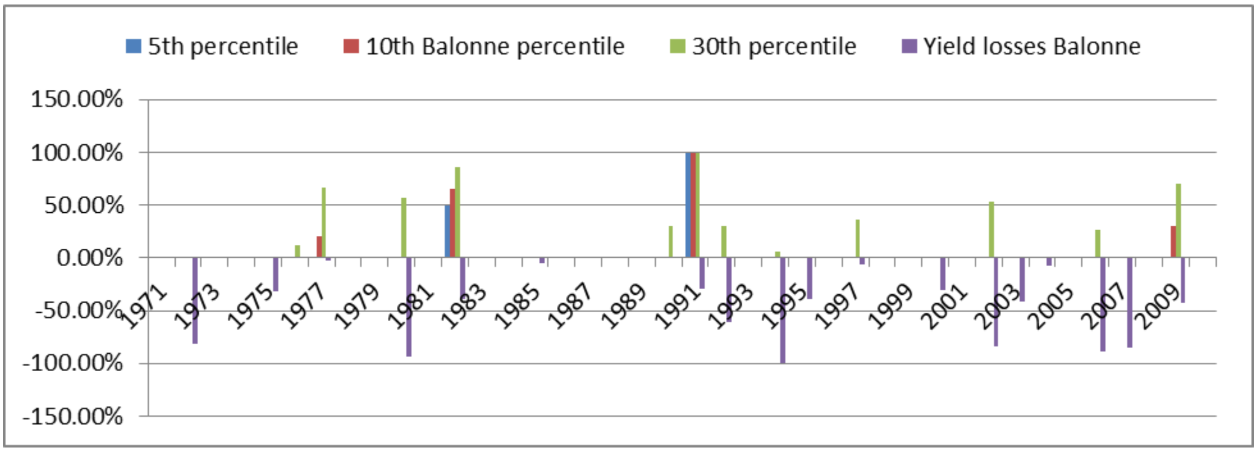

Figure 1.1: Pay out yield loss matches for equally weighted contracts in Balonne

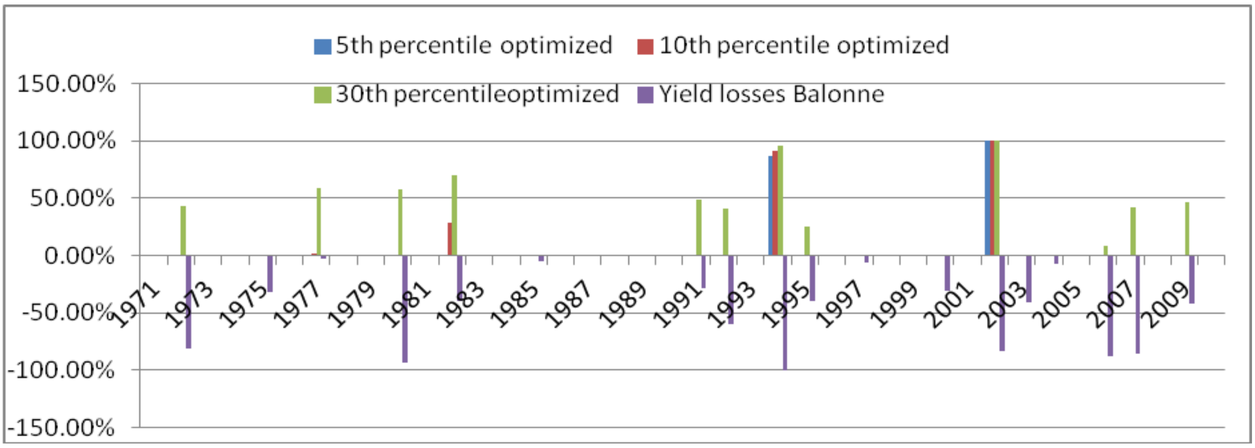

Figure 1.2: Pay out yield loss matches for optimized contracts in Balonne

Balonne and Ravensthorpe shires are used to demonstrate the effect of strike levels and optimization on weather index insurance contracts because their results were consistent under the two hedging efficiency measures used. In Balonne, the 5^{th} and 10^{th} percentile contracts matched with years when losses were experienced. That is, the two years with payouts matched with two of the eighteen years when yield losses were experienced under the 5^{th} percentile contract. The trend is the same for the 10^{th} percentile contract with and without optimization as seen in Table 1.1. However, at the 30^{th} percentile strike, two of the 12 years of payment were mismatched in that there was payment when the farmer did not actually experience any loss under the equally weighted regime. This mismatch was corrected with the optimized contract as all the 12 years of payouts matched with 12 of the 18 years when yield losses were experienced.

In the case of Ravensthorpe, the 5^{th} and 10^{th} percentile contracts followed the same trend as in Balonne, however, optimization reduced the mismatch in the payouts and losses from 4 to 3 only. It should therefore be expected that the hedging efficiency of the optimized contract will be lower in Ravensthorpe than in Balonne because of the mismatches that the optimization of the weights could not correct.

Table 1.1: Typical Payout-loss matches for Balonne and Ravensthorpe

Shire	Losses and payments	Equally weighted			Optimized contracts		
		5th	*10th*	*30th*	*5th*	*10th*	*30th*
Balonne Queensland	**Pay no loss**	0	0	2	0	0	0
	Loss no pay	16	14	8	16	14	6
	Matching years	2	4	10	2	4	12
	Total pays	2	4	12	2	4	12
	Total losses	18	18	18	18	18	18
Ravensthorpe Western Australia	**Pay no loss**	0	0	4	0	0	3
	Loss no pay	13	11	7	13	11	6
	Matching years	2	4	8	2	4	9
	Total pays	2	4	12	2	4	12
	Total losses	15	15	15	15	15	15

In all cases, optimization increased the linear relationship between the index and yield as indicated by the correlation coefficients (r_o and r_e). For Balonne, the correlation increased from 58.69% to 83.72% after optimization of the weights. The R square value based on the optimized contract should have been the square of the pearson correlation coefficient, 70.09% ($.8372^2$), however the adjusted-R-square was reported to make it comparable with models with more than one covariate should they be built in the future. Adjusted-R-square is a measure of the statistical efficiency of the models. The adjusted-R-square for Balonne is 69% indicating that the weather index explained 69% of the variation in yield. The highest statistical relationship between yield and index was experienced in Booringa shire with 89.77% of the variation in yield being explained by the weather index. This is followed by Bendemere and Clifton with R square adjusted values of 79.64% and 79.49% respectively. The lowest R square adjusted values were obtained in Katanning (22.29%), Broomehill (23.24%) and Bungil 34.66%. The distribution of the pseudo R square varies from shire to shire. Booringa indicated the strongest relationship based on the adjusted-R-square, a breakdown of this relationship into quantiles indicated that the relationship is loaded at the uppertail for Booringa which showed 76.07% and 78.50% at the 95th and 90th percentiles respectively. Bungil's quantile analysis tended more towards normality in that it showed an increase at the lower quantiles and peaked at 27.07% in the median (50th percentile) and declined after the median. Boddington shire showed a decreasing trend across the quantiles except at the 90th percentile.

The Panel Data Regression Analysis (PReg) as shown in Appendix 2 indicated that there is a panel effect among all the shires from both states and in each of the shires in each of the states of Queensland and Western Australia. The Random Effect (RE) was preferred over the Fixed Effect (FE) in the PReg because the Hausman test indicated the choice of RE for all the shires in each of the two states and all states when pooled together. The implication of the panel effect is that each shire will require different indices to capture the relationship between weather and yield and so a generic index will not suffice. This diversity may be due to differences in soil types and other variations across the states. The results of the RE for each of the states and both states indicated that there is a very strong relationship between the index and yield and therefore weather index could be a viable proxy for yield in calculating insurance premiums and payouts to wheat farmers ($P<0.05$).

Table 1.2: Regression and correlation analysis of yield and weather index

	Pseudo R square for QReg at different quantiles							Adjusted	r_o	r_e
Shires	**5th**	**10th**	**30th**	**50th**	**70th**	**90th**	**95th**	**R square for OReg**		
Queensland										
Balonne	53.07	54.17	52.14	49.35	40.14	20.68	15.33	69.00	83.72	58.69
Booringa	47.97	53.08	56.44	64.36	72.02	78.5	76.07	89.77	94.88	86.86
Bendemere	57.07	60.37	58.06	57.91	59.15	54.08	48.92	79.64	89.53	72.11
Bungil	4.66	12.15	25.17	27.07	23.05	14.73	0.79	34.66	60.28	26.08
Taroom	35.21	38.27	43.98	41.62	33.48	35.32	36.52	57.42	76.49	56.46
Waggamba	51.24	52.06	55.84	56.97	51.27	43.31	35.23	77.43	88.32	72.97
Clifton	67.26	62.13	58.51	55.82	50.44	43.51	41.26	79.49	89.45	71.31
Millmerran	47.53	42.93	45.66	46.57	40.47	43.26	47.47	68.08	83.00	63.82
Western Australia										
Boddington	55.52	45.4	13.43	3.41	0.27	0.34	0.16	46.33	69.07	45.67
Boyup Brook	59.32	43.48	18.52	12.53	9.82	2.4	2.98	49.14	71.02	37.24
Broomehill	40.55	25.18	4.1	1.25	0.67	5.1	0.63	23.24	50.20	27.72
Bruce Rock	16.73	14.06	7.62	19.92	18.55	2.05	0.06	41.88	65.85	43.28
Corrigin	53.4	47.08	29.22	28.8	16.96	9.55	5.38	46.16	68.95	48.69
Katanning	33.92	23.9	10.44	8.69	2.97	0.06	0.13	22.29	49.28	18.17
Kondinin	42.67	42.68	30.8	26.18	20.75	18.35	19.06	44.65	67.84	52.45
Tammin	47.11	42.91	35.32	34.19	20.7	7.81	5.58	51.43	72.86	54.61
Pingelly	51.02	51.92	44.95	33.48	32.4	18.97	14.89	61.62	79.12	58.20
Ravensthorpe	46.63	40.31	29.76	21.46	14.35	2.59	0.46	45.17	68.24	54.79

*r_e = Pearson correlation of yield and index for equally weighted contracts, r_o = Pearson correlation of yield and index for optimally weighted contracts, QReg = Quantile regression analysis for optimally weighted contract, OReg = Ordinary Least Square Regression for optimally weighted contract.

8.3: Objective 2: Hedging Efficiency

8.3.1: Kernel Density Plots of efficient and inefficient contracts

The Figure 2.1 shows the risk reducing effect of weather index insurance in Balonne shire. The variance in revenue is widest without insurance whereas with the insurance contracts, especially the 30th percentile contract, the farmer reduced variance in revenue. The case of an inefficient contract is shown in Figure 2.2 for Ravensthorpe where the insurance makes the farmer worse off. All three contracts made the farmer worse off than in Ravensthorpe but better off in Balonne.

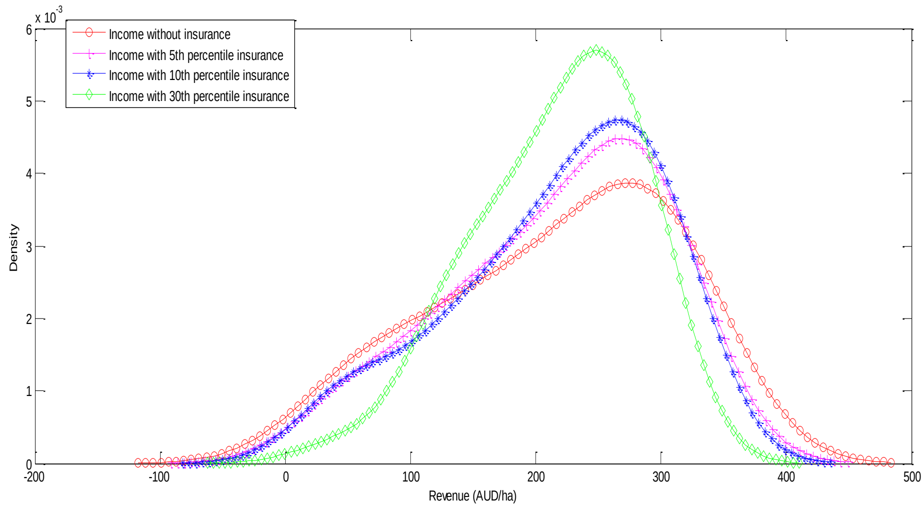

Figure 2.1: Risk reduction effect of an efficient weather index insurance contract – the case of Balonne.

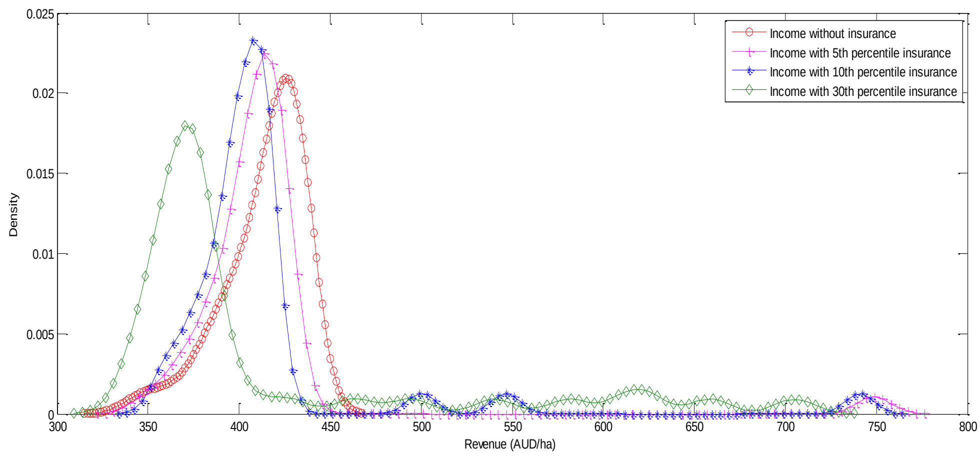

Figure 2.2: Risk increasing effect of an inefficient weather index insurance contract – the case of Ravensthorpe

8.3.2: Mean Root Square Loss and Hedging Efficiency

The Mean Root Square Loss (MRSL) reduces when a contract is efficient. The 5th, 10th and 30th percentile contracts were compared with the case without insurance. Balonne shire showed a 7.44% reduction in risk when the 5th percentile contract is used. The highest reduction was achieved in Broomehill with a 45.83% reduction with the 5th percentile insurance contract. Pingelly shire's risk increased by 75.08% to be the worst with the 5th percentile contract. Only twelve of the 18 shires showed evidence of risk reductions when MRSL is used as a measure of hedging efficiency at the 5th percentile. For the 10th percentile contracts, Broomehill as in the 5th percentile contract, has the highest risk reduction with the contract. The risk in Broomehill reduced by 49.05%. Pingelly shire also has the highest increment in risk under the 10th percentile contract as in the 5th percentile with an increase of 92.95%. For the 30th percentile contract, Pingelly remains the shire with the highest increment in risk of 253.42% but Boyup Brook reduced the semi-variance by 55.33% to be the shire with the highest risk reduction at the 30th percentile. Twelve of the shires showed risk reduction with the 5th and 30th percentile insurance contracts while risks were reduced for thirteen shires using the 10th percentile contracts.

Table 2.1: Mean Root Square Loss Analyses

Shires by states	Without contract	Strikes in percentiles					
		5th		10th		30th	
		With contract ($)	Changes (%)	With contract ($)	Changes (%)	With contract($)	Changes (%)
QLD							
Balonne	68.80	63.68	-7.44	63.46	-7.76	47.94	-30.32
Booringa	57.22	57.63	0.72	59.59	4.14	56	-2.13
Bendemere	69.61	65.69	-5.63	64.84	-6.85	58.21	-16.38
Bungil	76.76	74.39	-3.09	74.09	-3.48	78.8	2.66
Taroom	76.16	78.43	2.98	80.61	5.84	71.86	-5.65
Waggamba	66.39	62.84	-5.35	63.47	-4.40	55.25	-16.78
Clifton	61.78	56.59	-8.40	55.83	-9.63	48.96	-20.75
Millmerran	49.48	49.44	-0.08	48.61	-1.76	47.09	-4.83
WA							
Boddington	42.97	32.53	-24.30	25.56	-40.52	29.43	-31.51
Boyup Brook	78.68	45.52	-42.15	43.27	-45.01	35.15	-55.33
Broomehill	65.5	35.48	-45.83	33.37	-49.05	53.95	-17.63
Bruce Rock	40.37	33.86	-16.13	30.92	-23.41	33.54	-16.92
Corrigin	42.83	39.77	-7.14	40.06	-6.47	45.65	6.58
Katanning	51.34	32.18	-37.32	35.62	-30.62	64.11	24.87
Kondinin	27.8	30.53	9.82	30.15	8.45	32.43	16.65
Tammin	33.72	35.8	6.17	32.2	-4.51	33.09	-1.87
Pingelly	9.79	17.14	75.08	18.89	92.95	34.6	253.42
Ravensthorpe	17.76	19.21	8.16	24.4	37.39	46.16	159.91

8.3.3: Conditional Tail Expectation and Hedging Efficiency

When the value of Conditional Tail Expectation (CTE) increases when contracts are purchased, then the contract is efficient at that level for the location. CTE is calculated for the case with and without insurance at the different strikes and the alpha level corresponding to the strikes. For example, the 5% CTE was calculated for the revenue without insurance and compared with the 5% CTE for the revenue with the 5th percentile insurance contract whereas the 10% CTE was used to evaluate the efficiency of the revenue without insurance and the revenue with the 10th percentile contracts. The same approach was used for the 30th percentile strike. At the 5th percentile strike, Balonne recorded an increase in revenue from $57.25 to $62. This is 8.3% increase in utility. That is, the representative farmer in Balonne after accounting for the premium in the worst two years of rainfall in the 40-year period had sufficient payout to make him better off than the situation without insurance. At the 10th percentile strike, there was a 10.40% increase and only 5.49% at the 30th percentile strike. Fourteen out of the eighteen shires were better off with the 5th percentile contract. Boyup Brook had the highest change of 21.21% as revenue increased from $373.86 to $453.14 at the 5th percentile strike. Taroom shire was the worst among the shires that were worse off with insurance as revenue declined from $60.15 without insurance to $50.50 with insurance implying a 16.04% decrease in revenue for the representative farmer in the shire over the period in view.

For the 10th percentile contract, Balonne's revenue increased from $90.26 by 10.40% to $99.65. Taroom shire's revenue decreased from $91.34 to $81.37, a decrease of 10.92%. Taroom was also the worst shire with the 5th percentile contract. For the 30th percentile strike contract, Balonne increased in utility by 5.49% to be the shire deriving the highest benefit from the insurance while Katanning experienced the worst revenue change under the same contract strike level with a reduction in revenue by 10.91% although the shire was better off with the 5th and 10th percentile contracts. The 5th percentile contract was efficient in fourteen locations and the 10th percentile contract was efficient in eleven locations while the 30th percentile contract was efficient for only seven locations using CTE as a measure of hedging efficiency. It is obvious that the changes were highest at the most extreme tails and most shires would be better off with insurance at the most extreme tail than when droughts are mild as is the case at the 30th percentile strike level. The implication is that the benefit from drought insurance to the insured decreases as the strike level increases.

Table 2.2: Conditional Tail Expectations Analysis of Queensland and Western Australian shires.

	5% strike			10% strike			30% strike		
Shires	**Without contract ($)**	**With contract ($)**	**Change (%)**	**Without contract ($)**	**With contract ($)**	**Change (%)**	**Without contract ($)**	**With contract ($)**	**Change (%)**
QLD									
Balonne	57.25	62	8.30	90.26	99.65	10.40	183.47	193.54	5.49
Booringa	118.83	121.79	2.49	136.65	134.35	-1.68	186.07	187.48	0.76
Bendemere	129.48	145.06	12.03	165.97	179.15	7.94	247.33	256.68	3.78
Bungil	145.17	151.79	4.56	170.06	172.45	1.41	252.22	260.41	3.25
Taroom	60.15	50.5	-16.04	91.34	81.37	-10.92	193	194.11	0.58
Waggamba	114.05	120.52	5.67	141.07	145.43	3.09	220.43	230.39	4.52
Clifton	342.88	350.63	2.26	376.54	385.95	2.50	459.14	452.44	-1.46
Millmerran	300.89	279.19	-7.21	325.45	322.85	-0.80	385.44	380.94	-1.17
WA									
Boddington	390.91	415.88	6.39	438.58	459.53	4.78	488.62	465.15	-4.80
Boyup Brook	373.86	453.14	21.21	456.75	497.07	8.83	537.23	537.56	0.06
Broomehill	364.3	432.68	18.77	431.78	461.61	6.91	501.46	464.7	-7.33
Bruce Rock	257.9	280.1	8.61	293.83	306.74	4.39	345.72	333.73	-3.47
Corrigin	274.25	291.02	6.11	309.12	314.22	1.65	362.55	343.67	-5.21
Katanning	388.88	427.52	9.94	433.16	440.06	1.59	490.32	436.84	-10.91
Kondinin	318.56	319.11	0.17	334.23	330.37	-1.15	368.07	357.24	-2.94
Tammin	382.56	383.29	0.19	411.15	410.93	-0.05	452.88	436.18	-3.69
Pingelly	428.35	418.06	-2.40	433.53	417.43	-3.71	447.39	408.7	-8.65
Ravensthorpe	370.11	368.12	-0.54	382.6	376.76	-1.53	406.96	367.92	-9.59

8.4: Objective 3: Diversification

8.4.1: The effect of temporal risk pooling on a portfolio of weather index insurance contracts

For the 5th percentile contract in Table 3.1, the probability of a high profit was highest for a single year and two year pooling but this is also associated with high probability of loss. The lowest probability of loss ratio being less than 0.5 occurs when risk is pooled over ten years (19%). This decline from 73% for a single year pooling to only 19% for a ten-year pool is the cost of having no loss ratio greater than 3 for the ten year risk pooling. This trend persisted across the other strike levels. In addition, an increase in strike levels further tempered the risk in that the probability of extreme values decreases as movements are made to higher strike levels across the various years of pooling. This climaxed in zero probabilities for loss ratios less than 0.5 and greater than 3 for the 30th percentile strikes for ten years of risk pooling. Hence, one could conclude that temporal risk pooling, particularly at higher strike levels reduces systemic risk to the insurer. This analysis confirms the intuition that drought risks are most systemic at the tail in that extreme drought will affect several locations

simultaneously whereas moderate droughts are less systemic, and we also observed that insurers could make profits from bearing the risk in the long term.

Table 3.1: Loss ratio probability by strike level and years of pooling

Probability of loss ratio	Strike = 5%				Strike = 10%				Strike = 30%			
	Years of risk pooling				Years of risk pooling				Years of risk pooling			
	1	**2**	**5**	**10**	**1**	**2**	**5**	**10**	**1**	**2**	**5**	**10**
<0.5	0.73	0.58	0.39	0.19	0.65	0.51	0.36	0.10	0.50	0.26	0.03	0.00
0.5 to ≤1	0.05	0.10	0.31	0.68	0.08	0.18	0.22	0.71	0.13	0.28	0.56	0.65
1 to ≤ 2	0.10	0.20	0.28	0.10	0.10	0.15	0.39	0.19	0.20	0.36	0.41	0.35
2 to ≤ 3	0.02	0.02	0.00	0.03	0.10	0.13	0.03	0.00	0.10	0.10	0.00	0.00
> 3	0.10	0.10	0.02	0.00	0.07	0.03	0.00	0.00	0.07	0.00	0.00	0.00

8.4.2: The effect of spatial risk pooling on weather index insurance

From Table 3.2, it is obvious that the risk could be spatially pooled. Although there were some years when both Queensland and Western Australia shires had non-zero loss ratios, the values of the loss ratios show that they did not experience droughts to the same extent. Year 2010 is the most extreme case in that while Western Australia experienced drought with an accompanying loss ratio of 22.76, Queensland experienced no drought payout because of the flood experienced in the state during the same period. Pooling the risk across the two states delivered a loss ratio of 14.59. It should be noted that the loss ratios for shires in both states are not exactly halved because the number of shires in each states are not the same and they were not equally affected by drought every year.This explains why the pooling of risk across both states is not 11.38 (half of 22.76) but 14.59. The risk is further tempered at higher strikes as could be gleaned from the loss ratios. The standard deviations also revealed that the risk is higher for a single state than when risks are spatially pooled and higher strikes also delivered lower standard deviations. For instance, in Queensland, at the 5th percentile, the standard deviation is 3.35 but this steadily reduced to 2.51 and 1.47 across the 10th and 30th percentile contracts. When risks are pooled, the standard deviation reduced to 2.62 which is lower than 3.35 for Queensland and 3.72 for Western Australia. The trend in lower standard deviations as the strike level increases persists for each shire and all shires. It could also be noted that loss ratios in Western Australia shires were more volatile than those of Queensland because they have higher standard deviations across the strikes.

Table 3.2: Estimated Annual Loss Ratios at different strike levels

Year	Strike = 5%			Strike = 10%			Strike = 30%		
	QLD	WA	All	QLD	WA	All	QLD	WA	All
1971	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.16	0.09
1972	1.21	0.00	0.43	1.11	0.80	0.92	2.48	1.92	2.15
1973	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1974	0.00	0.00	0.00	1.38	0.00	0.55	0.64	0.00	0.26
1975	0.00	0.00	0.00	0.00	0.00	0.00	0.56	0.00	0.23
1976	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.24	0.14
1977	8.58	0.00	3.08	7.33	0.03	2.94	5.18	0.57	2.44
1978	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.20
1979	0.00	0.00	0.00	0.55	0.00	0.22	0.53	0.83	0.71
1980	0.00	6.13	3.93	0.21	5.75	3.54	2.50	3.66	3.19
1981	0.00	0.19	0.12	0.00	0.79	0.48	0.00	1.21	0.72
1982	3.44	1.07	1.92	4.97	0.84	2.49	2.80	1.19	1.85
1983	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.41	0.24
1984	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.02
1985	0.00	0.00	0.00	0.00	0.14	0.08	0.00	1.84	1.09
1986	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.20	0.24
1987	0.00	3.08	1.98	0.00	2.40	1.44	0.07	2.02	1.23
1988	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.15
1989	0.00	0.00	0.00	0.00	0.00	0.00	0.39	0.35	0.36
1990	0.00	0.00	0.00	0.00	0.19	0.11	0.41	0.99	0.75
1991	0.09	0.00	0.03	3.99	0.00	1.59	3.65	0.07	1.52
1992	0.00	0.00	0.00	0.25	0.00	0.10	2.24	0.00	0.91
1993	0.00	0.00	0.00	0.04	0.00	0.02	0.86	0.00	0.35
1994	19.30	0.42	7.20	12.98	1.21	5.91	5.82	2.58	3.89
1995	0.00	0.00	0.00	0.00	0.00	0.00	0.78	0.00	0.31
1996	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.36	0.21
1997	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.82	0.49
1998	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.15	0.09
1999	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.00	0.03
2000	0.00	1.70	1.09	0.00	2.80	1.68	0.91	3.66	2.54
2001	0.00	2.96	1.90	0.00	4.59	2.76	0.00	2.55	1.52
2002	2.37	0.00	0.85	3.63	1.19	2.17	2.67	1.75	2.12
2003	0.00	0.00	0.00	0.00	0.00	0.00	0.42	0.00	0.17
2004	1.67	0.00	0.60	1.50	0.00	0.60	1.09	0.95	1.01
2005	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01
2006	3.35	1.68	2.28	2.06	1.37	1.65	1.69	1.95	1.85
2007	0.00	0.00	0.00	0.00	0.03	0.02	0.88	0.50	0.66
2008	0.00	0.00	0.00	0.00	0.07	0.04	0.00	0.60	0.36
2009	0.00	0.00	0.00	0.00	0.00	0.00	3.04	0.15	1.33
2010	0.00	22.76	14.59	0.00	17.80	10.70	0.00	7.69	4.57
Mean	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**
SD	**3.35**	**3.72**	**2.62**	**2.51**	**3.00**	**2.03**	**1.47**	**1.48**	**1.12**

9. Discussion

Capturing the relative exposure of crops to risk at their different phenological stages is necessary to improve the relationship between yield and weather index as earlier noted in the work of Stoppa and Hess (2003). This could be achieved through optimization and expert weighting. We have used only the optimized model in this study. It was thought that hedging efficiency should result from the alteration of the distribution of the statistical efficiency across the quantiles on the yield–index relationship continuum as shown in the ordinary least square regression and quantile regression analyses. However, Vedenov and Barnett (2004) have shown that a strong statistical relationship between yield and index does not guarantee efficiency as we have also noted in this study. One could have insinuated that when the relationship is stronger at the lower tail there will be higher efficiency. This is true as in the cases of Balonne and Bendemere with higher relationships at the 5^{th}, 10^{th} and 30^{th} percentiles than their corresponding upper tail quantiles but the cases of Pingelly and Ravensthorpe contradicted this possible conclusion. More complex multi-trigger indices may have to be designed to capture the relationship required for significant improvements in hedging efficiency. The other variables may include soil moisture and temperature.

Furthermore, the pricing of weather index insurance contract does not capture the relative efficiency of the contracts. The most expensive contracts are not necessarily the most efficient and the cheapest contracts are not necessarily the least efficient. It seems that the actuarial burns analysis does not capture the relative efficiency of the contracts. This finding alludes to previous conclusions that data availability and methodological issues are among the bottlenecks hindering the proliferation of weather index insurance (Vedenov & Barnett 2004; Jewson & Brix 2005).

In addition, our panel data analysis for each of the two states and the two states, combined, indicated that there was a panel effect. The implication is that weather indices would have to be designed to capture geographical diversity in order to capture differences like soil types. This study concurs with the recommendation by scholars like Vedenov and Barnett (2004) on the localization of weather index contracts. Unfortunately, the localization of the contract will erode the cost savings anticipated from the use of weather index insurance. This is because the insurer will not be able to take advantage of economy of scale in the design of the product.

Another major finding of our study is that drought risk to the insurer is inversely proportional to strike levels, years of pooling and spatial pooling. These findings are in congruence with those of Chantarat (2009). Bardsley, Abey and Davenport (1984) implied that risk pooling could make weather index insurance more viable in Australia as we have equally noted. We further observed that the reduction in risk to the insurer's portfolio arising from increase in contract strike comes at the cost of

reduced benefits to the insured. The analyses obviously captured the year 2010 flood and drought in Queensland and Western Australia respectively in that there was a very heavy payout in Western Australia but none in Queensland (Agnew 2011; Hicks 2011).

Hedging efficiency depends on the risk measures used particularly at the higher strikes. Although, the MRSL (Mean Root Square Loss) reduced the semi-variance in revenue, it does not always lead to higher revenues in years when droughts are experienced. However, the risk measures are more congruent at the extreme tail. For instance, MRSL indicated efficiency for 12 shires, only one of them contradicted the results from the CTE (Conditional Tail Expectation) at the 5th percentile strike. At the 10th percentile strike, there were 13 shires benefiting from the contract based on MRSL but the CTE missed two of them. In the case of the 12 shires MRSL flagged as deriving value from the 30th percentile contracts, 6 of them were not captured by CTE. The incongruence in the efficiency measures increased with the strike levels. Generally, it seems that the MRSL does not respond to strike leves like the CTE. The number of locations flagging efficiency reduced with the strke level under the CTE efficiency test whereas there seems to be a relative consistency of hedging efficiency across locations with the MRSL. The findings of Vedenov and Barnett (2004) are similar to ours in that they used three efficiency measures and the efficiency results were found to be closely related but not perfectly the same.

Our study therefore suggests that insurers will be more comfortable bearing modest risk over the long term than the most extreme risks over the short term. To bear the extreme tail risk like the 5th percentile contracts, reinsurance cost may have to be factored into the pricing of the contract making it more expensive for farmers. It is however reasonable to expect that the Australian community may still be better off insuring the risk of drought than following the current pattern of risk management as noted in Quiggin and Chambers (2004) . It is also expected that experience, over time, will prove the worth of the insurance as insured farmers weather the storms of droughts unlike their uninsured counterparts. The effect of the insurance could also be tempered as farmers pass on part of the cost to consumers. This implies that the society at large bears the cost of the insurance and therefore the problem of equity or politicization of drought response would not arise. This arrangement should be more equitable in that the proportion of the insurance an individual pays indirectly by buying the product is the extent to which the individual has consumed the product whereas, spending public tax payers fund to bail out farmers translates into an assumption that everyone consumes the product to an equal extent. The equity debate and politicization of drought response remain major considerations in the current Australian Drought Policy (Kimura & Anton 2011).

10. Conclusions and recommendations

The pricing of weather index insurance contracts would have to be localized thereby reducing the cost reduction benefits anticipated from its usage. Also, the use of actuarial burns analysis for the pricing appears to be pareto-inefficient in that it does not reflect the relative exposure of the locations to risk and hedging efficiency. We also noted that statistical efficiency does not proportionately translate into hedging efficiency. The insurer could temper the risk of a portfolio of weather index insurance contract by spatially and temporally pooling the risks. Higher strike contracts are more diversifiable than the lower strike contracts that correspond to the very extreme tail events and could require reinsurance. The insurer interested in weather index insurance could only look forward to profit in the long run.

We recommend that researchers and practitioners investigate further into the methodological frameworks appropriate for the pricing of weather index insurance contracts and measurement of its efficiency. In addition, appropriate legal frameworks are required to enhance appropriate use of the products.

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Appendices

Appendix 1: Pricing of optimized insurance contracts in percentage

States and shires	Strike levels in percentiles			States and shires	Strike levels in percentiles		
5th QLD	5th	10th	30th	WA	5th	10th	30th
Balonne	4.67	5.55	15.90	Boddington	2.84	4.32	9.11
Booringa	4.07	5.20	14.71	Boyup Brook	3.19	3.44	6.84
Bendemere	4.45	5.07	15.00	Broomehill	4.83	5.22	14.35
Bungil	3.40	4.56	13.00	Bruce Rock	3.84	5.34	11.23
Taroom	3.79	6.76	17.69	Corrigin	3.84	5.49	15.43
Waggamba	2.71	6.16	16.57	Katanning	3.92	7.45	16.37
Clifton	3.23	6.97	14.63	Kondinin	3.82	5.32	8.98
Millmerran	4.73	5.15	11.11	Tammin	3.16	4.66	9.78
				Pingelly	2.51	5.26	11.11
				Ravensthorp e	2.68	4.56	13.18

Appendix 2: The results of the random model for the shires in all and each state.

Locations	Y	Coefficient	Standard error	Z	P>\z\	95%Confidence Interval limits		R-Square	Wald Chi	Prob Chi
						Lower	Upper			
All shires	p	2.12	0.07	29.30	0.00	1.98	2.26	0.0000	858.68	0.00
								0.0000		
								0.5446		
	Constant	1.03^{-09}	0.02	0.00	1.00	-0.05	0.05			
QLD shires	P	2.10	0.08	26.43	0.00	1.94	2.26	0.0000	698.56	0.00
								0.0000		
	constant	1.51^{-09}	0.03	0.00	1.00	-0.06	0.06	0.6872		
WA shires	p	2.10	0.08	26.43	0.00	1.94	2.26	0.0000	698.56	0.00
								0.0000		
	constant	1.51^{-09}	0.03	0.00	1.00	-0.06	0.06	0.6872		