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Weather Index-Based Rice Insurance

A pilot study of nine villages in Zhejiang Province, China

Master's Thesis

Management, Technology and Economics (MTEC)

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Acknowledgement

I am a Chinese student who has been living in Switzerland for four years. Only after I started to live and study in a new country, did I realize that how important my home country means to me and how little I knew about it. During all these years, I have carefully studied my home country, and tried to acquire a clear perspective of the current Chinese society. As you may read from a quotation of Confucius *"A superior person cares justice and morality, while a villain keeps his mind only on benefits"*, the ancient Chinese culture values justice and morality and abhors selfishness. However, after the reforming and opening-up policy was issued in 1992, the whole nation's attention was drawn to the fast cumulated wealth and the nouveau riche in this land. While thousands of years' of traditional virtues were gradually abandoned, money worship has grown to dominate the present Chinese society. The gap between the rich and the poor is becoming surprisingly large year by year. This situation could be depicted by a famous Chinese poem as "*The rich's wine and meat are left to rot, while the poor die frozen on roads"*.

The Chinese society has become so unevenly structured that I feel I am obliged to do something to help those disadvantaged and poor people. This is the reason why I choose China's agriculture insurance as my research topic. There are more than 0.7 billion farmers in China, earning an average annual income of about US$ 750 per capita in 2009, which is less than 1/3 of the urban dwellers' income. The farmers are the largest group of poor and disadvantaged people in China. It would be meaningful to me if my research result could be used to help these farmers, and to help the society to become more harmonious.

Given my lack of experience, I met with some problems in the process of my thesis. However, I am very thankful that I have my supervisors, teachers and many other friends to help me to overcome the difficulties and finally finish the thesis.

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Abstract

This Masters thesis presents the results of a pilot scale study on weather index-based rice insurance in Zhejiang province, China. The goal of this thesis is to find the best suited weather index-based rice insurance model for each rice cropping zone of Zhejiang. By testing a wide range of weather indexes for their relationship with the rice yield per unit land in each rice cropping zone using classic regression models, a set of weather indexes were selected for each rice cropping zone of Zhejiang. A rice insurance product was then designed based on the relationship between the chosen weather index and rice yield. Basis risks were studied in detail in this thesis, and were reduced in the insurance model by defining the insurable farming scale to rice cropping zone and by removing the time trend in rice yields. The results show diversified features in weather index and insurance product design of different rice cropping zones in Zhejiang.

Key words
Weather index, rice insurance model, rice cropping zone, Zhejiang

Table of Contents

List of Figures

List of Tables

Chapter 1

Introduction

1.1 The Goal of This Thesis

Agriculture insurance is recognized as a robust economic tool to minimize the economic impact of natural disasters and to protect farmers' interests. In China, relatively simple agriculture insurance models have been practiced in the past, however these traditional agriculture insurance models fail to offer the farmers adequate protection from natural disasters such as the severe drought in Yunnan in March 2010. More advanced and comprehensive agriculture insurance models tailored to each agricultural region are required. Weather index-based agriculture insurance models have been developed to overcome the effects of adverse selection and moral hazard in traditional insurance models; and such weather index-based insurance models are now being experimented with in China.

The aim of this Masters thesis is to identify a suitable weather index-based rice insurance model for Zhejiang province. Rice production data was collected from 9 villages in Zhejiang as a pilot scale program. Zhejiang is one of the most developed provinces in China, with a prosperous economy, highly educated population and good weather recording facilities. Additionally, Zhejiang is located in an area at high risk of typhoons as well as other extreme weather events such as rainstorms or autumn droughts. At present, the agriculture insurance penetration rate in Zhejiang is still at a low level, with a total indemnity of 52.54 million Yuan (about US$8.1 million) during 1996-2004 [1]. Thus, there is a great potential for a well developed weather index-based agriculture insurance to be introduced into the insurance market in Zhejiang which would protect the local farmers from severe income losses as a result of extreme weather.

The results of this pilot initiative presented in this thesis may be taken as a reference for further studies that would look to provide a more comprehensive and integral weather-based rice insurance products for Zhejiang in the future.

1.2 Thesis Structure

This master thesis composes of four main chapters – Introduction, Methodology, Data Analysis, and Conclusions.

Chapter 1 is an introduction to weather-indexed agriculture insurance specifically as it applies to Zhejiang. Firstly the goal and structure of this thesis is provided, followed by the importance of agriculture insurance at national and provincial level.

Chapter 2 provides an explanation of the methodology of weather index-based agriculture insurance modeling in Zhejiang tailored to rice cropping conditions in this region. Definitions of terms are introduced first, and different modeling methods are then depicted and discussed.

This chapter provides the theoretical basis for the data analysis in the following chapter.

Chapter 3 presents the analysis of rice yield data and builds weather index-based rice insurance model for Zhejiang. A detailed analysis is performed followed with discussions of the limitations of the model. A localized weather index-based rice insurance product is then designed based on the results of weather-based insurance modeling.

Chapter 4 contains the conclusions of the weather index-based rice insurance modeling and insurance contract design. The novelty and problems of this insurance design are pointed out, and some suggestions for future works on this issue are proposed in the end.

1.3 The Importance of Agriculture Insurance in China

China is one of the world's largest agricultural producers. Agriculture accounts for 11% of China's total GDP, and the sector engages 41% of the total labor force, according to a report from WFP and IFAD [2]. Although China is the fourth biggest country by total arable area in the world, its per capita arable land is only 29.6% of the world's average level in 1999 [3]. The arable land has continuously decreased in the last 40 years as a result of rapid economic development. According to the survey of the State Administration of National Land, an average of 466,700 ha arable land was taken for non-agricultural construction every year during the years from 1986 to 1995 [3]. (The State Administration of National Land is responsible for formulating, execution and implementation supervision of national land policies and regulations.) The population of China is also increasing with an annual rate of 0.6% over the latest 10 years [4] and coupled with decreasing arable land, agriculture is becoming one of the most critical issues facing China today.

Chinese farmers are already amongst the poorest in the society with an annual per capita net income of US$715 in 2008, while annual per capita net income of urban dwellers was US$2370 [5]. The gap between the rich and the poor is becoming surprisingly large in China and even growing. "The wealthiest 0.4 percent of households in China own more than 60 percent of the country's total personal wealth" (The Boston Consulting Group Report, 2006) [6].

The enlarging gap of wealth between the poor and the rich indicates that the majority of the farmers have not benefited from the economic development in China over the last decades. The Chinese government has recognized the importance of agriculture for its economy and for the social stability of the country. The Chinese central government published an official document known as a "No.1 Central Document" each year from 1982 to 1986, and from 2004 to 2010, and all were focused on agricultural issues in China [7]. (No.1 Central Document is the first document issued by the Chinese central government every year with fundamental guiding importance. The issues mentioned in this document are the most urgent problems for China of this year.) The regular publication of such documents reveals the focus of the Chinese government on its agricultural industry.

1.4 Agriculture Insurance in China

Farmers have been given a high priority on the government agenda since 2004, when Chinese government re-emphasized the importance of agriculture in the “No.1 Central Document”. A new Chinese agricultural subsidy system was established in 2004 to directly subsidize farmer in order to protect their interests [8]. One of the measures taken to subsidize farmers was by reducing agricultural tax. The Chinese government has gradually cancelled agricultural tax which has been imposed for more than two thousand years, and it was totally abolished in 2006 with the release of “Decision on the Abolition of Agriculture Ordinance” by the Standing Committee of the National People's Congress [8].

Another important measure taken by the government to protect farmers’ interests is agricultural insurance subsidy, which was driven by Chinese Insurance Regulatory Commission (CIRC) from 2004. In 2007, the State Council approved a 1 billion RMB Yuan fund for agriculture insurance subsidy in six provinces-Jilin, Sichuan, Hunan, Neimenggu, Xinjiang and Jiangsu. Central and provincial government paid around 50% of the premium, city and county government paid 10%-30%, and the rest were paid by the farmers. The premium rate varies from 3% to 10% according to regions, crops, and perils. Several natural disasters were covered: rainstorm, flood, windstorm, hail, and drought, and several diseases in crops and livestock, etc. Unfortunately, the insured amount was low and did not fully cover loss of earnings [9].

China’s total agricultural insurance premium has increased 28-fold, from 466.95 million Yuan (about US$72 million) in 2004 to 13297.5 million Yuan (about US$2046 million) in 2009 [10-14] (See Fig. 1.1). Year 2006 was the starting point of the rapid growth, probably due to the planned launch of State Council’s six province agricultural insurance subsidy policy in 2007. The number of insurance companies in this field also increased from 3 in 2004 to 21 in 2009, which is a 7-time growth (See Fig. 1.2) [10-14]. The inflation rate compared to year 2010 is also calculated in the data.

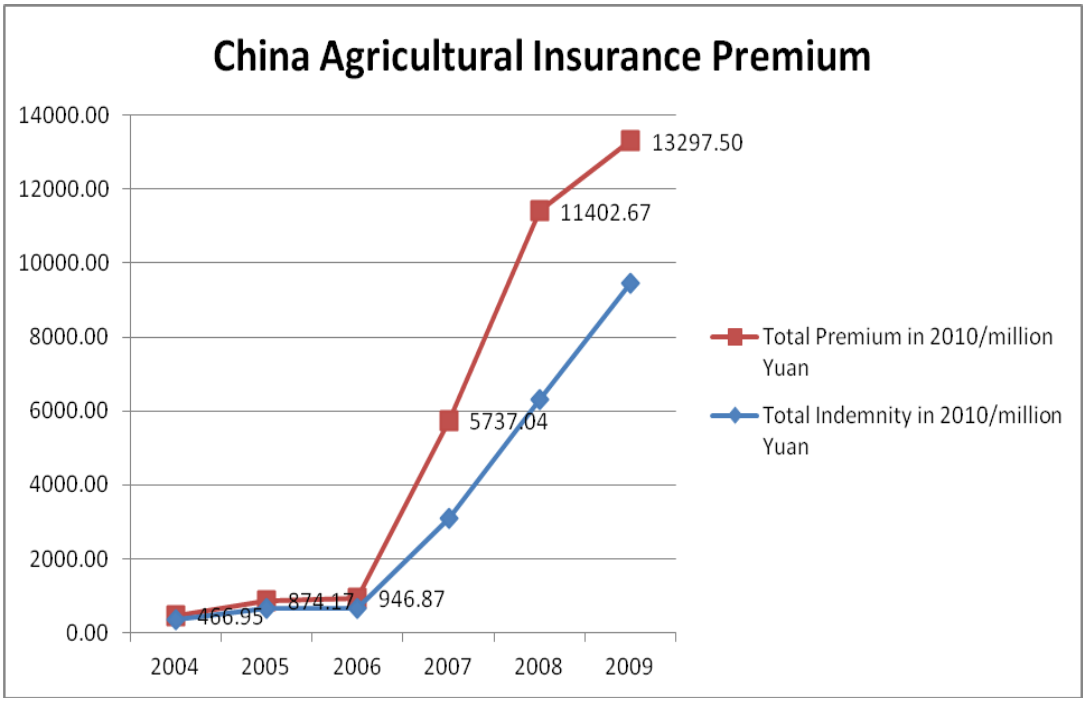

Figure 1.1 China Agricultural Insurance Premiums 2004-2009 [10-14]

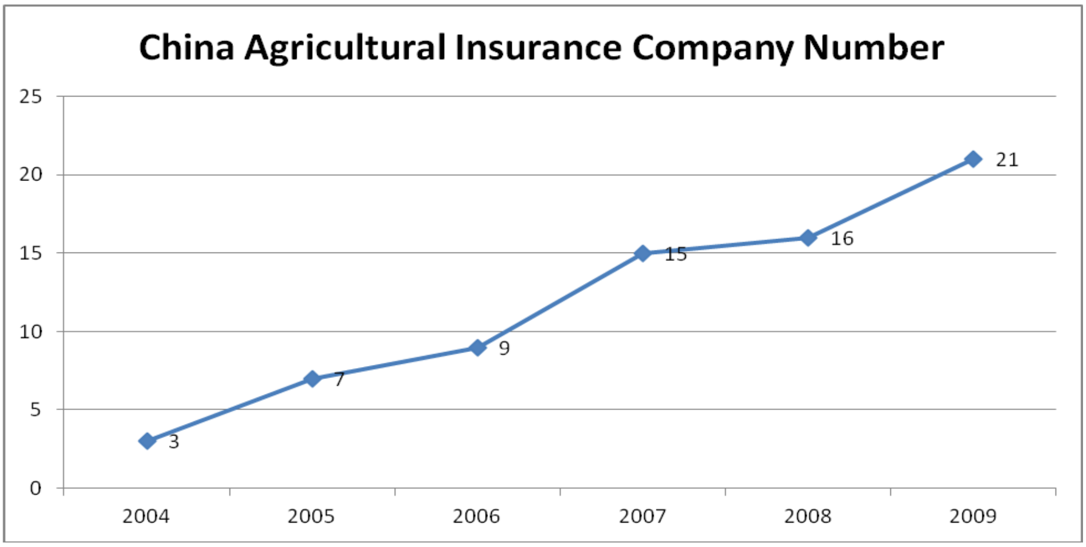

Figure 1.2 Total Numbers of Agricultural Insurance Companies in China 2004-2009 [10-14]

Although the agriculture insurance industry has been booming in China in recent years, the agriculture insurance policies in China still remain to be the traditional damage-based insurance, which exposes the farmer to the risk of serious problems such as adverse selection, moral hazard, low efficiency of indemnity after disasters, high transactional costs, and large damage assessment errors. This may have, to some extent, hampered the development of the agriculture insurance industry in China. [15] China performed initial agriculture insurance experiments in 1934, but since this time theoretical research into agriculture insurance has remained at a rather low level, with few successes translated into practice. [16] In a Swiss Re Focus report in 2008 it was stated that “It remains a challenge to create a robust agriculture insurance market for different climatic regions and various small-scale farming operations in

China. As in other emerging markets, a lack of historical loss data, limited access to farmers and little to no knowledge about insurance products among the wider population are also important issues.” [17] “Premium rates for the national agriculture insurance programs are negotiated between the insurers and provincial governments. The insurance premiums and policy terms and conditions are usually uniform within a province, and hence do not represent the variations of risk factors within a province.” [17]

“There are several traditional crop insurance products in China: [17]

1. Named Peril Insurance covers single perils (e.g. hail, fire, storm and frost, etc.). The sum insured is based on the value of agricultural inputs (e.g. seed, fertilizer, etc.).
2. Multi Peril Crop Insurance (MPCI) covers multiple perils (e.g. drought and flood and sometimes diseases) which can cause widespread losses. The sum insured is based on the value of crops insured and the payout is the yield shortfall below a pre-agreed threshold multiplied by a pre-agreed price. An extension of MPCI covers are revenue covers where farmers are also paid for a drop in commodity prices below the levels recorded at the time of planting.
3. Greenhouse insurance provides coverage for structures against natural perils, plants against frost and debris from damaged greenhouse structure, equipment against machinery breakdown or fire, and certain aspects of business interruption.”

1.5 Zhejiang Province

Zhejiang is one of the most developed provinces in China. It is located between latitude 27°12′ - 31°31′ and longitude118°00′ - 123°00′ on China`s south east coast. (See Figure 1.3) It is a relatively small province with a terrain of 185,900 km², of which 49.7% is mountain and hills, 21.4% is continental sea, 16.4% is plains & basins, 6.3% is territorial sea, 4.5% is lakes & rivers, and 1.7% is beaches [18]. (See Figure 1.4) The total area of arable land is 24,628 km², and 40% of the arable land is used to grow rice. Rice is the main grain product in Zhejiang, which takes about 90% of the total grain output [4].

Figure 1.3 Location of Zhejiang Province in China [19]

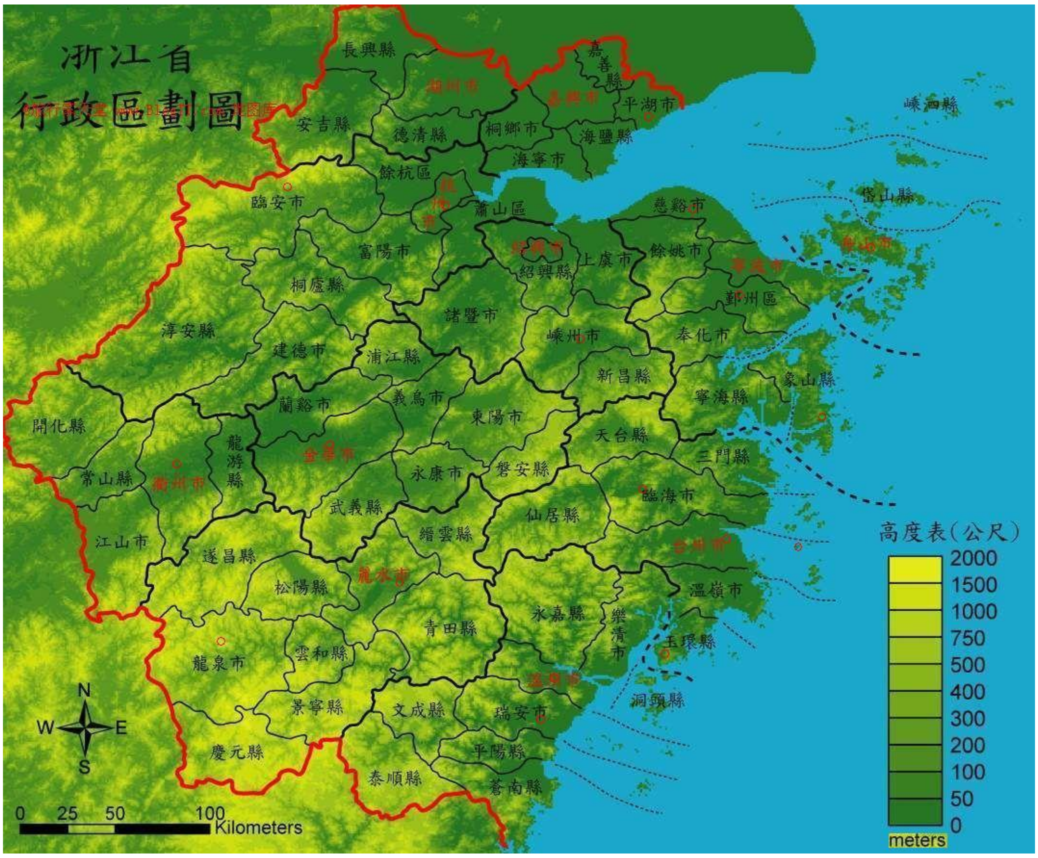

Figure 1.4 Landscapes of Zhejiang [20]

The climate in Zhejiang is subtropical monsoon climate with distinctive four seasons. It has an average annual sunshine of 1710-2100 hours and an average annual cumulative rainfall of 980-2000 mm [21]. The average annual temperature of Zhejiang is 15-18 ℃. There is an average of over 90 billion cubic meters’ annual flow of surface water in Zhejiang, which makes it an ideal location for agriculture. However, due to the subtropical monsoon climate, it is impacted by typhoons almost every year during summer [18]. In the last decade, there were an average of 1.9 typhoons landed on Zhejiang each year [22]. Zhejiang has constructed a good weather forecast system with 77 weather stations all over the province [23]. The historical weather data can be purchased from the stations under certain contracting conditions.

There are 11 large city areas in Zhejiang, within which there are 36 counties, 22 county level cities, and 30 city areas. Zhejiang has a population of more than 46 million, with a high population density of. Thanks to its convenient location next to Shanghai and its fast development, Zhejiang’s economics ranks number 4 in China in recent years, with an average growth rate of 12.7% in the last 30 years. The urbanization of Zhejiang has reached 57.2% in 2007. [24] With a large population, agriculture and food insurance is a big market in Zhejiang.

Zhejiang was the first province to implement the market-oriented reformation of purchasing and sales of grains. And with the development of agricultural economics, the structure of agriculture is also adjusted to time. The weight of aquaculture in agro-economics is slightly increasing. [18]

Zhejiang has a long history of culture, tracing back to 7000 years ago. [18] It was one of the origins of Chinese civilization, and it is still one of the best developed areas for culture, education, and living facilities in China. Zhejiang University is one of China’s oldest and most prestigious institutions of higher education, located in Hangzhou, the capital of Zhejiang province. There are 11 main categories of subjects: agriculture, philosophy, economics, law, education, Chinese literature, history, science, engineering, medical science, management. Zhejiang University has 8,241 teachers with 1336 professors and 43,368 full-time students, within which, 13,413 are Master’s students, 7,398 are PhD students, and 22,557 are Bachelor’s students. [25] As a large, well educated province Zhejiang is one of the most likely places in China for an advanced agricultural insurance industry to develop.

Zhejiang frequently suffers from natural disasters, and typhoon is one of the major disasters. This region was hit by typhoon every year in the last ten years, and the average direct economic loss to Zhejiang caused by typhoons was around 6.5 billion Yuan (about US$1 billion) for the last 10 years. [26-34] In 2005, agricultural loss alone caused by typhoons exceeded 10 billion Yuan (about US$1.6 billion). [35] In 2010, the economic loss caused by typhoon and other weather related disasters in Zhejiang reached over 40 million Yuan (about US$6.15 billion). [36] Besides typhoons, other extreme weather events such as rainstorms, high temperatures, autumn droughts, and floods have also impacted on agriculture to different extents in Zhejiang. [37]

Chapter 2

Methodology

2.1 Definitions

"The term **weather index-based insurance** refers to a special form of insurance that can be used to compensate for losses related to extremes in weather which often plague agricultural enterprises and increase the level of risk involved in agricultural endeavors. Weather index-based insurance can be used where there is an objective measurable event (e.g. extremes in rainfall, wind speed, heat, etc.) that demonstrates strong correlation with the variable of interest (e.g. crop yields). This measurable event serves as a proxy for losses and as the triggering mechanism for indemnity payments. The payment rate for a weather index –based insurance contract will be the same for each policyholder that has the same contract, regardless of the actual losses he or she sustains." (USAID，2008) [38]

One obstacle that suppressed the growth of weather index-based insurance is basis risk.
"**Basis risk** is the difference between the actual crop output at a farm unit level and the output that would be projected by a weather derivative (e.g. precipitation, temperature, etc) at the reference weather station that is used to create and settle the payout on the hedge. Although crop output is ultimately the result of the interaction of a myriad of variables (weather being the most influential), there are several factors – such as disease and fire – which are not directly related to weather production." (Ramachandran, 2009) [39] There are normally two types of basis risk: one is geographical basis risk which represents the risk that results from the difference between weather patterns on reference weather stations and the locations of famers; the other is production basis risk which is the risk from the imperfect correlation between the yield loss on farms and weather index [40].

There are two main problems of traditional agriculture insurance: moral hazard and adverse selection.
"**Moral hazard**" refers to a phenomenon that the insured person's optimal decision may change as a result of taking out insurance, because the insurance contract reduces the loss associated with the insured event. Such changes in behavior will normally increase the probability of the insured event occurring or increase the severity of the loss [41]. (Ahsan, 1982)
"**Adverse selection**" means that people who are more likely to suffer the insured event will be more willing to insure at a given rate. If the insurance company cannot detect such people, losses will occur. This is usually due to the information asymmetry between the insurer and insured, or because of regulations or social norms which prevent the insurer from using certain categories of known information to set prices (e.g. the insurer may be prohibited from using information such as gender or ethnic origin or genetic test results) [42]. (Polborn, 2006)

In the financial markets, "**weather derivatives** are contingent claims written on weather indices, through which risk exposure to weather may be transferred or reduced. Commonly referenced weather indices include, but are not restricted to, daily average temperature, cumulative annual temperature, heating degree days, cooling degree days, precipitation, snowfall and wind. ” (Goovaerts, 1998) [43]

There are many other insurance terms used in this thesis, whose definitions will be abbreviated in the following list (World Bank Report, 2007) [44]:

Actuarial
“Branch of statistics, dealing with the probabilities of an event occurring. Actuarial calculations, if they are to be at all accurate, require basic data over a sufficient time period to permit likelihood of future events to be predicted with a degree of certainty. ”

Indemnity
“The amount payable by the insurer to the insured, either in the form of cash, repair, replacement, or reinstatement in the event of an insured loss. This amount is measured by the extent of the insured’s pecuniary loss. It is set at a figure equal to but not more than the actual value of the subject matter insured just before the loss, subject to the adequacy of the sum insured. This means for many crops that an escalating indemnity level is established, as the growing season progresses. ”

Insurance
“A financial mechanism which aims at reducing the uncertainty of loss by pooling a large number of uncertainties so that the burden of loss is distributed. Generally each policyholder pays a contribution to a fund in the form of a premium, commensurate with the risk he introduces. The insurer uses these funds to pay the losses (indemnities) suffered by any of the insured. ”

Insurance Policy
“A formal document including all clauses, riders, endorsements which expresses the terms, exceptions, and conditions of the contract of insurance between the insurer and the insured. It is not the contract itself but evidence of the contract. ”

Premium
“The monetary sum payable by the insured to the insurers for the period (or term) of insurance granted by the policy. ”

Reinsurance
“When the total exposure of a risk or group of risks presents the potential for losses beyond the limit which is prudent for an insurance company to carry, the insurance company may purchase reinsurance i.e. insurance of the insurance. Reinsurance has many advantages including (i) leveling the results of the insurance company over a period of time; (ii) limiting the exposure of individual risks and restricting losses paid out by the insurance company; (iii) may increase an insurance company’s solvency margin (percent of capital and reserves to net premium income), hence the company’s financial strength; (iv) the reinsurer participates in

the profits of the insurance company, but also contributes to the losses, the net result being a more stable loss ratio over the period of insurance. ”

Risk Transfer

“Risk transfer is the process of shifting the burden of financial loss or responsibility for risk-financing to another party through insurance, reinsurance, legislation, or other means. ”

Risk Pooling

“The aggregation of individual risks for the purpose of managing the consequences of independent risks. Risk pooling is based on the law of large numbers. In insurance terms, the law of large numbers demonstrates that pooling large numbers of roughly homogenous, independent exposure units can yield a mean average consistent with actual outcomes. Thus, pooling risks allow an accurate prediction of future losses and helps determine premium rates.”

Subsidy

“A direct or indirect benefit granted by a government for the production or distribution (including export) of a good or to supplement other services. Generally, subsidies are thought to be production and trade distorting and cause rent-seeking behavior, resulting in an inefficient use of resources. ”

2.2 Weather Index-Based Agriculture Insurance

2.2.1 Introduction

Weather is one of the most uncontrollable and important sources of risk for agriculture. The weather fluctuation has been increasing in the last decades due to global climate change, and it is expected to continue increasing in the future [45]. This makes agriculture businesses more vulnerable to weather risks. Insurance is one tool to protect farmers against weather related yield losses.

Weather index-based insurance is a relatively new insurance subject started in 1990s. In contrast to the traditional damage-based or input-based agriculture insurance, the insurance measurements - weather derivatives (temperature, precipitation, wind, etc.), are objective and easy to access. The weather index-based agriculture insurance offers administrative advantages over traditional insurance on moral hazard, adverse selection and transactional costs [46]. The individual evaluation of damages on farms is no longer necessary, and the objectively measurable weather indexes will not be influenced by farmers or change farmers’ cropping behavior. In addition, the weather index-based insurance hedges against correlated risks, and the insurance policies are more transparent and easy for purchasers to understand. It also allows primary insurance companies to transfer the risk of weather correlated agricultural production loss to reinsurers.

There have already been a few promising practical experiences of weather-based agriculture insurances in the USA and Canada, though the market is current still relatively small [47]. In the USA, a rainfall index-based insurance is used to hedge the agricultural risk from drought and flood. In Canada, a weather index-based insurance was developed to hedge the yield risk of corns and forage grass from high temperature. India also started precipitation-based agriculture insurance from 2003, and in 2007, a temperature-based insurance was also practiced in India to hedge wheat yield risk by using satellite remote sensing images [48]. In China, an experimental practice of weather-based agriculture insurance has been implemented in Anhui province since 2009 [2, 49]. Cumulative rainfall index and high temperature index were chosen as the weather triggers for drought and heatwave in this pilot weather-based agriculture insurance in Changfeng county of Anhui province.

However, despite the merits of weather index-based insurance mentioned above, the insurance tool is actually accepted slowly by farmers, due in part to perceived obstacles such as basis risk. Non-weather factors such as pest plagues, diseases, technology improvement, etc., also have large impacts on the crop yield volatility. And even though agricultural businesses have a direct exposure to weather, their risks are not concentrated on one specific weather peril or location, which makes it difficult to standardize weather index-based insurance contracts [39]. This complicates the selection of weather indexes and the scale of the insured, which are common problems in the weather index-based agriculture insurance modeling.

There also has been some research on weather index-based agriculture insurance in China. For example, a set of weather-based indemnity indices was designed for heavy rain damage rice insurance in Zhejiang, China. The model was built upon the relationship between rice yield loss rate and meteorology factors and land surface factors in a county of Zhejiang [50]. However, this paper only studied one heavy rainfall typhoon event for a small county in Zhejiang, which lacks historical evidence to prove the model and of universality for insurance in the whole province. Another model of weather-based rice insurance was established on the reduction of rice yield and meteorological data for the whole Zhejiang province. Rainfall, temperature, sun shine hours, wind and atmosphere circulation factors were chosen as weather variables [51]. This data covers 68 counties in Zhejiang with 16 years' rice yield data from 1992 to 2007, but the paper does not show the detailed methodology of modeling, and there are no results of the rice yield reduction and meteorological index modeling in the paper either. Instead, the paper focuses more on the premium and premium rate calculation of the insurance product. Since the insurance premium calculation is based on the modeling of rice yield and meteorological factors, the latter part needs to be more carefully studied and indicated.

2.2.2 Research Object

Rice is chosen as the research object for the weather index-based crop insurance model in this thesis. Although corn and wheat are more commonly studied in previous weather-based crop insurance papers in industrialized countries due to their high yield volatility, rice is by far the most popular staple food in the south part of China. The production of rice takes 85%-90% of the total grain crop yield in Zhejiang province, which equals to about 45 times the corn production and 50 times the wheat production [52-57]. In addition to its importance in agricultural sector of Zhejiang, the unique location and meteorological conditions of Zhejiang also make rice ideal to the weather index-based insurance as mentioned in Chapter 1.

There are two methods of planting rice in China, transplanting or direct seeding. Transplanting is the only method of cropping rice in Zhejiang province. There are 7 important stages in the whole transplanting rice growing period: sowing stage, transplanting stage, spikelet branch primordial stage, metaphase of pollen mother cells, flowering & heading stage, milky & filling stage, harvesting stage. Rice seeds are first raised in rich land - either submerged in water or not - for germination, and then transplanted to a field submerged under a shallow layer of water during most part of its vegetation period until the harvest phase [58].

Rice has a complicated cropping system. There may be between one to three harvests of rice in different regions of China depending upon the local weather conditions. It is because that rice is a thermophilic crop, so it possible to growth more seasons of rice in the south part of China. In Zhejiang province, single seasonal cropping and double seasonal cropping are practiced all over the province. The proportion of single cropping rice and double cropping rice is changing over time. The single cropping rice area increased from less than 20% in 1993 to about 70% in 2004, while the double cropping rice area significantly decreased during these years (see Figure 2.1) [59]. The single seasonal cropping usually starts in May, and ends in late September or early October. While double seasonal cropping means there are two cropping seasons in a year. The first cropping season usually starts in March, and ends in late June or early July, and the second season starts right after the first season. Rice planted in each of the two steps in the double cropping method have different growing periods (see Table 2.1) [59-66].

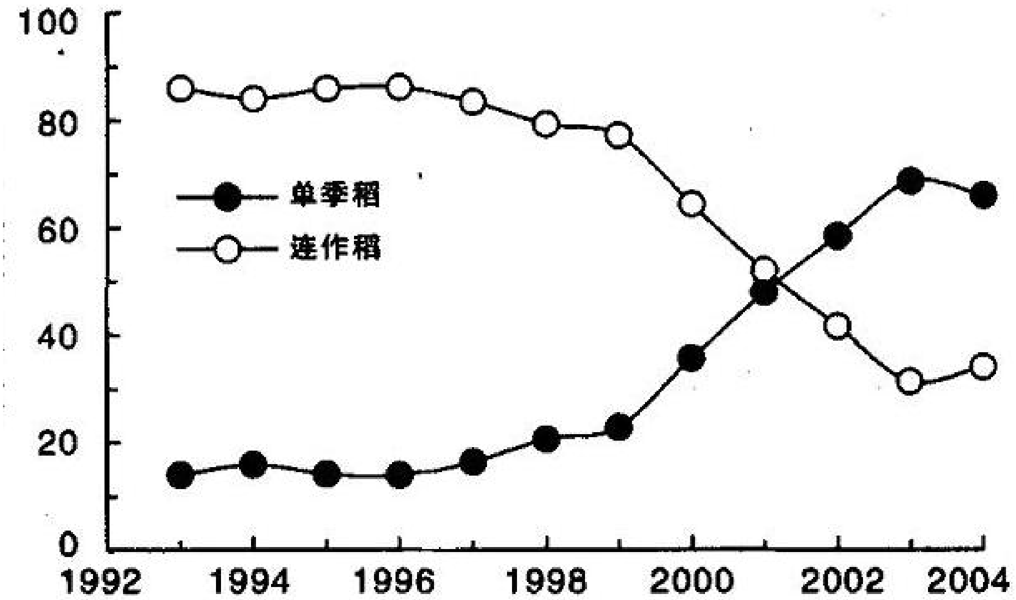

Figure 2.1 Area Proportion of Single and Double Cropping Rice in Zhejiang 1993-2004 [59]
Solid circle represents single cropping rice area proportion, while hollow circle represents double cropping rice area proportion.

Growing Stage	Double Cropping Early Rice	Single Cropping Middle Rice	Double Cropping Late Rice
Sowing	March 20-25	May 5-20	June 25-July 5
Transplanting	April 14-25	June 1-20	July 25- August 5
Spikelet Branch Primordial Stage	April 25-May 15	June 10-July 5	August 1-30
Metaphase of Pollen Mother Cells	May 15-June5	July 5-August 5	September 1-30
Flowering & Heading	June 1-20	July 25-August 25	September 15-October 10
Milky & Filling Stage	June 15-July 10	August 20-September 20	October 1-November 5
Harvesting	July 1-25	September 15-October 5	November 5-20

Table 2.1 Growing Stage Periods for Double and Single Cropping Rice

2.2.3 Methodology of Modeling

2.2.3.1 Reducing the Basis Risks

In weather index based insurance the indemnity is only triggered when the weather index reaches threshold levels, the relationship between the volatility of rice yield and weather index is the main concern of weather index-based rice insurance modeling. How to determine the volatility of rice yield caused by the weather is a critical question in the model design. In order to construct a good weather index-based rice insurance model, it is essential to minimize the impact of basis risks, in other words, to exclude the impacts of other non-weather factors on the rice yield. This is the first step of the model design in this thesis.

As mentioned in the definition above, there are two types of basis risks - the geographical basis risk and production basis risk. Geographical basis risk is related to several questions, such as how to determine the scale of the farming area to be insured, where the weather stations are located within the farming area, and whether the weather conditions are more or less homogeneous within the area that the same insurance contract would be applied. The production basis risk covers more factors. There are many non-weather parameters that could also largely affect the rice yield - rice species, mechanization, planting technology improvement, pest plagues, rice diseases, the change of rice cropping area, farmland ownership switch, the change of farming labor, the changes in soil management and fertilization, the change of public and private agricultural infrastructure, air and water pollutions, etc. In the case of rice in Zhejiang, this kind of information is extremely difficult to obtain, because there is no institute or administration that collects systematic historical information for non-weather factors impacting rice yield. The only way to get the information is from news and research papers, while the information is usually limited to one small local area for a short period. Despite this difficulty, some information has been collected to help reduce the basis risk here.

Geographic basis risk

Normally, in a weather index-based crop insurance design, the size of the area of estimation, number of weather stations within the area, and geometry of how the weather stations are dispersed need to reach some standards to reduce the geographic basis risk. Ideally, the insurable area would encompass an area no more than 10 kilometers from a weather station and the weather stations need to be uniformly distributed [67]. However, due to the lack of weather stations, irregular locations and limited data availability in many developing countries, such high requirement is rarely fulfilled. In such circumstances a maximum of 20 or 50 kilometers' distance between the insurable area and nearest weather stations are sometimes also accepted in the weather index-based crop insurance design.

Although Zhejiang has 77 weather stations, the available historical weather data matching rice yield data and those that meet the standard of cropping insurance are very limited. A total of 18 weather stations are selected here, which most closely meet the standard of 50 kilometers' distance between the insurable area and the nearest weather station and which are evenly dispersed within the rice cropping area. The locations of the 9 villages where we have the rice yield data and the weather stations in Zhejiang are found and positioned in the map of Zhejiang (see Figure 2.2). The weather stations marked in the map are the ones that offer continuous weather variable data during 1973-2010, which match the years of rice yield data of the 9 target villages.

Figure 2.2 Map of Target Villages and Weather Stations in Zhejiang [68]

The blue circles represent the locations of target villages where we have the rice yield data and red circles represent the locations of weather stations whose weather data are used in this thesis. The areas within white lines represent counties and county level cities in Zhejiang.

The areas within colored lines are the six rice cropping zones of Zhejiang [59]:

I. Zone of Japonica rice in single cropping system in Hangjiahu plain (the area within brown line in the very north).

II. Zone of Indica and Japonica rice in single and double cropping system in Ningshao plain (the area within yellow line in the northeast).

III. Zone of Indica rice in single and double cropping system in Wentai coast plain (the area within red line in the southeast).

IV. Zone of Indica rice in single and double cropping system in Jingqu basin (the area within purple line in the west).

V. Zone of Indica rice in single cropping system in hill area in the southwest of Zhejiang (the area within blue line in the southwest).

VI. Zone of Indica and Japonica rice in single cropping system in hill area of the northwest of Zhejiang (the area within pink line in the northwest).

Here is a projection of the rice cropping zones on topographic map of Zhejiang:

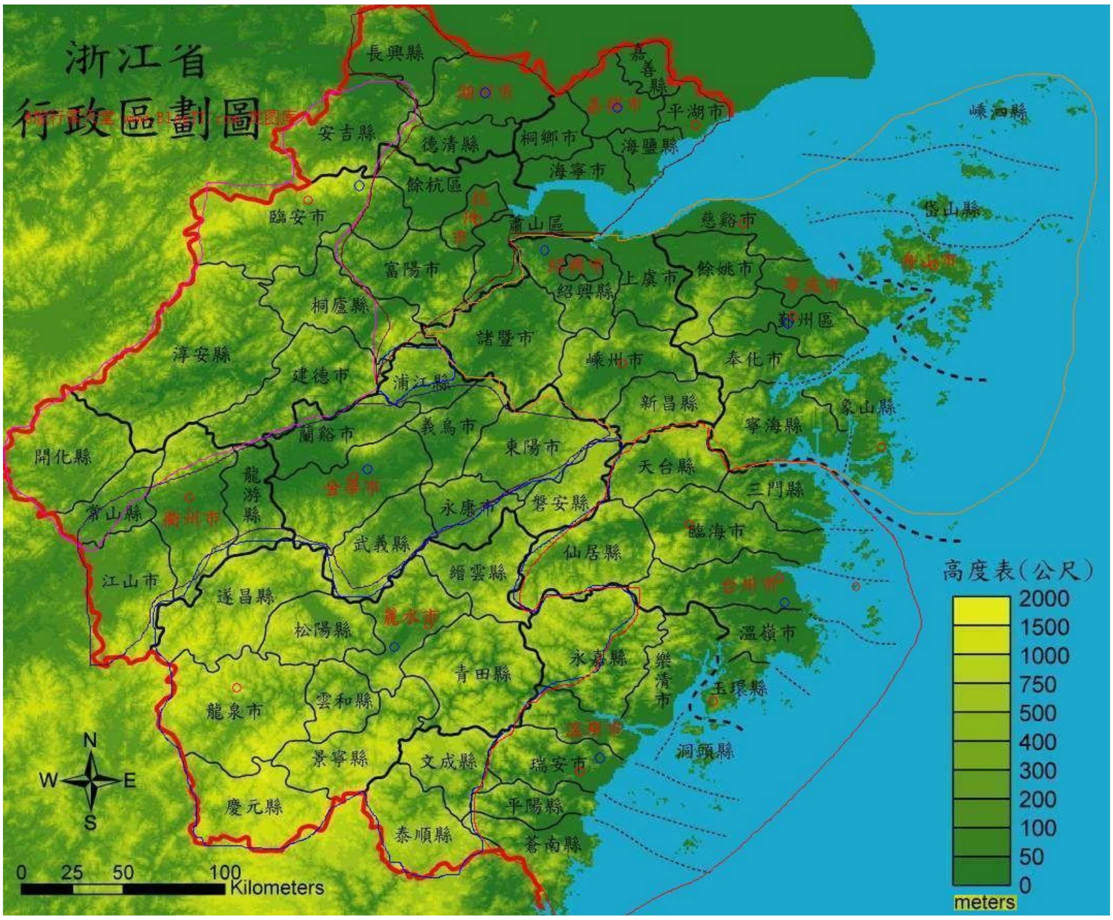

Figure 2.3 Topographic Map of Target Villages and Weather Stations in Zhejiang

The system was designed by the China National Rice Research Institute in Zhejiang according to the landscape, rice cropping system and the rice species in various regions of

Zhejiang. By using this rice cropping zone system, the geographical variance between different locations and landscapes can be largely reduced within each rice cropping zone, and at the same time, each zone is a relatively large area for risk pooling. Thus, the rice cropping zone is chosen as the farming land unit of each weather index-based rice insurance model in this thesis. The mean values of the weather stations' index data in each zone are taken as the weather index values for this zone, since weather stations are generally evenly dispersed in the cropping area of each zone.

$$I_i = \frac{1}{S_i} \sum_{s=1}^{s_i} I_{(i,\, s)} \tag{1}$$

Here, I_i represents the value of weather index in Zone i, $I_{(i,s)}$ represents the weather index value recorded by weather station s in Zone i, S_i represents the number of weather stations in Zone i.

A weighted per unit area rice yield according to the rice cropping area is chosen as per unit area rice yield for each zone.

$$Y_{(i,\, f)} = \sum_{v=1}^{v_i} Y_{(i,\, f,\, v)} \times L_v \Big/ \sum_{v=1}^{v_i} L_v \tag{2}$$

$Y_{(i,f)}$ represents the weighted per unit area rice yield of year f in Zone i, $Y_{(i,f,v)}$ represents per unit area rice yield of village v of year f in Zone i, vi represents the number of villages in Zone i, L_v represents the area of cropping land in village v.

Production basis risk

Although geographical basis risk is one of the most significant problems in the weather-based crop insurance modeling, other production basis risks are also very critical and should be considered. Time trend is commonly chosen as the parameter for production change due to technique improvement in previous research studies [69-70]. Nevertheless, in the case of rice production in Zhejiang, other non-weather parameters such as the choice of rice breed, the change of rice cropping area, pest plagues and rice diseases, the change of farming labor, the investment in production tools for agriculture production may also large impact on per unit land rice yield based on previous research and the available information on the topic.

Rice breeds

The research of rice breeding has been going on since the People's Republic of China was established. Thanks to the successful culture of hybrid rice in 1974, the rice yield raised 15%-20% at the beginning and another yield growth of 5%-10% followed with the improvement of the hybrid technology [71]. Since then, the hybrid rice breeding has become a hot topic for agriculture researchers and it was promoted to large areas of farm land. The Ministry of Agriculture of P.R.C. releases hundreds of validated new rice species every year in the last decades according to the information on the official website of the Ministry of Agriculture of P.R.C., and the Zhejiang provincial agricultural ministry also validated many new rice breeds every year (see Table 2.2) [72]. While new rice breeds keep coming out, the penetration of hybrid rice cropping on farms of Zhejiang has changed in the last ten years (see Figure 2.4).

Year	Number of newly validated rice breeds in China within the year	Number of newly validated rice breeds in Zhejiang within the year
1995		10
1996		5
1997		10
1998		13
1999		15
2000		14
2001	338	19
2002	343	12
2003	360	16
2004	341	25
2005	550	
2006	615	
2007	508	
2008	552	
2009	403	
2010	134	

Table 2.2 Number of Annual Newly Validated Rice Breeds in China and in Zhejiang [71-72]

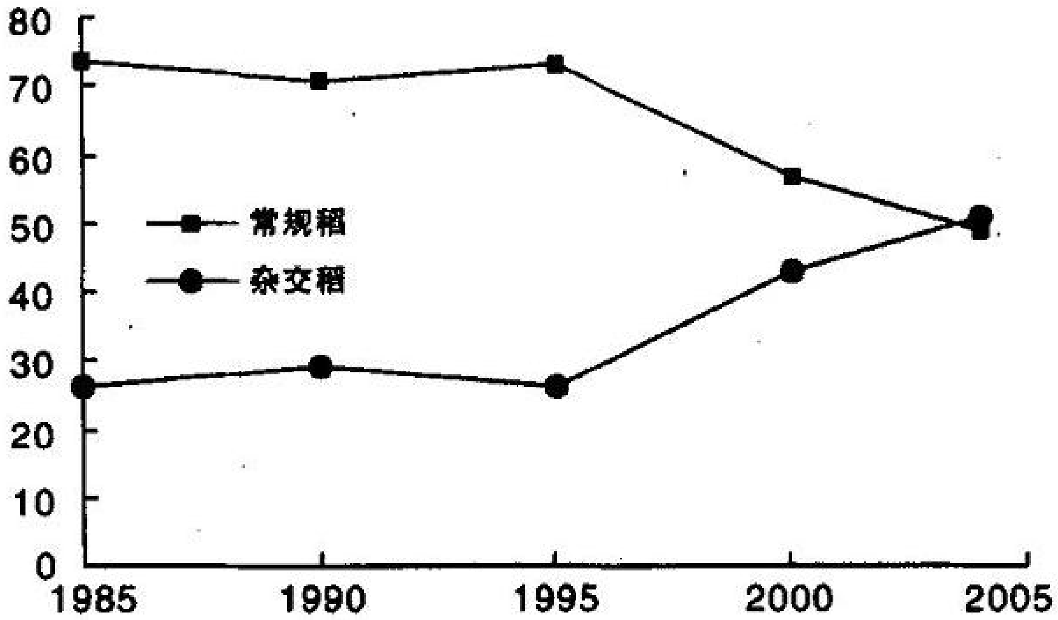

Figure 2.4 Area Percentages of Inbred Rice and hybrid Rice in Zhejiang [59]
Square dots represent inbred rice planting area proportions; solid circles represent hybrid rice planting area proportions.

Due to the large number of rice breeds in China and limited sources of relative information, it is difficult to quantify the rice breed's influence on the rice yield in Zhejiang province.

However, the sudden change of hybrid rice planting area proportion since 1995 may lead to a large change in the per unit area rice yield from that year. This change may be reflected in the per unit area rice yield's data.

Rice cropping area

Rice cropping area in Zhejiang was decreasing from 1995 to 2003 as the land was taken for other uses, and the rate of decrease was greatest during 1998-2002 (see Figure 2.5). The effect of this change on per unit area rice yield may be difficult to estimate. Farmers may pay more attention and give better attention to their reduced rice cropping land, which may cause higher rice per unit area yield. While some farmers may reduce the rice cropping land in order to run other more profitable businesses or to grow other cash crops, which may lead to reduction of rice per unit area yield. Due to the lack of detailed information for each rice cropping zone in Zhejiang, the effect of this non-weather factor on rice per unit area yield can not be quantified in this thesis.

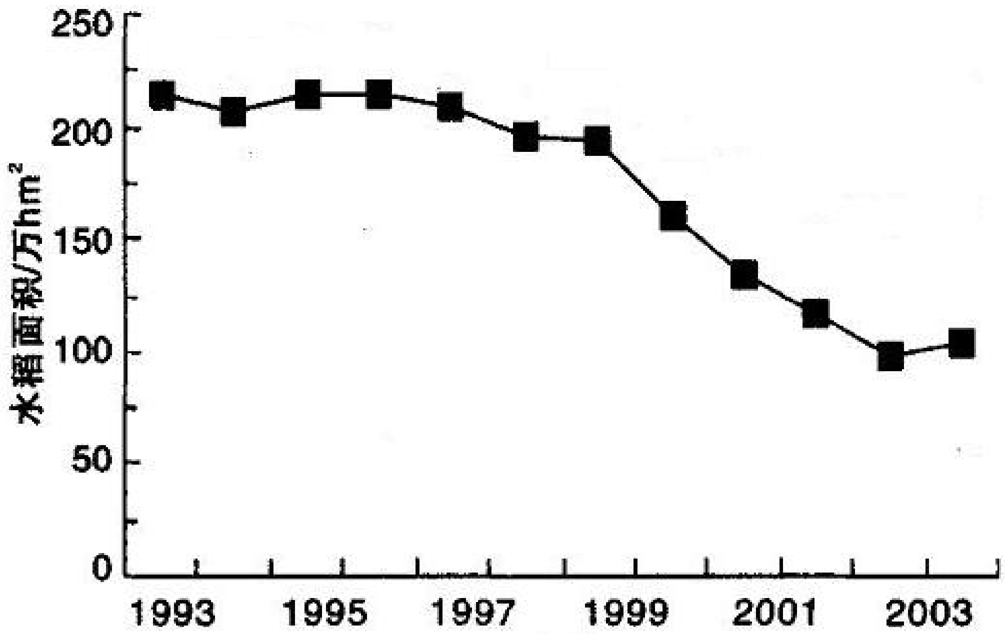

Figure 2.5 Rice Cropping Area in Zhejiang 1993-2003 (10^4 ha) [59]

Rice pests and disease plagues

There are two major pests of rice in Zhejiang, brown rice plant-hopper (*Laodelphax striatellus* Fallen) and stem borer (*Chilo suppressalis* Walker). Brown rice plant-hopper is the main transmitting medium for Rice black – Streaked Dwarf Virus, which was the major cause of rice disease prevalent in different regions of Zhejiang especially within rice cropping zone III, zone IV and zone V during 1995-2002 [73-75]. Stem borer is another major pest of rice in the whole area of Zhejiang. It started to occur again since 1993, and its number increased rapidly between 1997 and 2000 in some regions within rice cropping zone III and zone IV, which caused large damage to rice yield [76-78]. With the prevalence of rice pests and disease, pesticides are also tested and applied to protect rice. According to the previous research papers, the prevalence of pest may be considered as a major non-weather factor of rice yield reduction in the affected rice cropping zones. However, it is difficult to determine the actual effect of the pests and diseases, since the pesticides are also applied and improved with time and the affected areas are usually limited to a village or county level instead of a rice cropping zone level. Nevertheless, this factor will be considered if our data reflect significant reduction on rice per unit area yield during the particular outburst period in the affected rice cropping zones.

Farming labor

The data of farming laborers per unit land and the educational level of the village dwellers was also collected besides the rice yield data of nine villages in Zhejiang. The increasing number of farming laborers per unit land may lead to higher rice yield per unit land. If there is a strong correlation between these two variables, the basis risk caused by labor change should be excluded in the weather index-based insurance model. The educational level of the village dwellers may also have large influence on the rice yield. We will also check the correlation in the next section

Production tools

The common use of machinery in agriculture production may have a large impact on the per unit land rice yield. The fixed assets for large and medium man/horse powered agriculture production tools were recorded for each target village. The correlation between the investment of production tools and rice yield will be tested in the next chapter.

Basis risks cannot be completely excluded in any weather index-based crop insurance design, but fitting models with limited data to reduce basis risk is necessary especially in the pilot study of weather index-based rice insurance of Zhejiang. In this case, the geographical basis risk can be reduced by using rice cropping zone was the scale of insurable area, and the production basis risk can be reduced if all the non-weather parameters which could cause substantial rice yield change may be carefully studied. As a common tool, the time trend will be firstly checked in the next section. Other substantial parameter changes such as the increase of hybrid rice cropping area since 1995, the outburst of rice pests and diseases during 1995-2002, should be checked in the rice yield data. If there is a significant rice yield change in 1995 and 2002, the model should be structurally built for the periods before 1995, between 1995 and 2002 and after 2002. The change in the number of farming laborers per unit land, education level of the villages, and the investment of large and medium man/horse powered agriculture production tools will be checked in the next chapter. In addition, the correlation between these parameters and time trend will also be checked to decide whether the basis risk can be simplified by using time trend or any of these parameters alone.

2.2.3.2 Detrending Rice Yield Per Unit Land

When the main non-weather factors that have large impacts on per unit land rice yield are found, the next steps will be removing these impacts or detrending the rice yield to prepare for analyzing the rice yield variance correlation with weather index.

We first assume the time trend is chosen as the main factor to detrend the rice yield over time, since technique improvement may be the major impact on rice yield. “Generally, the least squares regression has been used for deterministic trends that have moved yields up over time. The trends may be liner or nonlinear." (Goodwin and Mahul, 2004) [70] The following function will be used for detrending a temporal series of crop yields:

$$y_t = \hat{y}_t + \varepsilon_t = X_t\beta + \varepsilon_t \tag{3}$$

Where y_t represents actual yield of year t, $\hat{y}_t$ represents the trend-predicted yield of year t, X_t represents some function of time, ε_t represents actual yield deviations from the trend.

If one wants to normalize yields to a 2003 level and one believes the magnitude of the error is not affected by the level of yield, the residuals of year t can be added to the 2003 yield prediction [70]:

$$\hat{y}_{t,2003} = \hat{y}_{2003} + \varepsilon_t \tag{4}$$

Here, $y_{t,2003}$ represents the normalized trend-predicted yield of year t based on 2003 yield level.

This function is based on the assumption that the variance of the crop yields remains constant over time.

Please pay special attention here that this ordinary least square regression (OLS) method is under the assumption that the expectation of regression error is zero. The estimator is consistent if the regression error term is uncorrelated with explanatory variables.

$$E\{(Y - X\beta)|X\} = E\{\varepsilon|X\} = E\{\varepsilon\} = 0 \tag{5}$$

However, Goodwin and Ker point out that the standard deviation of yields tended to be proportional to the trend-predicted yield [70]. This leads to a different normalizing approach of yields:

$$\hat{y}_{t,2003} = \hat{y}_{2003}(1 + \varepsilon_t / \hat{y}_t) \tag{6}$$

Both approaches have been adopted in literature though the latter probably has more empirical support. It means cov(ε | $\hat{y}$)＞0， since $\hat{y}$ =Xβ, so cov(ε, X)＞0,

$$E\{\varepsilon_t|X_t\} \neq 0$$

Because the precondition of the OLS is violated, the results of using this method will not be consistent [79]. Whether the rice yield variance is correlated with trend-predicted rice yield /time will be checked in our data in the next chapter to decide which function to use.

Another point of OLS to consider is that it is unbiased only if the errors have finite variance and are homoscedastic. If there is a systemically lagged effect from the previous year's rice yield deviation on the next year's yield, OLS estimator will be biased:

$$y_t = \alpha_0 + \alpha_1 x_t + \alpha_2 y_{t-1} + \varepsilon_t \tag{7}$$

$$\varepsilon_t = \rho\varepsilon_{t-1} + v_t$$

$$y_t = \alpha_0 + \alpha_1 x_t + \alpha_2 y_{t-1} + \rho\varepsilon_{t-1} + v_t$$

$$\because y_{t-1} = \alpha_0 + \alpha_1 x_{t-1} + \alpha_2 y_{t-2} + \varepsilon_{t-1}$$

$$\therefore E\{\varepsilon_{t-1} | y_t\} \neq 0$$

Here, x_t represents the time regressor of year t, α_0, α_1, α_2, ρ are parameters, v_t represents regression error in year t.

This is happening in the case of corn or wheat production. For example, if the previous year's precipitation is sufficient, the underground water table and the soil may contain more moisture, and this effect can remain till the next year, which may cause high production in the next year. In the rice production process, the farmers need to make sure that the soil is covered under water for most of the rice growth period, and water is not a scarce resource in Zhejiang. Thus the precipitation may not influence rice production as much as other crops, unless extreme heavy rainstorms attack the rice field. Other weather variables such as temperature may have some lagged effect on the rice yield, if the previous year's temperature is extremely high, and the soil may maintain some of the heat till next. But this effect is considered unlikely, and hence will not be considered in our model.

2.2.3.3 Weather Index Design

Temperature and precipitation are the main weather indices used for weather index-based agriculture insurance modeling in previous research on corn and wheat [69, 80-83]. Cumulative rainfall index which corresponds to the rainfall sum within a specific time period was one of the most commonly used precipitation indexes. And for temperature index, cumulative average temperature which is the sum of daily average temperature over a given accumulation period was also used in a research on weather–based wheat and corn insurance in China conducted by Leif Heimfarth [69].

However, there is limited research into weather index-based insurance for rice. It is probably because rice yield volatility is not as large as wheat or corn, despite the fact that it is the most important staple food in China. But based on much research into the impact of extreme weather events on rice yield in China and in Zhejiang [50, 84-92], temperature, precipitation and wind speed are the three main weather factors that have large impacts on rice yield. To sum up the conclusions from these studies, four types of weather conditions during certain stages of rice growing period may cause significant reduction of rice production in Zhejiang: low temperature damage – severe damage if average daily temperature drops below 18℃ for no less than 3 continuous days at the metaphase of pollen mother cells, less severe damage at flowering & heading stage, and even less severe damage at spikelet branch primordial stage; heat damage - severe damage if average daily temperature rises above 35℃ for no less than 3 continuous days at the metaphase of pollen mother cells, less severe damage at flowering & heading stage, and even less severe damage at spikelet branch primordial stage; wind damage - fierce winds are harmful at the heading, milky and filling stage of rice growing period, and the severity of the damage depends on the wind speed and the duration of the wind; rain damage, heavy rains are harmful at the flowering & heading, milky & filling stage of rice growing period, and the severity of the damage depends on how heavy the rain is and the amount of the rainfall (Check section 2.2.2 for information on the stages of rice growth).

The proportion of the area of single cropping rice and double cropping rice in each rice cropping zone of Zhejiang is an important parameter for weather index-based rice insurance design. As mentioned above, the time period of each rice growing stage is different for one and two seasonal cropping (see Table 2.1). The impact of extreme weather events varies if they occur during different stages of rice growth period, hence to find out the proportion of the single rice cropping area and double rice cropping area in each zone can help determine the time frame of the extreme weather events in the model design. However, there is no historical record on this topic in each zone of Zhejiang. The only information found is the area proportion of each rice cropping method in 2004 (Table 2.3) and the change of the area proportion in the whole province during 1993-2004 [59]. (See Figure 2.1)

	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6
Single cropping middle rice	90.4%	56.3%	43.9%	44.6%	80%	85.5%
Double cropping early rice	1.7%	18.0%	25.6%	28%	9.1%	7.5%
Double cropping late rice	7.9%	26.9%	30.4%	27.4%	10.9%	7%

Table 2.3 Area Proportions of Single Cropping Rice and Double Cropping Rice in Each Rice Cropping Zone of Zhejiang in 2004

The time frame of weather index may be selected on the basis of the rice growing period. What we can obtain from the limited information available is that a large time frame from March to November may be considered as the rice growth period for each zone, because all the rice cropping zones grow double seasonal rice to some extent. Although the coefficients of weather variables may differ due to the variance of area proportion of single cropping rice and double cropping rice in rice cropping zones, this will not be a problem for the models since they are designed for each zone specifically. The problem that may affect the fitness of the model is the change of area proportion of single cropping rice and double cropping rice over time within each rice cropping zone. However, since the change cannot be traced here, this factor will not be studied further.

A set of weather indexes will be tested in the next chapter for correlation with adjusted rice yield, based on the results of previous studies: temperature – average temperature in rice growth period from March to November (AT), average maximum temperature in rice growth period (XT), average minimum temperature in rice growth period (NT), the highest monthly average maximum temperature in rice growth period (HMXT), the lowest monthly average temperature in rice growth period (LMAT), the number of days under condition that at least 3 continuous days' maximum temperature is above 35 degrees centigrade from May to October which is the number of high temperature days for rice (HTD), the number of days under condition that at least 3 continuous days' average temperature is below 18 degrees centigrade from May to October which is the number of low temperature days for rice (LTD); precipitation – cumulative precipitation in rice growth period (CP), the highest monthly precipitation in rice growth period (HMP); wind speed – average wind speed in rice growth period (AW), average maximum wind speed in rice growth period (AXW), the highest monthly average maximum wind speed in rice growth period (HMXW).

Temperature Indices

AT: The average of daily average temperature in rice growth period from March to November.

$$AT_{(i,\,f)} = \frac{1}{n}\sum_{t=1}^{n} T_{(t,\,i,\,f)} \tag{9}$$

Here, $AT_{(i,f)}$ represents the average temperature of rice growth period of year f in Zone i; $T_{(t,i,f)}$ represents the daily average temperature of day t of year f in Zone i; n represents the total number of days of rice growth period in that year.

XT: The average of daily maximum temperature in rice growth period from March to November.

$$XT_{(i,\,f)} = \frac{1}{n}\sum_{t=1}^{n} T_{\max(t,\,i,\,f)} \tag{10}$$

$XT_{(i,f)}$ represents the average maximum temperature of rice growth period of year f in Zone i; $T_{max(t,i,f)}$ represents the daily average maximum temperature of day t of year f in Zone i.

NT: The average of daily minimum temperature in rice growth period from March to November.

$$NT_{(i,\,f)} = \frac{1}{n}\sum_{t=1}^{n} T_{\min(t,\,i,\,f)} \tag{11}$$

$NT_{(i,f)}$ represents the average minimum temperature of rice growth period of year f in Zone i;$T_{min(t,i,f)}$ represents the daily average minimum temperature of day t of year f in Zone i.

HMXT: The highest monthly average of daily maximum temperature in rice growth period from March to November.

$$HMXT_{(i,\,f)} = \max\left\{\frac{1}{n_m}\sum_{t=1}^{n_m} \mathrm{T}_{\max(t,\,i,\,f,\,m)}\right\} \tag{12}$$

$m \in [3,11]$

$HMXT_{(i,f)}$ represents the highest monthly average maximum temperature of rice growth period of year f in Zone i; $T_{max\,(t,i,f,m)}$ represents the daily average maximum temperature of day t of month m of year f in Zone i, n_m represents the number of days in month m.

LMAT: The lowest monthly average of daily average temperature in rice growth period from

March to November.

$$LMAT_{(i,\ f)} = \min\left\{ \frac{1}{n_m} \sum_{t=1}^{n_m} \mathrm{T}_{(t,\ i,\ f,\ m)} \right\} \tag{13}$$

$m \in [3,11]$

LMAT$_{(i,f)}$ represents the lowest monthly average temperature of rice growth period of year f in Zone i; T$_{(t,i,f,m)}$ represents the daily average temperature of day t of month m of year f in Zone i.

HTD (High Temperature Day): The number of days under condition that at least 3 continuous days' daily maximum temperature is above 35 degrees centigrade within certain stages of rice growth period from May to October.

$$HTD_{(i,\ f)} = \begin{cases} D_t & \mathrm{T}_{\max(t,i,f)} > 35,\ \mathrm{T}_{\max(t+1,i,f)} > 35,\ \mathrm{T}_{\max(t+2,i,f)} > 35 \\ 0 & \text{Other wise} \end{cases} \tag{14}$$

HTD$_{(i,f)}$ represents the number of days under condition that at least 3 continuous days' average maximum temperature is above 35 degrees centigrade from May to October of year f in Zone i.

LTD (Low Temperature Day): The number of days under condition that at least 3 continuous days' daily average temperature is below 18 degrees centigrade within certain stages of rice growth period from May to October.

$$LTD_{(i,\ f)} = \begin{cases} D_t & \mathrm{T}_{\max(t,i,f)} < 18,\ \mathrm{T}_{\max(t+1,i,f)} < 18,\ \mathrm{T}_{\max(t+2,i,f)} < 18 \\ 0 & \text{Other wise} \end{cases} \tag{15}$$

LTD$_{(i,f)}$ represents the number of days under condition that at least 3 continuous days' average temperature is below 18 degrees centigrade from May to October of year f in Zone i.

Precipitation Indices

CP: Cumulative precipitation in rice growth period from March to November.

$$CP_{(i,\ f)} = \sum_{t=1}^{n} P_{(t,\ i,\ f)} \tag{16}$$

CP$_{(i,f)}$ represents the cumulative precipitation of rice growth period of year f in Zone i; P$_{(t,i,f)}$ represents the precipitation of day t of year f in Zone i; n represents the total number of days of rice growth period in that year.

HMP: The highest monthly precipitation in rice growth period from March to November.

$$HMP_{(i,\,f)} = \max\left\{\sum_{t=1}^{n_m} P_{(t,\,i,\,f,\,m)}\right\} \tag{17}$$

$m \in [3,11]$

$HMP_{(i,f)}$ represents the highest monthly precipitation of rice growth period of year f in Zone i; $P_{(t,i,f,m)}$ represents the precipitation amount of day t of month m of year f in Zone i, n_m represents the number of days in month m.

Wind Indices

AW: The average of daily average wind speed in rice growth period from March to November.

$$AW_{(i,\,f)} = \frac{1}{n}\sum_{t=1}^{n} W_{(t,\,i,\,f)} \tag{18}$$

Here, $AW_{(i,f)}$ represents the average wind speed of rice growth period of year f in Zone i; $W_{(t,i,f)}$ represents the daily average wind speed of day t of year f in Zone i; n represents the total number of days of rice growth period in that year.

AXW: The average of daily maximum wind speed in rice growth period from March to November. The daily maximum wind speed stands for the maximum value of the average wind speed within every 10 minutes in a day.

$$AXW_{(i,\,f)} = \frac{1}{n}\sum_{t=1}^{n} W_{\max(t,\,i,\,f)} \tag{19}$$

$AXW_{(i,f)}$ represents the average maximum wind speed of rice growth period of year f in Zone i; $W_{max(t,i,f)}$ represents the daily average maximum wind speed of day t of year f in Zone i.

HMXW: The highest monthly average of daily maximum wind speed in rice growth period from March to November.

$$HMXW_{(i,\,f)} = \max\left\{\frac{1}{n_m}\sum_{t=1}^{n_m} W_{\max(t,\,i,\,f,\,m)}\right\} \tag{20}$$

$m \in [3,11]$

$HMXW_{(i,f)}$ represents the highest monthly average maximum wind speed of rice growth period of year f in Zone i; $W_{max\,(t,i,f,m)}$ represents the daily average maximum wind speed of day t of month m of year f in Zone i, n_m represents the number of days in month m.

2.2.3.4 Weather Index and Rice Yield Relationship Model Design

To model the weather index and rice yield relationship, we need to first understand the weather requirements of rice during its growth period. Rice is a thermophilic crop, so temperature requirement is one of the most important conditions for rice growth. Here is a table of temperature requirement of rice [93]:

Rice Growing Phase	Minimum Temperature ℃	Optimal Temperature ℃	Maximum Temperature ℃
Germination	10-12	18-33	45
Seedling Growth	12-14	20-32	40
Transplanting	13-15	25-30	35
Tillering	15-17	25-30	33
Spike Defferentiation	15-17	25-32	40
Metaphase of pollen mother cells	15-17	25-32	40
Heading & Flowering	18-20	25-32	35-37
Grain Filling	13-15	23-28	35

Table 2.4 Temperature Requirements of Rice [93]

High temperature within a certain range during day time will accelerate the photosynthesis of rice in rice growth period, which may have a positive effect on the rice yield. However, high temperature at night will accelerate respiration of rice, which may have a negative effect on the rice yield, especially during the grain filling phase. There is still no consensus on the question whether global warming leads to a higher or lower rice production in the scientific society. A more popular concept is that rice yields decline with global warming [94-96], which is largely due to the rising night time temperature that elevates the rice respiration at night. Yet, this is not always the case: A study in Japan shows that global warming reduced damage to rice production from cool summer throughout Japan, but enhanced the damage caused by heat stress in central to southwestern Japan, while in the north Japan no damage was found [97]. In contrast another international research study showed that the increasing and declining trends of rice production largely balanced out compared to a counterfactual analysis without climate trends [98].

The wind effect on rice yield is supposed to be negative in Zhejiang, because of the frequent occurrences of heavy wind and tropical cyclones as mentioned in Chapter 1.

The effect of precipitation on rice yield is ambiguous in Zhejiang. In the plain areas near the coast line, the rainfall is normally sufficient, and the water facilities are well constructed for rice planting; while in the mountain areas further away from the coast, where there are not many lakes or rivers, the precipitation may be not as sufficient for rice growth. So the impact of precipitation may vary with the location of rice cropping area.

Since it is not clear how the weather indexes affect the rice yield, in the next chapter, we will plot the yield and the weather index selected for each zone and try to find out the best fit function by using linear or quadratic regression, based on the meteorological information of rice collected.

2.2.4 Insurance Product Design

The design of an efficient insurance product relies first on the characterization of the relationship between the rice yield and the proxies for the indemnity schedule. When this part is completed, the next step is to design the rice insurance contract for Zhejiang province, based on the previous studies.

The purpose of the insurance is to hedge against the risk of contingent, uncertain loss. "By purchasing an insurance policy, an individual (the insured) can transfer this risk, or variability of possible outcomes, to an insurance company (the insurer) in exchange for a set payment (the premium). Because of the law of large numbers, the insurer will end up with an average risk that is relatively smaller compared to the original risk to individual policyholders through careful underwriting and selection." (Brown and Gottlieb, 2001) [99] The process of assessing the premium and risk exposure of potential clients by insurers is called underwriting. It is usually within the actuarial science domain.

In our case of Zhejiang, the weather index-based insurance product will be designed based on the modeling results of the relationship between weather index and rice yield. The detailed financial calculation of the risk load and pricing will not be discussed in depth here. This part may be done by the actuaries in the future development and modification of this insurance product.

In an insurance contract, the insurer promises to pay for the financial consequences of the claims produced by the insured risk, and the policyholders pay a fixed amount to the insurer for the risk coverage, called the premium. There are several layers of premium: pure premium is defined as the expected value of the claim amounts to be paid by the insurer; net premium is the pure premium added with a risk loading by the insurer; gross premium is the net premium adding acquisition and administration costs [100].

Gross Premium = Net Premium + Administration Costs

Net Premium = Pure Premium + Risk Loading

Pure Premium = Expected value of claim amounts

We will focus our model on calculating the net premium, since the acquisition and administration costs vary among different insurance companies. The net premium can be expressed by the following function [94]:

$$P(X) = E[X] + \lambda \cdot \sigma[X] \tag{21}$$

Where, E[X] denotes the expected value of claim amounts (pure premium), $\lambda \cdot \sigma[X]$ denotes the risk loading of the insurer, which we define as risk premium.

If the weather index data perfectly matches the rice yield data in our model, there will be no risk loading, thus the pure premium can be charged alone to the insurance policyholders, if administration costs and profits of the insurer are not considered. In this case, a strike level of the weather index needs to be defined, and when weather index data is below or above this strike level whichever corresponds to the rice yield loss, then indemnity occurs. For example, if the rice yield is positively correlated to cumulative precipitation in rice growth period, when the cumulative precipitation of the next year is lower than a strike level which corresponds to a level of rice yield loss. The indemnity that will be paid to policyholders can be indicated as [69]:

$$I(X) = \gamma \cdot \max(K - X, 0) \tag{22}$$

Where, I(X) represents the indemnity amount which will be paid to the policyholders in the insurance contract year, K represents the strike level of weather index at which a decrease of the observed underlying on the valuation date triggers a pay off, X represents the actual weather index value in this insurance contract year, γ is a tick size that monetizes the weather index points and quantifies the indemnity.

The pure premium can then be calculated as the sum of the annual indemnity of the weather index-predicted rice yield in our data history multiplied by its occurrence probability in our data sample period (risk premium is not considered):

$$P(X) = E[Loss] = \frac{1}{n}\sum_{i=1}^{n} \hat{I}_i \tag{23}$$

Here, P(X) denotes the pure premium in the insurance contract, n is the number of years of our rice yield data sample, 1/n denotes the probability of each level of indemnity occurrence in the data history, $\hat{I}_i$ represents the indemnity amount of the weather index-predicted rice yield in year i during our data sample period.

A hedging efficiency test may be conducted to check whether this insurance design can reduce variance in farmers' rice yield income. An after-insurance rice production income Y' will be calculated based on the insurance policy:

$$Y' = Y + I' - P' \tag{24}$$

Here, Y' represents the after-insurance rice production income, Y denotes the before-insurance rice production income, I' represents the amount of rice yield loss that would have been paid to policyholders under the insurance condition, P' denotes the pure premium each policyholder needs to pay for the insurance. The hedging efficiency can be tested as:

$$EF = \frac{Var(Y) - Var(Y')}{Var(Y)} \times 100\% \tag{25}$$

Where, EF denotes the hedging efficiency of our insurance model which represents the percentage reduction of the variance in policyholders' rice production income after insurance, Var(Y) is the variance of the original rice yield income of the policyholders, Var(Y') is the variance of the policyholders' calculated rice yield income after insurance.

However, in real cases, the risk premium cannot be ignored because of misspecification of the weather index process and parameter uncertainty in the model [101]. For the risk of misspecification of weather index process, the location of weather station and insurable farming land, the weather index design and risk exposure period need to be carefully checked. And for the risk of parameter uncertainty, the uncertainty of regressor coefficients in the model and rice price fluctuation should also be tested. To simplify the Zhejiang case, we suppose that the weather index processes are perfectly specified in our model and the rice price is a fixed value which is equal to the last year's price. Thus the regressor coefficient uncertainty is the only element to consider in the risk premium, which can be expressed by the standard deviation σ of the regressor. If there is a certain range of uncertainty σ in the regressor coefficient, the weather index predicted rice yield corresponding to the regression model will also vary, which will lead to an uncertainty in the expected rice yield loss, thus indemnity tick size in Function 22 will change. If the risk is quick high for the insurer, a risk premium may be charged to have the insurable farmers share the risk.

In Chapter 3, a test will be conducted to check the changing interval of the expected yield loss when the regressor coefficient varies within $\pm\sigma$. If there is a large interval, the insurer should consider sharing the risk with the policyholders by adding a risk premium or transfer the risk to reinsurers or to other insurance markets. However, since this decision making and underwriting is within the actuarial science domain, it will not be studied further in our case. Future works may be done to continue on this topic in insurance companies.

Chapter 3

Data Analysis

3.1 Data Sources and Quality

The rice yield data and various statistical data from the villages used in this thesis were collected by The Research Center for Rural Economy (RCRE) of the Ministry of Agriculture (MOA) of People's Republic of China (P.R.C.) on the purpose of rural economy policy research. RCRE was established in October 1990. It is a policy research and consulting institute directly under the MOA. The data range is from 1986 to 2003, excluding the years 1990, 1992, and 1994. The reason why the data from these years is missing is unknown.

Although the data was collected by the official governmental administration, the data quality is questionable, for example, the data of one village in 2001 was missing, certain information for year 1997 was recorded differently in two data summaries, the questionnaires were changed in 1995 and 2003 which caused inconsistencies in some of the information collected over the period of the study. The number of sample villages is too small for a comprehensive weather index-based rice insurance modeling. Despite this, it is a rare opportunity to have systematic data over such a long period of time in China. Considering the data quality problem, the data recording errors need to be taken into account in the data analysis.

The weather data are collected from the database of China's ground stations for international value exchange from China Meteorological Administration (CMA). CMA is the highest public meteorological service agency in China, which is directly affiliated to the State Council of P.R.C. The weather data contain 13 categories of weather conditions covering air pressure, temperature, humidity, wind speed, sunshine hours, and precipitation on a daily basis. The database is complete and well documented from 1973 to 2010 for most regions of Zhejiang province, China. However, the weather data for one station in the northwestern Zhejiang (rice cropping Zone 6) is only available from 1997 and the weather station is located in the mountain at high altitude. The data does not cover sufficient time range for the rice yield data analysis in that region and may cause geographical errors for the data analysis since the rice cropping area in that region is mostly at low altitude.

3.2 Removing Trend in Rice Yield

3.2.1 Time Trend

Time trend is one the most common tools used to remove the impacts of technological changes in yields observed over time. This is based on the hypothesis that the time trend may reflect the improvement of production techniques in crop yields observations [70]. In this section, the per unit area rice yield of each rice cropping zone in Zhejiang will be plotted by time trend, and correlation between these two variables will be tested.

Some other factors that impact the rice yield may also correlate with time trend, which could be simplified by using time trend alone to detrend the rice yield. This will also be tested in this section.

3.2.1.1 Time Trend and Rice Yield

The time series of per unit land rice yield of each zone in Zhejiang is plotted in the following chart:

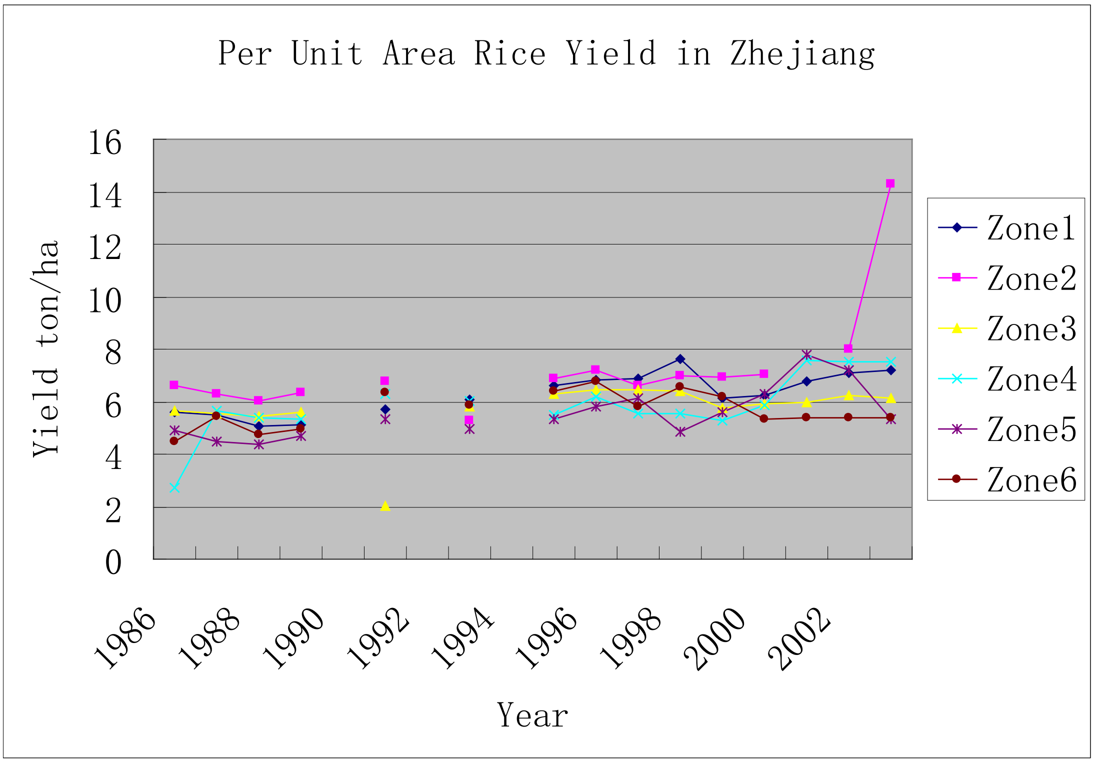

Figure 3.1 Per Unit Area Rice Yield in Zhejiang 1986-2003

There are three obvious outliers in the chart: the rice yield of 1986 in Zone 4, the rice yield of 1991 in Zone 3, and the rice yield of 2003 in Zone 2. The low rice production in 1986 in Zone 4 is unknown, and there is no obvious difference in other conditions recorded in the village data compared to the following few years. However, the per unit land rice production in 1986 is less than half the production in 1997, which casts doubt on the correctness of this value, so this outlier will be excluded. The abnormal point of Zone 3 in 1991 is probably because of a mistake in data recording - the rice yield of 1991 in one village of zone 3 was 8 times lower than the former and later years, while the other conditions remained stable that year. The substantial increase of per unit area rice yield in 2003 in Zone 2 is probably due to the dramatic change of cropping land in one village of Zone 2 – the land reduced about 20 times from 52.7 ha to 2.7 ha while the rice yield only reduced 10 times from 391 tonnes to 38 tonnes. The cause of this dramatic change is not clear; the selection of the most productive farm land for cropping might be the reason. But since the yield in 2003 is not compatible with the yield in the former year, this point needs to be excluded from the model here.

The new per unit land rice yield of each zone in Zhejiang with outliers removed:

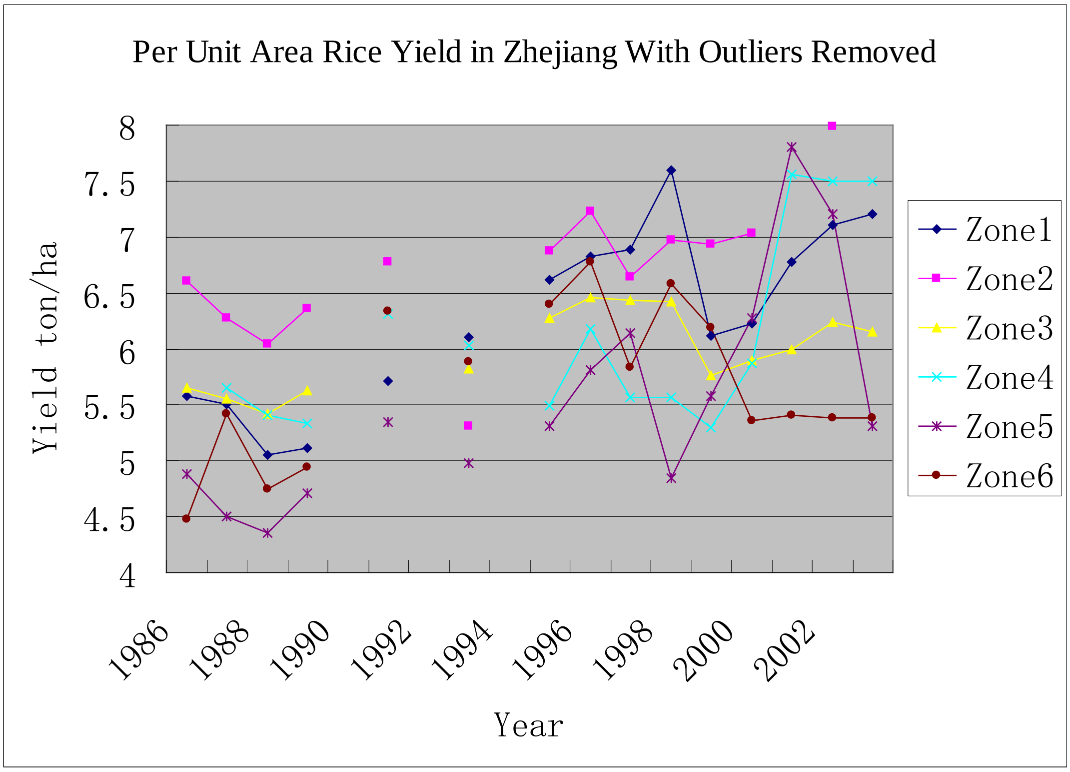

Figure 3.2 Per Unit Area Rice Yield in Zhejiang With Outliers Removed 1986-2003

The correlation between time trend and per unit area rice yield for each zone is calculated in Table 3.1:

	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6
Coefficient	0.82	0.64	0.65	0.61	0.72	0.35

Table 3.1 Correlation between Per unit Area Rice Yield and Time Trend

It seems that the correlations between per unit area rice yield and time trend are quite good for Zone 1-5. Per unit area rice yield in Zone 6 is not well correlated with time, which might be because Zone 6 is within a mountainous area which is not as well developed as the coastal zones in the east and thus the uptake of advanced techniques may not be as rapid.

3.2.1.2 Time Trend and Other Quantitative Non-weather Factors

Aside from improvement of farming production techniques, many other factors may also impact the rice yield, as discussed in the previous chapter. If these quantitative factors are also well correlated with time trend, it could be simplified by using time trend alone to detrend the rice yield. The correlation between time trend and non-weather factors such as the educational level of village dwellers (EL), the number of farming laborers per unit land (LPL), the fixed assets of large and medium man/horse powered agriculture production tools (FAP). The results are listed in Table 3.2:

	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6
EL	0.67	0.80	0.96	0.28	0.68	0.83
LPL	0.55	-0.76	-0.49	-0.20	0.79	-0.43
FAP	-0.59	0.84	-0.79	0.61	0.90	-0.47

Table 3.2 Correlation between Time Trend and Other Non-Weather Factors

From Table 3.2, we can see a clear trend of rising educational level of village dwellers with time. The other two quantitative factors i.e. the number of farming laborers per unit land and the fixed assets of large and medium man/horse powered agriculture production tools - are not correlated with time trend.

3.2.2 Other non-weather factors

As discussed in the previous chapter, to reduce the basis risk, many non-weather factors that may impact the rice yield should be considered in the model design. Each factor studied in Chapter 2 will be checked in this section.

Rice breeds

The rice planting area in Zhejiang that was planted with the hybrid breed rice dramatically increased in the mid 90s from ~25% of the total planted rice area to ~50% (see Figure 2.4). This trend could have had an impact on rice production, however, from Figure 3.2, we do not see an abrupt increase of per unit area rice yield from 1995, but rather the rice yield is increasing steadily from 1986 to 2003. This implies that the impact of rice breed on rice yield is not significant, thus it is not considered in the model used here.

Rice cropping area

The rice cropping area in Zhejiang decreased sharply from 1998 to 2003. However, this change is not clearly reflected in the per unit area rice yield Figure 3.2. Hence, this factor will also not be considered in our model.

Rice pests and disease plagues

The concentrated outburst of rice plant-hoppers and stem borers in Zone 3 and Zone 4 from 1995 to 2000 may have suppressed the increase of rice yield as we may see from the per unit area rice yield Figure 3.2. Nevertheless, it is not a very obvious effect compared with other zones, which may be due to the application of pesticides in the affected area. Since no significant decline of rice yield during this plague period is observed, this factor will also not be considered in the model.

Production Tools

The investment in production tools may also have an impact on rice yield. The correlation is tested and recorded in Table 3.3:

	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6
Correlation Coefficient	0.70	-0.47	-0.77	0.94	0.86	0.18

Table 3.3 Correlation between Fixed Assets of Large and Medium Production Tools and Per Unit Land Rice Yield

The correlation does not seem to be good for all the zones. One reason for this could be the small number of recorded years for this parameter. This parameter was recorded from 1995 to 2002 in the data, which is too short to study the trend. Another reason could be that the purpose of the production tools was not clarified in the data. If these tools were used for the processing of the rice after harvest or for other crops, they may not be considered as a parameter that could increase the rice yield. Due to these two reasons, the investment in production tools will not be considered in our model.

Although the non-weather factors discussed above are all crucial issues in rice production, the impact of these factors on per unit land rice yield is vague in Zhejiang. This is largely due to the lack of complete information and lack of good quality data records. The limitations of the data are a common problem for weather index-based insurance design in many other developing countries and regions [67]. Getting the most from the limited data is vital for agriculture insurance in developing countries. More investment and better structured research facilities are required in developing countries to aid research on this topic.

Farming labor

The correlation coefficients between the number of farming laborers per unit land (LPL), the educational level of the village dwellers (EL) and the per unit area rice yield are listed in Table 3.4. (The educational level of the village dwellers is measured by the number of high school and college graduates in the village.)

Correlation with per unit land rice yield	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6
LPL	0.58	-0.30	-0.10	0.05	0.84	0.48
EL	0.50	0.80	0.49	0.43	0.45	0.36

Table 3.4 Correlation between Farming Labor Factors and Per Unit Land Rice Yield

The result shows that the educational level of the village dwellers are positively correlated with rice yield, while there was no clear correlation between the number of farming laborers per unit land and rice yield. Furthermore, variability in skill levels or percentage of time working on rice cropping amongst farm laborers cannot be accounted for and so farming laborers per unit land was not considered in the model.

The educational level of the village dwellers is well correlated with rice yield per unit land and with time trend (see Table 3.2). Now here comes the question – the time trend or the educational level of village dwellers or both should be chosen as the non-weather parameters for removing the trend in per unit land rice yield?

3.2.3 Detrending Rice Yield Per Unit Land

3.2.3.1 Time Trend

Since time trend is most commonly used in detrending rice yield, it is first tested in our Zhejiang data by using OLS method. The results are shown in the following charts:

Significant codes:
0-0.001 ‘***’
0.001-0.01 ‘**’
0.01-0.05 ‘*’
0.05-0.1 ‘.’

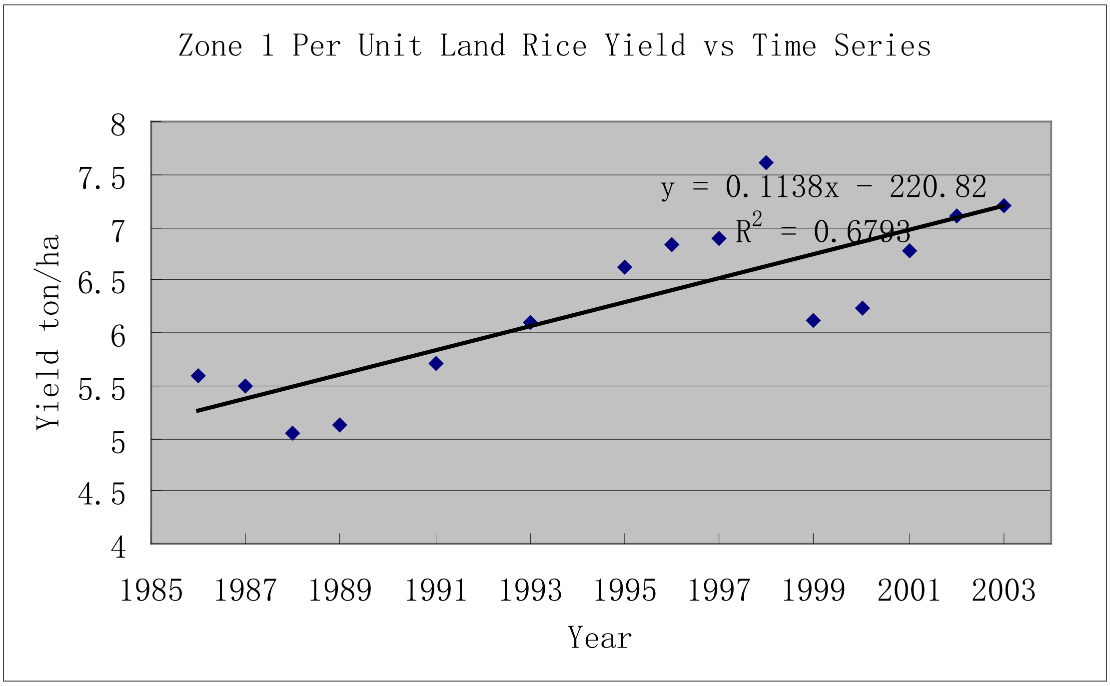

Figure 3.3 Zone 1 Per Unit Land Rice Yield with Time Trend’ Regression Line

Regression results using R:
Formula: y ~ a + b * x
Parameters:

	Estimate	Std. Error	t value	Pr(>|t|)
a	-220.81591	43.27946	-5.102	0.000203 ***
b	0.11384	0.02169	5.248	0.000158 ***

Residual standard error: 0.4622 on 13 degrees of freedom

The estimation of intercept of time trend is very good in this linear regression for rice cropping zone 1, which suggests it is a good model to fit the rice yield data.

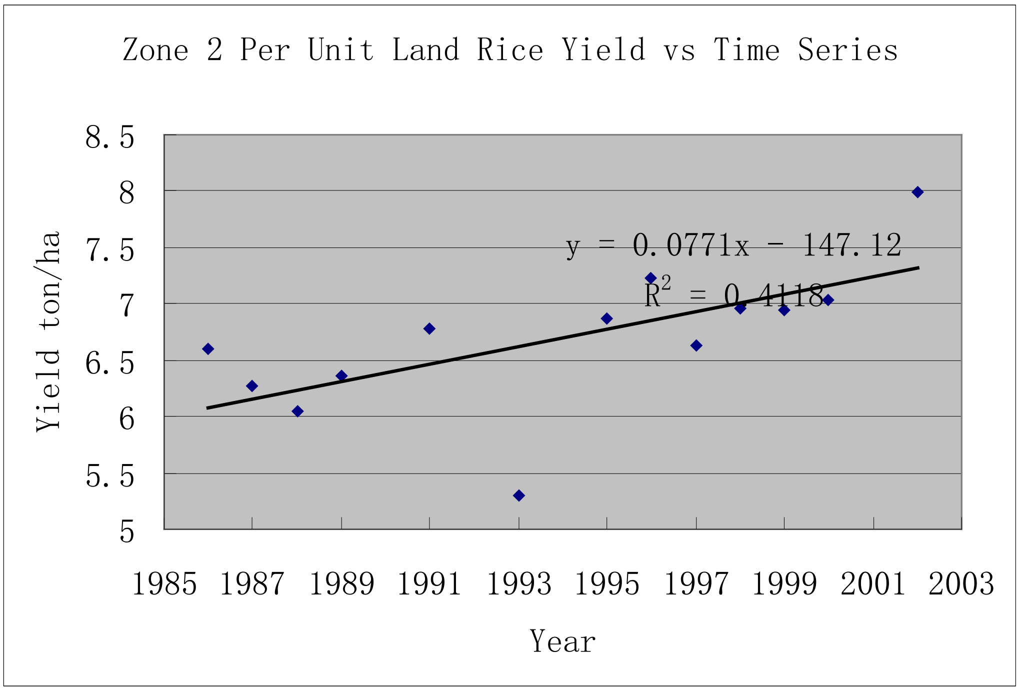

Figure 3.4 Zone 2 Per Unit Land Rice Yield with Time Trend' Regression Line

Regression results using R:

Formula: y ~ a + b * x

Parameters:

	Estimate	Std. Error	t value	Pr(>|t|)
a	-147.11898	55.42603	-2.654	0.0224 *
b	0.07714	0.02780	2.775	0.0181 *

The intercept estimation result for Zone 2 is acceptable, but not as good as Zone 1.

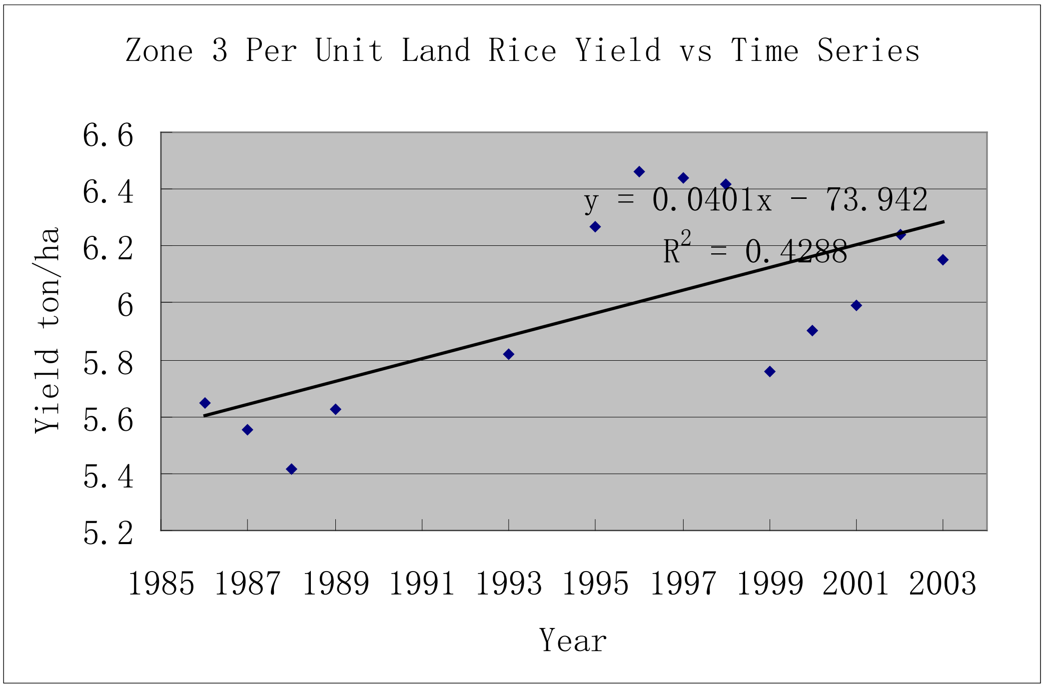

Figure 3.5 Zone 3 Per Unit Land Rice Yield with Time Trend' Regression Line

Regression results using R:
Formula: y ~ a + b * x
Parameters:

	Estimate	Std. Error	t value	Pr(>|t|)
A	-73.94187	26.62753	-2.777	0.0167 *
b	0.04005	0.01335	3.001	0.0110 *

The intercept estimation result for Zone 3 is acceptable, but not as good as Zone 1.

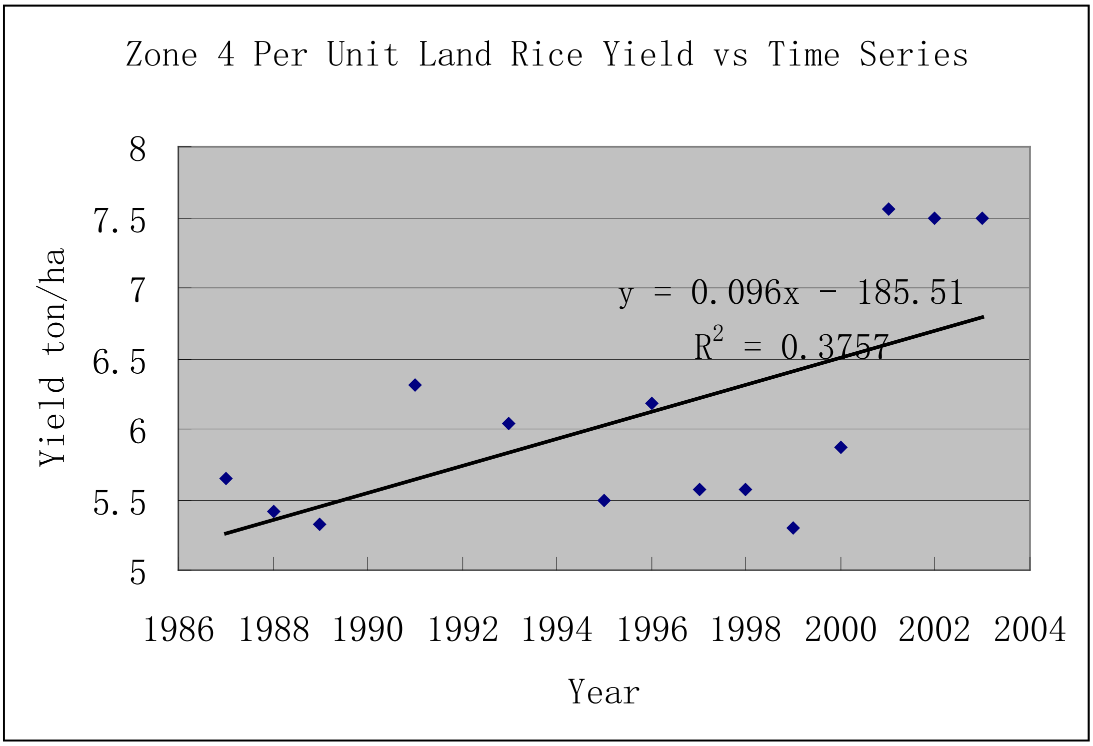

Figure 3.6 Zone 4 Per Unit Land Rice Yield with Time Trend' Regression Line

Regression results using R:
Formula: y ~ a + b * x
Parameters:

	Estimate	Std. Error	t value	Pr(>|t|)
a	-185.50894	71.29596	-2.602	0.0231 *
b	0.09601	0.03573	2.687	0.0198 *

The intercept estimation result for Zone 4 is acceptable, but not as good as in Zone 1.

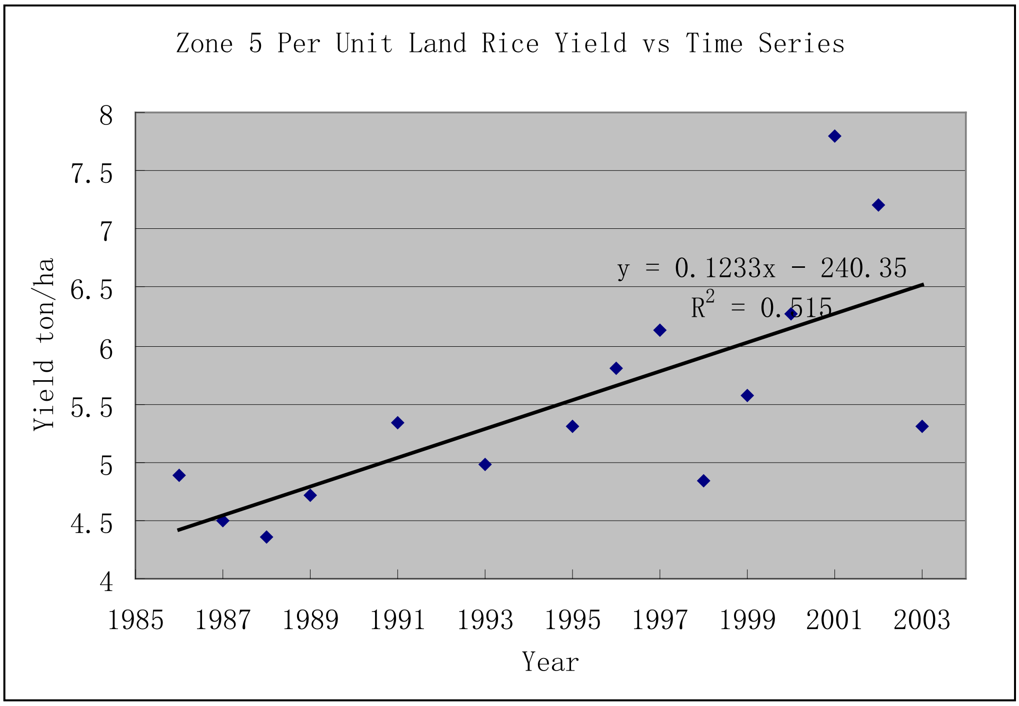

Figure 3.7 Zone 5 Per Unit Land Rice Yield with Time Trend' Regression Line

Formula: y ~ a + b * x

Parameters:

	Estimate	Std. Error	t value	Pr(>|t|)
a	-240.35330	66.18777	-3.631	0.00304 **
b	0.12325	0.03318	3.715	0.00259 **

The intercept estimation result for Zone 5 is better to Zone 2-4, but not as good as Zone 1.

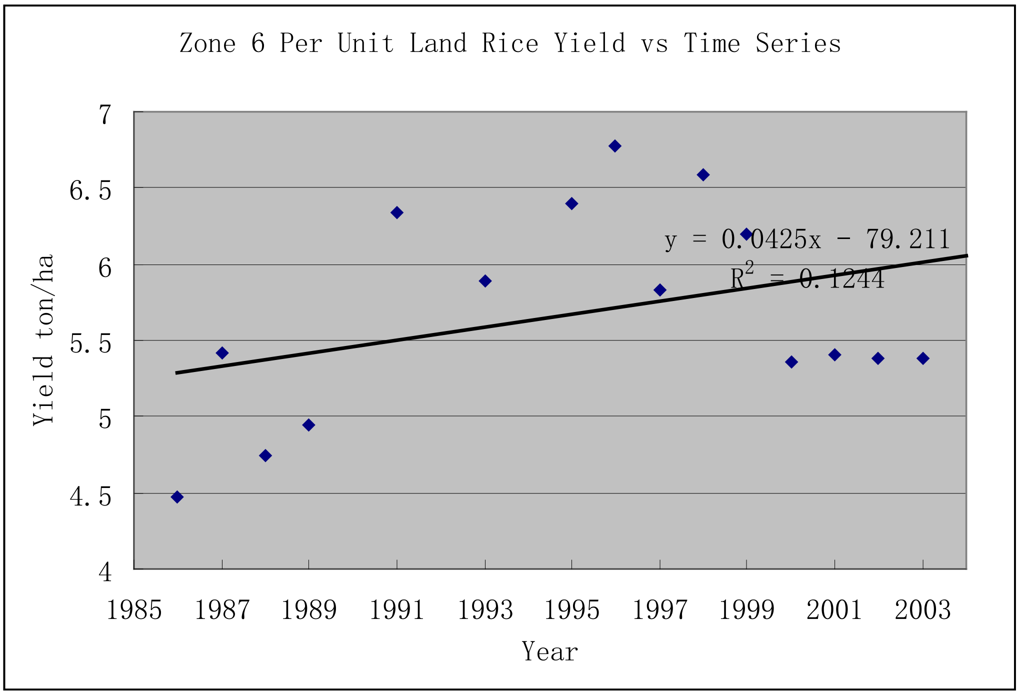

Figure 3.8 Zone 6 Per Unit Land Rice Yield with Time Trend' Regression Line

Formula: y ~ a + b * x
Parameters:

	Estimate	Std. Error	t value	Pr(>|t|)
a	-79.21117	62.45467	-1.268	0.227
b	0.04255	0.03131	1.359	0.197

The intercept estimation result of linear regression for Zone 6 is not good, which means the linear regression model is not well fit to this set of data.

Rather than the linear regression model used in Figure 3.8 above, a quadratic regression model was then tested to detrend the time trend in per unit land rice yield of Zone 6. The results are as shown in Figure 3.9:

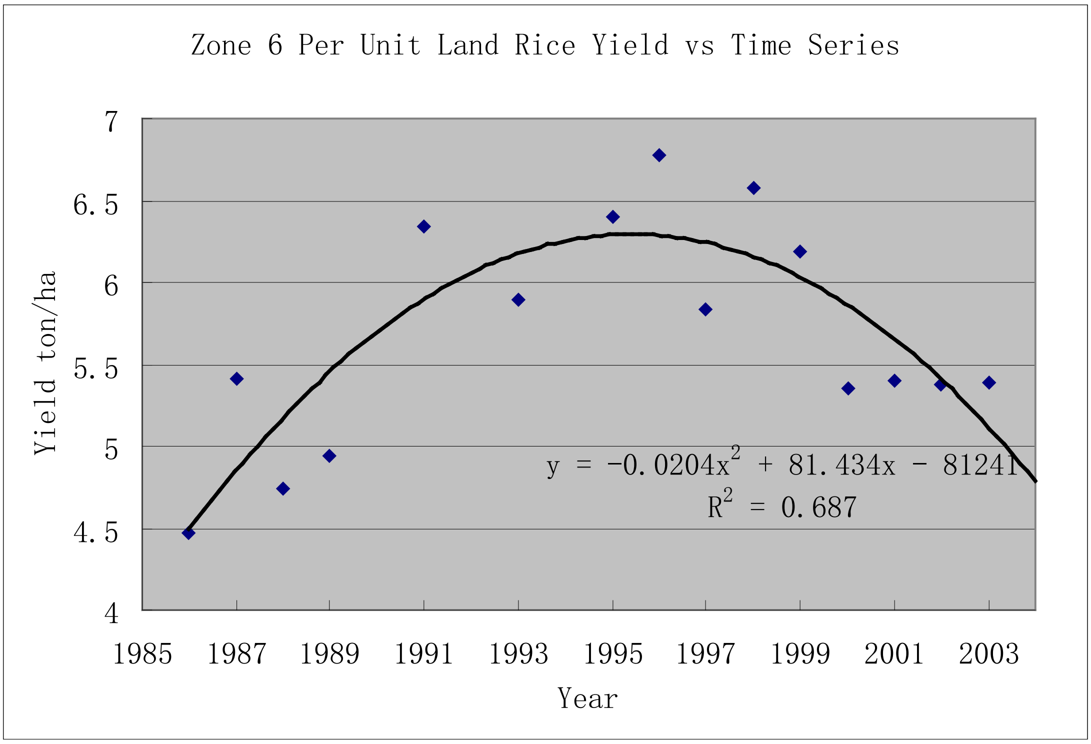

Figure 3.9 Quadratic Regression of Zone 6 Per Unit Land Rice Yield with Time Trend

Results from R:
Formula: y ~ a + b * x + c * x * x
Parameters:

	Estimate	Std. Error	t value	Pr(>|t|)
a	-8.124e+04	1.748e+04	-4.648	0.000562 ***
b	8.143e+01	1.753e+01	4.646	0.000564 ***
c	-2.040e-02	4.394e-03	-4.644	0.000567 ***

The parameters' estimations in quadratic regression of Zone 6 rice yield and time trend are very good. Nevertheless, in this case, the time trend shows a strange phenomenon that the per unit land rice yield in Zone 6 was increasing before year 1995, but decreasing after 1995. Yet, our assumption of time trend is that it represents the technological improvement in rice cropping, which suggests that the rice yield per unit land should be constantly increasing or at least not decreasing over time. Thus the quadratic regression results contradict our original assumption of time trend in per unit land rice yield. There is no additional information to explain the quadratic curve of rice yield trend in Zone 6, so we will not use this regression result to adjust the rice yield in Zone 6. Since linear regression was not well fit for Zone 6 yield data, original rice yields per unit land of Zone 6 will be used for the modeling in the next steps.

The result of time detrended rice yield deviation per unit land for Zone 1-5 in Zhejiang according to OLS models are shown in Figure 3.10: (This is calculated according to Function 3 in Chapter 2.)

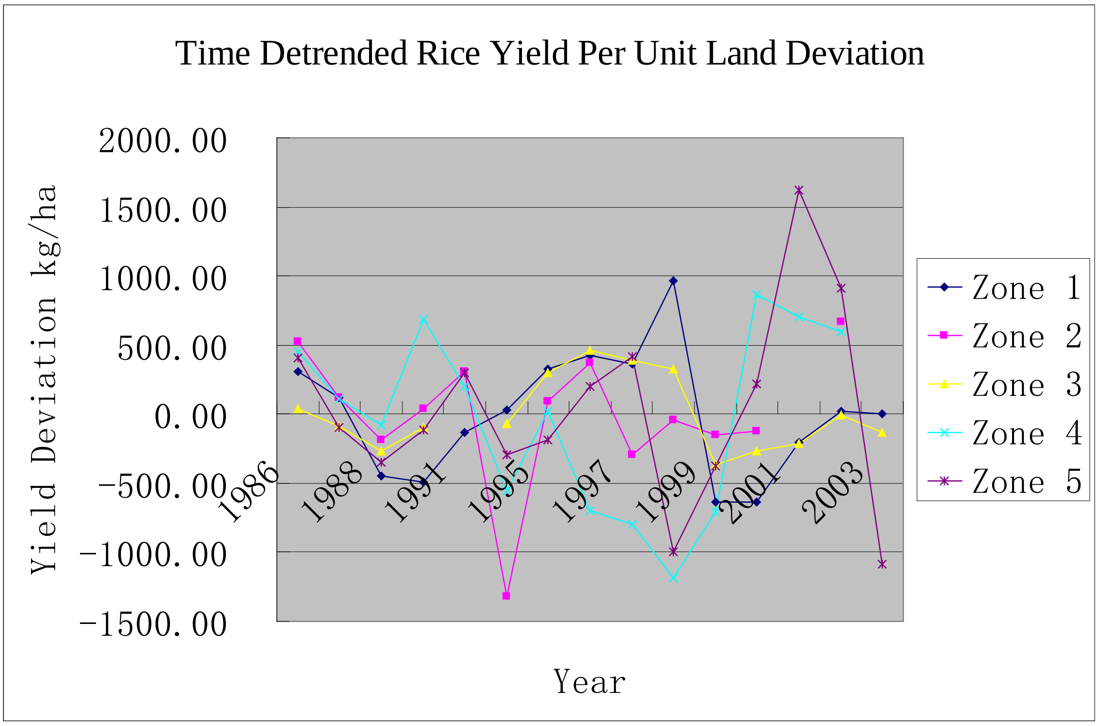

Figure 3.10 Rice Yield Per Unit Land Deviation from Time Trend' Detrending Function

The yield deviation does not seem to increase with time or with the time trend-predicted rice yield in the chart above (Figure 3.10). To check the feasibility of regression model for the data, the correlation of rice yield deviation and time trend is also tested in Table 3.5:

	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5
Correlation Coefficient	0.03	0.02	0.26	0.60	0.63

Table 3.5 Correlation between Per Unit Land Rice Yield Deviation and Time Trend-Predicted Rice Yield

The correlation coefficient in Zone 4 and Zone 5 is rather higher, while in other zones it is not the case. There is no obvious evidence in the data that shows the deviation of yields tends to be proportional to the trend-predicted yield similar to what Goodwin and Ker (1998) [70] found. Since this is not clearly observed in our data, we assume that the rice yield deviation is not changing with time. Thus the assumption of OLS that the random variables need to be homoscedastic is not violated.

3.2.3.2 Time Trend or Education Trend?

As mentioned in the previous section, the educational level of the village dwellers is also positively correlated with rice yield, so there is a question as to whether the time trend or the educational level of village dwellers or both should be chosen as the non-weather parameters for removing the trend in per unit land rice yield. As tested in Table 3.2, the educational level of the village dwellers is well correlated with time, which is easy to understand – more and more people are getting better education over time with the development of the region. This may suggest that the time trend can also represent the education trend in rice yield per unit land, but this needs to be tested in our data. In the time detrending function:

$$y_t = X_t\beta + \varepsilon_t$$

if $\varepsilon_t = \mu_t\gamma + e_t$, μ_t represents the educational level of people in year t, γ represents the parameter for μ_t, et represents yield deviation, then the time trend can not be used alone for detrending rice yield. Based on this, the correlation between ε_t (the yield deviation from time trend) and the educational level of the village dwellers is tested.

	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5
Correlation Coefficient	-0.09	0.29	0.07	0.65	0.02

Table 3.6 Correlation between Per Unit Land Rice Yield Deviation from Time Trend and Educational Level of Each Zone

There is no pattern in the result, which suggests that $\varepsilon_t \neq \mu_t\gamma + e_t$, so the rice yield deviation from time trend is not correlated with educational level of people. (The large correlation coefficient of Zone 4 is probably due the small sample size.) Thus educational level will not be considered in the model if time trend is taken as the parameter.

3.2.3.3 Adjusted Rice Yield

As indicated in Function 4 in Chapter 2, the adjusted rice yield is calculated based on the estimated rice yield of the final year in the data range. Since the yield is constantly increasing with time, the final year's rice yield level is expected to be the closest to the following year's rice yield. So adjusted rice yield can be used to predict the rice yield in the following year. In our case, the final year of the estimated rice yield is year 2003, so the adjusted rice yield will represent the predicted rice production level for 2004 based on 2003. However, in the design of a real insurance contract, the data should be collected until the present year, then the adjusted rice yield may have practical meaning for the current year.

Here is the list of adjusted rice yields of Zone 1-5 and the original rice yields of Zone 6:

Year	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6
1986	7.518	7.914	6.328		6.806	4.473
1987	7.325	7.511	6.196	7.359	6.304	5.414
1988	6.756	7.205	6.015	7.016	6.055	4.745
1989	6.713	7.437	6.186	6.828	6.291	4.942
1990						
1991	7.077	7.705		7.593	6.700	6.339
1992						

1993	7.237	6.075	6.220	7.105	6.105	5.888
1994						
1995	7.532	7.486	6.590	6.345	6.212	6.395
1996	7.627	7.763	6.744	6.927	6.603	6.781
1997	7.569	7.100	6.679	6.209	6.816	5.833
1998	8.171	7.353	6.617	6.106	5.404	6.582
1999	6.566	7.248	5.918	5.722	6.030	6.191
2000	6.571	7.270	6.021	6.196	6.616	5.353
2001	7.000		6.071	7.774	8.026	5.403
2002	7.224	8.066	6.280	7.607	7.313	5.381
2003	7.205		6.152	7.500	5.313	5.385

Table 3.7 The Adjusted Annual Rice Yields of Zhejiang Based on Year 2003 (ton/ha)

The adjusted annual rice yields of Zone 1-5 and the actual rice yields of Zone 6 will be used to test the relationship with weather indexes designed in the following steps.

3.3 Weather Index Design

In chapter 2, 12 weather indexes were introduced for the weather index design. Each of them will be tested in this section to find the best fit index for rice yield in each rice cropping zone in Zhejiang.

3.3.1 Weather Index Selection

Rice yields are first adjusted by time trend, and the adjusted rice yields (see Table 3.7) will then be tested as the dependent variable correlated weather indexes. The first step has been done in section 3.2.3.1 (Time Trend). The results of correlation between adjusted rice yields and weather indexes are shown in Table 3.8:

Correlation between Weather Indexes and Adjusted Rice Yield	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6
AT	0.29	0.12	0.14	0.09	-0.32	0.44
XT	0.34	0.09	0.15	0.09	-0.31	0.33
NT	0.23	0.13	0.07	0.05	-0.19	0.22
HMXT	0.12	0.16	0.07	0.40	-0.33	-0.22
LMAT	0.01	0.14	-0.07	-0.17	-0.09	0.38
HTD	0.05	0.14	0.15	0.30	-0.36	
LTD	-0.06	0.10	-0.07	0.55	-0.03	-0.17
CP	-0.02	-0.29	-0.08	0.01	-0.17	0.67
HMP	-0.20	-0.37	0.24	-0.47	-0.35	0.70
AW	-0.03	-0.20	-0.27	0.12	-0.62	0.01
AXW	0.06	-0.15	-0.09	0.06	-0.39	-0.22

HMXW	0.06	-0.28	-0.18	0.52	-0.40	-0.28

Table 3.8 Correlation between Weather Indexes and Adjusted Per Unit Land Rice Yield from Time Trend

The two strongest correlation coefficients in each zone are marked in red. It appears that the adjusted rice yield in Zone 1 is most likely to be positively affected by average maximum temperature in rice growth period. The warmer the weather is, the better rice production will be for Zone 1. In Zone 2, the highest monthly precipitation in rice growth period mostly affects the rice production. It may due to the frequent tropical cyclones and rainstorms in Zone 2 every year. In Zone 3, the average wind speed in rice growth period is mostly correlated with adjusted rice yield. In Zone 4, the data shows that the numbers of low temperature days from May to October and the average maximum wind speed have positive correlation with adjust rice yield, which is unexpected. Low temperature and high maximum wind speed are supposed to cause damage to rice production, thus these two weather indexes will not be taken as weather parameters for Zone 4. The next strongest correlated weather index, the highest monthly precipitation, may be chosen for rice yield in Zone 4. In Zone 5, the average wind speed in rice growth period is most closely correlated with adjusted rice yield. In Zone 6, the highest monthly precipitation in rice growth period has the strongest correlation with rice yield. To sum up, the weather index chosen for each zone based on their correlation with rice yields is shown in Table 3.9:

	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6
Weather Index Chosen for each zone	XT	HMP	AW	HMP	AW	HMP

Table 3.9 List of Weather Indexes Chosen for Each Zone

3.3.2 Relationship between Adjusted Rice Yield and Weather Index

Based on this weather index design, the relationship between adjusted rice yield and weather index in each zone is presented here to prepare for the insurance product design.

Zone 1

For Zone 1, the average maximum temperature is the weather index that most correlated with per unit land rice yield. To explore the relationship between XT and rice yield, we need to refer to the requirements of temperature during rice growth period. If XT is within a certain optimal range for rice growth as shown in Table 2.4, the relationship between rice yield and XT may show a consistent pattern in the chart.

A linear regression model will firstly be tested here.

Significant codes:

0-0.001 ‘***’

0.001-0.01 ‘**’

0.01-0.05 ‘*’

0.05-0.1 ‘.’

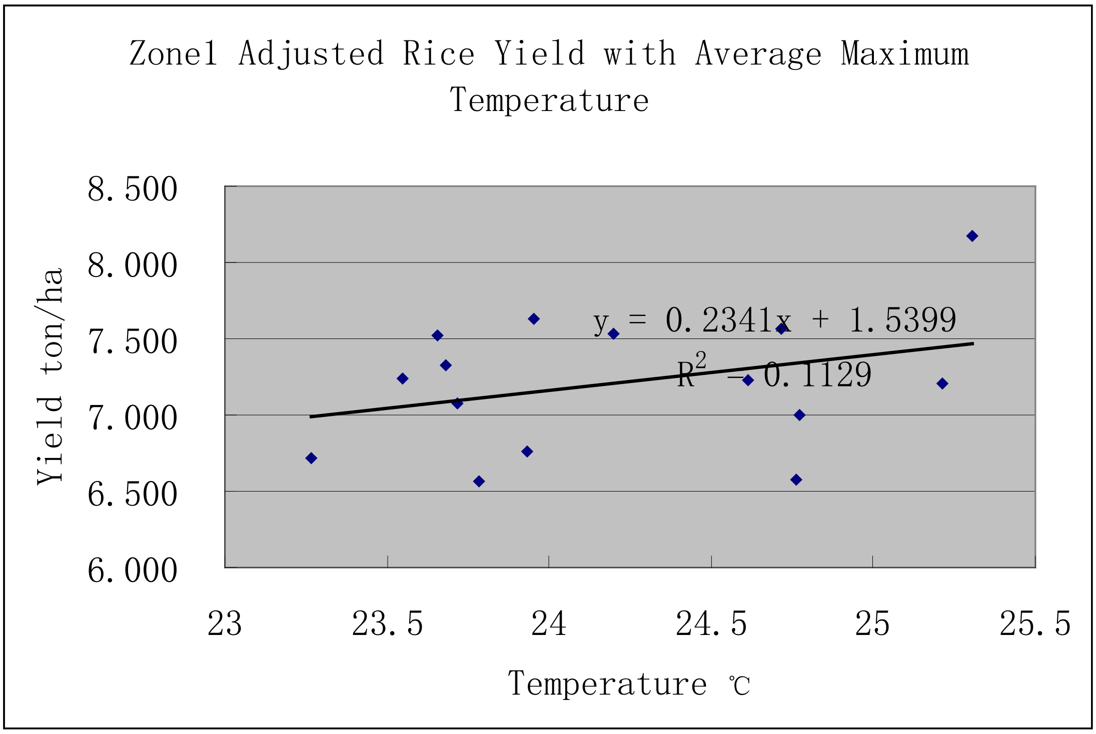

Figure 3.11 Linear Regression of Zone 1 Adjusted Per Unit Land Rice Yields with Average Maximum Temperature in Rice Growth Period

The regression is tested in R software, and the results are shown here:
Formula: y ~ a + b * xt
Parameters:

	Estimate	Std. Error	t value	Pr(>|t|)
a	1.5399	4.4066	0.349	0.732
b	0.2341	0.1820	1.286	0.221

Residual standard error: 0.4354 on 13 degrees of freedom
$R^2 = 0.1129$

The estimation of parameter for weather index is not good in this linear regression model.

A quadratic regression is also tested for Zone 1:

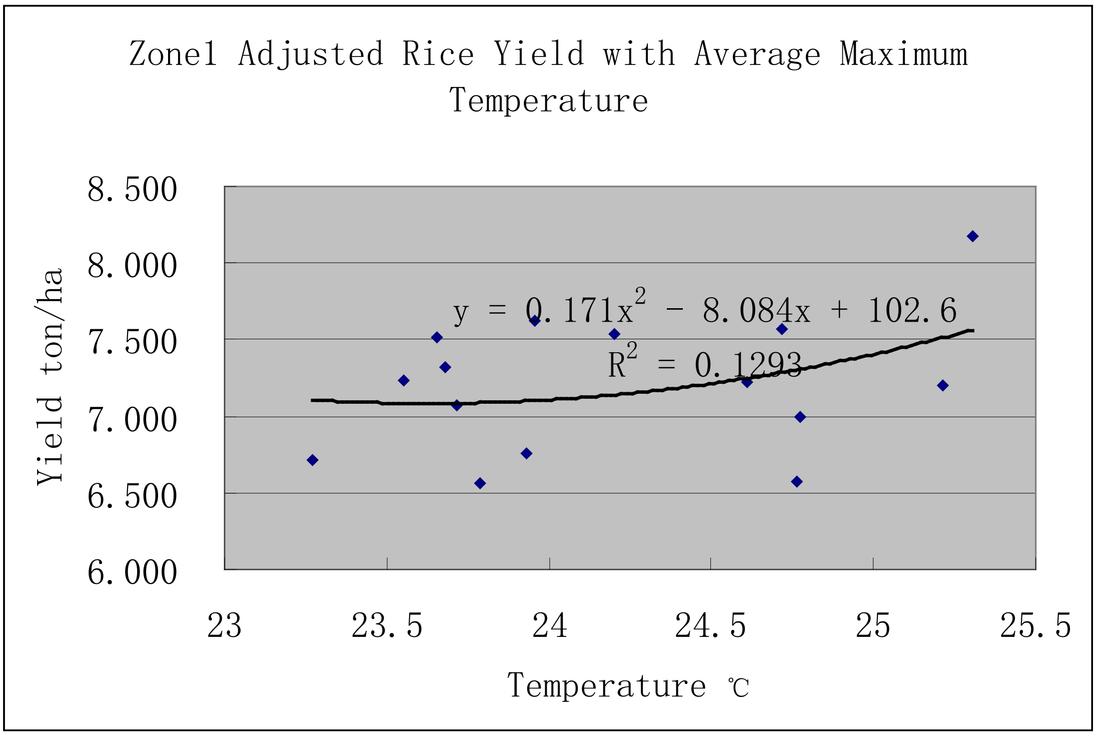

Figure 3.12 Quadratic Regression of Zone 1 Adjusted Per Unit Land Rice Yields with Average Maximum Temperature in Rice Growth Period

The regression results from R software:
Formula: y ~ a + b * xt + c * xt * xt
Parameters:

	Estimate	Std. Error	t value	Pr(>|t|)
a	102.5980	212.9394	0.482	0.639
b	-8.0840	17.5240	-0.461	0.653
c	0.1711	0.3603	0.475	0.644

Residual standard error: 0.4489 on 12 degrees of freedom
R^2 = 0.1293

Although the value of R^2 in quadratic regression is slightly larger than in the linear regression, the parameter estimation of weather indexes are all very bad in quadratic regression. The linear and quadratic regression models are both unsuitable for Zone 1. Since average maximum temperature is the weather index that most closely correlates with rice yield in Zone 1, other weather indexes designed in the previous section are expected to be more poorly correlated with rice yield. Thus, the weather index-based rice insurance cannot be built for Zone 1 by using this method.

Zone 2

For Zone 2, the same regression method with the highest monthly precipitation and rice yield per unit land is tested.

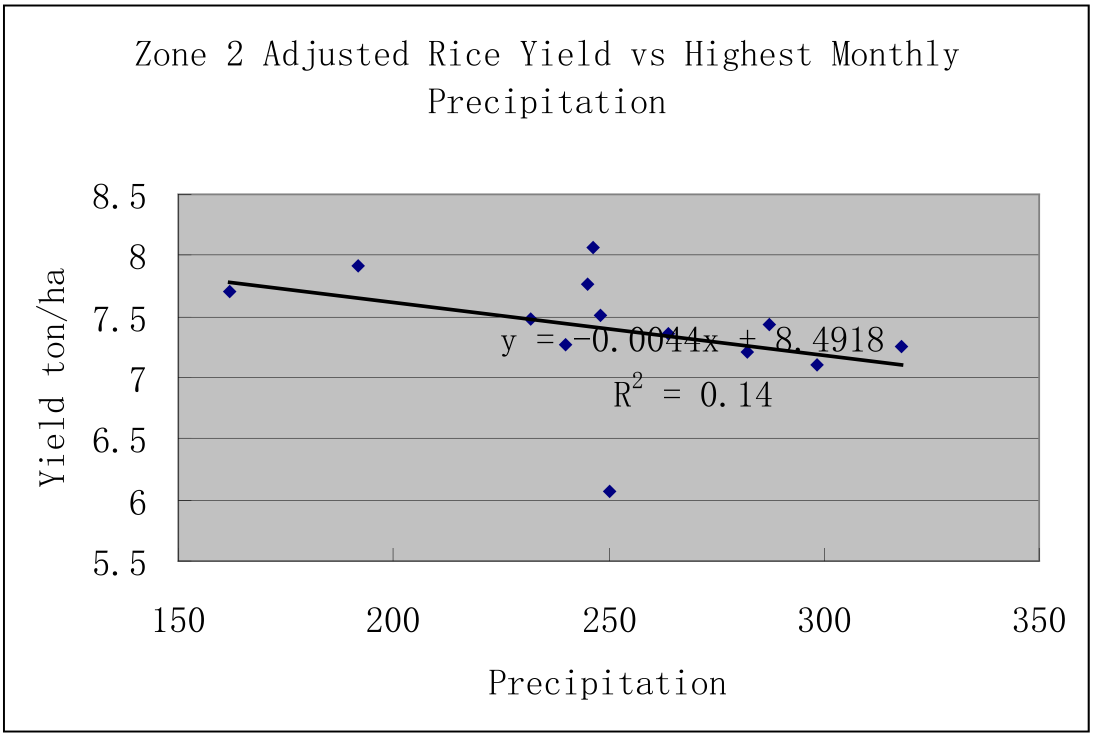

Figure 3.13 Linear Regression of Zone 2 Adjusted Per Unit Land Rice Yields with Highest Monthly Precipitation in Rice Growth Period

Regression result:

Formula: y ~ a + b * p

Parameters:

	Estimate	Std. Error	t value	Pr(>|t|)
a	8.491810	0.830143	10.229	5.89e-07 ***
b	-0.004367	0.003263	-1.338	0.208

Residual standard error: 0.4746 on 11 degrees of freedom

$R^2 = 0.14$

The estimation of parameter for weather index is not good in this linear regression model.

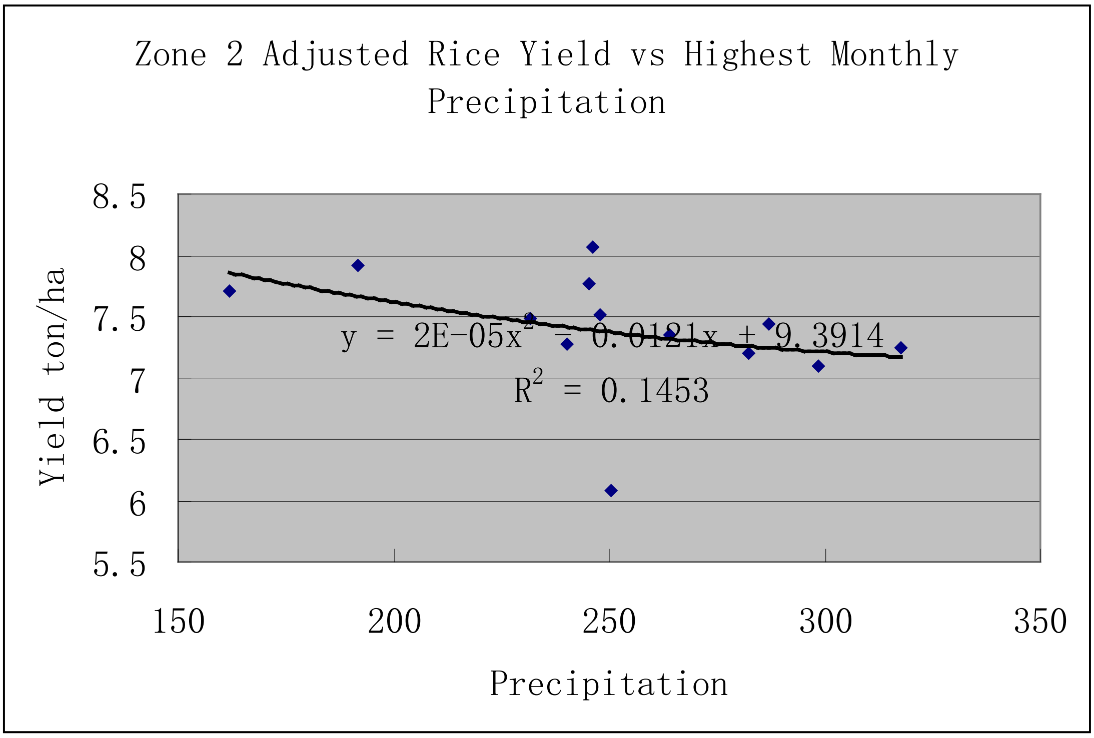

Figure 3.14 Quadratic Regression of Zone 2 Adjusted Per Unit Land Rice Yields with Highest Monthly Precipitation in Rice Growth Period

Regression result:

Formula: y ~ a + b * p + c * p * p

Parameters:

	Estimate	Std. Error	t value	Pr(>|t|)
a	9.391e+00	3.721e+00	2.524	0.0302 *
b	-1.208e-02	3.120e-02	-0.387	0.7068
c	1.602e-05	6.443e-05	0.249	0.8087

Residual standard error: 0.4962 on 10 degrees of freedom

$R^2 = 0.1453$

The parameter estimations of quadratic regression for Zone 2 are very poor. Since neither linear regression nor quadratic regression shows significance in parameter estimation, no weather index-based rice insurance will be built for Zone 2 using this method.

Zone 3

For Zone 3, the average wind speed is the weather index that most correlated with per unit land rice yield. Linear regression result is shown in Figure 3.15:

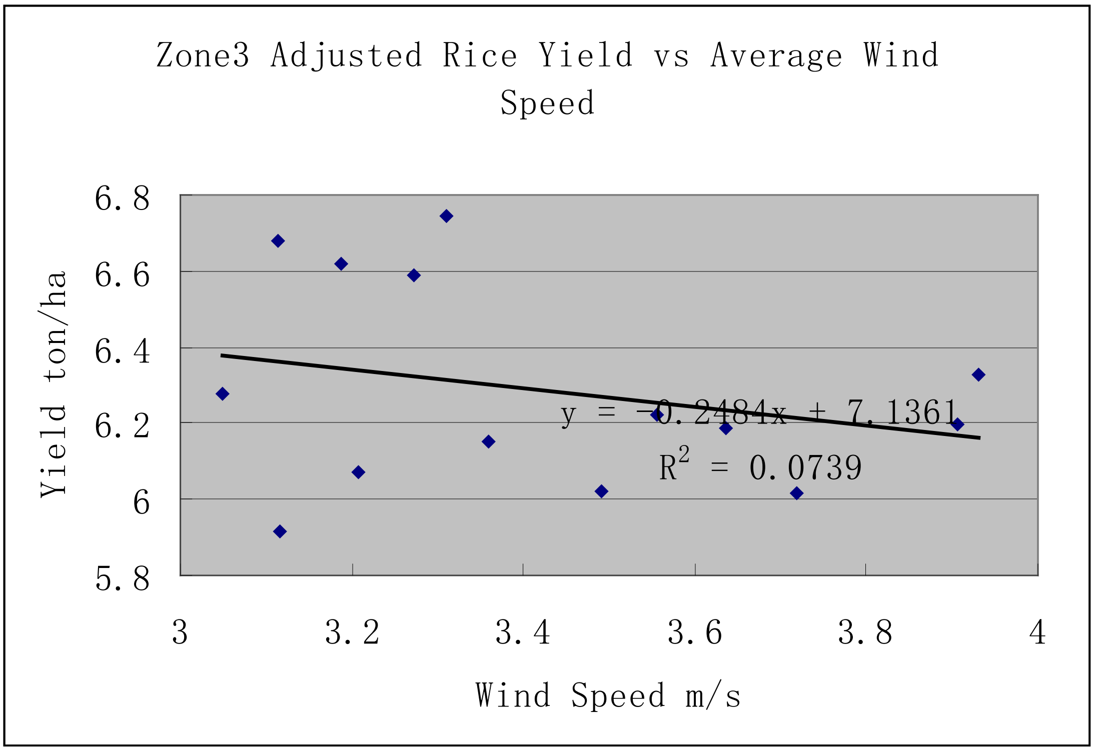

Figure 3.15 Linear Regression of Zone 3 Adjusted Per Unit Land Rice Yields with Average Wind Speed in Rice Growth Period

Regression result:

Formula: y ~ a + b * w

Parameters:

	Estimate	Std. Error	t value	Pr(>|t|)
a	7.1361	0.8708	8.195	2.94e-06 ***
b	-0.2484	0.2539	-0.978	0.347

Residual standard error: 0.2684 on 12 degrees of freedom

$R^2 = 0.0739$

The parameter estimation for weather index is poor in this linear regression model.

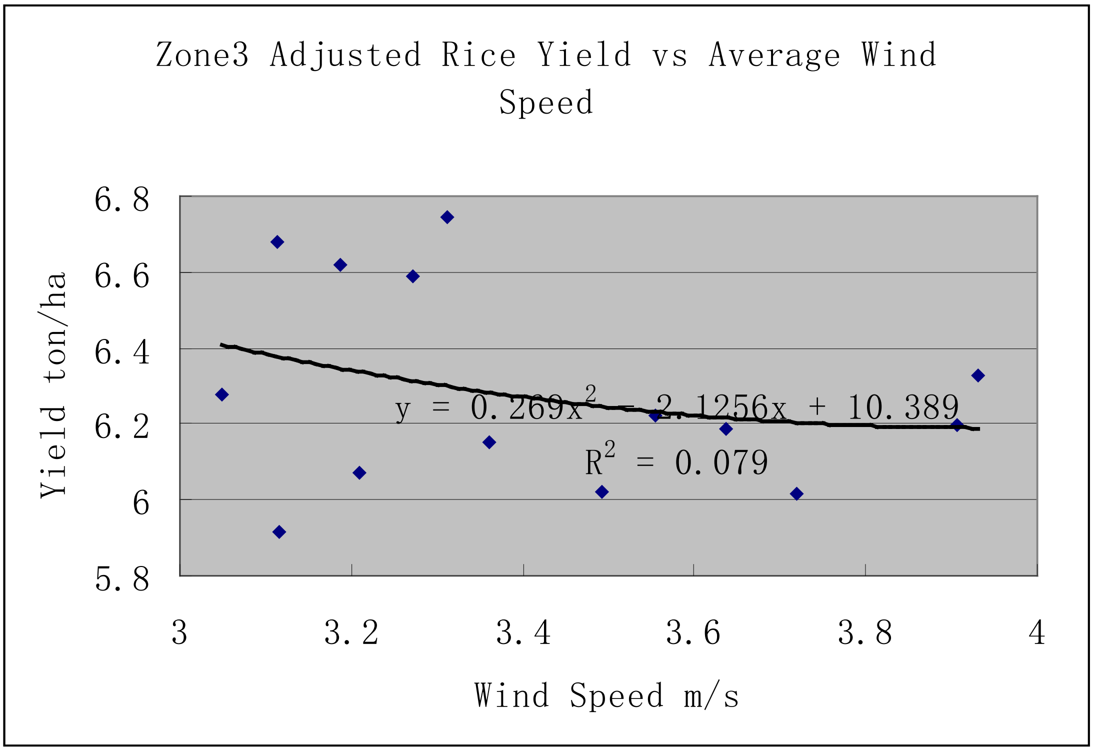

Figure 3.16 Quadratic Regression of Zone 3 Adjusted Per Unit Land Rice Yields with Average Wind Speed in Rice Growth Period

Regression result:
Formula: y ~ a + b * w + c * w * w
Parameters:

	Estimate	Std. Error	t value	Pr(>|t|)
a	10.389	13.199	0.787	0.448
b	-2.126	7.604	-0.280	0.785
c	0.269	1.089	0.247	0.809

Residual standard error: 0.2796 on 11 degrees of freedom
$R^2 = 0.079$

The parameter estimations of quadratic regression for Zone 3 are also very poor. Since neither linear regression nor quadratic regression shows significance in parameter estimation, no weather index-based rice insurance will be built for Zone 3 in this method.

Zone 4

For Zone 4, the same regression method with the highest monthly precipitation and rice yield per unit land will be tested.

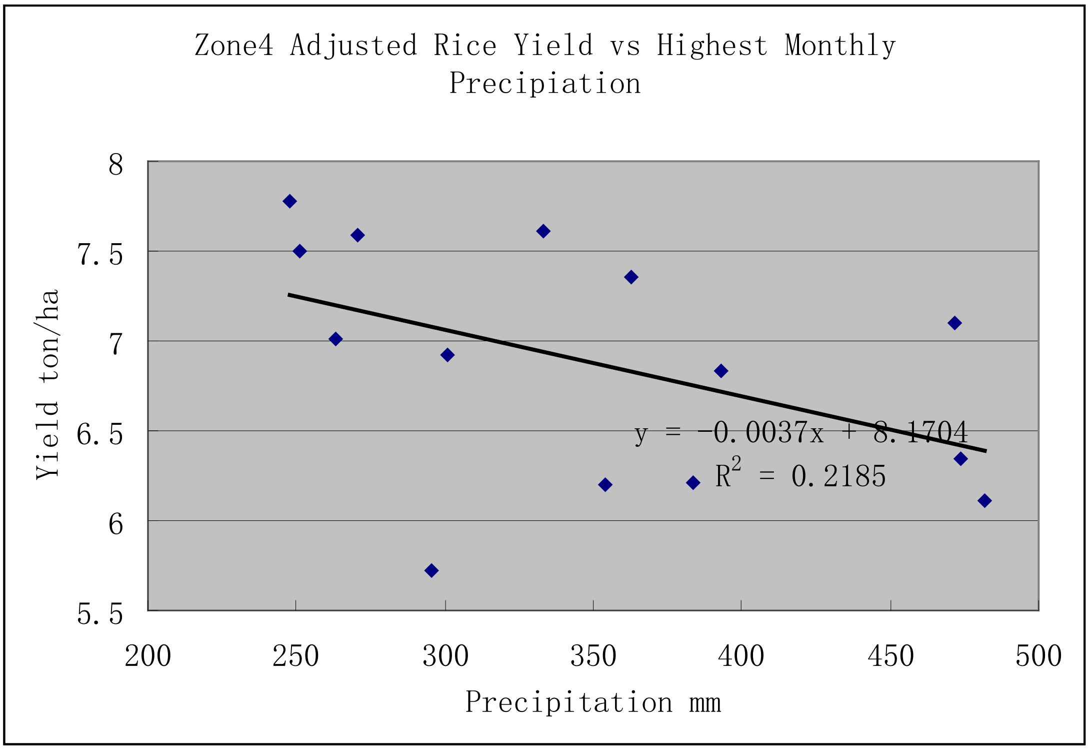

Figure 3.17 Linear Regression of Zone 4 Adjusted Per Unit Land Rice Yields with Highest Monthly Precipitation in Rice Growth Period

Regression result:

Formula: y ~ a + b * p

Parameters:

	Estimate	Std. Error	t value	Pr(>|t|)
a	8.170374	0.724085	11.284	9.57e-08 ***
b	-0.003706	0.002023	-1.832	0.0919 .

Residual standard error: 0.6076 on 12 degrees of freedom

$R^2 = 0.2185$

The estimation of parameter for weather index is not very good but acceptable in this linear regression model.

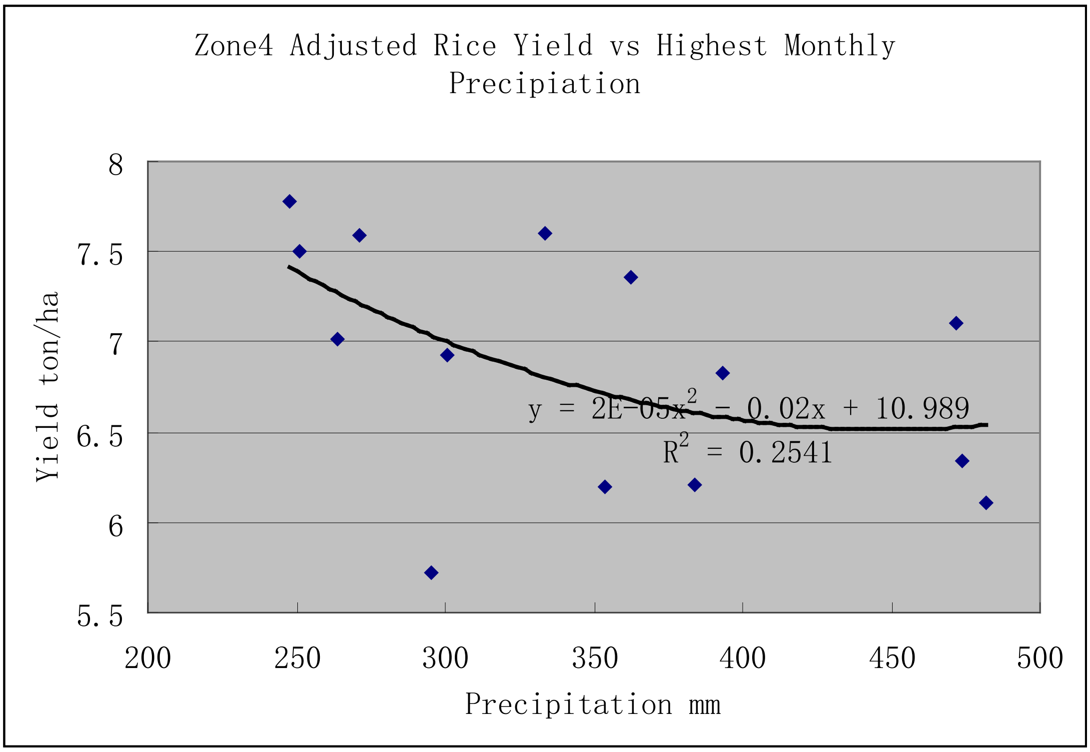

Figure 3.18 Quadratic Regression of Zone 4 Adjusted Per Unit Land Rice Yields with Highest Monthly Precipitation in Rice Growth Period

Regression result:
Formula: y ~ a + b * p + c * p * p
Parameters:

	Estimate	Std. Error	t value	Pr(>|t|)
a	1.099e+01	3.961e+00	2.774	0.0181 *
b	-1.995e-02	2.253e-02	-0.886	0.3947
c	2.224e-05	3.071e-05	0.724	0.4840

Residual standard error: 0.620 on 11 degrees of freedom
$R^2 = 0.2541$

The parameter estimations of quadratic regression for Zone 4 are very poor compared to the linear regression function, although the R^2 value is slightly larger. The linear regression model will be chosen for the weather index insurance model for Zone 4.

Zone 5

For Zone 5, the average wind speed is the weather index that most correlated with per unit land rice yield. The linear regression result is shown in Figure 3.19:

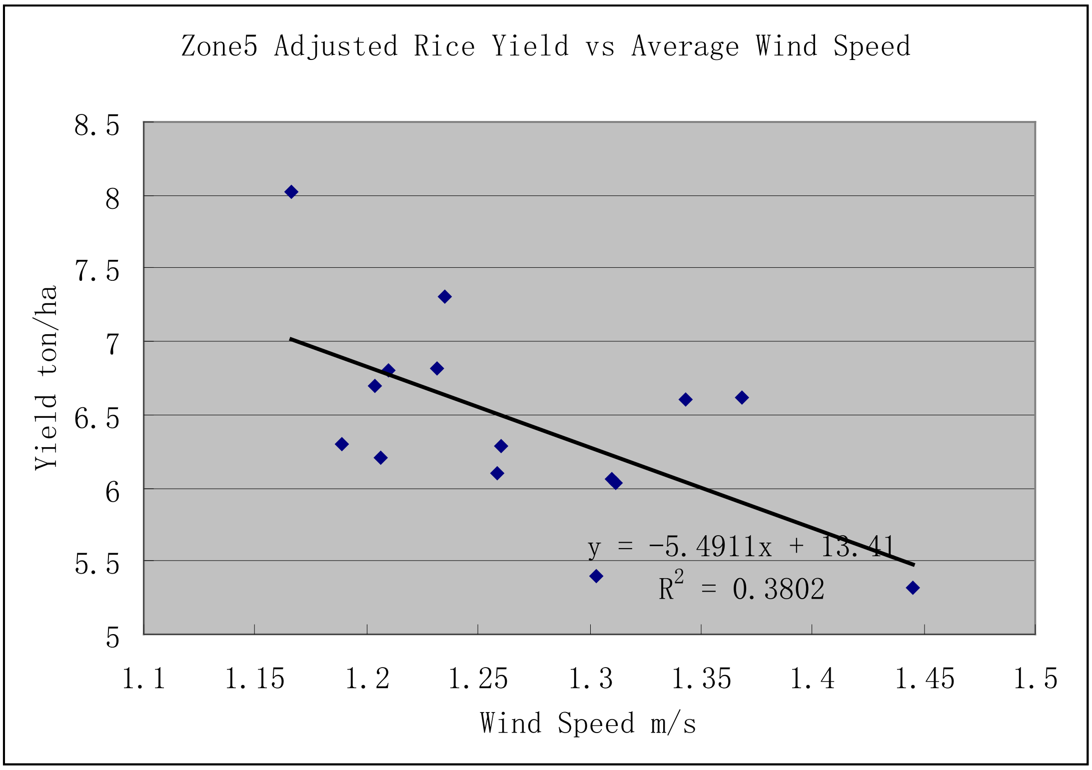

Figure 3.19 Linear Regression of Zone 5 Adjusted Per Unit Land Rice Yields with Average Wind Speed in Rice Growth Period

Regression result:

Formula: y ~ a + b * w

Parameters:

	Estimate	Std. Error	t value	Pr(>|t|)
a	13.410	2.473	5.423	0.000116 ***
b	-5.491	1.945	-2.824	0.014365 *

Residual standard error: 0.5586 on 13 degrees of freedom

$R^2 = 0.3802$

The parameter estimation for weather index is quite good in this linear regression model for Zone 5.

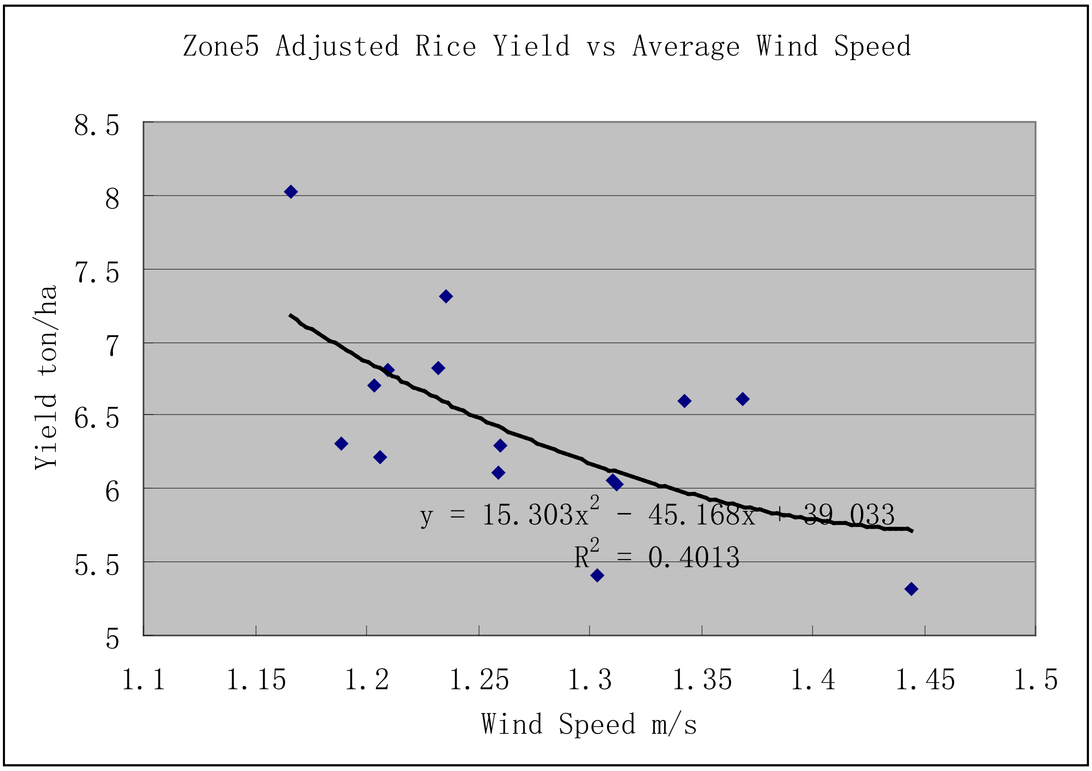

Figure 3.20 Quadratic Regression of Zone 5 Adjusted Per Unit Land Rice Yields with Average Wind Speed in Rice Growth Period

Regression result:
Formula: y ~ a + b * w + c * w * w
Parameters:

	Estimate	Std. Error	t value	Pr(>|t|)
a	39.03	39.40	0.991	0.341
b	-45.17	60.91	-0.741	0.473
c	15.30	23.48	0.652	0.527

Residual standard error: 0.5714 on 12 degrees of freedom
$R^2 = 0.4013$

The parameter estimations of quadratic regression for Zone 5 are very poor compared to the linear regression function, although the R^2 value is slightly larger. The linear regression model will be chosen for the weather index insurance model for Zone 5.

Zone 6

For Zone 6, the highest monthly precipitation is the weather index that most correlated with per unit land rice yield. The regression results are shown in Figure 3.21 and Figure 3.22:

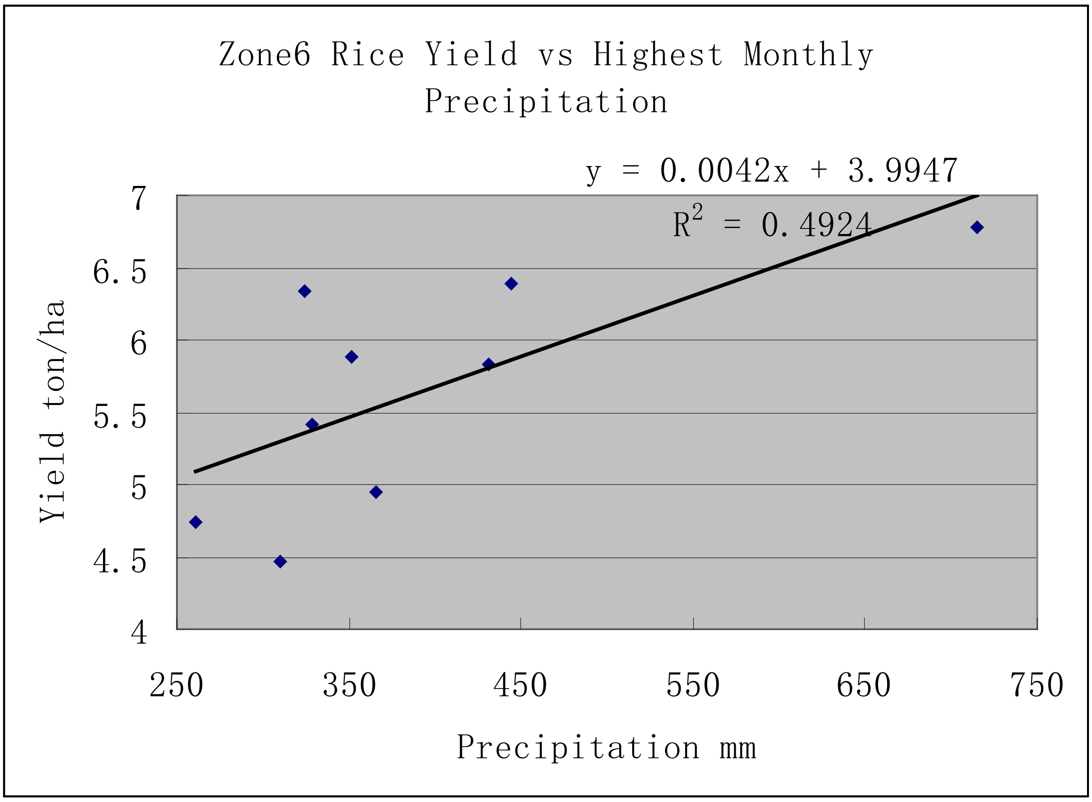

Figure 3.21 Linear Regression of Zone 6 Per Unit Land Rice Yields with Highest Monthly Precipitation in Rice Growth Period

Regression result:

Formula: y ~ a + b * p

Parameters:

	Estimate	Std. Error	t value	Pr(>|t|)
a	3.994666	0.665527	6.002	0.000541 ***
b	0.004209	0.001615	2.606	0.035116 *

Residual standard error: 0.6117 on 7 degrees of freedom

$R^2 = 0.4924$

The estimation of parameter for weather index is quite good in this linear regression model for Zone 6.

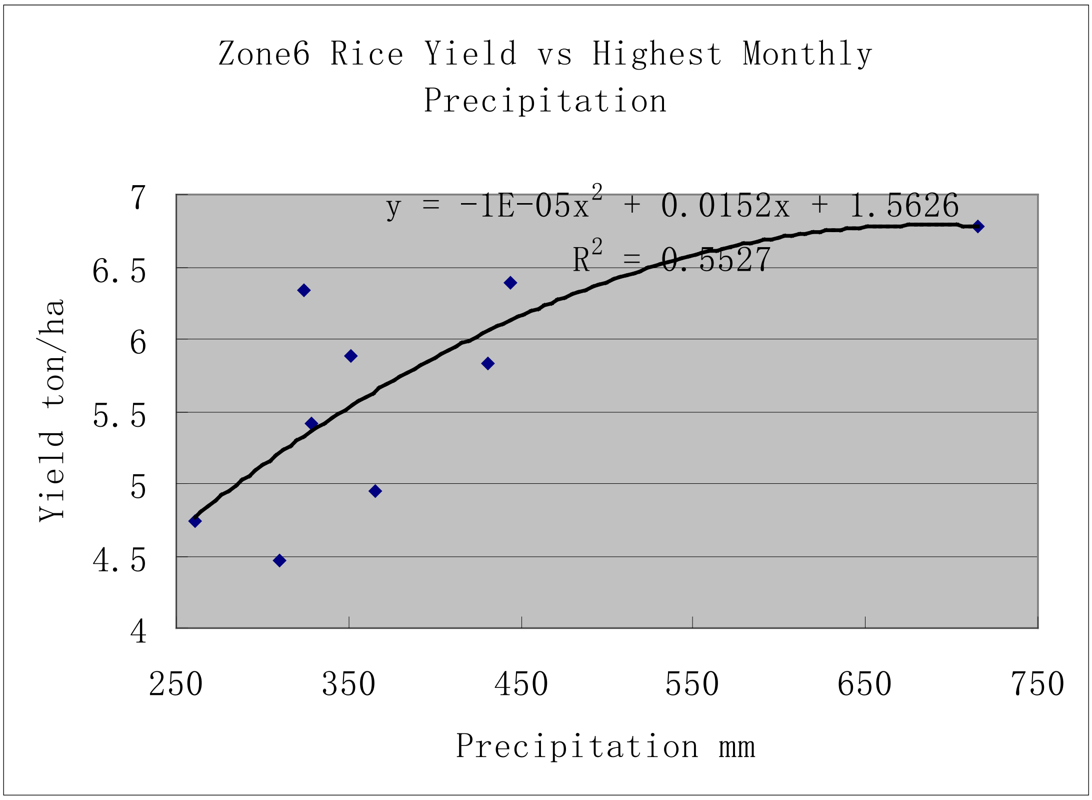

Figure 3.22 Quadratic Regression of Zone 6 Per Unit Land Rice Yields with Highest Monthly Precipitation in Rice Growth Period

Formula: y ~ a + b * p + c * p * p

Parameters:

	Estimate	Std. Error	t value	Pr(>|t|)
a	1.563e+00	2.788e+00	0.561	0.595
b	1.518e-02	1.231e-02	1.233	0.264
c	-1.102e-05	1.226e-05	-0.899	0.403

Residual standard error: 0.6203 on 6 degrees of freedom

$R^2 = 0.5527$

The R^2 value is larger in quadratic regression than in linear regression for Zone 6. However, the parameter estimations in quadratic regression are very poor. Therefore the linear regression function will be chosen for the weather index insurance model for Zone 6.

Here is a summary of the function chosen for each rice cropping zone in Zhejiang:

Rice Cropping Zone	Function
Zone 1	None
Zone 2	None
Zone 3	None
Zone 4	y= -0.003706 * hmp + 8.170374
Zone 5	y= -5.4911 * aw + 13.41
Zone 6	y= 0.004209 * hmp + 3.994666

Table 3.10 Function Chosen for Each Rice Cropping Zone in Zhejiang

3.3.3 Discussion

Weather index modeling part is largely completed for Zhejiang province as shown above. No suitable weather index can be found for Zone 1-3, because of a bad correlation between rice yield per unit land and the weather indexes. For Zone 4-6, a linear regression model may be the best fit for the relationship between rice yield per unit land and the weather index which is most correlated with the rice yield. In Zone 4, highest monthly precipitation in rice growth period is negatively correlated with rice yield per unit land, which may suggest that the rainfall is more than sufficient for rice planting in Zone 4. In Zone 5, the rice yield per unit land is negatively correlated with average wind speed, which suggests that high wind has the largest impact on the rice production in this region. In Zone 6, the highest monthly precipitation in rice growth period is positively correlated with rice yield per unit land, which may suggest that water is scarce in Zone 6 for rice planting.

However, before we go further to the insurance product design, we first look back at the results of the weather index modeling to check whether the regression method is really feasible here. The ordinary least squares method can be fitted only when its underlying assumptions are true, which include that the error term of the observations has a constant variance (homoscedastic variables) and there should be no outliers which come from different data-generating process as the rest of the data. Regarding these assumptions in our data, there seems to be an outlier in Zone 2. Furthermore, in Zone 3 the sequence of the observations tends to be heteroscedastic (see Figure 3.13 and Figure 3.15).

Due to the limited information and small sample size in our case study, it is not clear what the reason was for the abnormal point in Zone 2, and whether it is an outlier or just a random error. If it is an outlier, using OLS will lead to inefficient and biased results. In this situation, the robust regression [102], which is designed to be not overly affected by violation of assumptions by the underlying data-generating process especially in presence of outliers, may be an alternative of OLS to fit in here.

The adjusted rice yield variables in Zone 3 tend to be heteroscedastic as observed in Figure 3.15, because the variables seem to converge to the regression line along with the increase of x axis. The correlation between the absolute value of the error term and independent variable is -0.56. In this case, the assumption of OLS that error term should not correlate with regressor is violated. Since the data sample is rather small, we cannot accurately distinguish whether the heteroscedastic error observation is a systematic trend or just a part of the randomly distributed errors. But if it is a systematic trend, then the average wind speed alone can not be chosen as the weather index for the linear regression in Zone 3. An instrumental variable [103], which is correlated with the endogenous explanatory variables and uncorrelated with the error term, should be found to replace the present independent variable.

Because of limited time and resources, these two problems will not be studied further in this thesis. However, special attention should be paid to these problems in the future works on this topic, because they are critical issues when estimating the efficiency and consistency of the regression modeling methods.

3.4 Insurance Product Design

In this section, the weather index-based rice insurance product will be roughly designed based on the weather-yield model in the previous section. The premium and indemnity will be calculated at assumed strike level for the insurable farmers in Zhejiang.

3.4.1 Rice price

Because of the complicated rice cropping system, the rice price of each rice cropping zone differs. Based on the rice price information of year 2003 [104], the rice price of each zone is calculated according to the planting area proportion of each kind of rice in that region. The rice price of each zone is listed in Table 3.11:

		Indica early rice	Indica late rice	Japonica rice	Weighted Sum
Zone 1	Price Yuan/kg	1.4	1.5	1.7	1.68
	Planting Area	1.7%	7.9%	90.4%	100%
Zone 2	Price Yuan/kg	1.4	1.5	1.7	1.59
	Planting Area	18.0%	25.7%	56.3%	100%
Zone 3	Price Yuan/kg	1.4	1.5	1.7	1.60
	Planting Area	25.6%	33.2%	43.9%	100%
Zone 4	Price Yuan/kg	1.4	1.5	1.7	1.56
	Planting Area	28.0%	27.4%	44.6%	100%
Zone 5	Price Yuan/kg	1.4	1.5	1.7	1.65
	Planting Area	9.1%	10.9%	80.0%	100%
Zone 6	Price Yuan/kg	1.4	1.5	1.7	1.66
	Planting Area	7.5%	7.0%	85.5%	100%

Table 3.11 Rice Price of Each Rice Cropping Zone in Zhejiang

The weighted sum of price for each kind of rice in the zone will be used as the zonal rice price in the insurance product design for 2004.

3.4.2 Indemnity

As introduced in Function 22 in Chapter 2, the indemnity amount in the insurance contract is a function of weather index-based rice yield strike level K and tick size γ. The tick size γ can be replaced by the rice price calculated in section 3.4.1 above. So to determine the indemnity amount, we just need to set the strike level K. We assume that the potential insurance clients are absolutely risk adverse, which means they will get payoff when any loss occurs in the rice yield in the next year. The strike level K should be set at the average level of the rice yield in our data history. Based on the regression result in Table 3.10, we have the strike level K for each zone as following:

Strike Level K	Zone 4	Zone 5	Zone 6
Weather Index	HMP >348.8 mm	AW >1.269 m/s	HMP <392.3 mm
Rice Yield (ton/ha)	6.878	6.439	5.646

Table 3.12 Strike Level K for Rice Cropping Zone 4-6 of Zhejiang

For Zone 4, when the highest monthly precipitation is more than 348.8 mm the rice yield loss occurs, compared to the average rice yield 6.878 ton/ha; for Zone 5, when the average wind speed is more than 1.269 m/s the rice yield loss occurs, compared to the average rice yield 6.439 ton/ha; for Zone 6, when the highest monthly precipitation is less than 392.3 mm the rice yield loss occurs, compared to the average rice yield 5.646 ton/ha.

The indemnity amount for each rice cropping zone for year 2004 is then calculated according to Function 22 in Chapter 2:

	Indemnity (Yuan/ha)
Zone 4	= 30.76 * max(X-348.8, 0)
Zone 5	= 8370 * max(X-1.269, 0)
Zone 6	= 23.89 * max(392.3-X, 0)

Table 3.12 Indemnity Amount for Weather Index-based Rice Insurance Contract in Rice Cropping Zone 4-6 of Zhejiang

Of course, the strike level K is not a fixed value in the insurance design; we can set different values for the strike level of weather index to satisfy different demands of the farmers. If the potential insurance clients are risk-loving farmers, and they will buy the insurance product only when severe rice yield loss occurs, then we may set the strike level at another point of the weather index where the rice yield loss exceeds a certain high level (e.g. 50% of the average rice yield). In this case, the premium that the farmers need to pay to the insurer will be lower, but the farmers themselves need to bear a higher risk of rice yield loss compared to the strike level we set above. An investigation needs to be done before underwriting the insurance policy to estimate the potential clients' behavior whilst exposed to risk. The decision of strike level K should be based on the result of this investigation.

3.4.3 Pure Premium

According to Function 23 in Chapter 2, the pure premium is the expected annual loss of historical rice yield data, which equals to the sum of indemnity in our data history multiplied by its occurrence probability. To continue the insurance design based on the strike level set in section 3.4.2, we show the calculation results of pure premium in rice cropping Zone 4-6 in the following tables:

Zone 4

Year	HMP (mm)	Adjust Rice Yield (ton/ha)	HMP Predicted Rice Yield (ton/ha)	Annual Yield Loss (ton/ha)
1987	362.5	7.359	6.827	0.051
1988	263.5	7.016	7.194	0
1989	393.15	6.828	6.713	0.164

1991	270.85	7.593	7.167	0
1993	471.65	7.105	6.422	0.455
1995	473.75	6.345	6.415	0.463
1996	300.8	6.927	7.056	0
1997	383.75	6.209	6.748	0.130
1998	481.75	6.106	6.385	0.493
1999	295.55	5.722	7.075	0
2000	353.75	6.196	6.859	0.018
2001	247.9	7.774	7.252	0
2002	333.3	7.607	6.935	0
2003	251.3	7.500	7.239	0
Average	348.8	6.878	6.878	0.127

Table 3.13 Zone 4 Annual Rice Yield Loss Calculation Results

Zone 5

Year	AW	Adjust Rice Yield ton/ha	AW Predicted Rice Yield ton/ha	Annual Yield Loss ton/ha
1986	1.210	6.806	6.768	0
1987	1.189	6.304	6.883	0
1988	1.310	6.055	6.217	0.223
1989	1.260	6.291	6.489	0
1991	1.203	6.700	6.803	0
1993	1.259	6.105	6.498	0
1995	1.206	6.212	6.787	0
1996	1.343	6.603	6.036	0.404
1997	1.232	6.816	6.645	0
1998	1.303	5.404	6.255	0.185
1999	1.312	6.030	6.206	0.234
2000	1.369	6.616	5.895	0.544
2001	1.166	8.026	7.008	0
2002	1.235	7.313	6.627	0
2003	1.445	5.313	5.477	0.963
Average	1.269	6.440	6.439	0.170

Table 3.14 Zone 5 Annual Rice Yield Loss Calculation Results

Zone 6

Year	HMP	Adjust Rice Yield ton/ha	HMP Predicted Yield ton/ha	Annual Yield Loss ton/ha
1986	310.3	4.473	5.301	0.345
1987	328.3	5.414	5.376	0.269
1988	260.4	4.745	5.091	0.555
1989	365.5	4.942	5.533	0.113

1991	323.9	6.339	5.358	0.288
1993	351.8	5.888	5.475	0.170
1995	444.4	6.395	5.865	0
1996	714.8	6.781	7.003	0
1997	431.1	5.833	5.809	0
Average	392.3	5.646	5.646	0.193

Table 3.15 Zone 6 Annual Rice Yield Loss Calculation Results

Please note that because of the lack of weather data from 1998 to 2003 for Zone 6, the weather index-based rice insurance model can only be built upon the rice yield data till 1997.

So we have the pure premium results of Zone 4-6 as shown in Table 3.16:

	Zone 4	Zone 5	Zone 6
Expected Annual Yield Loss (ton/ha)	0.127	0.170	0.193
Pure Premium (Yuan/ha)	197.7	280.8	320.8

Table 3.16 Pure Premium for Weather Index-based Rice Insurance Contract in Rice Cropping Zone 4-6 of Zhejiang

If we do not consider the risk loading of the insurer in our insurance model, the weather index-based rice insurance design is so far complete for Zhejiang. The weather index-based rice insurance cannot be applied in rice cropping zone 1-3, because of bad parameter estimation in the weather index and rice yield model fitting. For Zone 4 – 6, the weather index-based rice insurance is designed as following:

		Zone 4	Zone 5	Zone 6
Weather Index	Designation	Highest Monthly Precipitation	Average Wind Speed	Highest Monthly Precipitation
	Reference Point	Weather Station Jinhua 58549, Quzhou 58633	Weather Station Lishui 58646, Longquan 58647	Weather Station Tianmushan 58445
	Period	March-November	March-November	March-November
	Calculation	$HMP = \max\left\{\sum_{t=1}^{nm} P_{(t,m)}\right\}$	$AW = \frac{1}{n}\sum_{t=1}^{n} W_t$	$HMP = \max\left\{\sum_{t=1}^{nm} P_{(t,m)}\right\}$
	Strike Level	348.8 mm	1.269 m/s	392.3 mm
Tick Size		30.76 Yuan/ index point	8370 Yuan/ index point	23.89 Yuan/ index point
Contract Time		1 year till 31.12.2004	1 year till 31.12.2004	1 year till 31.12.1998
Payoff		30.76 * max(X-348.8, 0)	8370 * max(X-1.269, 0)	23.89 * max(392.3-X, 0)
Pure Premium		197.7 Yuan/ha	280.8 Yuan/ha	320.8 Yuan/ha

Table 3.17 Weather Index-based Rice Insurance Contract Design in Rice Cropping Zone 4-6 of Zhejiang

The hedging efficiency of our insurance model is tested according to Function 24 and Function 25 in Chapter 2, the results are shown in Table 3.18:

	Zone 4		Zone 5		Zone 6	
Insurance Contract	Without	With	Without	With	Without	With
Variance in Farmers' Rice Yield Income $(ton/ha)^2$	0.4360	0.3802	0.4675	0.3602	0.6451	0.4798
Hedging Efficiency	12.79%		22.94%		25.63%	

Table 3.18 Hedging Efficiency of the Weather Index-based Rice Insurance Model

The results show that the variance in farmers' rice yield income in Zone 4, Zone 5 and Zone 6 would have been reduced by 12.79%, 22.94%, and 25.63% if our insurance model were applied during the data sample years.

3.4.4 Risk Premium

In the pure premium model, the risk loading of the insurer is not considered in the premium calculation, which means that the insurer has to bear all the risk of the misspecification of the weather index process and parameter uncertainty in the weather index-based insurance model. If the risk is rather high for the insurer, an additional risk premium may be added to the pure premium to have the policyholders share part of the risk.

Based on the models for rice cropping zone 4-6 in the last section 3.3, a plotting of the weather index-predicted rice yield has been made with regressor parameters varying within $\pm\sigma$. Since the significance of the intercept in all three regression functions is very good, thus it is supposed that the intercept is a fixed value, and only the weather index parameter varies within $\pm\sigma$. The graphs of Zone 4-6 are shown in Figure 3.23 to Figure 3.25:

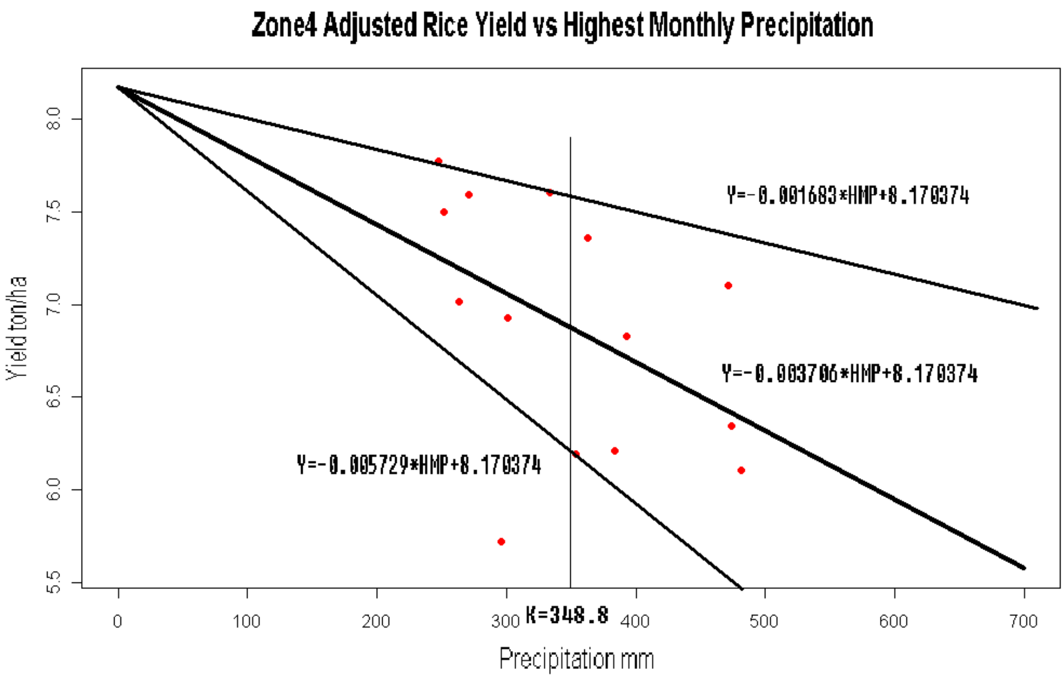

Figure 3.23 Zone 4 Ajusted Rice Yield with Highest Monthly Precipitation when Regressor

Parameter Varies within $\pm\sigma$

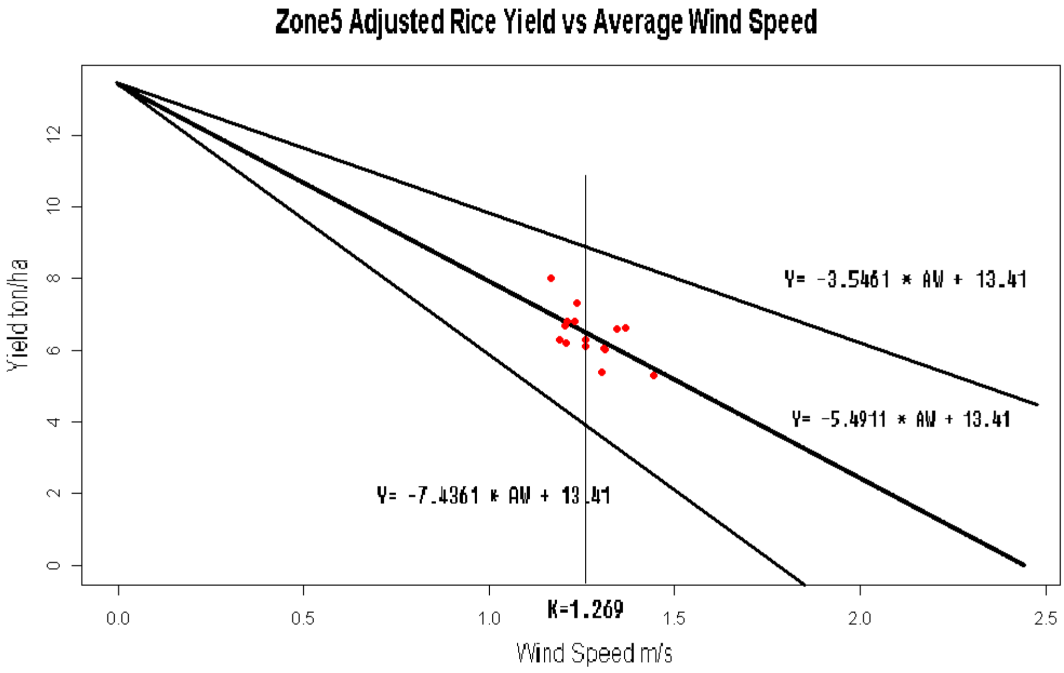

Figure 3.24 Zone 5 Ajusted Rice Yield with Average Wind Speed when Regressor Parameter Varies within $\pm\sigma$

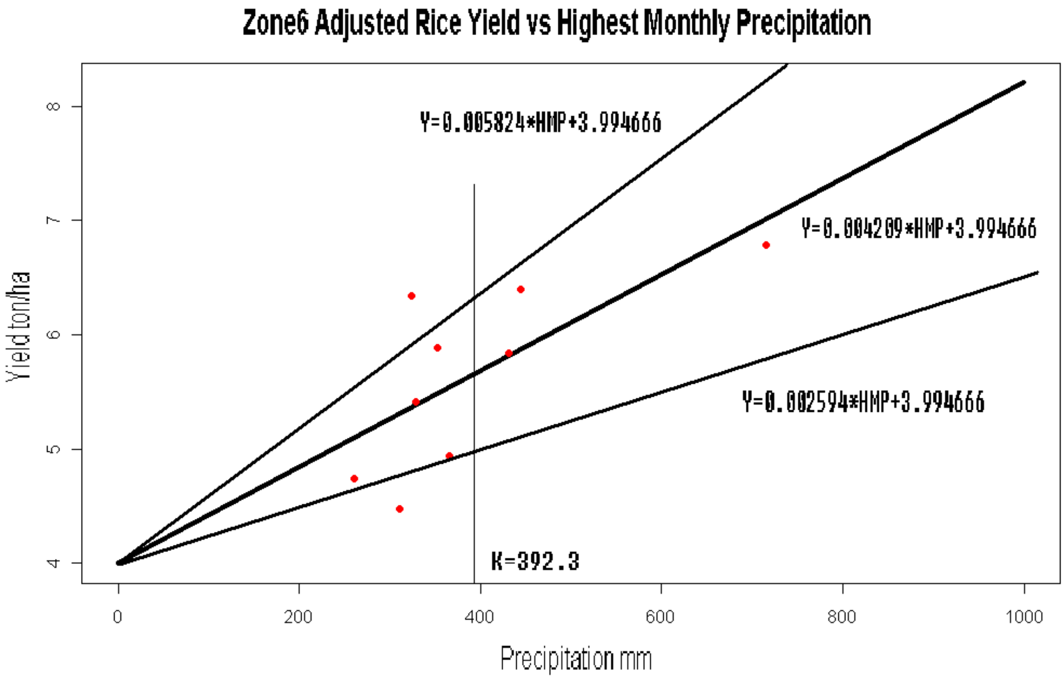

Figure 3.25 Zone 6 Ajusted Rice Yield with Highest Monthly Precipitation when Regressor Parameter Varies within $\pm\sigma$

At the present weather index strike level K for each zone, the average annual yield loss is calculated when the regressor parameter α varies within $\pm\sigma$. The results of the calculation are shown in Table 3.19:

		Parameter α	Parameter α+σ	Parameter α-σ
Zone4	Average Annual Yield Loss (ton/ha)	0.127	0.058	0.196
	% Change in Average Annual Yield Loss		-54.6%	54.5%
Zone5	Average Annual Yield Loss (ton/ha)	0.170	0.110	0.230
	% Change in Average Annual Yield Loss		-35.4%	35.4%
Zone6	Average Annual Yield Loss (ton/ha)	0.193	0.268	0.119
	% Change in Average Annual Yield Loss		38.4%	-38.3%

Table 3.19 Change of Average Annual Yield Loss when Regressor Parameter Varies within $\pm\sigma$ for Zone 4-6

The calculation result shows that: for Zone 4, the average annual yield loss has a $\pm$54.5% change when regressor parameter varies within $\pm\sigma$; for Zone 5, the average annual yield loss has a $\pm$35.4% change when regressor parameter varies within $\pm\sigma$; for Zone 6, the average annual yield loss has a $\pm$38.4% change when regressor parameter varies within $\pm\sigma$. The percentage change in average annual yield loss equals to the expected annual yield loss change, and hence equals to the change of the pure premium. The insurer should consider whether this risk loading of loss due to the regressor parameter uncertainty will be borne by the insurer himself alone or by sharing with the insurable farmers. If a risk premium is added in the insurance contract to share the weather model risk with the insurable farmers, the coefficient λ of Function 21 in Chapter 2 should be calculated and tested. Since it is within the actuarial science domain, we will not go further in the risk premium calculation in this thesis. This part may be studied in depth by the actuaries in insurance companies if our weather index-based rice insurance model is applied in practice.

3.4.5 Discussion

The insurance product design in this thesis is rather simple compared to real insurance products, and detailed actuarial calculation may be continued later to further develop the methodology used in this pilot study. There are several points to be studied further in future insurance design:

1. Price volatility for different rice species and different seasonal rice should be considered in the model. In our insurance contract design, the rice price of the next year is supposed to be the same as the average value of all the rice species in the last year to simplify the insurance product design. However, the rice price had a quite big jump in 2003 and 2004 for some rice varieties with an increase of almost 50%. And from the second half year of 2004, the rice price of all rice varieties started to decline gradually [104]. If the price volatility is considered in the insurance model design, the risk of such dramatic pricing change may be reduced to some extent.
2. The pure premium calculation in section 3.4.3 was based on the assumption that the next

year’s weather conditions and the relationship between rice yield and weather index would be identical to what happened during our data sample period. However, there exist two critical questions: First, the time range of our data sample is rather short, thus it is unlikely that the weather observed in this short period can represent the real weather conditions for a wider time period including the insurance contract year; Second, if there is a trend in the change of our weather indexes, which may be caused by industrial development or pollutions, the probability of the occurrence of certain weather index levels will be different as the statistic results of the historical weather data (e.g. if the average temperature is increasing over time the probability of high average temperature will be higher than the statistic result in the past because of the increasing trend). To solve these problems, further studies should be conducted to collect weather and rice yield data over a longer period of time. In the present case study, the pattern of climate change is depicted in Appendix I, but not studied further.

3. As discussed in section 3.4.4, the risk premium part in the insurance contract design needs to be carefully studied by actuaries in the future.

Chapter 4

Conclusions and Discussions

4.1 Results and Conclusions

The pilot study of weather index-based rice insurance design for Zhejiang province is so far completed. The rice cropping zone is chosen as the insurable farming land unit for each rice insurance contract in Zhejiang. The rice yield data was first treated by removing the time trend if there is a clear technology improvement in the time series. A correlation test was then conducted to determine the weather index which is most correlated with the adjusted rice yield data. The relationship between the adjusted rice yield and weather index was found out by testing linear and quadratic regression functions. A weather index-based annual rice insurance contract was finally designed based on the weather-yield model, and the pure premium and indemnity amount were calculated for the contract. The results of the weather index-based rice insurance contract design for each rice cropping zone in Zhejiang are shown in Table 4.1 and Table 4.2:

	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6
Insurability	No	No	No	Yes	Yes	Yes

Table 4.1 The Insurability of Weather Index-based Rice Insurance for Each Rice Cropping Zone in Zhejiang

<table>
<tr><td colspan="2"></td><td>Zone 4</td><td>Zone 5</td><td>Zone 6</td></tr>
<tr><td rowspan="5">Weather Index</td><td>Designation</td><td>Highest Monthly Precipitation</td><td>Average Wind Speed</td><td>Highest Monthly Precipitation</td></tr>
<tr><td>Reference Point</td><td>Weather Station Jinhua 58549, Quzhou 58633</td><td>Weather Station Lishui 58646, Longquan 58647</td><td>Weather Station Tianmushan 58445</td></tr>
<tr><td>Period</td><td>March-November</td><td>March-November</td><td>March-November</td></tr>
<tr><td>Calculation</td><td>$HMP = \max\left\{\sum_{t=1}^{nm} P_{(t,m)}\right\}$</td><td>$AW = \frac{1}{n}\sum_{t=1}^{n} W_t$</td><td>$HMP = \max\left\{\sum_{t=1}^{nm} P_{(t,m)}\right\}$</td></tr>
<tr><td>Strike Level</td><td>348.8 mm</td><td>1.269 m/s</td><td>392.3 mm</td></tr>
<tr><td colspan="2">Tick Size</td><td>30.76 Yuan/ index point</td><td>8370 Yuan/ index point</td><td>23.89 Yuan/ index point</td></tr>
<tr><td colspan="2">Contract Time</td><td>1 year till 31.12.2004</td><td>1 year till 31.12.2004</td><td>1 year till 31.12.1998</td></tr>
<tr><td colspan="2">Indemnity</td><td>30.76 * max(X-348.8, 0)</td><td>8370 * max(X-1.269, 0)</td><td>23.89 * max(392.3-X, 0)</td></tr>
<tr><td colspan="2">Pure Premium</td><td>197.7 Yuan/ha</td><td>280.8 Yuan/ha</td><td>320.8 Yuan/ha</td></tr>
</table>

Table 4.2 Weather Index-based Rice Insurance Contract Design for Zone 4-6 in Zhejiang

The insurance model design is tailored to the local rice cropping system and environment in

Zhejiang, which is delineated by 6 rice cropping zones in the province. The vast geographical diversities between the rice cropping zones lead to the large differences in the rice production due to the weather conditions in these areas. These also cause the differences in the insurance contract design. Each insurance contract is designed for each rice cropping zone, according to the relationship between the weather index and rice yield per unit land in that area. The result shows distinctive features in the weather index design, insurance premium and indemnity for each rice cropping zone.

For Zone 1 to Zone 3, there is no well-fitted function that could represent the relationship between the weather index and rice yield, which is due to the non-significant estimation of the regression parameters. This means that the correlation between the weather index and rice yield is not very strong, so that a weather index-based rice insurance model cannot be built for these three zones.

For Zone 4, the average data of highest monthly precipitation within March to November from Weather Station Jinhua 58549 and Quzhou 58633 was chosen as the weather index. The weather strike level is set at 348.8 mm of the highest monthly precipitation, with the assumption that the insurable farmers are risk averse. The policyholder will get an indemnity of 30.76 * max(X-348.8, 0) Yuan/ha, with a precondition that the policyholder pays a pure premium of 197.7 Yuan/ha. Since our rice yield data sample ends in year 2003, this insurance model may only be applied in year 2004.

For Zone 5, the average data of average wind speed within March to November from Weather Station Lishui 58646 and Longquan 58647 was chosen as the weather index. The strike level is set at 1.269 m/s of the average wind speed, with the assumption that the insurable farmers are risk averse. The policyholder will get an indemnity of 8370 * max(X-1.269, 0) Yuan/ha, with a precondition that the policyholder pays a pure premium of 280.8 Yuan/ha. Since the rice yield data end in year 2003, this insurance model may only be applied in year 2004.

For Zone 6, the highest monthly precipitation data within March to November from Weather Station Tianmushan 58445 was chosen as the weather index. The strike level is set at 392.3 mm of the highest monthly precipitation, assuming that the insurable farmers are risk averse. The policyholder will get an indemnity of 23.89 * max(392.3-X, 0) Yuan/ha, with a precondition that the policyholder pays a pure premium of 320.8 Yuan/ha. Since the weather station data end in year 1997, this insurance model may only be applied in year 1998.

4.2 Novelty of This Study

This study is a pilot case study of the weather index-based rice insurance modeling for the whole Zhejiang province. Although relevant research has been conducted for rice insurance in Zhejiang [49-50], the studies were either limited to a single extreme weather event in one small region of Zhejiang or were not well grounded with solid theoretical analysis for the insurance product design.

The novelty of this study lies in several aspects: 1. systematic and geographical basis risk has been largely reduced by using rice cropping zone as the insurable farming unit for the rice insurance design, while the rice insurance contract still remains standardized at a rather large area level; 2. various basis risks are considered during the construction of the modeling; 3. a wide range of weather indexes have been selected based on previous relevant research, and have been tested for the relationship between the rice yield per unit land and weather conditions to make sure that the most fitted weather index is chosen for the rice cropping zone.

Rice cropping zone

Basis risks are the major obstacles that have hampered the popularization of weather index-based crop insurance products in the agricultural sector. There are several critical basis risks in the weather-based crop insurance – cropping environment diversity within the insurable farming land, lack of standardized insurance products throughout a rather large area, or potential mismatch between actual losses and weather index. Because of the complex landscapes and latitude differences in Zhejiang, the rice cropping environment shows vast diversity from the west to east and from north to south. Thus it is not possible to adopt a uniformed provincial weather-based rice insurance product for Zhejiang. However, if the area for an insurance product is reduced to a small region such as village or county, it may minimize the geographical and spatial basis risks within the insurable area, but it also cause a serious practical problem in that the insurance contracts will vary among close villages or counties. This would cause suspect and distrust from the farmers since the weather-based insurance policy making process itself is not very transparent or easy to understand. So there exists a dilemma in the weather index-based crop insurance design in that a larger area where the same rice insurance contract is applied would be better for the product standardization and promotion. However, this would be worse for the accuracy of the product modeling because of the spatial diversity within the farming area. The opposite would then be true for rice insurance contract design in a small area. To solve this problem, the rice cropping zone system is applied in this thesis to determine the farming area of an insurance product in Zhejiang. The rice cropping zone was divided according to the rice cropping seasons and rice types, and other factors such as the geographical location, landscape, meteorological resources. The rice cropping system is more or less homogenous within each rice cropping zone. By using this rice cropping zone as the area of rice insurance contract, the systematic and geographical basis risk can be largely reduced and at the same time guarantee a rather large area for the promotion of a standardized insurance contract.

Other basis risks

As mentioned earlier, many other non-weather basis risks may have a large effect on the rice yield as well, which would impact on the weather index-based rice insurance model. In this thesis, these other non-weather factors are also considered and studied before constructing the insurance model, in order to minimize the basis risk in the model. The effect of rice breed, pest plagues, rice diseases, the change of rice cropping area, educational level of the farming villages, the number of farming laborers, investment in production tools are all studied here. Due to the lack of systematic historical data, there are no confirmed quantitative conclusions of their effects on rice yield in this thesis, these factors are essential elements in empirical rice planting practices. However, they are usually neglected in previous relevant studies, probably because of the complexity of the relationship between these factors and the difficulty in determining their effects on the rice production.

Weather index selection

Another novelty in this thesis is that a wide range of weather indexes have been selected to test the relationship between the rice yield per unit land and weather conditions for the development of the insurance model. How to identify the weather indices which are mostly correlated with crop yield is always one of the most critical issues in the weather-based crop insurance modeling. Weather indices are usually selected based on the researchers' individual empirical opinion on the issue in many of the previous studies, which is not well grounded with scientific evidences. In this thesis, a good amount of effort has been made on collecting the information about the weather perils and their effects on rice yield in Zhejiang, in order to build an integral pool of weather indices that could have a close relationship with the rice yield. A large pool of weather indices make sure that the weather index chosen for each zone is the one most correlated with rice yield from all the potential weather indices that could influence rice production. Hence the weather index presented in this thesis is more reliable than the ones selected by individual empirical opinions.

4.3 Problems in This Study

As a pilot study of weather index-based rice insurance modeling, several problems arose during the model construction and data analysis. Data quality is the main problem in this study. Other issues such as the fitness of the classic regression models, interaction between multiple weather indices that affect rice yields, actuarial methods in insurance product design, and insurance promotion should also be noted and studied further in future works.

Data quality

A good insurance model can only build upon high quality data. Without a set of good quality data, any comprehensive simulating model would be in vain. However, to obtain good quality data for a quite big region such as a province in China requires a complete data collecting system and heavy investment in data collecting facilities and administration works for the region. This is unlikely to be implemented by any individual company or research institute. The local government is the best candidate to play this role for the sake of economic efficiency and administrative feasibility. This will then lead to the surrender of data quality, since the data is not collected by scientists but by governmental agencies. In this thesis, the quality of the yield data collected by RCRE is not to a high standard. There are a number of very obvious recording mistakes and some data are either missing or inexplicably marked as 0 in the database, which significantly negatively affects the quality of the remaining rice yield data. Besides the quality of the data, the number of villages with recorded rice yield data in Zhejiang is not sufficient for an integral insurance design for the whole province, but can only be taken as a pilot case study. The quality of weather station data for Zhejiang is better than the rice yield data, because the weather stations have been built since 1951 and constantly improved over time. However, the number of the weather stations with agricultural meteorological data available is still limited, especially for rice cropping zone IV in Zhejiang. The weather indices cannot therefore be accurately constructed for the local farming land to reduce the geographical basis risk. Another critical problem of both the rice yield data and weather data is that the time period of this data is not up-to-date. This means that we cannot build a practical weather index-based insurance model for the up-coming year, but only build a trial model for a pilot case study. Further studies must be continued with contemporary data in order to apply this method in the real rice insurance market.

Classic regression models with climate change

In this thesis, two classic regression models – linear regression and quadratic regression models were tested to simulate the relationship between rice yield and weather indexes. Although these classic regression models are widely used to infer causal relationship between dependent and independent variables and to predict or forecast, the performance of these regression models depends on making assumptions about the data-generating processes. If certain assumptions are violated, the simulation results might be inconsistent or biased, and thus misleading. The gradually recognized climate change in the last decades, however, may act as a violator in the classic regression model assumptions in this study. The historical weather data in this study shows that the average temperature is continuously rising, while the average wind speed is gradually decreasing (refer to Appendix I). If the rice yield deviation is well correlated with these weather indices with a clear pattern, it means that the variance of rice yield error term is heteroscedastic, which violates one basic assumption of the linear regression. Another problem is that, if the climate change pattern is true, the probability of high temperature and low wind speed will tend to increase in the future, thus the probability of historical occurrence of weather index cannot be used alone to predict what would happen in the future. These problems were discussed in detail in Chapter 3, but not studied further due to the complication of this issue and limitation of time here. Future studies could continue on this problem if one can identify an actual pattern in climate change.

Interaction between multiple weather indices

In our weather-yield model, only one weather index which was most correlated with rice yield was chosen as the weather index for a rice cropping zone. Nonetheless, the rice yield turbulence could be influenced by a complex interaction between multiple weather indices. In this case, it will be quite difficult to design an effective weather index insurance model for rice yield. Future studies could be continued to discuss the possible models for this problem.

Actuarial method

Since it is only a pilot study of the weather index-based rice insurance in Zhejiang, this thesis focuses more on weather index and rice yield loss relationship modeling. The actuarial method of insurance pricing is not introduced or studied in detail in this thesis. Risk premium calculation needs to be studied in depth by actuaries in the future, if the modeling method introduced in this thesis is going to be taken into practice.

Insurance promotion

Because of the potential mismatch between the index-triggered indemnities and actual losses suffered by the policy holder, one notable weakness of the weather index-based crop insurance is that it is possible for policyholders to not receive the indemnity when they have suffered a loss or receive an indemnity even when they have suffered no losses [2]. This may cause distrust of the insurance policy among the farmers, and thus hamper the popularization of the insurance product. Although it is impossible to eliminate the basis risk between weather index and crop yield, a carefully designed insurance model will largely reduce the probability of this mismatch and thus reduce the negative impacts of this basis risk on the promotion of the insurance product. Another consequence of the failure of the weather-based crop insurance popularization is that it will be difficult to transfer the yield loss risks of weather indexes from a small region to another if the insurable area is not large enough. This will weaken the pooling effect of the insurance, and hence load the insurer with high risk.

4.4 Proposals for Future Works

This study is a preliminary trial of weather index-based rice insurance modeling in Zhejiang province, China. In addition to the insurance product, it also revealed many problems in the process of original data collection, model construction and insurance design. Based on these problems in our study, there are some proposals for the future works to different stakeholders involved in this issue:

To the Chinese government

1. A centralized agricultural database for each province should be officially created. This database should include meteorological data, agricultural crop yield statistics, and information of seed breed, planting time, farming labor, fertilization, soil components, pest plagues, crop diseases, pesticide application, cropping mechanization, water facilities, public infrastructure, air and water pollution. The database should ideally be collected from each farm or village level, or at least from each county in the province. Data collecting and inspecting systems should be built to guarantee the data quality.
2. The access to the agricultural database should be facilitated by the government for insurance product studies. This database should not be regarded as a monopoly commercial product from which the government can earn profit, but rather as a research resource or tool to better serve the agricultural insurance market to benefit all the stakeholders within this market, especially the farmers.
3. An appropriate legal and regulatory framework should be developed to support agriculture insurance. The weather index-based crop insurance can only work when it is legally recognized and supported.
4. Insurance product education and introduction programs for farmers should be promoted and supported by the local government as a key step for the development of a robust agriculture insurance market in the region.

To researchers and insurance companies

1. The scale and quality of the database decides the quality of the insurance product. Further

studies should be conducted on the integral weather index-based crop insurance in Zhejiang when a complete database of rice yield and local weather indices can be obtained. Satellite climate data and remote sensing images should also be collected and considered in the weather index model, if they are available. By using more advanced technology for monitoring weather, the quality of the weather data may be improved.

2. Climate change factors should be considered in the model and the insurance contracts need to be studied further in depth by actuaries.
3. The efficiency of the weather index-based rice insurance should also be tested compared to a traditional rice insurance contract to check whether weather index-based rice insurance is superior to other insurance product.
4. The complete weather index-based rice insurance contract should be introduced and promoted to the government and to farmers affiliated with insurance educations. In China, the government's intervention in insurance market is strong (see Appendix II) by issuing insurance policies. The insurance policy makers in the government must understand the weather index-based rice insurance themselves, and this requires the insurance product education and promotion operated by the insurance companies and researchers. The insurance product distribution and promotion channel should be built in cooperation with the local government, since the local officers are more familiar and trustworthy to the local farmers than insurance companies from empirical experiences in the past.
5. Weather index-based rice reinsurance model should be studied and introduced to reinsurance companies. When an insured event occurs, all the policyholders must be paid at the same time, which will increase the total amount of insurer's payouts in one season. By transferring the risk to reinsurance companies or insurance commodity markets, the primary insurance companies may be able to reduce the large capital reserves required to hedge against the extreme weather events which cause yield losses.

Appendix

Appendix I

Patterns in Climate Change

Great amount of studies have been conducted on global climate changes, and global warming concept has been gradually recognized and accepted by many scientists in the recent years. In this thesis, the weather data collected from 18 weather stations in Zhejiang affiliated under China Meteorological Administration also showed some patterns in climate change from 1973 to 2010. Because of the incomplete weather data for rice cropping zone 6, the data from Zone 6 is not analyzed here. The trends of temperature, wind speed and precipitation change in 5 rice cropping zones in Zhejiang are shown in the following charts.

Temperature

The average temperature during rice growth period in rice cropping zones 1-5 in Zhejiang seems to keep increasing from 1973 to 2010. The trend is more clear from the beginning of 1990s when the revolutionary economic reform started in China. However, the temperature drop in the last few years may be an interrupt of the temperature increasing trend or it may signal the end of the trend, which is ambiguous at present.

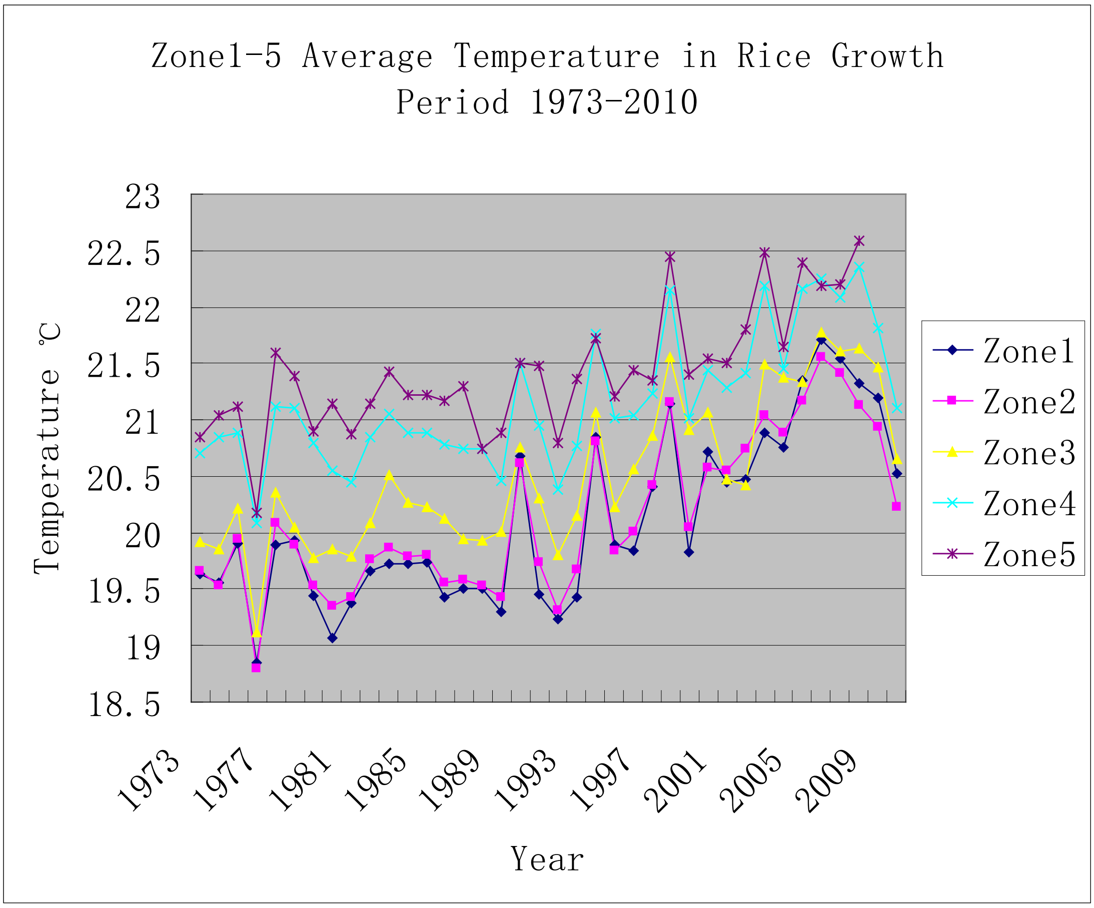

Figure A1 Average temperature trend during rice growth period in rice cropping zones of Zhejiang

1973-2010

Wind Speed

The average wind speed during rice growth period in rice cropping zones 1-3 in Zhejiang shows a clear declining trend from 1973 to 2010. While the trends in zone 4 and zone 5 are not obvious.

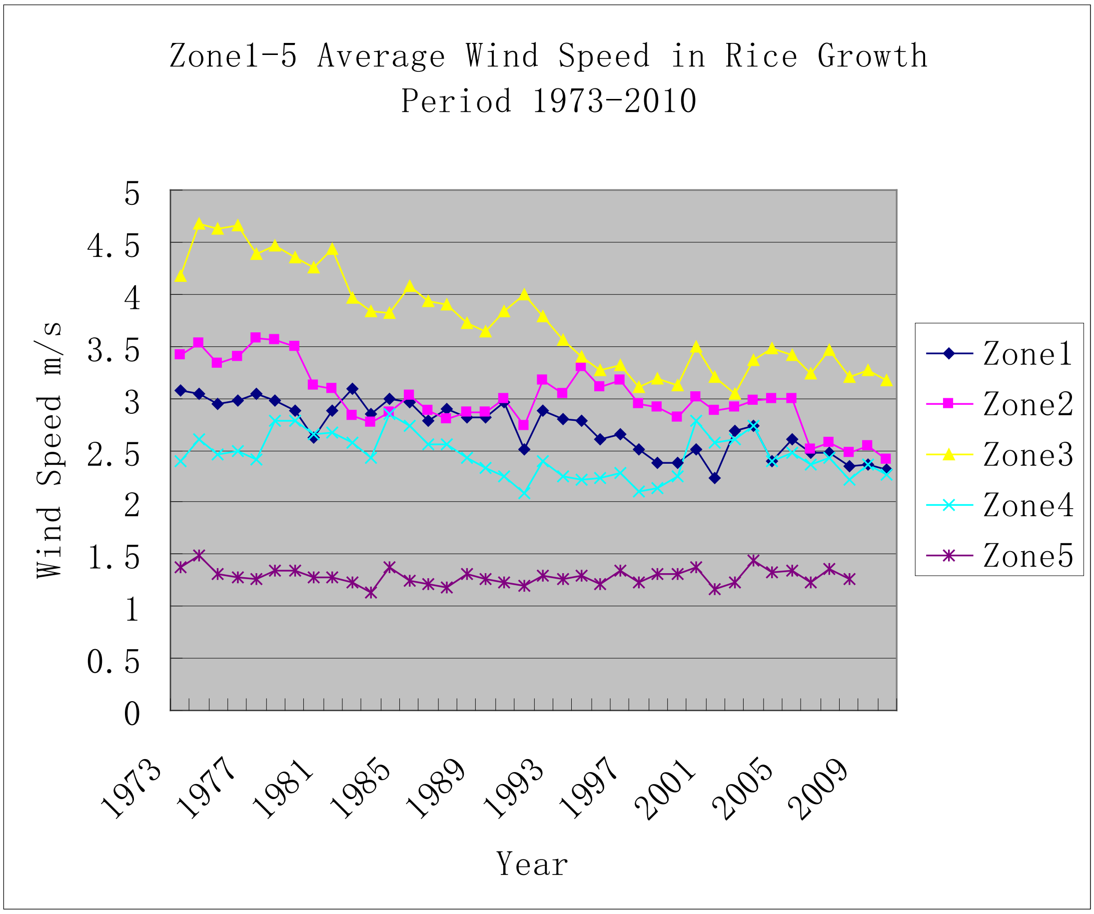

Figure A2 Average wind speed change during rice growth period in rice cropping zones of Zhejiang 1973-2010

Precipitation

Unlike the other weather indices, the cumulative precipitation during rice growth period in rice cropping zones 1-5 in Zhejiang seems to remain constant with quite large fluctuation from 1973 to 2010. There is no obvious trend in the cumulative precipitation curve for these zones.

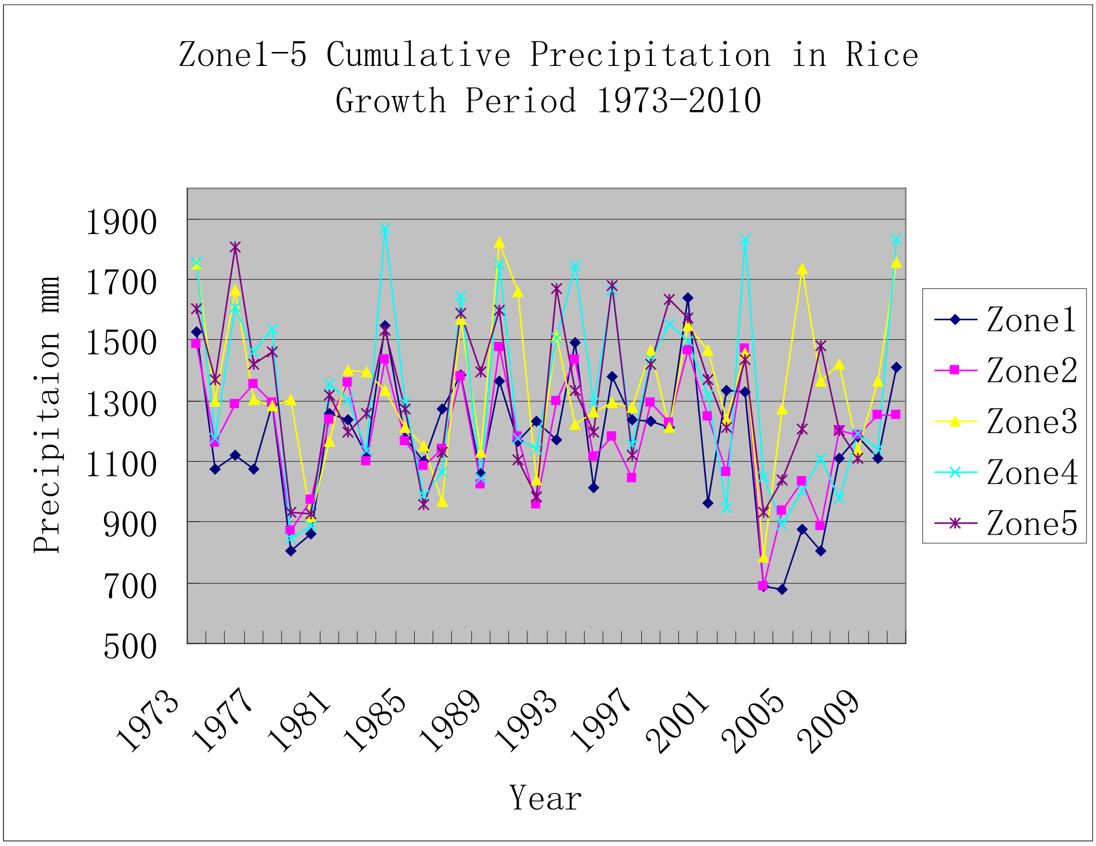

Figure A3 Cumulative precipitation change during rice growth period in rice cropping zones of Zhejiang 1973-2010

These figures show heterogeneous features of climate trends in different regions of Zhejiang. And even the trend for increasing temperature is relatively clearer compared to the other two weather indices, it is still not very convincing to prove the climate change pattern, because of the short observation time period of the weather data. In a larger time frame, e.g. 100 years or 1000 years or even longer period, the trend may disappear or become simply a set of turbulences for a larger temperature picture. Thus, the climate trend question remains vague, and was not considered as existed in the modeling method of this thesis. If one believes that the climate change pattern is rather clear, further research related to the climate change could be performed in future for weather index-based crop insurance modeling.

Appendix II

Agriculture Insurance Policies in Zhejiang

China's agriculture insurance market was totally in control of the government and state-owned insurance companies before the reform and opening-up policy was issued. Although several adjustments of agriculture insurance supervising frameworks and pilot initiatives have been conducted in the last few years to enhance the market itself [105-107], China's agriculture insurance market is still a government policy controled market. The agricultural policies from the Chinese central government guide the provincial and local agriculture insurance implementation.

In Zhejiang province, the present rice insurance policy for polite programs is as following [108]:

1. The premium subsidy for rice insurance is 50%. The local government can increase the premium subsidies if conditions permit. 60% of the premium subsidy will be shared by provincial government for under-developed and island cities and counties. While for the other cities and counties, the provincial government shares 40% of the premium subsidy, and the rest is afforded by the local government.
2. The maximum risk liability is limited within 5 times the insurance premium. A policy-oriented agricultural co-insurance funding body should be established. When the agriculture insurance indemnity is within 2 times of the insurance premium, the co-insurance body should commit the full indemnity responsibility; the surpass part will be shared by the government and co-insurance body. The part of indemnity within 2-3 times the insurance premium will be shared 1:1 by the government and co-insurance body; the part of indemnity within 3-5 times the insurance premium will be shared 2:1 by the government and co-insurance body. The government share of indemnity will be divided according to policy 1.

This policy was published on the Zhejiang government official website on 24 March 2006.

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