RISK MANAGEMENT IN AGRICULTURE FOR NATURAL HAZARDS

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TABLE OF CONTENTS

Lists of Figures, Tables, and Boxes .......................................................... iii
Acronyms ................................................................................................. vi
Authors ..................................................................................................... ix
Preface ...................................................................................................... xi

CHAPTER 1 INNOVATIONS IN RISK-TRANSFER MARKETS IN
AGRICULTURE FOR NATURAL HAZARDS ........................................ 1
1.1 INTRODUCTION.............................................................................. 1
1.2 FRAMING THE PROBLEM.............................................................. 4
1.3 AGRICULTURAL RISK AND MANAGEMENT.................................. 6
1.4 INSURING AGRICULTURAL RISK .................................................. 7
   Insurability Conditions........................................................................ 8
   Correlated Risk ................................................................................ 9
   Implications for Agricultural Risk Transfer........................................ 10
1.5 THE CROP INSURANCE EXPERIENCE IN NORTH AMERICA........... 11
   The United States............................................................................ 12
   Canada............................................................................................ 13
1.6 COMMON ELEMENTS OF U.S. AND CANADIAN CROP INSURANCE..... 14
   Mixing Social and Market-Based Goals............................................ 15
   Covering Individual Farm Yields for Multiple Perils.......................... 15
   Subsidies as a Percent of Premium.................................................. 16
   Subsidies to Cover Administrative Costs of Agricultural Insurance.... 16
   Significant Government Expenses................................................... 17
   Using Government to Pool and Hold Catastrophic Risk...................... 18
1.7 IMPLICATIONS: MARKET FAILURE OR LOGICAL MARKET RESPONSE? 18
1.8 INDEX INSURANCE ALTERNATIVES.............................................. 21
   Basic Characteristics of an Index...................................................... 23
   Relative Advantages and Disadvantages of Index Insurance.............. 27
   When Weather Index Insurance Is Inappropriate............................... 35
1.9 DEVELOPING POLICY PRESCRIPTIONS......................................... 36
   Layering Catastrophe Risk.............................................................. 36
   Structured Disaster Response to Complement Private Products.......... 40
   Pooling the Risk Within the Country................................................. 42
1.10 CONCLUSIONS AND IMPLICATIONS............................................. 44

CHAPTER 2 WEATHER RISK MANAGEMENT FOR AGRICULTURE........ 46
2.1 INTRODUCTION TO WEATHER RISK............................................. 46
   The Financial Impact of Weather...................................................... 46
   The Weather Market........................................................................ 49
   Weather Risk and Agriculture.......................................................... 54
2.2 STRUCTURING A WEATHER RISK MANAGEMENT SOLUTION.......... 56
# Table of Contents

- Identifying the Risk ................................................................. 56
- Quantifying the Risk ............................................................... 69
- Structuring The Product ........................................................... 73
- Execution ................................................................. 81
- 2.3 VALUING WEATHER RISK ................................................... 85
  - Pricing Overview ......................................................... 85
  - End User Perspective ..................................................... 94
- 2.4 WEATHER DATA ................................................................. 101
  - Data Requirements ....................................................... 101
  - Data Sources .................................................................. 102
  - Cleaning and Adjusting Data .......................................... 104
  - Detrending Data ............................................................ 105
- 2.5 FURTHER READING ............................................................ 111

## CHAPTER 3 CASE STUDIES FOR AGRICULTURAL WEATHER RISK MANAGEMENT

- 3.1 INDEXED-BASED INSURANCE FOR FARMERS IN ALBERTA, CANADA: THE (AFSC) CASE STUDY ................................................................. 113
  - Introduction to AFSC ...................................................... 113
  - Corn Heat Unit Insurance .............................................. 113
- 3.2 ALTERNATIVE INSURANCE THROUGH WEATHER INDEXES IN MEXICO: THE AGROASEMEX CASE STUDY ......................................................... 120
  - Introduction to Agroasemex ........................................... 120
  - Designing a Weather Risk Transfer Solution for the Agroasemex Agricultural Portfolio ......................................................... 121
  - Valuation of the Weather Derivative Structure and the Agroasemex Transaction ................................................................. 131
  - Developments Since 2001 .................................................. 135
- 3.3 WEATHER INSURANCE FOR FARMERS IN THE DEVELOPING WORLD: CASE STUDIES FROM INDIA AND UKRAINE ......................................................... 136
  - The Importance of Weather Risk in the Developing World ........ 136
  - Weather Insurance for Agriculture in India ..................... 137
  - Weather Insurance for Agriculture in Ukraine .................. 156

## APPENDIX GRASSLAND INDEX INSURANCE USING SATELLITE IMAGERY

- USE OF THE NORMALIZED DIFFERENCE VEGETATION INDEX (NDVI) FOR INSURANCE PURPOSES ................................................................. 171
- GRASSLAND INSURANCE IN ALBERTA (AFSC OPERATED) ................................................................. 172
- GRASSLAND INSURANCE IN SPAIN ................................................................. 175

## REFERENCES

- ......................................................................................... 177
LISTS OF FIGURES, TABLES, AND BOXES

Figures

Figure 1.8.1 Payout Structure for a Hypothetical Rainfall Contract ........................................ 25
Figure 1.9.1 Distribution of August Rainfall for Andhra Pradesh ........................................... 37
Figure 1.9.2 Estimate of Loss Function for the U.S. Crop Insurance Industry .......................... 39
Figure 2.1.1 Notional Value of All Weather Contracts in US$ .................................................. 51
Figure 2.1.2 Percentage of Total Weather Contracts by Location (Excluding CME Trades) ........ 51
Figure 2.1.3 Potential End User Market by Economic Sector 2004/2005 ............................. 52
Figure 2.1.4 Percentage of Total Weather Contracts by Index (Excluding CME Trades) ....... 53
Figure 2.2.1 Call Option Payout Structure and Wheat Grower’s Losses ................................. 76
Figure 2.2.2 Collar Payout Structure and Agrochemical Company’s Deviation from Budgeted Revenue .................................................................................................................. 78
Figure 2.3.1 Schematic of Historical Revenues of a Business and the Impact of Weather Hedging .......................................................................................................................... 95
Figure 3.1.1 Relationship between the Daily Rate of Development of Corn Minimum and Maximum Temperatures .................................................................................................. 115
Figure 3.2.1 Weather Stations Used in the Initial Product Design ........................................ 125
Figure 3.2.2 Comparative Accumulated Distribution Probability Function Based on a “Probability of Exceedence Curve” for the Historical and Modeled Results (Payouts in US$) ................................................................................................................ 132
Figure 3.3.1 Mahabubnagar District Groundnut Yields versus Groundnut Rainfall Index ............................................................................................................................ 143
Figure 3.3.2 Payout Structure of Groundnut Weather Insurance Policy for Small, Medium, and Large Farmers .................................................................................................... 145
Figure 3.3.3 An Example of a Weather Insurance Policy for Castor in Mahabubnagar, 2003 ..................................................................................................................................... 147
Figure 3.3.4 Payout Structure of Groundnut Weather Insurance Policy for Narayanpet Mandal, Mahabubnagar District, 2004 ........................................................................... 151
Figure 3.3.5 An Example of the Marketing Leaflet for Groundnut (DGN), Castor (DCN), and Excess Rainfall Protection (EN) in Narayanpet Mandal, Mahabubnagar District, 2004 .......................................................... 154
Figure 3.3.5 Winter Wheat Yields for Kherson Oblast, 1971–2001 ........................................... 158
Figure 3.3.6 Cumulative Rainfall and Average Temperature for Behtery Weather Station for April 15–June 30, 1973–2002 ................................................................................. 166
Figure 3.3.7 SHR Index for Behtery Weather Station, 1973–2002 ............................................. 167
Figure 3.3.8 Sample Contract for Behtery Weather Station .................................................... 168
Tables

Table 2.2.1  Reported Base Temperatures for GDD Computations for Crops and Insects ..........................................................60
Table 2.2.2  Growing Degree Day Requirements for Different Phenology Stages of a 2700 GDD Corn Hybrid .................................................................61
Table 2.2.3  Critical Temperatures that Result in Freeze Damage to Crops .................................................................66
Table 2.2.4  Deviations in Average Temperature and Cumulative Rainfall and the Impact on Winter Wheat Yields in Kherson, April 15–June 14 .................................................................68
Table 3.1.1  Weather Station Groupings for the CHU Program .................................................................116
Table 3.1.2  Coverage Limits for CHU Insurance ...............................................................................116
Table 3.1.3  Options for CHU Contracts .....................................................................................118
Table 3.1.4  Payment Rates for Contract Based in Station Grouping A ........................................119
Table 3.2.1  Crops and Risks Selected for the Design of the Weather Risk Transfer Program ....122
Table 3.2.2  Total Liability Factored into the Agroasemex Business Plan for Autumn–Winter 2001/2002 that Served for the Design of the Weather Derivative Contract .........................122
Table 3.2.3  Monthly and Seasonal Accumulated DDD-12 in Nayarit from 1991 to 2000 ........................................................................................................126
Table 3.2.4  Summary of the 11 FCDD Indexes for the Crops and Risks Selected to be Included in the Weather Derivative .........................................................................................127
Table 3.2.5  Summary of the Methodology to Calculate the 11 FCDD Indexes .................................................................128
Table 3.2.6  Summary of the Individual Equations that Constitute the Basket of Indexes of the Weather Derivative ........................................................................................................129
Table 3.2.7  Comparative Analysis Between the Real Indemnities and the Estimated Indemnities for the Agroasemex Portfolio (Figures in US$) .................................................................130
Table 3.2.8  Comparative Analysis Between the Observed Historical Severity Indexes (Indemnities/Total Liability) and the Estimated Severity Indexes for the Crops and Risks Selected (Figures in Decimals) .........................................................................................131
Table 3.2.9  Specifications of Call Option Structures Considered by Agroasemex .................................................................132
Table 3.2.10  Actuarial Fair Value Price Based on Historical Burn and Simulation Analysis (in US$) ........................................................................................................133
Table 3.2.11  Estimated Commercial Premium for Weather Derivative Structures (in US$) ........................................................................................................135
Table 3.3.1  Comparison of NAIC Area-Yield Indexed Crop Insurance to Weather Index Insurance by BASIX ........................................................................................................139
Table 3.3.2  Economics of Groundnut, Per Acre of Cultivation ..................................................................................141
Table 3.3.3  Economics Of Castor, Per Acre of Cultivation ..................................................................................141
Table 3.3.4  10-day Cumulative Rainfall Weighting for Groundnut Rainfall Index .................................................................144
Table 3.3.5  Weather Insurance Contracts Offered to Groundnut and Castor Farmers ..................................................................................145
Table 3.3.6  Number of Contracts Sold .................................................................................................146
Table 3.3.7  Pilot Statistics, 2003 ........................................................................................................149
Table 3.3.8  Payout Structure Per Acre for Groundnut Weather Insurance Policy for Narayanpet Mandal, Mahabubnagar District, 2004 ..................................................................................150
Table 3.3.9  Payout Structure Per Acre for Castor and Groundnut Excess Rainfall
Weather Insurance Policy for Narayanpet, Mahabubnagar.................................152

Table 3.3.10  Breakdown of all Weather Insurance Contracts sold by ICICI Lombard in
Andhra Pradesh through BASIX for Khariff 2004..................................................153

Table 3.3.11  Relationship Between SHR and Winter Wheat Yields During the Vegetative
Growth Phase of Plant Development........................................................................161

Table 3.3.12  Relationship Between SHR and Financial Losses Associated with Winter
Wheat Yield Fluctuations............................................................................................162

Table 3.3.13  Correlation Coefficients for the Interannual Variability of Cumulative
Rainfall, Average Temperature, and the SHR Index Measured at Five UHC
Weather Stations in Kherson Oblast.........................................................................164

Table 3.A.1  Correlation Coefficients (r) Between Clipped Yield and PVI Analyzed by
Month and Region for 2001 and 2002...................................................................174

Boxes

Box 1.8.1  Other Forms of Index Insurance.................................................................24
Box 1.8.2  What Is Needed to Make the Innovations Work?.......................................30
Box 2.2.1  The Corn Grower’s Weather Hedge: Growing Degree Days ......................62
Box 2.2.2  The Corn Grower’s Weather Hedge: Unit Exposure.....................................71
Box 2.2.3  The Corn Grower’s Weather Hedge: Put Option........................................77
Box 2.3.1  The Corn Grower’s Weather Hedge: Historical Burn Analysis..................90
Box 2.3.2  The Corn Grower’s Weather Hedge: Revenue Volatility............................95
Box 2.4.1  The Corn Grower’s Weather Hedge: Detrending the Data.........................109
<table>
<thead>
<tr>
<th>ACRONYMS</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>AFRD</td>
<td>Agriculture, Food, and Rural Development, Ministry in Alberta, Canada</td>
</tr>
<tr>
<td>AFSC</td>
<td>Agriculture Financial Services Corporation</td>
</tr>
<tr>
<td>ARD</td>
<td>Agriculture and Rural Development Department of the World Bank Group</td>
</tr>
<tr>
<td>BASIX</td>
<td>Livelihood promotion and microfinance entity of Andhra Pradesh</td>
</tr>
<tr>
<td>BSFL</td>
<td>Bhartiya Samruddhi Finance Limited (part of BASIX)</td>
</tr>
<tr>
<td>BUA</td>
<td>Bore Well Users’ Association</td>
</tr>
<tr>
<td>CAT</td>
<td>Catastrophe</td>
</tr>
<tr>
<td>CDD</td>
<td>Cooling Degree Day</td>
</tr>
<tr>
<td>CHU</td>
<td>Corn Heat Unit</td>
</tr>
<tr>
<td>CLC</td>
<td>Corine Land Cover</td>
</tr>
<tr>
<td>CME</td>
<td>Chicago Mercantile Exchange</td>
</tr>
<tr>
<td>CRMG</td>
<td>Commodity Risk Management Group (ARD, World Bank)</td>
</tr>
<tr>
<td>CU</td>
<td>Chilling Unit</td>
</tr>
<tr>
<td>DDD</td>
<td>Damage Degree Days</td>
</tr>
<tr>
<td>DRP</td>
<td>Disaster Response Program</td>
</tr>
<tr>
<td>DS</td>
<td>Daily Simulation</td>
</tr>
<tr>
<td>ECMWF</td>
<td>European Center for Medium Range Forecasting</td>
</tr>
<tr>
<td>ENSO</td>
<td>El Niño Southern Oscillation (Sea surface temperatures)</td>
</tr>
<tr>
<td>FAO</td>
<td>United Nations Food and Agriculture Organization</td>
</tr>
<tr>
<td>FCDD</td>
<td>Factores Climaticos Dañinos Diarios—damage degree days or periods</td>
</tr>
<tr>
<td>FCIP</td>
<td>Federal Crop Insurance Program</td>
</tr>
<tr>
<td>GDD</td>
<td>Growing Degree Day</td>
</tr>
<tr>
<td>GDP</td>
<td>Gross Domestic Product</td>
</tr>
<tr>
<td>GTS</td>
<td>Global Telecommunication System</td>
</tr>
<tr>
<td>HBA</td>
<td>Historical Burn Analysis</td>
</tr>
<tr>
<td>HDA</td>
<td>Historical Distribution Analysis</td>
</tr>
<tr>
<td>HDD</td>
<td>Heating Degree Day</td>
</tr>
<tr>
<td>Acronym</td>
<td>Description</td>
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<td>--------------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>ICICI Lombard</td>
<td>Private general insurance company in India</td>
</tr>
<tr>
<td>ICRISAT</td>
<td>International Crops Research Institute for the Semi-Arid Tropics</td>
</tr>
<tr>
<td>IFCCO-TOKIO</td>
<td>Private general insurance company in India—joint venture between Tokio-Marine and the Indian Fertilizer Association</td>
</tr>
<tr>
<td>IFC-PEP</td>
<td>International Finance Corporation Partnership Enterprise Projects</td>
</tr>
<tr>
<td>IMD</td>
<td>Indian Meteorological Department</td>
</tr>
<tr>
<td>IMF</td>
<td>International Monetary Fund</td>
</tr>
<tr>
<td>IS</td>
<td>Index Simulation</td>
</tr>
<tr>
<td>ISD2</td>
<td>EU Investment Services Directive</td>
</tr>
<tr>
<td>ISDA</td>
<td>International Swaps and Derivatives Association</td>
</tr>
<tr>
<td>KBS LAB</td>
<td>Krishna Bhima Samruddhi Local Area Bank</td>
</tr>
<tr>
<td>LEWS</td>
<td>Livestock Early Warning System</td>
</tr>
<tr>
<td>LOESS</td>
<td>Detrending method</td>
</tr>
<tr>
<td>MFE</td>
<td>Microfinance Entity</td>
</tr>
<tr>
<td>MGDD</td>
<td>Modified Growing Degree Day</td>
</tr>
<tr>
<td>MVCI</td>
<td>Maximum Value Composite Index</td>
</tr>
<tr>
<td>NAIC</td>
<td>National Agricultural Insurance Company</td>
</tr>
<tr>
<td>NCAR</td>
<td>National Center for Atmospheric Research</td>
</tr>
<tr>
<td>NCEP</td>
<td>U.S. National Center for Environmental Prediction</td>
</tr>
<tr>
<td>NDVI</td>
<td>Normalized Difference Vegetation Index</td>
</tr>
<tr>
<td>NGO</td>
<td>Nongovernmental Organization</td>
</tr>
<tr>
<td>NIR</td>
<td>Near-infrared Light</td>
</tr>
<tr>
<td>NMS</td>
<td>National Meteorological Service</td>
</tr>
<tr>
<td>NOAA</td>
<td>National Oceanographic and Atmospheric Administration</td>
</tr>
<tr>
<td>OTC</td>
<td>Over-the-Counter</td>
</tr>
<tr>
<td>PDSI</td>
<td>Palmer Drought Severity Index</td>
</tr>
<tr>
<td>PGDD</td>
<td>Pest Growing Degree Days</td>
</tr>
<tr>
<td>PI</td>
<td>Production Insurance (Canada)</td>
</tr>
<tr>
<td>PIP</td>
<td>Private Insurance Product</td>
</tr>
<tr>
<td>PVI</td>
<td>Pasture Vegetative Index</td>
</tr>
<tr>
<td>PWC</td>
<td>PricewaterhouseCoopers</td>
</tr>
<tr>
<td>RMA</td>
<td>Risk Management Agency of the USDA</td>
</tr>
<tr>
<td>RMS</td>
<td>Risk Management Solutions</td>
</tr>
</tbody>
</table>
### Acronyms

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>RWS</td>
<td>Reference Weather Station</td>
</tr>
<tr>
<td>SERP</td>
<td>Society for Elimination of Rural Poverty (in Andhra Pradesh)</td>
</tr>
<tr>
<td>SHRI</td>
<td>Selyaninov Hydrothermal Ratio Index</td>
</tr>
<tr>
<td>SI</td>
<td>Satellite Imagery</td>
</tr>
<tr>
<td>SI</td>
<td>Severity Index</td>
</tr>
<tr>
<td>SRA</td>
<td>Standard Reinsurance Agreement</td>
</tr>
<tr>
<td>SYNOP</td>
<td>Meteorological Codes for use at Observing Stations</td>
</tr>
<tr>
<td>TCHU</td>
<td>Threshold Corn Heat Unit</td>
</tr>
<tr>
<td>UHC</td>
<td>Ukrainian Hydrometeorological Center</td>
</tr>
<tr>
<td>VaR</td>
<td>Value-at-Risk</td>
</tr>
<tr>
<td>WFP</td>
<td>World Food Program of the United Nations</td>
</tr>
<tr>
<td>WMO</td>
<td>World Meteorological Organization</td>
</tr>
<tr>
<td>WRMA</td>
<td>Weather Risk Management Association</td>
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PREFACE

Weather plays a fundamental role in crop disasters. Thanks to the development of insurance and financial markets, it is now possible to transfer significant portions of weather risks off the farm. A new generation of financial products, known as weather derivatives and weather insurance, enable farmers to make risk management decisions about their operations that are affected by specific weather events, thereby providing them with greater income stability.

ISMEA has been assigned to closely monitor financial innovation in the Italian system of agricultural risk management. This charge motivated the Institute to develop a publication with the support of an international team of experts that sets forth the current state of the art in weather risk management for agricultural production. The use of weather derivatives for stabilizing income has become a common practice in various economic sectors—from energy to tourism. In agriculture, apart from a few important exceptions, the main applications of these new techniques are taking place in developing countries, with a major contribution from the World Bank. Developed countries typically have high levels of domestic support that crowd out the need for using weather derivatives. However, even in developed countries, the structure of support to agriculture is rapidly changing, and ISMEA considers it important to monitor and understand the development of solutions that may complement traditional agricultural policy approaches.

This volume, with contributions by Jerry Skees and Jason Hartell (University of Kentucky), Jo Syroka and Hector Ibarra (World Bank), and the coordination of Raffaele Borriello and Andrea Stoppa, provides a policy framework for why weather insurance may be a suitable, as well as, solid analytical approach that clearly illustrates characteristics and potential applications of the new instruments. In addition, the volume provides the economic and statistical details needed to fully understand the design and operation of these new instruments.

The first chapter of the volume provides a policy framework focused on the specific features of risk in agriculture and the limitations of traditional risk management tools. Two common problems make the social cost of traditional crop insurance challenging: 1) the correlated nature of crop disasters, meaning a large number of insured will generally suffer losses at the same time; and 2) the high transaction costs of monitoring the insurance on individual farm yields because the insurer cannot control adverse selection and moral hazard. The case is made for why weather derivatives can be used to remedy these problems.

The second chapter illustrates in more detail the development of weather insurance. It provides a brief history of the weather market, together with a
description of the various stages of developing such contracts: the identification and quantification of the risk exposure; the acquisition, analysis, and control of production and meteorological data; and the contractual structure needed for users given the host countries legal and regulatory environment.

The third and final chapter focuses on weather insurance programs in Canada, Mexico, Ukraine, and India. These four applications use weather data for the instruments. The Appendix introduces experience in Canada and Spain that uses satellite imagery to index and indemnify for extreme conditions for pastureland. This is promising, as few countries have ever tried to develop insurance products for pasture.

A special thanks goes to Celeste Sullivan of GlobalAgRisk for her painstaking and valuable work of editing and revising the text.

Arturo Semerari
President of ISMEA
CHAPTER 1

INNOVATIONS IN RISK-TRANSFER MARKETS IN AGRICULTURE FOR NATURAL HAZARDS

JERRY R. SKEES AND JASON HARTELL

1.1 INTRODUCTION

The challenge of developing effective and efficient risk-transfer markets for crop losses caused by natural hazards has eluded private and public sectors in countries around the world. In developed countries, the agricultural policy debate has been how and to what extent government should intervene in assisting market development. Now it seems the debate has been largely resolved—governments have assumed significant obligation to farmers suffering from catastrophic production loss (Glauber, 2004), resulting in the development and delivery of highly subsidized crop insurance products and significant retention of risk by government.¹

Among the themes of this chapter and book is that when governments are intent on providing some level of response to catastrophic events, it should be better to do so with \textit{ex ante} structured rules that follow insurance principles rather than to provide \textit{ad hoc} relief that over time is subject to budget constraints and the politics of the day. As will be developed, it is possible to blend socially motivated \textit{ex ante} disaster response with market-based insurance products that are facilitated with less government cost. The goal should be to make certain that the two forms of government intervention are complementary and not working at cross-purposes.

¹ The exception may be South Africa, where a private multi-peril crop insurance program exists for some of the largest farms. Named-peril crop insurance products, such as private hail insurance, also are an exception.
It is assumed that most governments would prefer to meet the needs for natural disaster risk transfer with at least three primary performance criteria: 1) fiscal constraint; 2) social relief for serious catastrophes; and 3) a keen desire to facilitate more market-oriented risk transfer. To that end, specific recommendations are developed that allow for layering risk and separating the \textit{ex ante} disaster response social programs from market-based insurance products facilitated with less government fiscal exposure, making certain that these two forms of government intervention are complementary and not working at cross-purposes.

To provide a clear conceptual path for the recommendations that are made, the following questions are examined:

- Are most developed countries, and even developing countries, that attempt to intervene in crop insurance markets destined to repeat many of the same mistakes that plague most contemporary government supported crop insurance programs?
- What is the public policy rationale for such heavy intervention?
- What are the core problems that preclude private-sector markets from emerging to handle crop losses from natural hazards?
- Are there more cost effective ways to facilitate both market and social goals in this complex arena?

To address these questions, it is useful to frame the general problem of risk and risk management in agriculture, highlighting some of the unique characteristics of agricultural risk, and explaining why it is difficult to insure production risk via traditional insurance concepts. In particular, the focus is on correlated risk and the high transaction costs of traditional insurance that come with monitoring. Factors like the cognitive failure of potential buyers of natural hazard risk insurance and the ambiguity of sellers toward insuring extreme event risk are used to highlight a fundamental problem—prices charged can be greater than the willingness to pay.

The response of governments to agricultural risk has been heavy intervention and significant subsidies. In this context, the North American experience is reviewed as a means of distilling and assessing some commonalities in the use of government resources to cope with the problems of insurability. When revealing the true cost of these programs, it becomes clear that the social benefits and costs must be considered before any government implements similar agricultural policies.

Once the problems of traditional insurance and an understanding of the type of risk that is being insured have been highlighted, indexed weather insurance contracts are introduced. Index insurance contracts provide an alternative risk-
transfer mechanism that avoids many of the problems of traditional insurance. The basic details of an indexed weather insurance contract are discussed along with relative advantages and disadvantages. Importantly, indexed weather insurance must be viewed as an “in-between” (Skees and Barnett, 1999) contingent claims contract that combines elements of traditional insurance and financial derivatives.

Despite its promise, there are concerns about the use of indexed weather insurance as a “one-size-fits-all” substitute. In particular, caution must be used when drawing conclusions from limited data, as statistical errors can be large when using a small sample to design weather index insurance. The problems of basis risk are real for weather index insurance. Presenting these limitations in a clear fashion to potential buyers is vital to mitigate misunderstandings that may arise and compromise future developments. While research is useful in the development of tailored weather index insurance, a first step could be to simply ask potential buyers what weather risks are most worrisome.

While basis risk is an inherent problem with weather index insurance products, there are means to address this limitation. Weather index insurance can clear the way for other innovations so long as it is successful in largely removing correlated risk. More fundamentally, as will be developed, this new insurance can be coupled with bank and non-bank solutions that facilitate savings and borrowing to mitigate basis risk. Beyond linkages to savings and lending via banking solutions, index insurance also clears the way for tailored insurance products that mitigate basis risk, since such risks are more likely to meet one criterion of classic insurance—they are more independent in nature.

Reviewing the conceptual development and background of risk management in agriculture motivates specific recommendations regarding the role of government. Government should focus on systems to remove the correlated risk and markets should be used to remove the independent risk. By using weather index insurance, governments can assist in removing the correlated risk. Furthermore, governments can perform dual roles—advancing their societal and market-based goals by providing a social response for truly catastrophic events and facilitating the development of markets in risk transfer for natural hazards in agriculture. Weather index insurance products can be used for layering risk, creating a distinct social role for government to provide response to catastrophes, and in a fashion that facilitates more market-based solutions for less severe natural hazard risks. Governments can also facilitate risk-pooling arrangements to retain as much risk as possible within the country via risk layering and special regulatory structures that also open the way for greater access to reinsurance in the global markets. By using market principles, these objectives can be
accomplished more efficiently and with less fiscal resources than traditional crop insurance programs.

1.2 FRAMING THE PROBLEM

Government emergency catastrophic disaster relief and heavy government subsidies have been repeatedly criticized by economists as being inefficient and distorting of private incentives. These interventions and subsidies may lead to economy-wide outcomes that are worse than those resulting from the perceived failure of markets to independently supply risk-transfer products, and may further contribute to conditions that make the impact of future catastrophes even worse (Barnett, 1999). Nonetheless, governments are prone to respond to catastrophes in some fashion. A structured and thoughtful *ex ante* response can be superior to *ad hoc* disaster assistance. A key may be merging insurance principles into a standing catastrophic disaster response program that is directly linked to participation in a market-oriented insurance program involving no direct premium subsidies.

Despite criticism of schemes used by many governments, access to an efficient risk-transfer mechanism is an important economic objective. When producers are able to transfer some portion of their risk exposure, through mechanisms like insurance and banking, they are more likely to specialize, adopt new technologies, and make product- or management-specific investments that can enhance long-term productivity. These activities may offer a higher level of mean earnings, but frequently at a cost of potentially greater volatility in earnings. Risk-averse decision makers are reluctant to make such investments without the aid of risk transfer given their preference for more predictable, albeit lower, income. This conceptual development demonstrating that effective risk-transfer markets lead to greater investment in productive activities, along with subsequent economic benefits for producers and local communities, dates to early works by noble laureate Kenneth Arrow (Arrow, 1996, 1974, 1964).

Thus, the economic linkages to improvements in private firm-level, *ad hoc* decision making motivates a wide range of stakeholders to search for alternative ways to approach the issue of incomplete risk-transfer markets for agriculture and to efficiently mix government and markets and find improved ways to insure against crop losses created by natural hazards.

This book serves an important and useful role in this search by helping a wide range of stakeholders consider alternative ways to approach the issue of incomplete risk transfer markets for agriculture. Chapters 2 and 3 will expand the idea that weather events that are highly correlated to crop failure can potentially
be insured. Chapter 2 provides detailed information about how to design index insurance contracts, and Chapter 3 provides case studies from countries where such instruments are being introduced—the entire effort of this book is thus directed toward how to mix government and markets and find improved ways to insure against crop losses created by natural hazards.

Government is clearly motivated to do something to assist producers in coping with catastrophic production risk. Assessing the appropriate role of government involvement is difficult since social and market aspects of the risk problem often get blended together and even confused. Government intervention in the first place is usually justified on the grounds of an insurance market failure—private firms simply have trouble obtaining insurance against multiple events that create crop failure. But this diagnosis and the subsequent proliferation of government agricultural insurance programs have done little to help correct the source of problems and facilitate true markets; Rather, markets have been largely replaced by government. For this reason, the approach used here is to identify specific and significant factors that contribute to incomplete markets for catastrophic risk transfer in agriculture. Three main factors that inhibit private market development can be identified:

- Correlated risk
- Limited cognitive capacity
- High transaction costs

These constraints are investigated in more detail below with several suggestions of corrective action that government can take to mitigate each.

Agricultural production risk has been described as “in-between” risk (Skees and Barnett, 1999) on the continuum spanning perfectly correlated to completely independent risk. Indexed weather derivatives should similarly be thought of as “in-between” instruments that combine elements of both financial derivatives and insurance. While all these types of instruments can be broadly viewed as contingent claims contracts, the governing regulatory environment for the latter instruments may not be appropriate to safeguard the integrity of highly tailored indexed weather insurance contracts. Thus, government is needed to help build appropriate institutions and a regulatory environment that facilitate this market development while safeguarding the interest of the contracting parties.

While there are specific actions that governments can take to facilitate agricultural risk markets, government participation in market development needs to be examined carefully, especially when considering the application of either implicit or explicit subsidies. For example, despite the presence of highly subsidized crop insurance products, there are circumstances when producers choose not to protect themselves from catastrophic loss. Experience from several
countries also has demonstrated that rent-seeking activity from market participants can appropriate government resources well beyond the start-up phase of these markets. Government investments in developing agricultural risk-transfer markets should also have minimal perverse impacts on resource allocation decisions of farmers and rural decision makers. Understanding the reasons for these behaviors and how policy design can create incentive structures that lead to more efficient outcomes is vital in designing and structuring new mechanisms that bring value to individual producers and meet societal goals of economic efficiency.

1.3 AGRICULTURAL RISK AND MANAGEMENT

Agricultural producers are susceptible to a variety of risks. Among these are variations in market prices for agricultural commodities and production inputs. The focus here is on crop yield or output risk, rather than price risk. This discussion is also applicable to situations where the productivity of pasture and grazing land is at risk. Many of the non-weather perils that impact yields including insect infestation, biotic and abiotic infection, and even congestion caused by poorly controlled weedy plant species can be addressed via improved management practices. However, agriculture’s greatest risk exposure is to adverse weather events (Harwood, et al., 1999). There are many examples, including drought stress, sudden freezing temperatures, hail and wind damage, insufficient snow cover, and excess moisture. In some cases, the weather event itself may not be directly damaging but contributes to the growth and spread of other harmful agents like molds.

For any business, including agriculture, the purpose of risk management is to reduce the variance of expected financial returns given the uncertainties encountered in a stochastic production and demand environment. Risk management seeks to smooth income over time by taking specific actions to protect against downside risk, which in exchange, often requires giving up some upside earnings potential. Risk-averse agents are willing to make this exchange because there is greater utility in predictable, steady income (Hardaker, et al., 2004).

Farmers use a variety of strategies to address the financial consequences of risk. In general, these strategies can be categorized into risk mitigation, risk transfer, and management of retained risk. Risk mitigation refers to actions that reduce either or both the probability of a loss occurring and the severity resulting from a loss event. Common strategies include irrigation; integrated pest management systems; the adoption of risk-reducing technologies, such as pesticides or improved seed varieties, and diversification across commodities (including
mixing crop and livestock activities) or regions; and engagement in off-farm enterprises.

Risk transfer shifts a portion of a producer’s risk exposure, at some cost, to another entity willing and more able to diversify the risk. In developed countries, farmers often have access to risk-transfer mechanisms, such as futures market contracts, to manage output price risk. Various crop insurance schemes are often available to help manage yield risk. Vertical integration and forward contracting are also strategies that can change the distribution of risk, usually price risk, between contracting parties. In the developing world, the availability of risk-transfer mechanisms is much more limited and informal.

Even if they utilize available risk mitigation and/or risk-transfer mechanisms, farmers still retain some degree of risk exposure and must use additional strategies for coping with the financial implications of loss events. Typically, these are mechanisms for smoothing inter-temporal consumption across low- and high-income periods, such as private savings or maintaining credit reserves with formal lending institutions. While these mechanisms may work well for low-magnitude losses, even if they are frequent, they often prove to be inadequate for retained risk that is rare but severe. Retained weather risk is always present either in whole or in part, and is wholly retained in situations where existing crop-yield insurance is either not purchased or unavailable by location or crop. Even in cases where crop-yield insurance is utilized, the loss deductible is retained.

While this discussion casts risk management strategies as complimentary, there may also be instances when risk mitigation and coping mechanisms for retained risk substitute for risk transfer, as seen in the U.S. crop insurance experience (Glauber, 2004). There are likely several explanations, but risk mitigation and risk coping strategies may potentially be overwhelmed by catastrophic loss events in the absence of risk transfer. Building systems, whereby insurance transfers highly correlated and catastrophic losses out of the community, and bank and non-banking systems facilitate savings and borrowing to assist in coping with more frequent and less severe events, is at the core of designing effective institutions for agricultural output risk.

### 1.4 INSURING AGRICULTURAL RISK

Insurance is a commonly used risk-transfer mechanism. Throughout the developed world, and in many developing countries, insurance is available to protect against the financial implications of events such as automobile collision, theft, and property damage caused by fire, wind, and other perils. Personal liability risk is also commonly transferred, as is the risk of illness or injury.
When purchasing these insurance policies, individuals choose to accept a relatively small, consistent stream of losses (the insurance premiums) rather than face the risk of a large loss that is unlikely but possible. Production risk transfer in agriculture using insurance is much less common, however. This section first reviews the necessary conditions for risk to be transferred in traditional insurance markets, examines the special problem of spatial correlation of weather effects for agricultural insurance, and outlines what this means when considering how to transfer agricultural risks.

**Insurability Conditions**

Not all risks can be insured. Uninsurable risks violate one or more of five necessary conditions identified in the insurance literature (Rejda, 2001). In particular, agricultural risks are unlikely to sufficiently meet these conditions:

**Determinable and measurable loss**

It must be possible to determine clearly when a loss has occurred and its magnitude; if not, settlements of claims will frequently require costly litigation. This dramatically increases the cost of providing insurance.

**Accidental and unintentional loss**

Indemnities should be paid only when a loss has occurred due to a random event over which the insured has little or no control. If insureds can engage in hidden actions (including, but not limited to, fraud) that increase the probability of loss and/or its magnitude, indemnities will be higher than anticipated. Insurers often call this the “moral hazard” problem. Insurers can attempt to address this problem through increased monitoring of policyholder behavior, but this can be very expensive. Deductibles and co-payments can also be used to reduce the incentive for moral hazard.

**Calculable expected frequency and magnitude of loss**

To develop a premium rate, the insurer must be able to estimate accurately both the expected frequency and expected severity of loss. Of course, insurers understand that these estimates are likely to be imperfect. For that reason, insurers often load premium rates to account for uncertainty in estimating these factors. If the uncertainty is minimal, the load will be rather small. However, if the uncertainty is large, the load can be so high that the insurance is unaffordable.

**Potential insureds can be accurately classified into roughly homogeneous pools**

Insurers typically do not develop premium rates on an individual basis. It would be very expensive to calculate the expected frequency and magnitude of loss for each individual insurance applicant. Instead, insurers attempt to classify applicants into risk pools and develop a premium rate for everyone in that pool. This is why automobile insurance applications often have questions about the
type of car being insured, the distance that the automobile will be driven from the home to the work place, and the number of teenage drivers in the household. These questions are among those used to classify potential insureds into risk pools. Problems occur when applicants recognize that the insurer has not classified them accurately. Within a given risk pool, the higher risk applicants will be more likely to purchase the insurance while the lower risk applicants will be less willing to purchase the insurance because they consider the premium cost to be excessive. Thus, while the insurer bases the premium rate on the expected performance of the entire pool, in reality only the highest risk individuals purchase the insurance. As a result, indemnities will likely exceed what was expected when the premium rate was set. If the insurer responds by increasing the premium rate, more low-risk individuals will cease to purchase insurance, further compounding the problem. This “adverse selection” problem can only be corrected by better classification methods that typically involve collecting more information from applicants. This, however, may significantly decrease insurance purchasing due to higher transaction costs that ultimately must be added to loads on the insurance premium rates.

Large number of independent exposure units
Insurers invest in a portfolio of insurance policies. The variance in returns on the insurer’s portfolio can be reduced by diversifying over a large number of insurance policies if the indemnities paid on those policies are independent or, at least, not highly positively correlated. If indemnities paid on the insurance policies are highly positively correlated, the variance in net returns from the portfolio will be quite large. Insurers seek to manage this portfolio risk by purchasing reinsurance and/or maintaining financial reserves. Note, however, that each of these risk management strategies comes at a cost. Insurers must pay a premium for reinsurance, and financial reserves must be maintained in a liquid state in case they are needed to pay indemnities. These funds would likely earn a higher rate of return if they were invested for longer periods of time.

Despite laying out such clear-cut conditions of insurability, many insurance products are available for risks that deviate somewhat from these ideal conditions. However, these deviations must be recognized and addressed when insurance products are being designed. Failure to do so may jeopardize the long-term viability of the product. Risks characterized by extreme violations of these ideal insurability conditions are likely not insurable.

Correlated Risk
When considering the potential functionality of any risk-transfer instrument, a major consideration is the degree of correlation in financial losses caused by the risk, and building a diversified portfolio of insureds. Aggregating uncorrelated
risks into a single insurance pool reduces the variance of loss. In other words, when considering a pool of uncorrelated loss events, the mean of the individual variances is always greater than the variance around the mean loss of the pool. This result follows from the statistical property known as the “law of large numbers.” Society benefits from insurance markets that pool uncorrelated risks, since the risk faced by the pool is less than the pre-aggregated sum of individual risks (Priest, 1996).

Agricultural production losses tend to be characterized by some degree of positive spatial correlation. This is especially the case when considering losses due to weather events since weather patterns are generally similar over large geographic areas. Thus, the degree of positive correlation is often inversely related to the size of the region under consideration: relatively small (large) countries are likely characterized by more (less) positively correlated agricultural losses. Positive spatial correlation of losses limits the risk reduction that can be obtained by pooling risks from different geographical areas. This increases the variance in indemnities paid by insurers. As a result, it also increases the cost of maintaining adequate reserves or reinsurance to fund potentially large indemnities caused by systemic loss events. In general, when losses are more positively correlated, insurance is less efficient as a risk-transfer mechanism.

Other risk-transfer markets are better suited to highly positively correlated risks. For example, well-developed futures exchange markets exist to transfer risks associated with commodity prices, interest rates, and exchange rates and in each case, the underlying price generally moves together. In recent years, various capital market instruments have developed for transferring highly correlated weather risks or risks associated with natural disasters (Doherty, 2000; Skees, 1999).

In general, agricultural production losses are typically neither uncorrelated nor highly positively correlated. They are what have been referred to as “in-between” risks (Skees and Barnett, 1999). This implies that, if used exclusively, neither insurance nor capital market instruments are well suited for transferring agricultural production risks. However, a careful blending of these instruments can foster further development of agricultural risk-transfer opportunities, and weather index insurance contracts lend themselves to facilitating that blending.

Implications for Agricultural Risk Transfer

Given the insurability conditions and also some understanding of the current systems that producers use to manage risk (Anderson, 2002), there are a number of implications for anyone considering developing risk-transfer products for natural disasters in agriculture:
• Relative risk varies by crop and region and these differences must be reflected in the price of the risk-transfer instruments.
• Individuals have many choices for managing risk; development must occur with an awareness of current risk management systems.
• Risk management comes at a cost.
• Not all risks are insurable.
• Not everyone wants (or needs) insurance.
• With insurance, one size does not fit all.
• Adverse selection and moral hazard are impediments to managing risk and more information is needed to control and mitigate these problems.
• One must have sufficient data to calculate premium rates. Uncertainty about the frequency and/or magnitude of the risk being insured leads to higher premium rates via premium loads for the ambiguity of risk and builds catastrophe loads more quickly.
• Multiple-year risks are almost impossible to insure without significant experience, therefore new product development should focus on single-year risks.

1.5 THE CROP INSURANCE EXPERIENCE IN NORTH AMERICA

The Unites States and Canada have long established and sophisticated multiple-peril crop insurance programs, and they dominate the global market for reinsurance of agricultural insurance. In both countries, the programs have undergone significant changes in the past twenty to thirty years and are heavily subsidized by government. These subsidies mask many of the characteristic underwriting problems of individual multiple-peril crop insurance. If farmer premiums are subsidized, it makes the premiums more attractive to those farmers who represent better risk than the pool of farmers who would purchase without the subsidies. Thus, given premium subsidies with little attention to individual underwriting, the higher risk farmers will still end up with more transfers.

Two major differences between the U.S. and Canadian crop insurance programs involve the delivery systems and the role of provinces in designing alternative products in Canada. The United States uses the private sector to deliver crop insurance, while Canada delivers crop insurance via provincial government entities. The Risk Management Agency (RMA) in the U.S. Department of Agriculture is solely responsible for the maintenance of existing products and development of new products. The RMA also sets premium rates. Unlike the
U.S. program, Canadian provinces have a degree of autonomy to design products that fit their region. Provinces have a relationship with the federal government to provide some of the subsidy and reinsurance capacity under the broader umbrella of a Canadian agricultural safety net policy.

While both the United States and Canada have greatly expanded beyond crop insurance products, the focus here is on crop insurance products not revenue-based products, which have expanded significantly. Around three-quarters of U.S. premiums are tied to revenue insurance products. Canada has been more aggressive in protecting shortfalls in whole-farm revenue than has the United States.²

The United States

In the United States, multiple-peril crop-yield insurance and crop revenue insurance are offered through the Federal Crop Insurance Program (FCIP), a public-private partnership between the federal government and various private-sector insurance companies. The program has both social and market-based goals. On the social side, no eligible farmer can be refused regardless of a bad risk history or size of the policy. At the same time, the program aims to be actuarially sound. Excluding pasture, rangeland, and forage, approximately 72 percent of the nation’s crop acreage is currently insured under the FCIP. Currently, about 73 percent of the total premiums collected by the FCIP is for revenue (price and yield) policies, while 25 percent is for yield insurance.³

Policies are available for over 100 commodities, but just four crops—corn, soybeans, wheat, and cotton—account for approximately 79 percent of total premiums. Both area-yield and area-revenue insurance policies offered in the United States are county-based index insurance policies. In 2004 they accounted for 7.4 percent acreage insured, but less than 3 percent of the US$4 billion in total premiums. A predominance of policies remain based on farm- or sub-farm-level yields and, in the case of revenue products, these yields are combined with a price index that is generally driven by national price changes.⁴

FCIP policies are sold and serviced (including loss adjustment services) by private insurance companies. The government establishes the premium rates for

³ The remaining 2 percent of premiums is for a variety of other insurance products.
⁴ Under certain conditions, policyholders can choose to divide farms into smaller units that are insured separately.
all products sold by private companies. There are four components of subsidy in the U.S. program:

1. The total premium is subsidized at rates from 100 percent for catastrophic (CAT) policies to 38 percent for policies at the highest coverage levels. After mixing all coverage levels and products in the United States, the average premium subsidy for 2004 was 59 percent of total premiums.
2. Administrative and operating expenses for private companies are subsidized at rates that average approximately 22 percent of total premiums.
3. The risk-transfer arrangement has an embedded subsidy with an expected value of about 14 percent of total premiums.
4. The program, by law, is allowed to be called, actuarially sound, at a loss ratio of 1.075, an additional 7.5 percent subsidy.

Once all levels of subsidies are considered, one can estimate the total cost of the program by adding all subsidies to the farmer contribution. On a percentage basis, farmers pay about 30 percent of all costs for the U.S. risk-transfer programs.

The federal government provides farmers with a base, catastrophic, yield insurance policy, free of any premium costs. Farmers may purchase higher coverage levels of either yield or revenue insurance. The federal reinsurance mechanism allows insurance companies to (within certain bounds) determine which policies they will retain and which they will cede to the government. This arrangement is referred to as the standard reinsurance agreement (SRA). The SRA allows for retention of risk by state, with three different pools for the different insurance plans. The SRA is quite complex with both quota-share reinsurance and stop losses by state and pool. In essence, the SRA allows companies to adversely select against the government as a necessary component since the companies do not establish premium rates but are required to sell policies to all eligible farmers.

**Canada**

The newly reformulated Canadian Production Insurance (PI) scheme offers producers a variety of multiple-peril production or production value loss products that are similar to many of those sold in the United States. One major distinction, however, is that the Canadian program is marketed, delivered, and

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5 The catastrophic policy only covers yield losses in excess of 50 percent of the expected yield. The rate of indemnity is only 60 percent of the expected market price.
serviced entirely and jointly by federal and provincial government entities, although it is the provincial authorities who are ultimately responsible for insurance provision. This allows provinces some leeway in tailoring products to fit their regions and to offer additional products.

Production insurance plans are offered for over 100 different crops, and include plans for livestock losses as well. Crop insurance plans are available, based on individual yields (or production value in the case of certain items such as stone fruits) or area-based yields. In contrast with the U.S. program, Canadian producers are not allowed to separately insure different parcels, but rather must insure together all parcels of a given crop type. This allows high and low yields to be offset, or averaged, in determining production loss. Insurance can also be purchased for loss of quality, unseeded acreage, replanting, spot-loss, and, emergency works—a loss mitigation benefit meant to encourage producers to take actions that reduce the magnitude of crop damage caused by an insured peril.

Cost sharing between the federal government and each province for the entire insurance program is to be fixed at 60:40, respectively, by 2006. However, federal subsidies as a percentage of premium costs vary from 60 percent for catastrophic loss policies to 20 percent for low deductible production coverage. Combined, governments subsidize approximately 66 percent of program costs, including administrative costs. This is roughly equivalent to subsidy levels in the United States. In Canada, provincial authorities are responsible for the solvency of their insurance portfolio. The federal government competes with private reinsurance firms by offering deficit-financing agreements to provincial authorities.

### 1.6 COMMON ELEMENTS OF U.S. AND CANADIAN CROP INSURANCE

The North American crop insurance programs have several elements in common:

1. Blending of both social and market-based goals
2. Core products that insure farm-level multiple perils
3. Government subsidies linked to premiums on a percentage basis
4. Government subsidies or government agencies used for administrative costs of the programs
5. Significant government expenses used for administrative support, premium support, or both
6. A major role for government that pools and retains some of the most catastrophic risk

A fundamental challenge for any country rethinking current approaches to agricultural insurance programs or attempting to design new instruments, including indexed weather derivatives, is to critically assess each of these common features of existing government-facilitated agricultural insurance programs. The goals are to improve upon what has already been tried and highlight those areas most important to a program’s long-term viability, economic efficiency, and equity effects. The following sections examine the common elements of the North American crop insurance experience and help lay the groundwork for later recommendations on framing and beginning agricultural insurance programs that must also cope with catastrophic risk.

**Mixing Social and Market-Based Goals**

Leveraging limited government resources in attempting to accomplish the joint goals of offering something from government on the social side, as well as the market-based side, may be at the core of this challenge. There are two dimensions of the social side of many of the agricultural insurance programs: 1) compensation for extreme losses when a true catastrophe occurs, and 2) something akin to income enhancement in the name of risk management. Markets may fail to develop for low-frequency, high-consequence catastrophic events. As will be developed below, there is a cognitive failure problem among many decision makers as they simply forget, and fail to plan for bad events. Income enhancement is a political decision that has little to do with improving market efficiency and those motives are dismissed for this analysis. On the other hand, making a clear distinction between what is done by government to address cognitive failure problems can lead to recommendations for designing agricultural insurance programs that have both a social and a market dimension. We should be mindful that other types of government social policies might contribute to catastrophic losses in unanticipated ways. For example, programs that provide ongoing support to agricultural activities in less favored areas, almost by definition, encourage production on riskier disaster-prone lands.

**Covering Individual Farm Yields for Multiple Perils**

Without some serious underwriting efforts, covering individual farm yields for multiple perils is problematic. As an example of what happens when proper attention is not given to individual underwriting, consider the U.S. program. In the United States, the only mechanism to underwrite risk is a requirement that farmers prove their yields. Actuarial soundness has been an issue with the program since the private sector was allowed to sell crop insurance. Three
different crop insurance bills passed in 1980, 1994, and 2000 (Glauber and Collins, 2002) have subsequently added higher premiums subsidies to the program. Each time a subsidy is introduced, a greater number of lower risk farmers are enticed to buy crop insurance. These farmers improve the pool and the actuarial performance of the program. However, higher risk farmers or farmers who have a tendency to abuse the program are also beneficiaries of added subsidies (Skees, 2001a). The obvious consequences of such actions are both a more expensive program and a reward system for the highest risk farmers. Neither of these consequences is desirable for a sustainable agricultural insurance program.

**Subsidies as a Percent of Premium**

Premium subsidies for crop insurance have almost exclusively been anchored as a percent of the unsubsidized premium. Since subsidies are an income transfer—evidenced by the math of this transfer—those facing higher risk will receive a greater transfer. It is quite logical to expect that such a mechanism is effectively paying those facing more risk to take on more risk and buy up higher levels of coverage. Such incentives can lead to long-run negative consequences as the cycle creates more exposure and more losses when the next disaster arrives. For crop insurance, higher premium subsidies as a percent of premium encourage greater plantings in higher risk areas. As more marginal acres are added, the risk exposure also increases and subsequently, environmental concerns often arise since the additional marginal acreage may also be more environmentally sensitive.

Persistent free disaster assistance can be thought of as a 100 percent premium subsidy. Without careful consideration of the thresholds for implementing free disaster assistance, it will have the same impact on decision makers and subsequent disasters as does adding higher levels of subsidy to an insurance product (Milete, 1999). Some argue that government disaster assistance is not equitable because taxpayers compensate for losses that individuals chose to assume (Rossi, et al., 1982). This argument has less credence when one is concerned that the poorest of the poor may concentrate in disaster-prone areas. Nonetheless, free disaster aid should have structure and only be provided for extreme events so not to encourage perverse behavior.

**Subsidies to Cover Administrative Costs of Agricultural Insurance**

Since many agricultural insurance programs facilitated by government are meant to be universally available, the government chooses either to incur the delivery and service costs of the program via government agencies or via subsidies to the
private sector. This is a complicated issue. Markets would allocate the cost using market principles, whereby farmers would pay for administrative costs in premiums. Costs for selling and servicing a policy are roughly equal regardless of the size of the policy. Thus, small policyholders would pay a higher portion of their premiums for administrative costs if the program were left solely to the private sector. When loss adjustments of individual farm losses are involved, this is likely to compound the differences between what small holders pay versus larger holders.

What has become increasing clear in the United States is that how to subsidize a private-sector delivery system requires careful thinking. As a means of simplicity, these subsidies have been set as a percentage of unsubsidized premiums. As subsidies have increased, farmers have also gravitated to products with higher levels of unsubsidized premiums. Thus, the private sector has had some windfall gains from the simple rule. As unsubsidized premiums per policy have increased, the reimbursement levels per policy have also increased significantly. This experience suggests that if government feels compelled to subsidize the administrative costs of a private-sector agricultural insurance company, they should at least consider setting subsidies on a per policy basis in some fashion. Still, there are likely better ways for government to incur some of the development and administrative costs of agricultural insurance programs that can facilitate market-based charges for many of the features tied to delivery from the private sector.

**Significant Government Expenses**

When governments attempt to use insurance as the means to avoid disaster payments, they find new ways of justifying more subsidies to get higher levels of participation. The perennial debate over these subsidies surrounds both the U.S and Canadian crop insurance programs. As Glauber (2004) documents, it has not worked in the United States. More and more costly crop insurance programs have co-existed with disaster payments for well over 20 years. Again, this experience and the experience of other countries in attempting to accomplish both the social protection goal for catastrophes and the risk management goal of insurance markets, point to the need for new thinking about how to build programs that complement and facilitate these two goals while using less fiscal resources to do so.

In addition, governments routinely misrepresent the actuarial performance of their subsidized insurance programs by only focusing on farmer-paid premiums relative to indemnities paid out to farmers. Hazell (1992) demonstrates that actuarially sound insurance requires, on average, that premiums collected meet or exceed administrative costs plus indemnities for insured losses. This is the
standard that private insurers must meet for long-term solvency. However, when governments report loss ratios, or cost-to-premium ratios, they normally calculate the farmer-paid premium to include the premium subsidy. In recent years, both the United States and Canada report loss ratios near 1.0 and cite this as evidence of improvements in the performance of their programs. But the correct procedure to calculate loss ratios is to subtract the contribution made by taxpayers, and then calculate the loss ratio using unsubsidized premiums, giving actual loss ratios of about 3.6 for the United States and 2.9 for Canada. It is clear from these figures that governments pay the larger part of the costs of crop insurance provision.

Using Government to Pool and Hold Catastrophic Risk

Among the common features of the national crop insurance programs identified here, the attempts to pool risk within the country via some formal institutions are likely the most important. This can make the “in-between” risk move toward the end of the scale that is more independent. At least the idea of creating more pooling within the country before accessing global risk-sharing markets is attractive and can motivate behavioral responses by a host of private decision makers that may (or may not) lead to the desired goal—effective risk management with minimal distortions and appropriate incentives for underwriting risk.

In fact, a prerequisite for effective and efficient financial markets is an appropriate enabling environment. Setting rules that assure premiums will be collected and indemnities will be paid is not a simple undertaking.

1.7 IMPLICATIONS: MARKET FAILURE OR LOGICAL MARKET RESPONSE?

When attempting to explain the lack of effective insurance markets for catastrophic agricultural risk transfer, one should ask if this is a bona fide market failure or a logical market outcome. Transaction costs preclude many markets from emerging, but this does not necessarily mean that government should intervene. For example, insurance products for small and frequent risks are seldom offered because the transaction costs required in determining if losses are due to an insured peril rather than bad management, quickly become larger than the value of the insurance protection. To some extent, it is presumptuous to

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assume farmers are unable to cope with small and frequent risks in agricultural production. Nonetheless, a conundrum emerges given the cognitive failure of decision makers to tend to forget bad events (Kunreuther, et al., 1993). Potential buyers of a crop insurance product are unlikely to pay its full cost when the low probability of extreme events does not factor into their decision making. Also, people who buy insurance (with the exception of life insurance) generally want to experience some payments. Thus, insurance products for crop failure will need to have some level of payment at a reasonable frequency level (say, 1-in-10 years).

The cognitive complexity and ambiguity surrounding any assessment of low-probability, high-consequence events may merit some special considerations. Low-probability events, even when severe, are frequently discounted or ignored altogether by producers trying to determine the value of an insurance contract. This happens because forming probability assessments over future events is complex and often entails high search costs. On the other side, insurers will typically load heavily for low probability but costly events when there is ambiguity surrounding the risk assessment. Ambiguity is especially serious when considering highly skewed probability distributions with long tails as is typical of much agricultural risk. Uncertainty is further compounded when the historical data used to form empirical distributions are incomplete or of a short time series. Together, these effects introduce a price wedge between consumers and suppliers and markets, causing the failure of catastrophic insurance to develop.

Generally, severe crop failure events will also impact many individuals at the same time. This correlated risk problem and the ambiguity of the infrequent high-consequence risk also mean that private-sector markets will load premiums beyond the buyer’s willingness to pay. The government has an important role in providing data and information about extreme events. Public support for weather services can help educate decisions makers about what is possible, as well as those who venture to write insurance against these events. There is a “public good” dimension to providing weather data systems that is critical to facilitation of any type of crop insurance product. Beyond the data that help a wide range of stakeholders understand the complex risk, government can also play an effective role in organizing pooling arrangements for natural hazard risks. Institutional arrangements that facilitate making correlated risk more diversifiable can be a legitimate role for government.

If governments are to support insurance markets, the social benefits of reducing the inefficiencies brought on by risk must outweigh the social cost of making agricultural insurance work. Furthermore, even though a risk-transfer market may not exist, it does not mean that a true inefficiency does exist. Asking if there
is true market failure is a critical first step before governments embark upon what could be an expensive proposition.

Market failure, or in this case, insurance failure, is the usual justification for government intervention to supply products or services that are not sufficiently provided by private enterprises. Given the loss ratios and significant government expenditures identified above, it is doubtful this standard has been achieved. The problem of government performance is additionally complicated by mixing social and market goals, making it even more difficult to determine whether the lack of risk-transfer opportunities is being adequately addressed.

It is critical to ask whether a true inefficiency exists, even though certain risk-transfer markets may appear incomplete. What exactly are the sources of inefficiency, and is government better equipped to solve the problem? Trying to force the development of individual farm-yield indemnification crop insurance may not be the best use of government resources and advantages. What role should government take when there is a perceived need, but the current formula is not sustainable? Reviewing the sources of market inefficiency may give clues to why insurance for agricultural production risks is not readily available through private market channels, and what effective avenues government might take.

Moral hazard and adverse selection are examples of situations where suppliers of insurance have less information than potential buyers and are understood to be the classical conditions contributing to insurance market failure. Moral hazard and adverse selection arise from asymmetry in information that can be extremely expensive for insurance suppliers to overcome. This problem of asymmetric information can be reduced to one of prohibitively high transaction costs for observing risk levels and monitoring behavior, at least for certain types of insurance products.

One advantage that government has over private insurance providers is the ability to completely require all producers to purchase insurance, such as catastrophic insurance coverage. While this may mitigate the inherent problems of moral hazard and adverse selection, it most certainly does not make these problems go away. If the program does not properly classify different risks, it will transfer premiums from lower risk and better-managed farms to higher risk and more poorly managed farms. This has equity and efficiency implications that are difficult to fully comprehend as the asymmetric information problem will mask these transfers and the inherent inefficiencies associated with forcing everyone into a mandatory insurance program. High subsidy rates can also be used to bring the lower risk farmers into the pool and improve the “before subsidy” actuarial experience. Nonetheless, when government must resort to such subsidies to bring in the better risk class and does not properly classify
these risks (as has been done in the United States) they are not only asking taxpayers to pay for a failed system of risk classification, they are also asking lower risk farmers to transfer premiums to higher risk farmers.

Government supply of traditional crop insurance products does not by itself contribute much to reducing the effects of cognitive complexity on the demand side of the insurance market. On the supply side, government may have an impact to the extent that it is less sensitive to risk ambiguity when rating insurance than are private suppliers. More often than not, governments have used premium subsidies to overcome the price wedges that emerge due to cognitive complexities associated with natural disaster risk. Of some considerable concern is that premium subsidies are nearly universally locked in as a percentage of the unsubsidized premiums. Such a mechanism for subsidy transfers more to higher risk regions and has many of the accompanying resource allocation problems associated with free disaster payments that encourage those producing in higher risk areas to take on more risk by planting more.

Problems with asymmetric information, correlated risk, and cognitive errors and ambiguity—all have contributed to the lack of private transfer markets for agricultural production risk. Government has responded by becoming a primary insurance provider, but has not been able to meaningfully overcome these hurdles other than through heavy subsidization, begging the question of how economically efficient the response has been. Alternative models for government involvement in these markets are desperately needed.

The question now becomes whether there is a role for government in correcting for cognitive error and whether indexed insurance products could have meaningful advantages in overcoming the limitations of traditional insurance. The goal is to reduce the inflating effects of ambiguity on insurance premiums, bringing buyers and sellers closer together in terms of recognizing and agreeing on the probabilities of loss, and reducing the costs of insurance provision.

The observations suggest there may be gains in cognitive recognition and a lessening of the ambiguity problem by layering out the tail of a loss distribution, that segment containing the fewest observations, greatest uncertainty, and highest loss. Doing so would remove much of the justification for very high ambiguity loads on insurance products over the remainder of the distribution. Less risk loading and lower premiums will encourage insurance demand.

1.8 INDEX INSURANCE ALTERNATIVES

There are potentially lower cost approaches to providing crop insurance that are less susceptible to the asymmetric information problems associated with
multiple-peril crop insurance. Index-based insurance products are alternative forms of a contingent claims contract and offer some promise for avoiding the problems with traditional multiple-peril crop insurance products. With index-based products, payments are based on an independent measure that is highly correlated with farm-level losses. Unlike traditional crop insurance that attempts to measure individual farm yields, index insurance makes use of variables largely exogenous to the individual policyholder, such as area yield, or some objective weather event such as temperature or rainfall, that have a strong relationship to individual yields.

Index insurance is a different approach to insuring individual crop yields. Unlike most insurance where independent risk is a precondition for insurability (Rejda, 2001), the requirement for index insurance is that risk be correlated over space. When expected losses are correlated in this manner, it is possible to offer index contracts to anyone who shares the risk of an areawide crop failure. Index insurance is an effective policy alternative to traditional crop insurance as it seeks to protect the agricultural production sector from widespread, positively correlated crop-yield losses.

In some situations, index insurance offers superior risk protection compared to traditional multiple-peril crop insurance when the provider must impose large deductibles. A deductible basically means that the insurance policy will not pay until the loss is very serious. Deductibles, co-payments, or other partial payments for loss are commonly used by insurance providers to mitigate adverse selection and moral hazard problems. Asymmetric information problems are much lower with index insurance because 1) a producer has little more information than the insurer regarding the index value, and 2) individual producers are generally unable to influence the index value. This characteristic of index insurance means there is less need for deductibles and co-payments, making insurance protection potentially more valuable. Similarly, unlike traditional insurance, there is little reason to place restrictions on the amount of coverage an individual purchases. As long as the individual farmer cannot influence the outcome that results in payments, placing limits on liability is not necessary. However, one may want limits on liability if governments decide to offer premium subsidies.

Finally, the value of index insurance is enhanced when it is blended with banking and credit services. The role of index insurance is to manage the correlated risk of widespread crop losses by shifting it to those willing and better able to assume those risks, generally financial and reinsurance markets. In turn, the local banking sector should be able to work with individual producers to help them manage idiosyncratic and basis risk; if a producer has an independent loss that the index insurance does not pay, it should be possible to borrow from the bank to smooth that shock. By combining insurance with banking in this manner, it is...
possible to remove basis risk—one of the main concerns associated with index insurance.

**Basic Characteristics of an Index**

Thoughtful construction of the weather events to be used for an index is important since it not only defines the unit of measurement, but also should reflect a revenue outcome for a number of producers in a contiguous geographic area. In this sense, an index reflects real value which permits the possibility of trading locally among producers who may experience different levels of loss when the event occurs, or more sophisticated trading in more formal financial markets whereby even those who are not at risk from the event may be interested in carrying and supporting the risk as another investment in a diversified portfolio of equities. The later markets are particularly interesting conceptually since natural hazard risks are not generally correlated with the traditional equity markets.

There are a number of characteristics for an index to be used satisfactorily as the basis for contingent claims. In general, these are related to the degree of confidence or trust that market participants have that the index is believable, reliable, and void of human manipulation—that is, measurement risk must be low (Ruck, 1999). The nature of weather events and the established presence of national reporting systems for both weather and yields generally satisfy these properties. The requirements for a suitable index are that the measured variable is

- Observable and easily measured,
- Objective,
- Transparent,
- Independently verifiable, and
- Reportable in a timely manner (Turvey, 2002; Ramamurtie, 1999).

The units of measurement for an index can be any that convey meaningful information about the state of a weather variable during the contract period, and are often shaped by the needs and conventions of market participants. Indexes are frequently cumulative measures, such as inches of precipitation or temperature above or below a specified degree. Cumulative measures have worked well for a variety of industries, but other types are used such as indexes based on average temperature or average yield.

New innovations in technology, from low-cost weather monitoring stations that can be placed in many locations to sophisticated satellite imagery, will expand the number of locations where weather variables can be measured, as well as the
types of variables it is possible to measure. Measurement redundancy and automated instrument calibration further increase the credibility of an index.

Box 1.8.1 Other Forms of Index Insurance

Weather events are not the only measures used to develop index insurance contracts. Any independent measure that is secure and highly correlated with agricultural losses can be used as a means of forming an index insurance product. Three examples are profiled below:

1. Use of area-yield insurance
2. Use of satellite vegetative images
3. Use of widespread mortality rates for animals

**Area Yield Insurance.** While the idea of insurance based on weather indexes is more contemporaneous, area-based insurance is an index-based insurance product that has been promoted for sometime. Chakravati wrote about area-yield insurance for India as early as 1920. Halcrow was writing about the usefulness of this approach for the United States as early as 1949. Area-yield programs exist in the United States, India, Brazil, and Canadian province of Quebec (Skees, Black, and Barnett, 1997; Mishra, 1996; Miranda, 1991). New thinking about how to use area-yield insurance is advancing the efforts in both the United States and India.

**Satellite Vegetative Images.** In Alberta, Canada, efforts are underway to pilot tests using satellite images of the vegetative cover to provide effective and affordable insurance for ranchers. Advances in technology may make such systems quite attractive as farmers and ranchers could provide the geographic coordinates, and an index to proxy the value of the pasture or crop on the surface could be created to make index payments.

**Mortality Rates for Livestock.** In Mongolia, the death rate of livestock is highly correlated due to harsh winters. Mongolia performs a complete census of every species each year. Thus, a historic data set is available at the local level to estimate mortality rates. The World Bank is working with the government of Mongolia to introduce index-based livestock insurance that would pay based on the local mortality rates (Skees, and Enkh-Amgalan, 2002).

Index insurance contracts closely follow the model proposed by Martin, et al. (2001), having a unique language similar to language in futures markets contracts. For example, rather than referring to the threshold where payments begin as a “trigger,” index contracts refer to the threshold as the “strike.” In an attempt to make things more straightforward, they also pay in increments called “ticks.”

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7 Chapter 2 presents many of these details with more examples.
Consider an example of a contract written to protect against deficient rainfall during a cropping season (see Figure 1.8.1). The writer of that contract may choose to make a fixed payment for every 1 mm of rainfall below the strike. If an individual purchases a contract where the strike is 100 mm of rain and the limit is 50 mm, the amount of payment for each tick would be a function of how much liability is purchased. If $50,000 of insurance is purchased, and there are 50 ticks between the 100 mm strike and 50 mm limit, the payment for each 1 mm below 100 mm would be equal to $50,000/(100-50) or $1,000.

Once the tick and the payment for each tick are known, the indemnity payments are easy to calculate. For example, if the rainfall is measured at 90 mm, there are 10 ticks of payment at $1,000 each; the indemnity payment will equal $10,000. Figure 1.8.1 maps the payout structure for a hypothetical $50,000 rainfall contract with a strike of 100 mm and a limit of 50 mm. An example of an area-yield contract is given in the case examples to follow.

Figure 1.8.1 Payout Structure for a Hypothetical Rainfall Contract

Indexes and contracts written to protect against unfavorable weather events have gained a lot of attention and are developed well enough in some markets to become standardized exchange traded products, used primarily by the energy sector. However, the range of weather phenomena that can potentially be insured against appears to be limited only by imagination and the ability to parameterize the event. A few examples include excess or deficient precipitation either in the form of rain or snow during different times of the year, insufficient or damaging
wind, tropical weather events such as typhoons, various measures of temperature, measures of sea surface temperature that are tied to El Niño and La Niña (ENSOs), and even celestial weather events such as disruptive geomagnetic radiation from solar flare activity. Contracts are also designed for a combination of weather events, such as snow and temperature (Dischel, 2001; Ruck, 1999). The potential for the use of index insurance products in agriculture is significant (Skees, 2001b).

A major challenge in designing an index insurance product is minimizing basis risk. “Basis risk” is a term most commonly heard in reference to commodity futures markets. In that context, basis is the difference between the futures market price for the commodity and the cash market price in a given location. Basis risk also occurs in insurance. It occurs when an insured has a loss and does not receive an insurance payment sufficient to cover the loss (minus any deductible). It also occurs when an insured has a loss and receives a payment that exceeds the amount of loss.

Since index insurance indemnities are triggered by area-yield shortfalls or weather events, an index insurance policyholder can experience a yield loss and not receive an indemnity. The policyholder may also not experience a farm-yield loss and yet, receive an indemnity. The effectiveness of index insurance as a risk management tool depends on how positively correlated farm-yield losses are with the underlying area yield or weather index. In general, the more homogeneous the area, the lower the basis risk and the more effective area-yield insurance will be as a farm-yield risk management tool. Similarly, the more a given weather index actually represents weather events on the farm, the more effective the index will be as a farm-yield risk management tool.

While most of the academic literature focuses on basis risk for index-type insurance products, it is important to recognize that farm-level multiple-peril crop insurance has basis risk as well. To begin, a very small sample size is used to develop estimates of the central tendency in yields. Given simple statistics about the error of estimates with small samples, it can be easily demonstrated that large mistakes are made when estimating central tendency. This makes it possible for farmers to receive insurance payments when yield losses have not occurred, and not to receive payments when payable losses have occurred. Thus, basis risk occurs not only in index insurance but also in farm-level yield insurance.

Another type of basis risk results from the estimate of realized yield. Even with careful farm-level loss adjustment procedures, it is impossible to avoid errors in estimating the true realized yield. These errors can also result in under- and over-payments. Between the two sources of error: measuring expected yields and
measuring realized yields, farm-level crop insurance programs also have significant basis risk.

Longer series of data are generally more available for area yields or weather events than for farm yields. The standard deviation of area yields is also lower than that of farm yields. Since the number of observations is higher and the standard deviation is lower, the square-root-of-$n$ rule suggests that there will be less measurement error for area-yield insurance than for farm-yield insurance when estimating both the central tendency and the realization. In most developed and many developing countries, long series of weather data are available.

**Relative Advantages and Disadvantages of Index Insurance**

Index contracts offer numerous advantages over more traditional forms of farm-level multiple-peril crop insurance:

*Less moral hazard*
Moral hazard arises with traditional insurance when insured parties can alter their behavior so as to increase the potential likelihood or magnitude of a loss. This is less possible with index insurance because the indemnity does not depend on the individual producer’s realized yield.

*Less adverse selection*
Adverse selection is a misclassification problem caused by asymmetric information. If the potential insured has better information than the insurer about the potential likelihood or magnitude of a loss, the potential insured can use that information to self-select whether or not to purchase insurance. Index insurance, on the other hand, is based on widely available information, so there are little informational asymmetries to be exploited.

*Lower administrative costs*
Unlike farm-level multiple-peril crop insurance policies, index insurance products do not require underwriting and inspections of individual farms. Indemnities are paid solely on the realized value of the underlying index as measured by government agencies or other third parties.

*Standardized and transparent structure*
Index insurance policies can be sold in various denominations as simple certificates with a structure that is uniform across underlying indexes. The terms of the contracts would therefore be relatively easy for purchasers to understand.

*Availability and negotiability*
Since they are standardized and transparent, index insurance policies can easily be traded in secondary markets. Such markets would create liquidity and allow policies to flow where they are most highly valued. Individuals could buy or sell
policies as the realization of the underlying index begins to unfold. Moreover, the contracts could be made available to a wide variety of parties, including farmers, agricultural lenders, traders, processors, input suppliers, shopkeepers, consumers, and agricultural workers.

**Reinsurance function**

Index insurance can be used to transfer the risk of widespread correlated agricultural production losses. Thus, it can be used as a mechanism to reinsure insurance company portfolios of farm-level insurance policies. Index insurance instruments allow farm-level insurers to transfer their exposure to undiversifiable correlated loss risk while retaining the residual risk that is idiosyncratic and diversifiable (Barnett, et al., 2005).

There are also challenges that must be addressed if index insurance markets are to be successful:

**Basis risk**

The occurrence of basis risk depends on the extent to which the insured’s losses are positively correlated with the index. Without sufficient correlation, basis risk becomes too severe, and index insurance is not an effective risk management tool. Careful design of index insurance policy parameters (coverage period, trigger, measurement site, etc.) can help reduce basis risk. Selling the index insurance to microfinance or other collective groups can also pass the issue of basis risk to a local group that can develop mutual insurance at some level. Such a group is in the best position to know their neighbors and determine how to allocate index insurance payments within the group.

**Security and dissemination of measurements**

The viability of index insurance depends critically on the underlying index being objectively and accurately measured. The index measurements must then be made widely available in a timely manner. Whether provided by governments or other third party sources, index measurements must be widely disseminated and secure from tampering. Possible approaches for mitigating potential problems with the weather data include 1) more secure, tamper-proof stations and instruments, and 2) verification of measurements using comparisons with adjacent stations or with remote sensing data.

**Precise actuarial modeling**

Insurers will not sell index insurance products unless they can understand the statistical properties of the underlying index. This requires both sufficient historical data on the index, and actuarial models that use these data to predict the likelihood of various index measures.
Education
Index insurance policies are typically much simpler than traditional farm-level insurance policies. However, since the policies are significantly different than traditional insurance policies, some education is generally required to help potential users assess whether or not index insurance instruments can provide them with effective risk management. Insurers and/or government agencies can help by providing training strategies and materials not only for farmers, but also for other potential users such as bankers and agribusinesses.

Marketing
A marketing plan must be developed that addresses how, when, and where index insurance policies are to be sold. Also, the government and other involved institutions must consider whether to allow secondary markets in index insurance instruments and, if so, how to facilitate and regulate those markets.

Reinsurance
In most transition economies, insurance companies do not have the financial resources to offer index insurance without adequate and affordable reinsurance. Effective arrangements must therefore be forged between local insurers, international reinsurers, national governments, and possibly international development organizations. The insurer faces high risk because of the covariant nature of the insured risk. When a payment is due, then all those who have purchased insurance against the same weather station must be paid at the same time. Moreover, if the insured risks at different weather stations are highly correlated, then the insurer faces the possibility of having to make huge payments in the same year. To hedge against this risk, the insurer can either diversify regionally by selecting weather stations and risks that are not highly (positively) correlated, or sell part of the risk to the international reinsurance and financial markets.

Market size
As with the introduction of any new product, the volume of insurance sold could be too small to be profitable. The insurance will only appeal to people whose economic losses are highly correlated with the insured weather event. If the index does not sufficiently approximate actual loss experiences then the insurance will not sell. Also, if the probability of loss is high, then the cost of the insurance could be prohibitive. To overcome these problems, the insurance might be limited only to truly catastrophic events that though infrequent, impose large losses. Collective action by agricultural cooperatives, microfinance groups, or farmer associations offers significant promise for the use of index contracts and adds value by developing mutual insurance products whereby members have a vested interest in mitigating fraudulent behavior.
Weather cycles

The actuarial soundness of the insurance could be undermined by weather cycles that change the probability of the insured events. It may be necessary to adjust the cost of the insurance whenever a specific weather event is confirmed, though this would require sufficient lead-time between knowledge of the pending event and the time of selling insurance.

As more sophisticated systems are developed to measure events that cause widespread problems (such as satellite imagery) it is possible that indexing major events will be more straightforward and accepted by international capital markets. Under these conditions, it may become possible to offer insurance to countries that traditional reinsurers and primary providers would previously have never considered. Insurance is about trust. If the system to index a major event is reliable and trustworthy, there are truly new opportunities in the world to offer a wide array of index insurance products.

**Box 1.8.2  What Is Needed to Make the Innovations Work?**

There are market makers who are keenly interested in offering rainfall index insurance. For example, PartnerRE New Solutions* presented the following list of items that are needed to get them interested in offering such contracts:

- Historic weather data
- Prefer 30+ years of data, especially to cover extreme risk
- Limited missing values and out-of-range values
- Prefer less than 1 percent missing observations
- Data integrity
- Availability of a nearby station for a “buddy check”
- Consistency of observation techniques: manual versus automated
- Limited changes of instrumentation / orientation / configuration
- Reliable settlement mechanism
- Integrity of recording procedure
- Little potential for measurement tampering

*Tobben, 2004

In principle, one might expect the private sector to take the initiative in developing weather-based insurance, but on a number of important fronts that involve information and public goods, it would be advantageous for government to:

1. Identify key catastrophic weather events that correlate strongly with agricultural production and income in different types of agricultural regions;
2. Educate rural people about the value and use of weather insurance;
3. Ensure secure weather stations;
4. Establish an appropriate legal and regulatory framework for weather insurance; and
5. Underwrite the insurance in some way (perhaps through contingent loans) until a sufficient volume of business has been established so that international reinsurers or banks are willing to come in and assume the underwriting role for themselves.

Government support for these various roles need not be costly, but could prove crucial in launching weather insurance. Using government resources to support the infrastructure is superior to using heavy premium subsidies to begin a crop insurance program. Infrastructure support will be less distorting for private insurers and farmers who must make decisions in a risky environment.

The Role of Technology in Providing Needed Information
In recent years, state-of-the-art methods to forecast food shortages created by bad weather have significantly improved. For example, the East African Livestock Early Warning System (LEWS) is now able to provide reliable estimates of the deviation below normal up to 90 days prior to serious problems. These systems use a variety of information: 1) satellite images; 2) weather data from traditional ground instruments; 3) weather data from new systems; and 4) sampling from grasslands to determine nutrient content. More important, these systems allow problems to be forecast at a local level using geographic information systems. Since many early warning systems have been in place for as long as twenty years, it is now possible to model the risk and begin pricing insurance contracts that match the risk profile.

Reinsurance and Weather Markets
Much can be said about the international reinsurance community and their resistance to entering new and untested markets. The use of capital markets for sharing “in-between” risks remains in the infant stage, leaving the issue of capacity and efficiency in doubt. This raises questions about the role of government in sharing such risk. For the United States, Lewis and Murdock (1996) recommend government catastrophic options that are auctioned to reinsurers. Part of the thinking is that the government has adequate capital to back stop such options and may be less likely to load these options as much as the reinsurance market. Skees and Barnett (1999) write about the role of government offering insurance options for catastrophes as a means of getting affordable capital into the market. However, the demand for catastrophic insurance will be limited where free disaster assistance is available.
Reinsurers have acquired many of the professionals who were trading weather. SwissRE acquired professionals from Enron and PartnerRE, and ACE acquired professionals from Aquila. Reinsurers are now in a position to offer reinsurance using weather-based indexes. This type of reinsurance should be more affordable since it is not subject to traditional adverse selection and moral hazard problems.

Mitigating Basis Risk with Market Solutions
Weather index insurance products should only be used when there are specific weather events that create significant crop failures. Under these conditions, weather index insurance products will remove most catastrophic risks that involve correlated losses and present a major challenge for private-sector financing of these types of losses.

Once a weather index insurance product removes the largest risk, a host of private market efforts can be used to mitigate the basis risk. These efforts can be classified as follows:

- Self-retention of smaller basis risk by the farmer
- Supplemental products underwritten by private insurers
- Blending index insurance and rural finance

Self-Retention of Smaller Basis Risk by Farmers
One aspect of index insurance that many people often miss is that offering something to transfer some of the big risk is likely a better option than offering nothing. A key consideration must still be the social costs and benefits of offering one type of insurance versus another. That index insurance products have basis risk and therefore are not worth considering is too simplistic a conclusion. As farmers have many ways of coping with risk in an environment where there are no crop insurance markets, one answer to the basis risk challenge is providing some level of risk transfer that can enhance many of the risk-coping strategies farmers currently use. To the extent that the basis risk is not too high, it is easy to argue that farmers can retain this level of risk, in particular, in light of the fact that the index insurance product gives them some level of risk transfer that they currently do not have.

Supplemental Products That Are Underwritten by Private Insurers
Developing tailored insurance products for individual farm yields is complex. Index insurance products could be used as a starting point in the development of more sophisticated products. Again, to the extent that index-based insurance products remove much of the correlated risk, they can effectively serve as a form of localized reinsurance. A private-sector insurance provider may be able to offer a companion product with an index insurance product.
To some extent, even multiple-peril crop insurance could be offered to a select group of farmers. For example, if an index insurance product is offered with a relatively low deductible, a multiple-peril crop insurance product with a higher deductible could be offered alongside that product. The contract could simply be designed to pay the higher of the two contracts. Under such conditions, the private insurance provider would offer insurance on the events where the index-insurance contract did not pay, thus eliminating the major source of basis risk — of most concern to farmers. With proper underwriting such contracts could cover only risks that are much more independent—precisely what an insurance company should be able to do. The challenge of effective underwriting would still be an issue, but one that is left to the private sector to fix.

Blending Index Insurance and Rural Finance

Progress has been made in designing and offering index insurance contracts for a variety of correlated risks in developing countries. The motivation has developed for using the index insurance contract rather than individual indemnity. Index insurance can shift correlated risk out of small countries into the global market. To the extent that the index is based upon a secure and objective measure of risk, this approach provides an important risk-shifting innovation for developing countries where commonly, legal structures for more sophisticated insurance products are woefully inadequate. Index insurance contracts involve significantly lower transaction costs and can be offered directly to end users from companies that operate in a global market, particularly if the end user is positioned to aggregate large amounts of risk (e.g., microfinance entities or, MFEs).

It is possible that offering index insurance directly to the MFE can circumvent bad government, poor macroeconomic policies, and inadequate legal frameworks. To the extent that the writer of the index insurance is a reputable global partner, the MFE could pay premiums in dollars and be paid indemnities in dollars as well. This would mitigate inflation risk within the country. The legal framework needed to allow MFEs to purchase these contracts from a global writer should be much more straightforward than the legal framework needed to offer traditional insurance. For developing countries the major challenge is knowing whether the global partner has the reputation and the resources to pay indemnities. Should the International Finance Corporation of the World Bank Group become more involved in partnering the writing of index insurance contracts for price, yield, weather, and livestock, many of these concerns could be eased.

The issue of basis risk is of some concern if one is selling index insurance contracts to individuals. However, if these contracts are sold to MFEs, the MFE should be in a position to mitigate basis risk in a number of creative ways. It is useful to illustrate some potential arrangements that could emerge between
global sellers of index insurance contracts and rural finance entities. Consider a microfinance group or a small rural MFE with members having household activities in the same neighborhood. While this group of individuals may use many informal mechanisms to pool risk and assist individuals when bad fortune visits one of their members, they are unable to cope with a major event, such as drought, that adversely impacts all members at the same time.

If the group could purchase an index insurance contract that would simply make payments based upon the level of rainfall (an excellent proxy for drought), the group would be in a much better position to cope when everyone suffers a loss at the same time. The MFE would need to develop _ex ante_ rules regarding how indemnity payments from index insurance would be used. The following are examples of how those _ex ante_ rules may be developed:

**Indemnity payments could be used to forgive debt**

Since making loans is a major activity of most MFEs, the ability to repay the loans will likely be in jeopardy when there is an event that adversely impacts everyone. Having loan defaults from a large number of borrowers at the same time is likely to put the MFE at some risk. Thus, indemnity payments from index insurance can be used to offset defaults that occur due to natural disaster. Effectively, indemnity payments become a form of credit default insurance. The MFE would still need to implement rules regarding debt forgiveness for individuals.

**Indemnity payments could be used to facilitate a form of mutual insurance**

The indemnity payments from index insurance could be directly distributed to members of the MFE via insurance-like rules that are determined by the members. Given that only actual indemnity payments received would be distributed, a common problem among mutual insurance providers in developing countries would be avoided — inadequate cash to pay for indemnities that are specified in insurance contracts (McCord, 2003). To the extent that the MFE is relatively small and members know one another, the asymmetric information problems discussed earlier would be avoided. This, of course, is the advantage of mutual insurance.

**Indemnity payments could be used to facilitate better terms of credit**

Since lending is an excellent means of smoothing consumption when there are unexpected cash flow problems, the MFE could tie the index insurance directly into the loan arrangements. Loans that are made immediately following a good season where no indemnity payments are made could be higher than normal to collect premiums that would pay for the index insurance. Interest rates could be lowered using indemnity payments directly, immediately after a major event.
Interest rate reductions could be tied directly to the severity of the event (Parchure, 2002).

**When Weather Index Insurance Is Inappropriate**

Weather index insurance contracts are not the final answer to agricultural insurance. There are many parts of the world where agricultural commodities are grown in microclimates. For example, much of the coffee in the world is grown up and down the sides of small and large mountains. Fruit such as apples and cherries is also grown in areas that can have very large differences in weather patterns within a few miles. Under these conditions, a weather index insurance contract should either be localized or it should be written so that it handles only the most extreme events.

Some regions of the world also have strong negative trends in rainfall. This can compound the complexity and mistakes that can be made in writing any type of insurance, including index-based insurance products. Likewise, there are regions in the world with significant crop production that suffers from a significant drought every 1-in-3, or 1-in-5 years. Even under the best of circumstances, it is difficult to envision creating a sustainable index insurance product given such high and frequent crop failures. Other solutions are needed.

Another concern with weather index insurance can be overfitting the data. Fitting the statistical relationship between weather and a limited amount of crop-yield data can become problematic. Limited sample size and fitting regressions within a sample can lead to complex contract designs that may or may not be effective hedging mechanisms for individual farmers. Typical procedures that assume linear correlation relationships are likely to give the wrong answers if it is extreme events that create the most serious losses. In other words, it is logical to assume that beyond certain thresholds crops simply fail. While scientists are tempted to fit complex relationships to crop patterns, interviews with farmers may reveal more about what type of weather events concern them most. Furthermore, when designing a weather index contract, it is tempting to focus on the relationship between weather events and a single crop. When it fails to rain for an extended period of time, many crops will be adversely impacted. Likewise, if it rains for an extended period of time and there is significant cloud cover because of persistent rain during a critical photosynthesis period, a number of crops will also be adversely impacted.

Finally, significant care must be taken to assure that the insured knows no more than the insurer when designing index insurance contracts. Endogenous forecasts of weather by farmers are many times quite good. Potatoes farmers in Peru forecast El Niño better than many climate experts. In 1988 a major company offered drought insurance in the U.S. Midwest. As the sales closing data neared,
the company noted that farmers were increasing the purchase of these contracts in a significant fashion. Rather than recognize that these farmers had already made a conditional forecast that the summer was going to be very dry, the company extended the sales closing date and sold even more rainfall insurance contracts. The company had a major failure and rainfall insurance for agriculture in the United States suffered a significant setback. The lesson learned is that one must be diligent in understanding the forecasting of weather events if they are going to write insurance based upon those weather events. Farmers all over the world understand the weather and climate. Insurance providers who venture into weather insurance must know just as much as the farmer, or else the adverse selection problem is not solved and index insurance is not sustainable.

1.9 DEVELOPING POLICY PRESCRIPTIONS

A few key points of the discussion above merit reemphasis:

1. Cognitive failure is common for infrequent and severe natural disasters.
2. Natural disasters involve correlated risks whereby large financial losses can occur at the same time.
3. Monitoring individual farmer behavior involves high transaction costs and, without proper consideration for incentive compatibility issues, government attempts to offer individual crop insurance should be avoided.
4. Properly designed weather index insurance products can clear the way for other more efficient market-based solutions to handle idiosyncratic or basis risk.

With these key points in mind, a more structured approach for policy intervention in natural disaster risk for agriculture can begin.

Layering Catastrophe Risk

To focus the discussion, Figure 1.9.1 presents the probability distribution function for August rainfall in Andhra Pradesh, India. Figure 1.9.1 was developed using concepts that are similar to those being proposed for the Mongolian livestock insurance pilot program. A number of individuals have been involved in the development of those recommendations. From the World Bank insurance side, Rodney Lester and Olivier Mahul have provided significant input into these designs. Jerry Skees has been the primary consultant working with these professionals and others involved in the Mongolian pilot program. Nathan Belete is the task manager and Richard Carpenter is the legal consultant.
developed using historic data from the period 1871 to 2000 from the coastal region of Andhra Pradesh using nonparametric kernel-smoothing procedures.

Figure 1.9.1 Distribution of August Rainfall for Andhra Pradesh

Source: Authors developed the kernel distribution using historic weather data from Andhra Pradesh.

In reality, there are few observations above the 2,500 mm level. For sake of exposition, assume that rainfall in excess of 2000 mm creates crop losses. A private insurance provider could write a contract that would use 2000 mm as the strike and 2500 mm as the limit.\(^9\) It is common for insurance providers to place limits on their exposure, as they do not want open-ended exposure for extreme rainfall events that represent true catastrophes. The index insurance contract could be quite straightforward. The insured would select the amount of insurance (the liability) and the pay rate would be calculated as follows:

\[
\text{PayRate} = \frac{\text{Liability}}{(\text{Limit} - \text{Strike})}
\]

Assume that a farmer has a crop that could easily sell for $15,000 given a normal crop. Should rainfall reach the 2500 mm level, it is estimated that the farmer will lose two-thirds of the value of the crop. Thus, the farmer purchases $10,000 of liability and the payout rate for every mm would be $20 ($10,000 divided by

\(^9\) The example could just as easily focus on shortfalls of rainfall. However, in this case, the limit is clear. The lower bound on rainfall is zero. The upper bound on rainfall is unknown.
In the language of futures markets, each mm of rainfall would be referred to as a “tick.” For example, at 250 ticks (or 2250 mm of rainfall) the payout would equal 250 x 20 = $5000.

The insurance provider has limited the losses beyond 2500 mm for this insurance product. Without setting this limit, the contract would be quite expensive as insuring against risk in the upper tail of the probability distribution is extremely expensive. Sellers of the insurance would load the price based on the ambiguity of the risk that may actually be in the tail of the distribution above the 2500 mm. On the other hand, buyers of any contract beyond 2500 mm would be inclined to exhibit the behavior previously mentioned—cognitive failure—and, the buyers would fail to properly acknowledge the true risk of events in excess of 2500 mm. Thus, even if the insurance provider offered a contract that paid for losses beyond the 2500 mm level, there would likely be a market failure, as the seller would have a price that is greater than the buyer would be willing to pay.

The story of layering risk does not end here. Even if a local insurance company offers a number of “layered” rainfall insurance contracts in the region in such a fashion that each one has a limited exposure, the portfolio of these contracts would very likely have a long tail of extreme losses. This is relatively easy to understand given extreme rainfall in even an expanded region would likely be highly correlated—if the rainfall is close to 2500 mm in Andhra Pradesh, it is likely to be very high in a number of states in that area. To illustrate this point, an estimate of the loss function for the reinsured companies selling crop insurance in the United States is presented in Figure 1.9.2. This distribution suggests that a company with a national book of crop insurance and the benefits of the U.S. standard reinsurance agreement could still suffer losses in excess of premiums. These estimates suggest that the company could lose more than the premium approximately 13 percent of the time. Without the benefits of the special reinsurance agreement, this level and the severity of the losses would be much higher.

The loss function presented in Figure 1.9.2 is very typical of any insurance product that attempts to insure against losses that are correlated.

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10 These are the author’s estimates and include all of the very complex rules of the standard reinsurance agreement in the United States. This agreement allows companies to select the business they wish to keep and the business they wish to pass on to the government. In addition, the government offers a stop loss agreement for every state at the loss ratio of 500 percent.
Once again, layering the risk of the losses is a critical means of financing these large losses. Reinsurance is used to accomplish this task. The easiest way to consider the role of reinsurance is to consider that the insurer of events that create a loss function (as presented in Figure 1.9.2) would purchase insurance on these losses. For example, insurers may decide that they could build adequate reserves that would cover losses beyond 105 percent of premiums; however, they would be unable to cover losses beyond that point. They could purchase what is called a “stop loss” contract to pay for all losses beyond 105 percent of the premium. More complex arrangements allow for quota shares, whereby the local insurance provider shares both premiums and losses with a global reinsurance market.

Just as with any insurance product, one can estimate the premium rates of a simple stop loss on the insurance losses using the information in Figure 1.9.2. The area above the stop loss is the first estimate for such reinsurance. Thus, as one works to sell more contracts across a wider region (i.e., a more diversified portfolio), the area above the stop loss will become smaller. However, as a company expands into new areas and new products, the likelihood of making mistakes may also increase. For that reason, concentrating in known markets may be a good strategy at some level. Still, the more concentrated the portfolio of the insurance company, the more skewed the loss function (i.e., there is both a higher likelihood and severity of large financial losses). Pooling index insurance among a number of insurance companies within a country can offer concentrated companies the chance to take advantage of pooling. However, insurance
companies would be ill advised to pool more traditional insurance contracts without excellent knowledge of the underwriting companies and their actuarial procedures. With relatively standard index insurance contracts, this type of concern is lessened considerably, making pooling among insurance companies a much easier proposition. Nonetheless, rules for pooling and some government involvement may be needed to facilitate this activity.

Structured Disaster Response to Complement Private Products

Given that the cognitive failure is tied directly to the extreme tail risk and the inability of decision makers to discern this risk, government and non-government organizations (NGOs) could be involved in paying for this ambiguity risk. This can be accomplished by layering out index insurance contracts. Such systems could be designed for either put option risk (e.g., severe shortfalls in rain) or call option risk (e.g., excess rain, wind speed).

Returning to the example in Figure 1.9.1, the government could design a structured disaster response product (DRP) that would pay for losses beyond the 2500 mm level. The same structure could be used to extend payments received from the insurance provider that would protect for the layer of losses between 2000 and 2500 mm. Government could select the thresholds for the DRP, based on statistical properties. The idea would be to select thresholds likely to be in the realm of cognitive failure. The approach should attempt to develop thresholds that reflect relatively rare events (e.g., 1-in-15 years). Furthermore, as more advanced statistical methods are developed with the data, one can imagine government attempting to set the thresholds and payout rules so that the implicit transfer is roughly equal across different regions. This would be more equitable and create less protectionist incentives for taking on more risk in higher risk regions.

Simple rules that encourage farmers to purchase the private-sector insurance product can be considered. For example, if farmers select only to sign up for the DRP, they should be required to pay a relatively small administrative fee. If they purchase the private-sector insurance, they could automatically be given the DRP. Such a tie would reduce the problems associated with government disaster programs that crowd-out private insurance products (PIP).

For the hypothetical case presented in Figure 1.9.1, there would be three layers of risk and three different entities involved in holding these risks:

1. For rainfall below 2000, farmers would retain the risk either on their own or with other bank and non-bank entities.
2. For rainfall between 2000 and 2500, the risk would first be transferred to a local insurance company via a private insurance product (PIP).\textsuperscript{11}
3. For rainfall levels above 2500, the government would provide insurance with the disaster response product (DRP).

The example can be generalized. Let \( x \) be a measure of the exposure loss needed to be hedged and let \( f(x) \) be the probability density function of claims in an individual region. The payment functions for three decompositions can be represented by a truncated function. \textit{Strike} is the attachment point of the contract, i.e., the point on the index at which indemnity payments would begin. \textit{Cap} is the maximum limit of the insurer’s liability. The Cap greatly reduces the insurers’ exposure to catastrophic losses.

If \( x < \text{Strike} \), the loss is retained by individuals or communities.

If \( \text{Strike} \geq x \leq \text{Cap} \), losses are paid by the local insurance company.

If \( x \geq \text{Cap} \), the loss is paid by the disaster response product provided by the government.

A major motivation for this arrangement is that the government takes on the extreme risk at the local level. Many proposals would have the government removing the extreme risk only after the insurance has been pooled, as with the U.S. standard reinsurance agreement. The arrangement proposed here would institutionalize the social role of government in removing extreme risk events at the local level. This would significantly lower premium rates, as the ambiguity risk would not need to be priced. Furthermore, by organizing these types of contracts at the local level, isolated severe events that do not capture the attention of the national policymakers could still have some structured assistance in the form of a structured disaster response.

To summarize the major advantages of offering a structured DRP that uses weather index contracts:

1. Structured rules allow for better planning than ad hoc disaster payments.
2. Structured rules can account for low probability events explicitly, attempting to address the cognitive failure problem, and provide for structure that provides more equity in expected payouts.
3. Governments can set levels and rules that complement the development of private insurance products.

\textsuperscript{11} Even though the local insurance company provides the PIP, it is very likely that it will still have to use other means to transfer the tail risk associated with selling a concentrated portfolio of correlated risk.
4. Governments can estimate their own cost exposure associated with the DRP, and plan for the fiscal exposure accordingly.

5. Having localized DRPs can provide for some level of catastrophic protection when events are not widespread enough to command national attention that results in ad hoc disaster payments.

Pooling the Risk Within the Country

Thus far, the solutions offered for a private-sector insurance product that uses weather index insurance products have addressed most of the conceptual problems raised in this chapter. Still, even with a layered PIP as developed above, there will be loss functions that are at least as skewed as the one in Figure 1.9.2. The correlated risk problem remains a constraint for domestic insurance companies wanting to write PIPs. Nonetheless, international reinsurers may still be more willing to offer reinsurance to a local company offering weather index insurance because there are less asymmetric information problems (i.e., moral hazard and adverse selection should be lower).

One final role for government could be used to develop the regulatory structure to allow companies selling PIPs to pool their contracts within the county first before going to the global market. Such activity would make the index insurance contracts more affordable as the tail of the loss distribution would be less formidable than for an individual insurance company that was unable to diversify their portfolio. Numerous structures can be envisioned to facilitate pooling index-based insurance contracts among insurance companies. Again, to the extent that the contracts have used information that is of similar quality and have also used similar procedures for ratemaking, insurance companies should be able to pool these risks without the same concerns that they would have if pooling more complex insurance products subject to moral hazard and adverse selection.

One structure could have a syndicate relationship among insurance providers. Each could deposit the premiums into the pool. They could arrange to have a stop loss on the pool either from government or from a major reinsurer. For example, if they chose to purchase a stop loss of 110 percent of all premiums from the stop loss, they would receive the benefits of the pooling by having a lower reinsurance premium rate than they could obtain on their own if they went to the reinsurance market. Companies working together to aggregate a significant volume of risk would also enhance their chances of attracting an international reinsurer.

To elaborate on a structure that could be implemented, each insurance company would be required to pay reinsurance that was consistent with the profile of risk they bring into the pool. They would also be required to estimate the total
premium they would sell. Thus, the insurance companies who participate would prepay an amount equal to the stop loss layer (10 percent in this case) and the reinsurance cost for the business they anticipate bringing into the pool. The pool would purchase the reinsurance stop loss from either the government or the global reinsurance market. Once the reinsurance is purchased, the benefits of pooling could be passed on to each insurance provider via discounted reinsurance premiums to the pool. The idea would be to leave enough premium in the pool (110 percent in this case) to fully pay for all indemnities. Once the insurance cycle is complete, the underwriting gains would be distributed to each participating insurance provider, based on their share of the premiums sold. Of course, the pool would also earn interest over the insurance cycle. Thus, there would always be something to share at the end of the insurance cycle, even if losses exceeded the 110 percent level.

Again, the concept of layering risk can be used for this pooling arrangement. Once again, governments may decide that they wish to spur the insurance market. They could offer a layer of stop loss reinsurance at a pure premium rate (this would be significantly lower than the global reinsurance market). For example, they could offer the pool a stop loss at 130 percent. This would effectively make the insurance to the end user more affordable and be a superior way to introduce a subsidy, as it would again be working with extreme event risk and catastrophe type risk. If the government offered a stop loss at 130 percent, the pool would still likely need to go to the global market to obtain a stop loss at a lower level.

The real advantage of the pooling arrangement of these standardized index insurance contracts is that the individual insurance company’s share in the pooling arrangement could be treated as an asset. If a company had a 25 percent share in a pool, that share could ultimately be sold to any other member of the consortium or to a global reinsurer. For example, an easy arrangement would be to have a 50/50 percent sharing between the local company and a global reinsurer (this is similar to a quota share). More fundamentally, one could envision an exchange-traded market emerging to dynamically trade shares of the pool as the crop year progresses. Such an arrangement should result in more efficient pricing.

The other strong advantage of a pooling arrangement just described—it guarantees farmers would be paid for losses with less regulation than what is needed now to assure that companies have the financial wherewithal to pay. Companies would effectively be prepaying for losses below the stop loss. The major concern would be to assure that the reinsurance above the stop loss would be fully protected.
1.10 CONCLUSIONS AND IMPLICATIONS

Insurance for natural hazard risk is indeed complex. For this reason, experience with government involvement to facilitate markets for crop insurance has been poor. This chapter has reviewed some of the problems with attempts to provide crop insurance in North America. The problems of correlated risks, cognitive failure, and high transaction costs have been introduced to explain why true markets for these risks have not emerged. Index insurance products offer some hope for dealing with problems associated with monitoring and high transaction costs to mitigate moral hazard and adverse selection problems that plague traditional multiple-peril crop insurance. However, as was discussed, one must still consider further developments and other institutional arrangements to mitigate the basis risk that may accompany index insurance products.

More work is still needed on the basis risk issue. The conceptual thinking to date focuses on use of risk aggregators who could, in turn, develop both formal and informal mechanisms for mitigating basis. This could emerge as a mutual insurance company or simply become the function of banks to give contingent loans to individual who suffer hardships when the index insurance does not pay. The notion of blending index insurance instruments with the banking community merits more serious consideration. Once again, banks should be well suited to handle small event risks that are generally associated with basis risk.

Numerous innovations can emerge from the concepts of index-based insurance. For example, ongoing work in Mexico examines the extent to which index insurance contracts can be used to hedge the inflow of water from the stream that feeds an irrigation reservoir. This could be a quite important means of using both engineering solutions and market-based solutions to plan for the size of dams and the rules for allocating water. The conceptual goal is to have contracts with water users that guarantee either water delivery or some combination of water and indemnity payments when the water is not available (Skees and Zeuli, 1999). Such capital market solutions could accelerate the movement towards more efficient water markets in many developing countries.

Finally, as promised, this chapter closes with specific policy recommendations that build on the use of weather index insurance. The recommendations presented in Section 1.9 explicitly recognize the social goals of government to cover extreme catastrophic events via what is termed a Disaster Response Product (DRP). This approach provides structure to disaster response without undue transfers and in a fashion that may not create market distortions. It also explicitly recognizes that markets are expensive for extreme risk and that decision makers are limited in their cognitive assessment of these types of risk. Finally, the structure facilitates markets rather than crowding them out.
Even with the social response of a DRP program, local insurance providers of a layer of risk for weather events will still have a correlated risk problem that creates extreme losses for their portfolio of insurance products. To address this problem, Section 1.9 develops recommendations for a unique pooling arrangement to retain as much risk within the country as possible before going to the international reinsurance markets. Once such pooling arrangements have been organized, the consortium of insurance companies who participate in the pool can more effectively approach the global reinsurance market for a stop loss. Should governments decide they want to provide more support for the overall insurance program, the government can also select various stop loss levels to protect the catastrophic risk of the pooled risk. The stop loss from government can be sold at heavily discounted rates or even at an actuarially fair premium rate to provide for more support and allow companies to offer premium rates that are discounted.

The concept of layering risk written on a standard measure, using the same ratemaking procedures, opens many possible avenues for securitizing weather risks. Ideas presented in this book are only the beginning. Should the structures that are reviewed prove viable, one can envision many possible ways to trade correlated risk dynamically, ultimately improving the pricing and efficiency of a weather market that is currently underdeveloped globally.
CHAPTER 2
WEATHER RISK MANAGEMENT FOR AGRICULTURE
JOANNA SYROKA

2.1 INTRODUCTION TO WEATHER RISK

The emerging weather risk market offers new risk management tools and opportunities for agriculture. The aim of this chapter is to illustrate how an end user in the agricultural industry could use a market-based solution to mitigate the financial impact of weather on its business operations. The chapter draws information from the wealth of literature written on the subject of weather risk management, with an aim to provide the reader with a step-by-step guide to how weather risk management instruments could be used and developed for the agricultural sector. The chapter is divided into five sections. Section 2.1 introduces the concept of weather risk management and gives a background to the weather market. Section 2.2 focuses on the key steps required to structure a weather risk management solution, from identifying the risk to execution. Section 2.3 focuses on the pricing of weather risk management instruments, giving a brief overview of how the weather market approaches and values weather risk and the implication for the end user. Section 2.4 focuses on the prerequisites for weather risk management instruments: the weather data used to construct weather indexes and to settle contracts. This section will also touch upon data cleaning and analysis that must be considered when pricing and structuring a potential transaction. Section 2.5 summarizes the chapter and offers suggestions for further reading on weather risk management.

The Financial Impact of Weather

Weather risk impacts individuals, corporations, and governments with varying degrees of frequency, severity, and cost. Around the world, people face the vagaries of the weather on a daily basis. The media continually reports catastrophic weather events—floods, hurricanes, and droughts—that impact individuals’ property, health, and lives. Consequently, governments are also financially exposed to weather risk. They are called upon to provide direct financial, nutritional, and housing support to their citizens in the event of
weather-related disasters and must increase spending for rehabilitation and reconstruction of infrastructure and assets as a result of damage incurred. Moreover the economy of a country is also at risk to weather through business interruption, supply shocks, diversion of domestic investment from productive activities to mitigation of disasters’ impacts and, for some countries, a reduction in foreign investment in the aftermath of an extreme weather-related event. While often such effects are reversible and short-term, the impact on the economy of a poor country can be significant and long lasting. Between 1997 and 2001, the average damage per natural disaster in low-income countries was 5.8 percent of GDP (IMF, 2003). Evidence from sixteen Caribbean countries shows, for example, that one percentage point of GDP in direct damage from natural disasters can reduce GDP growth by half a percentage point in the same year (Auffret, 2003). Furthermore, the humanitarian cost of weather-related disasters is also greater in the developing world: approximately 80 percent of all fatalities due to weather disasters from 1980–2003 occurred in the “uninsured world,” comprising predominantly low-income countries (Loster, 2004).

However, even non-catastrophic weather events have a financial impact. The U.S. Department of Commerce estimates that nearly one-third of the U.S. economy, or US$1 trillion (U.S. Congress, 1998), is modulated by the weather and that up to 70 percent of all U.S. companies are weather sensitive. Weather risk can impact a business through its overall profitability or simply through the success or failure of an initiative as a consequence of the weather. Like governments, businesses can face both demand- and supply-driven weather risks. Energy companies, for example, can be exposed to demand-driven weather risk. For instance, in the event of a warmer than average winter, gas companies, in particular those who deal with domestic customers, face a potential drop in gas sales as customers do not use as much gas as expected to heat their homes. Therefore even if the company has adhered to prudent price risk management practices by protecting their sales margin from fluctuations in the gas supply price, a drop in sales volume from expected levels can still have a significant impact on budgeted revenues simply through weather-driven demand fluctuations. A supply-side example of weather risk can be found in the construction industry. Cold and wet weather conditions can impact construction progress as building materials have specific weather requirements, for example concrete cannot be poured in wet or below-freezing conditions. The contractor therefore must assume this supply-driven weather risk, which can significantly delay a construction project and result in hefty penalties if the project is not completed on schedule. This recent excerpt from the Central New Jersey Home News Tribune (2004) illustrates the example.
The extension of Route 18 into Piscataway, which had been discussed for more than four decades and has frustrated motorists since construction began in June, 2002, may not be completed until fall 2005 because of adverse weather conditions. The first phase of the project—to provide a River Road overpass and an extension of Metlars Lane from the John A. Lynch Sr. Bridge to Hoes Lane—had been scheduled to be completed by November. But the project’s construction company, Slattery Skanska Inc. of Whitestone, N.Y., hampered by a wet spring and summer and sustained cold weather this winter, has applied for a delay, according to Department of Transportation spokesman Mike Horan.

“A lot of our projects have been hampered by the weather,” said Horan. Horan explained that when the ground is frozen a proper bed cannot be laid for roadways, and asphalt cannot be used until the temperature remains above freezing...Horan explained that the application for a delay beyond November will be studied by the DOT. “Unless a delay is granted, the construction company could face penalties,” according to Horan.”

Weather has traditionally been the scapegoat in business for poor financial performance (Clemons, 2002). Annual reports, financial statements, and press releases frequently contain declarations such as, “cooling degree days were 21 percent below last year’s quarter and 16 percent below normal. The effects of milder weather compared with last year had a negative impact on earnings before interest and taxes] of about $35 million for the quarter,” (Duke Energy, 2003); “4 cents per share [decline] for lower gas deliveries due to warmer weather in the fourth quarter of 2003,” (Energy East, 2003); and, “Europe's performance continued to be impacted by unfavorable summer weather with volume down 12 percent in the third quarter and year-to-date volume down 6.5 percent,” (Coca-Cola, 2004). Given such examples it is not surprising that the financial community has begun to seek practical solutions to controlling the financial impact of weather. For example, Centrica Plc, one of the largest domestic gas supplier in Great Britain, is one of a number of utilities that has chosen to manage its weather risk in order to “protect the company against variability in earnings of its gas retail business due to abnormal winter temperatures in the UK,” (Ulrich, 2002) and has been doing so since 1998. London-based Corney and Barrow Wine Bars Limited deploys several weather hedges to provide financial protection against cool summers resulting in poor customer patronage, “after the exceptional summer of 2003 Corney and Barrow was keen to secure protection against the possibility of the reverse
experience [in 2004],” (XL Trading, 2004). With the emergence of a market for weather risk management products, a business can now be protected from such ancillary risks that create unpredictable earnings streams. Just as interest rate and currency risks are currently managed through market-based solutions, weather risks that increase business uncertainty can now be neutralized, allowing a company to focus on its core business and to protect earnings per share forecasts and growth.

As financial analysts are beginning to highlight the impact of weather on operations and corporate earnings, they are also beginning to recognize the advantage of weather risk management, as echoed in a recent Fortune (Lustgarten, 2005) article.

Looking at it another way, dealing with weather head-on presents an opportunity for a company to gain a competitive advantage. According to Matthew Kiernan, CEO of the New York City-based investment firm Innovest … the companies that soften their weather-related volatility first will open a gap between themselves and rivals.

It is clear a company that actively manages its weather risk is in a stronger position than one that does not.

The Weather Market

In 1997 a formal weather risk market was born through the first open market derivative transaction indexed to weather in the United States. Motivated by the deregulation of the energy industry, which led to the break-up of regulated monopolies in electricity and gas supply, the nascent weather market responded to the need for energy companies to increase operational efficiency, competitiveness, and shareholder value. In 1996 the Kansas-based energy company, Aquila, entered into a transaction with New York-based Consolidated Edison that combined temperature and energy indicators, protecting the latter against a cool August that would reduce power sales. However the first publicized transaction in 1997 was between energy companies Koch Energy and Enron. Additional deals soon followed with other energy market participants wanting protection against risks, primarily temperature, associated with volumetric fluctuations in energy.

In the context of the weather market, weather risk is defined as the financial exposure that an entity—an individual, government, or corporation—has to an observable weather event or to variability in a measurable weather index that causes losses to either property or profits. All weather contracts are based on the actual observations of weather at one or more specific weather stations. In contrast to traditional insurance products, where recovery is determined on a
loss-adjustment basis, weather risk management products—packaged as either (re)insurance or derivatives—are primarily settled off of the same index that has been determined to cause losses. Weather-indexed risk management instruments therefore provide financial protection based on the performance of a specified weather index in relation to a specified trigger. The design of a verifiable and objective index which correlates closely with the underlying weather impact not only streamlines traditional insurance practices but also creates opportunities to manage non-catastrophic—or near-the-mean—risk that impacts a company’s earnings. Previously, traditional insurance products primarily dealt with physical losses of assets (e.g., property and infrastructure) that were associated with low frequency/high severity catastrophic weather events.

In 2001 the Weather Risk Management Association (WRMA)—the industry body—commissioned PricewaterhouseCoopers (PWC) to conduct a survey of weather risk contracts executed among WRMA members and survey respondents from October, 1997 to March, 2001, and since then, on an annual basis. Since 1997, the survey has shown that over US$28 billion has been transacted through the weather risk market\(^\text{12}\)—the market has grown to around US$8.4 billion outstanding risk for the year April, 2004—March, 2005 (PWC, 2003, 2004, 2005; see Figure 2.1.1), although some believe this to be an underestimate.\(^\text{13}\)

There is active trading in U.S., European, and Japanese cities (Figure 2.1.2) with a few transactions outside these three main trading hubs, most notably agricultural transactions in Mexico, India, and South Africa.

\(^{12}\) The last PWC Survey was published in November, 2005; therefore, this figure includes transactions up to March, 2005. A new PWC survey is expected in November, 2006.

\(^{13}\) In the publication *Energy Risk*, survey respondents estimate that the market is worth around 45 percent more in 2004. The WRMA survey in 2004 relied on figures from 19 companies—all members of the Washington DC-based organization. Some large weather trading operations, such as Deutsche Bank and Calyon, are not WRMA members and therefore the true size of the market is hard to determine.
Figure 2.1.1 Notional Value of All Weather Contracts in US$

Source: Author's figure using PricewaterhouseCoopers industry survey data, 2003, 2004, and 2005

Figure 2.1.2 Percentage of Total Weather Contracts by Location (Excluding CME Trades)

Source: Author's figure using PricewaterhouseCoopers industry survey data, 2003, 2004, and 2005
The market has also evolved to include non-energy applications. Survey respondents, when asked to list requests received from potential end users of weather risk management products, identified end users in the retail, agriculture, transport, and leisure and entertainment industries (Figure 2.1.3) although energy still contributes approximately 69 percent of the potential weather risk management end user market. As a result of this expansion, the market has also broadened its product offering to include transactions on non-temperature indexes\(^{14}\) such as rainfall, wind, and snow (Figure 2.1.4). With the coming deregulation of energy markets in continental Europe and Japan and with increased focus on shareholder value and risk management in the financial markets, the weather market is forecast to grow further.

**Figure 2.1.3 Potential End User Market by Economic Sector 2004/2005**

Source: Author’s figure using PricewaterhouseCoopers industry survey data, 2005

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\(^{14}\) Most energy-related weather transactions are based on temperature indexes such as Heating Degree Days (HDDs) and Cooling Degree Days (CDDs), designed to correspond to fluctuations in demand for gas (heating) and power (cooling, i.e., air conditioning).
Figure 2.1.4 Percentage of Total Weather Contracts by Index (Excluding CME Trades)

Source: Author's figure using PricewaterhouseCoopers industry survey data, 2003, 2004, and 2005

Today the key market participants include (re)insurers, investment banks, and energy companies. (Re)insurers and investment banks provide weather risk management products to end user customers—such as Corney and Barrow Wine Bars Limited, and Centrica Plc—and form the primary market; all three participate in a secondary market in which players transfer weather risk among themselves through over-the-counter (OTC) financial transactions and exchange-based derivative contracts on the Chicago Mercantile Exchange\textsuperscript{15} (CME) to diversify and hedge their portfolios.

Weather risk management is also being introduced to the developing world through the work of organizations such as the World Bank Commodity Risk Management Group (CRMG) and the United Nations World Food Program (WFP). The World Bank was involved in the first index-based weather risk management program in India in June, 2003, and is currently working on several projects around the world. The small pilot program was launched by Hyderabad-based microfinance institution BASIX and Indian insurance company ICICI

\textsuperscript{15} In 1999 the Chicago Mercantile Exchange (CME) began listing and trading standard weather futures and options contracts on temperature indexes. They now list 22 locations in the United States, Europe, and Japan.
Lombard in conjunction with CRMG, when 230 groundnut farmers in Andhra Pradesh bought weather insurance to protect against low monsoon rainfall (Hess, 2003). Currently the WFP, in conjunction with the World Bank, are investigating the feasibility of weather-based derivative as a reliable, timely, and cost-effective way of funding emergency operations in countries such as Ethiopia (The Economist, 2004) where the concept is being piloted to protect against drought during the 2006 agricultural season. Work is also underway to see if developing country governments in southern Africa can benefit from weather risk management products and strategies (Hess and Syroka, 2005). The global weather-risk market is particularly interested in these types of transactions, as they provide much sought after diversification to their books through new locations and risks.

**Weather Risk and Agriculture**

One of the most obvious applications of weather risk management products, weather insurance, or weather derivatives is in agriculture and farming. Indeed 7 percent (PWC, 2005) of the end user requests in the weather market are now focused on the agricultural sector (Figure 2.1.3). Weather impacts many aspects of the agricultural supply and demand chain. From the supply side, weather risk management can help control both production or yield risk and quality risk. Technology plays a key role in production risk in farming. The introduction of new crop varieties and production techniques offers the potential for improved efficiency; however, agriculture is also affected by many uncontrollable events that are often related to weather—including excessive or insufficient rainfall, hail, extreme temperatures, insects and diseases—that can severely impact yields and production levels. Countless examples can be given on the impact of cold temperatures on deciduous fruit (GuaranteedWeather, 2005b), deficit rainfall on wheat (Stoppa and Hess, 2003), excess rainfall on potato yields (Meuwissen et al., 2000) and even temperature stress on cattle and thus dairy production (GuaranteedWeather, 2005a). In 2003, 59 percent of Ukraine’s winter grain crop was destroyed due to winterkill temperatures (USDA, 2003) and 40-50 percent of northeastern England’s oil rapeseed crop was lost due to excessive rain at harvest in August, 2004 (BBC, 2004). The costs associated with drops in expected or budgeted production due to such uncontrollable factors can have a significant impact on a producer’s revenues and contractual obligations as reflected in a financial statement of J.G. Boswell (1998), the largest U.S. cotton grower.

Both 1997 and 1998 fiscal results were impacted by extremely harsh winter patterns that flooded over 41,000 acres of the Company’s Corcoran farming districts causing a decrease of $1,000 per acre or
$41 million in gross revenues. Additionally, cold and wet spring weather delayed cotton planting by up to six weeks, which resulted in some of the worst farming conditions management has ever seen.

A producer may seek protection against adverse weather conditions that impact the yield of the crop farmed.

Weather can also impact the quality, if not the absolute production levels, of a crop. An example can be taken from the brewing industry (GuaranteedWeather, 2005c). A large brewery needs a specific quality of barley for its production of beer and contracts land for barley production in order to have direct access to the quality of barley it needs. The key risk to the quality of the barley produced occurs once the plant is mature where excessive rain and humidity will cause the seed to lose weight and discolor. In years where the crop quality is insufficient, the barley can be used for animal feed or alcohol at a lower market value, but the brewery will still need to purchase the barley at market prices incurring an additional cost to the brewery—a cost that can be insured against by the purchase of an appropriate weather risk management product.

On the demand side, weather also impacts related agricultural products through the use of pesticides, fertilizers, and herbicides. Agricultural chemical producers, for example, can use weather risk management instruments to hedge against the costs associated with fluctuations in the demand for chemicals by farm operators. For example, cotton boll weevil, which costs cotton producers in the United States US$300 million a year, 16 is an example of a weather sensitive pest whose numbers differ from year to year largely due to the severity of the winter. In extremely cold winters, weevil numbers drop significantly, directly affecting the net earnings of an agrochemical company. Chemical producers could hedge their earnings volatility through fluctuations in pesticide sales by purchasing a weather risk management instrument specifically indexed to the phenology of pests that their products target.

Index-based weather insurance is a relatively new product and the use of weather risk management products in the agricultural sector is still in its infancy, with very few publicized transactions in the United States and Europe. However there have been a number of agricultural transactions outside of the main weather market trading hubs, most notably in Canada (Ontario—maize; Alberta—forage); Argentina (Sancor—dairy); South Africa (Gensec Bank—apple cooperative freeze cover); and India (ICICI Lombard—many crops including groundnut, cotton, coriander, and orange). Given weather is one of the biggest risks faced by farmers, weather-indexed risk management products have been

suggested as a potential alternative to the traditional crop insurance programs for smallholder farmers in the emerging markets. Traditional multi-peril crop insurance programs have several problems when they are translated from the developed world to emerging markets (see Chapter 1 for further discussion). Most notably the high unit administration costs, high entry barriers for farmers and difficulties of control make traditional crop insurance schemes neither practical nor cost effective in small-farmer economies. These new weather risk management insurance instruments provide a viable alternative to traditional insurance instruments, potentially offering advantages to households, businesses, and governments in developing countries.

### 2.2 STRUCTURING A WEATHER RISK MANAGEMENT SOLUTION

Developing a successful weather risk management and transfer program for agriculture involves four essential steps:

1. Identifying significant exposure of an agricultural grower/producer to weather;
2. Quantifying the impact of adverse weather on their revenues;
3. Structuring a contract that pays out when adverse weather occurs; and
4. Executing the contract in optimal form to transfer the risk to the international weather market.

Each of the steps is outlined in the following four subsections and they are fully explored in the case studies in the next chapter.

#### Identifying the Risk

Identifying weather risk for an agricultural grower or producer involves three steps: identifying the regions at risk to weather and the weather stations that reflect that risk; identifying the time period during which risk is prevalent; and identifying the weather index that is the best proxy for the weather exposure. This latter step is the most critical in designing a weather risk management strategy based on an index. Rather than measuring the actual impact on crop yields—or related fluctuations in demand, supply or profitability—the index acts as a proxy for the loss experienced due to weather and is constructed from actual observations of weather at one or more specific weather stations.

#### Location and Duration

All weather contracts are based on the actual observations of weather variables at one or more specific weather stations. Transactions are based on either a single
station, a basket of several stations, or on a weighted combination of readings from multiple stations. More information on the weather station and data requirements for weather risk management instruments will be given in Section 2.4. If an individual farmer is interested in purchasing weather protection for his particular crop, the index-based weather contract must be written on a weather station nearest the farmer’s land in order to provide the best possible coverage for the farmer client. A larger grower, with several production regions, may be more interested in purchasing a weather contract based on several weather stations that reflects the weather conditions in all areas covered by the business. The grower’s risk management strategy can be either to purchase a weather contract on each of the identified weather stations or to purchase a single contract on a weighted average of several stations, with the weightings chosen to reflect the importance of the different stations to the overall weather exposure of the business. The approach chosen depends on the risk preferences and risk retention appetite of the grower, although generally the latter is a cheaper and more efficient approach. Retaining localized risks will most probably be a more cost-effective solution than transferring them to a third party, but will still provide protection in situations when adverse weather affects several regions impacting the overall production portfolio of a producer. The latter approach will also reduce the risk of reliance on one weather station and hence the associated issue of basis risk, which will be covered in Section 2.3.

All contracts have a defined start and end date that limit the period over which the underlying index is calculated. This calculation period describes the effective dates of the risk protection period during which relevant weather parameters are measured at the specified weather stations. For agricultural end users, the duration of the weather contracts will be determined by the specific requirements of their business. The duration of contracts have the flexibility to address individual end user business exposures and can be weekly, monthly, seasonal, and even multi-annual. Final settlement of the weather contracts typically occur up to 40 days after the end of the calculation period, once the collected weather data have been crosschecked and quality controlled by the relevant data-collecting body, usually the National Meteorological Service.

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17 Basis risk is a potential mismatch between insured party’s actual loss and the weather contract payment. See Chapter 1 and Section 2.3 for a discussion of basis risk.

18 Section 2.4 gives more information on the weather station and data requirements and providers.
Underlying Indexes

A weather index can be constructed using any combination of measurable weather variables and any number of weather stations that best represent the risk of the agricultural end user. Common variables include temperature and rainfall, although transactions on snowfall, wind, sunshine hours, streamflow, relative humidity, and storm/hurricane location and strength are also possible and are becoming more frequent. In contrast with energy, where the relationship between energy demand and weather is more transparent and linked primarily to temperature, in agriculture the relationship between crop yields or pesticide use is generally more complex, albeit still quantifiable.

For example, the normal process for designing an index-based weather insurance contract for an agricultural grower involves identifying a measurable weather index that is strongly correlated to a crop’s yield rather than measuring the yield itself. After gathering the weather data, an index can be designed by 1) looking at how the weather variables have or have not influenced yield over time; 2) discussing key weather factors with experts such as agro-meteorologists and farmers; and/or 3) referring to crop growth models which use weather variables as inputs for yield estimates; phenology models can be used to establish how weather variations relate to pest development. A good index must account for the susceptibility of crops to weather factors during different stages of development, the biological and physiological characteristics of the crop and the properties of the soil. If a sufficient degree of correlation is established between the weather index and yield or crop quality, a farmer or an agricultural producer can insure his production or quality risk by purchasing a contract that pays in the case of the specified weather event occurs (or does not occur). The index possibilities are limitless and flexible to match the exposure of the agricultural grower or producer, as long as the underlying data are of sufficient quality (Section 2.4). A few examples weather indexes for specific agricultural exposures are given below. Although the examples are based on temperature and precipitation, the principles apply to all weather parameters recorded by ground-based meteorological weather stations. More examples are given in the case studies in Chapter 3.

Temperature

Temperature-based indexes account for over 80 percent of the risk in the current weather market (PWC, 2005). Although most of these transactions are based on indexes specifically designed for the energy industry—such as cumulative
Heating Degree Day (HDD)\(^{19}\) values, days in which energy is used for heating, and cumulative Cooling Degree Day (CDD)\(^{20}\) values, days in which energy is used for air conditioning—temperature is also a pertinent weather variable for agriculture. Whereas irrigation systems can often be used to regulate soil moisture for crops, temperature and its impact on crop yield and quality is often a more difficult parameter to control, particularly over the course of a growing season. Temperature indexes can be based on hourly, average, maximum or minimum temperature, either calculated on a cumulative (e.g., growing degree day) or event driven basis (e.g., frost risk).

**Growing Degree Days**

Growing Degree Days (GDDs) is a common index used in the agricultural sector, similar to HDDs and CDDs in the energy sector. GDDs are a measurement of the growth and development of plants (both crops and weeds) and insects during a growing season. Organisms that cannot internally regulate their own temperature are dependent on the temperature of the environment to which they are exposed. Development of an organism does not occur unless the temperature is above a minimum threshold value, known as the base temperature, and a certain amount of heat is required for development to move from one stage to the next. The base temperature varies for different organisms and is determined through research and scientific considerations. A list of reported base temperature examples is given in Table 2.2.

A GDD is calculated by the following equation:

\[
\text{Daily GDD} = \text{max} \ (0, (T_{\text{average}} - L)); \ T_{\text{average}} = (T_{\text{max}} + T_{\text{min}})/2
\]  \hspace{1cm} (1)

where \(L\) is the baseline temperature and \(T_{\text{average}}\) is the daily mean temperature, defined as the average of the daily maximum \(T_{\text{max}}\) and minimum \(T_{\text{min}}\) temperatures. If this average is greater than the threshold temperature \(L\), the GDD accumulated for that day is the threshold temperature minus the daily average temperature. If the daily average temperature is less than the base temperature, then the GDD for that day is zero. Adding the GDD values of consecutive days gives the accumulated GDDs over a specific period.

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\(^{19}\) A HDD is calculated according to how many degrees an average daily temperature varies below a baseline of 65 degrees Fahrenheit (18 deg Celsius) and is defined as HDD = \text{max}(0, 65 - T) where T is the daily average temperature.

\(^{20}\) A CDD is calculated according to how many degrees an average daily temperature varies above a baseline of 65 degrees Fahrenheit (18 deg Celsius) and is defined as CDD = \text{max}(0, T - 65) where T is the daily average temperature.
Table 2.2.1 Reported Base Temperatures for GDD Computations for Crops and Insects

<table>
<thead>
<tr>
<th>Base Temperature (deg Celsius) for GDD Computation</th>
<th>Crop/Insect Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.44</td>
<td>Wheat, Barley, Rye, Oats, Flaxseed, Lettuce, Asparagus</td>
</tr>
<tr>
<td>7.22</td>
<td>Sunflower, Potato</td>
</tr>
<tr>
<td>10.00</td>
<td>Sweet Corn, Corn, Sorghum, Rice, Soy Bean, Tomato</td>
</tr>
<tr>
<td>6.67</td>
<td>Corn Rootworm</td>
</tr>
<tr>
<td>8.89</td>
<td>Alfalfa Weevil</td>
</tr>
<tr>
<td>10.00</td>
<td>Black Cutworm, European Corn Borer</td>
</tr>
<tr>
<td>11.11</td>
<td>Green Cloverworm</td>
</tr>
</tbody>
</table>

Source: Midwestern Regional Climate Center, [http://mcc.sws.uiuc.edu/](http://mcc.sws.uiuc.edu/)

However, high temperatures can also cause development of certain organisms to cease. The underlying temperature data can be modified to take this into account: if the daily minimum temperature is less than the baseline it is reset to the baseline level to avoid negative growing degree days; if the maximum temperature is greater than the upper limit it is reset to the upper limit, indicating no growth benefit from temperatures above that level. Once the minimum and maximum temperatures have been modified and a new average computed, the Modified Growing Degree Day (MGDD) value for the day is computed by comparing the modified average with the base temperature as in Equation 1. MGDDs are typically used to monitor the development of corn, the assumption being that development is limited once the temperature exceeds 30 deg Celsius. Other, more accurate methods to calculate GDDs when considering the relationship between the growth rate and temperature of an organism include either estimating the diurnal variation in temperature (see Chapter 3, the Canadian case study) or using hourly temperature readings.

Accumulated GDDs are a good proxy for establishing the development stages of a crop, weed, or insect and can give an indication as to the development and maturity of a crop or to when pesticide or herbicide applications should be scheduled. Measuring the amount of heat accumulated over time provides a physiological time scale that is biologically more accurate than calendar days (Neild and Newman, 2005) and specific organisms, pest or plant, need different accumulated GDDs to reach different stages of development within these broad periods. Different maturity phases require different GDD accumulations and Table 2.2.2 shows an example of growing cycle requirements of a 2700 GDD corn hybrid.
Table 2.2.2  Growing Degree Day Requirements for Different Phenology Stages of a 2700 GDD Corn Hybrid

<table>
<thead>
<tr>
<th>Phase</th>
<th>Development Stage</th>
<th>GDD</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Planted</em></td>
<td></td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Two leaves fully emerged</td>
<td>200</td>
</tr>
<tr>
<td>Vegetative</td>
<td>Four leaves fully emerged</td>
<td>345</td>
</tr>
<tr>
<td></td>
<td>Six leaves fully emerged</td>
<td>475</td>
</tr>
<tr>
<td></td>
<td><em>Growing point above soil</em></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Eight leaves fully emerge</td>
<td>610</td>
</tr>
<tr>
<td></td>
<td><em>Tassel beginning to develop</em></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Tenth leaves fully emerged</td>
<td>740</td>
</tr>
<tr>
<td></td>
<td>Twelve leaves fully emerged</td>
<td>870</td>
</tr>
<tr>
<td></td>
<td><em>Ear formation</em></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fourteen leaves fully emerged</td>
<td>1000</td>
</tr>
<tr>
<td>Reproductive</td>
<td><em>Silks developing on ear</em></td>
<td>1135</td>
</tr>
<tr>
<td></td>
<td>Sixteen leaves fully emerged</td>
<td></td>
</tr>
<tr>
<td></td>
<td><em>Tip of tassel emerging</em></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Silks emerging/pollen shedding</td>
<td>1400</td>
</tr>
<tr>
<td></td>
<td><em>Plant at full height</em></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Kernels in blister stage</td>
<td>1660</td>
</tr>
<tr>
<td></td>
<td>Kernels in dough stage</td>
<td>1925</td>
</tr>
<tr>
<td></td>
<td>Kernels denting</td>
<td>2190</td>
</tr>
<tr>
<td>Maturation</td>
<td>Kernels dented</td>
<td>2450</td>
</tr>
<tr>
<td></td>
<td>Physiological maturity</td>
<td>2700</td>
</tr>
</tbody>
</table>

Source: Neild and Newman, 2005

By comparing accumulated GDD totals with previous years it can be seen if a normal amount of heat energy has been made available to a crop. If GDDs are running behind normal, this usually means that plant development is delayed. A late maturing crop may be at risk to frost or other adverse weather conditions if it does not reach maturity by a specific time. For example, at 2700 GDDs dry matter is no longer being translocated to the grain, indicating that corn has reached physiological maturity and is safe from freezing conditions; however, if the 2700 GDD limit has not been reached the crop may be susceptible to damage if frost occurs (Neild and Newman, 2005). In general, assuming adequate moisture supplies are available, the total GDDs received by the end of the growing season are often related to crop yield; therefore, GDDs can be a good index for crop production. The cumulative temperature index can be used to
establish a relationship between GDDs and production and thus ultimately with a producer’s revenues (Box 2.2.1).

Box 2.2.1 The Corn Grower’s Weather Hedge: Growing Degree Days

A corn grower is worried about his corn production. He has a 3700-acre dry-land farm and is worried that the growing degree accumulation for the coming growing season will not be enough to ensure a good harvest. The grower is one of the few corn producers in the region and he has just won a contract to deliver 500,000 bushels of corn to a local buyer at harvest. However there are penalties in the contract associated with under-delivery. The grower remembers 2000 was a cool summer when his farm yields were low and he is worried that this summer will be the same. He has read about weather derivatives and is interested to see if a weather derivative contract could adequately protect him against this risk.

The grower grows a corn hybrid that needs 2500 GDDs to mature and assure a maximum yield and quality harvest. He knows from the seed company where he purchases the seed that his particular hybrid’s maturity is rated using modified growing degree days (MGDDs) defined as:

\[
\text{Daily MGDD} = \max(0, \left( \max(0, 30 - T_{\text{max}}) + \max(0, T_{\text{min}} - 10) \right) / 2 - 10)
\]

where \(T_{\text{max}}\) and \(T_{\text{min}}\) are the daily maximum and minimum temperature measured in degree Celsius for each day during the growing season. The grower has a weather station on his farm, which he installed a year ago, but he knows there is an official National Meteorological Service (NMS) weather station in the local airport 10km away. The grower purchases 30 years of daily maximum and minimum temperatures from the local NMS office. He compares the past year of data from the NMS station with the data he has been collecting on his farm for the past year and he finds that the daily minimum and maximum temperatures correlate highly with a correlation coefficient of 98% and an average difference in temperatures of 0.3 deg Celsius. He is happy that the NMS represents the weather on his farm well. The grower has seven years of historical corn yield data from his farm. He wants to analyze this data further, so he contacts the local agricultural university in a nearby town to ask if they would be willing to give him some technical assistance and analysis advice. A postgraduate student who is studying arable farming is interested in the project and agrees to help.

The grower has always grown the same hybrid. He knows from experience that the optimal planting date for corn in his region is May 6, that the hybrid corn he grows takes approximately 110–130 days to mature, and that he usually harvests his crop in the first week of September. He knows during the later half of September and early October the probability of frost in his region begins to increases, therefore, he knows he always wants to harvest before October. Using this information the postgraduate calculates the cumulative MGDDs, as
defined by the equation the grower has from the seed company, for May 6–September 15, for the past seven years from the NMS data and compares them to the historical yield data for the farm. He makes a table (Table A) and plots the results.

**Table A: Corn Grower’s Historical Farm Yields versus Cumulative MGDDs**

<table>
<thead>
<tr>
<th>Year</th>
<th>Farm Yield (bu/acre)</th>
<th>MGDDs (May 6–September 15)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1998</td>
<td>106.6</td>
<td>2551</td>
</tr>
<tr>
<td>1999</td>
<td>184.2</td>
<td>2651</td>
</tr>
<tr>
<td>2000</td>
<td>58.9</td>
<td>2249</td>
</tr>
<tr>
<td>2001</td>
<td>206.6</td>
<td>2602</td>
</tr>
<tr>
<td>2002</td>
<td>128.3</td>
<td>2399</td>
</tr>
<tr>
<td>2003</td>
<td>234.8</td>
<td>2649</td>
</tr>
<tr>
<td>2004</td>
<td>194.9</td>
<td>2550</td>
</tr>
</tbody>
</table>

Source: Author

He finds that there is a strong relationship between the accumulated MGDDs at the local NMS station and the farm yield. The correlation coefficient, $r$, between the interannual variations in MGDDs and the interannual variations in yield is 85%, i.e., the variation in the MGDDs explains nearly 73% of the total interannual variability of corn yield on the grower’s farm. From the plot (Figure A below) he can see that there is a linear relationship between cumulative MGDDs and yield. He performs a least squares regression on the data to find the best-fit line, given by:

$$\text{Corn Yield (bu/acre)} = 0.365 \times \text{MGDD} - 761.1$$  \hspace{1cm} (a)

with a $R^2$ of 72.7%. He can see that that linear relationship captures the grower’s worst year, 2000, when the accumulated MGDDs were 2249 and his average yield was only 58.9bu/acre. However he notices that fit is not perfect—1998 is an outlying year. The accumulated MGDDs in 1998 were 2551, as in 2004, but his yield was nearly 50% less. The postgraduate asks the grower about this. The grower tells the postgraduate that 1998 was the first year in which his farm was in operation. Normally rainfall in his region is plentiful for dry-land farming of corn, with over 500 mm of rainfall on average during the growing season. However he remembers 1998 was an extremely dry year and, being a new grower, he knew that in that particular year he hadn’t appropriately reduced his seeding and fertilizer rates to accommodate the low levels of soil moisture in his fields prior to the growing season. However he knows that this year the stored soil moisture on his land is adequate to for good crop development. Using this new information the postgraduate decides to
remove 1998 from his regression and finds the new relationship between corn yield and cumulative MGDDs to be:

\[ \text{Corn Yield (bu/ht)} = 0.38 \times \text{MGDD} - 791.8 \]

with a \( r^2 \) of 91.3%. The postgraduate is now confident that MGDDs are a good index for corn production on the grower’s farm.

**Figure A: Historical Modified Growing Degree Days versus Grower’s Corn Yield**

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**Chilling Degree Hours**

Another example of a cumulative temperature based index is chilling degree hours or units. Although cold temperatures are often detrimental to crop production they can also been an essential requirement for certain cultivars as described by Byrne and Bacon (2001):

*Stone fruit trees such as peaches develop their vegetative and fruiting buds in the summer and, as winter approaches, the already developed buds go dormant in response to both shorter day lengths and cooler temperatures. This dormancy or sleeping stage protects these buds from oncoming cold weather. Once buds have entered dormancy, they will be tolerant to temperatures much below freezing and will not grow in response*
to mid-winter warm spells. These buds remain dormant until they have accumulated sufficient chilling units (CUs) of cold weather. When enough chilling accumulates, the buds are ready to grow in response to warm temperatures. As long as there have been enough CUs the flower and leaf buds develop normally. If the buds do not receive sufficient chilling temperatures during winter to completely release dormancy, trees will develop one or more of the physiological symptoms associated with insufficient chilling: 1) delayed foliation, 2) reduced fruit set and increased buttoning and, 3) reduced fruit quality.

There are various models used to define and calculate chilling degree units, which could be used as an index for a weather risk management strategy. The three most common models are: 1) the number of hours during the winter period where the temperature is below 7.2 degrees Celsius; 2) the number of hours where the temperature is between 0 and 7.2 degrees Celsius; and 3) a model that associates varying chill units according to the actual hourly temperature, known as the Utah model (Byrne and Bacon, 2001). The first two models are simple and define a chilling unit as one hour below or between certain temperatures. The Utah method is more complex because it introduces the concept of relative chilling effectiveness and negative chilling accumulation. Average monthly temperature can also be used to estimate accumulated chilling units.

**Event-Based Indexes**

Crop damage can also be the result of specific or critical temperature events that can be detrimental to yield or quality. For instance, freezing conditions were reported to have caused more than US$600 million in damage to the U.S. citrus crop in a single week of December, 1998, with US$300 million occurring in Tulare County, California, alone (GuaranteedWeather, 2005b). Critical temperatures causing crop damage may vary depending on the length of time that temperatures remain below freezing as well as the variety, health, and development stage of a plant. Table 2.2.3 gives approximate critical temperatures for a selection of crops.
### Table 2.2.3 Critical Temperatures that Result in Freeze Damage to Crops

<table>
<thead>
<tr>
<th>Critical Temperature for Freeze Damage</th>
<th>Crop Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 to -1 deg Celsius</td>
<td>Strawberries and Raspberries (blossom and fruit), Tomatoes, Cucumbers, Melons, Peppers, Squash and Pumpkin (plants), Beans, Tobacco</td>
</tr>
<tr>
<td>-1 to -2 deg Celsius</td>
<td>Potatoes, Corn, Apples and Plums (blossom), Pears and Cherries (blossom and fruit), Beans</td>
</tr>
<tr>
<td>-2 to -4 deg Celsius</td>
<td>Apples (fruit and buds), Blueberries, Alfalfa, Pears</td>
</tr>
</tbody>
</table>

Source: Ministry of Agriculture and Food, Ontario, Canada

Preventative and proactive measures can often be taken to protect crops from such events, but these may have limited impact or become more difficult for crops that are farmed in large areas, such as cereals and grains. For example, winter wheat yields at harvest depend to a great extent on how well the plants survive the winter hibernation period. In the territory of Kherson in Ukraine winter wheat crops have been known to die as a result of air and therefore, soil temperatures falling below a critical level for one day or longer. These winterkill events cause damage and death of the plants’ tillering node, “[with little or no snow, plants begin to die when] the daily minimum air temperature drops below -16 deg C; [a crop can be completely lost if this happens for] four days in a row or in the minimum temperature drops below -21 deg C,” (Adamenko, 2004). Snow cover considerably improves conditions of winter wheat hibernation, as the difference between air and soil temperature increases from 0.5 to 1.1°? per centimeter of snow cover. However, snow cover on the territory of Kherson is often unstable hence complete winter wheat crop failure due to winterkill is a potential risk in the southern steppe zone of Ukraine—the crop usually dies in years with no snow cover or when the stable snow cover appears late in winter, as in 2003. A winterkill index, based on days when the daily minimum temperature is less than -16°?, could therefore be used by a farmer to obtain protection against such crop failure risk. For instance, a farmer could enter into a contract with the recovery the full value of the crop, as expected under normal weather conditions, if the recorded daily minimum air temperature is less than -16°? for four or more consecutive days at anytime during the winter period, November to March. Although soil temperature is perhaps a more pertinent variable for the farmer it is not a variable that is often measured by meteorological weather stations and therefore could not be used to design a
winterkill risk management solution. Air temperature is generally recorded at the 2m level by National Meteorological Services, however a combination of air temperature and snow-cover at the nearest measuring location could be used, for example, to construct a more accurate index reflecting the winterkill risk for wheat.

Excessive heat can also damage crop production and quality and can be a lot more difficult to control than freezing temperatures. For example significant losses in winter wheat harvest are very likely when daily maximum air temperatures exceed +30°C (at the height of 2m) in the critical shaping and ripening stages of winter wheat kernels in late spring and early summer. One such heat stress event can lead to up to a 4 percent decrease in yields at harvest time due to excessive drying and underdevelopment of the wheat ears and kernels (Adamenko, 2004).

Precipitation
Precipitation, either rainfall or snowfall, can also be vital to crop growth and development. In the example above, it was clear that a snowfall has a critical role in protecting hibernating crops from the damaging effects of low air temperatures. However rainfall variability is often the most critical factor in agriculture.

Deficit Rainfall and Drought
Meteorological drought is usually defined in terms of deviations of precipitation from normal levels and the duration of dry periods in a region. Agricultural drought refers to situations in which moisture in the soil is no longer sufficient to meet the needs of crop growing in an area due to insufficient rainfall. Crops, particularly rain-fed crops, often have a minimum overall threshold of cumulative rainfall for successful and healthy plant development. For example, dry beans can consume up to 368 mm of water during the growing season, depending on plant variety, soils, climate, and weather conditions (Efetha, 2002). For dry-land corn farming, 450–500 mm or more is required for high yields during the growing season (Neild and Newman, 2005). These water requirements must be met by natural rainfall, stored soil moisture from precipitation prior to the growing season, or from supplemental irrigation. A deficit of rainfall therefore below these levels, in the absence of irrigation, can cause plant moisture stress that affects development and consequently reduces yields. A simple cumulative rainfall index could be developed to suit a grower’s specific requirements with regard to such decreases in rainfall and therefore, yield. By looking at historical yield data, for example, an empirical relationship between seasonal cumulative rainfall and yield can be established. However, the distribution of rainfall during the growing season or at specific stages of a plant’s development is often more important and customized indexes must be developed.
to capture this risk (Stoppa and Hess, 2003). Such indexes may also include other weather parameters, such as temperature and relative humidity.

A good index must account for the susceptibility of crops to moisture stress during the different stages of development, taking into account the biological and physiological characteristics of the crop and the properties of the soil. Although actual soil moisture—the amount of water present in the soil that is available for plant uptake—is not in general an observed variable at meteorological weather stations, given knowledge of the crop and soil type, rainfall and temperature data can be used to create objective indicators to capture drought risk during the various stages of a plant’s development. Water-balance crop growth models or historical yield data can be used to infer the empirical relationship between rainfall amounts and yield/quality for specific soil and crop types.

For example, it is known that winter wheat yields can be strongly influenced by plant moisture stress during the leaf-tube formation to milking stages of development. Crop growth model results for the territory of Kherson, Ukraine, show how wheat yields vary as a function of deviations in cumulative rainfall (CR) and average air temperature ($T_{\text{average}}$) from normal levels during this period, assuming normal weather conditions for the rest of the growing season in the region (Table 2.2.4).

**Table 2.2.4 Deviations in Average Temperature and Cumulative Rainfall and the Impact on Winter Wheat Yields in Kherson, April 15–June 14**

<table>
<thead>
<tr>
<th>Deviation in Average Temperature ($T_{\text{average}}$ - $T_{\text{norm}}$) from Normal (deg C)</th>
<th>Deviation in Cumulative Rainfall (CR) - CR from Normal</th>
<th>Winter Wheat Yield Decrease at Harvest (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 &lt; $T_{\text{average}}$ - $T_{\text{norm}}$ &lt; 1</td>
<td>(CR$<em>{\text{norm}}$ - CR)/CR$</em>{\text{norm}}$ &lt; 50%</td>
<td>20</td>
</tr>
<tr>
<td>1 &lt; $T_{\text{average}}$ - $T_{\text{norm}}$ &lt; 3</td>
<td>60% &lt; (CR$<em>{\text{norm}}$ - CR)/CR$</em>{\text{norm}}$ &lt; 90%</td>
<td>20</td>
</tr>
<tr>
<td>1 &lt; $T_{\text{average}}$ - $T_{\text{norm}}$ &lt; 3</td>
<td>50% &lt; (CR$<em>{\text{norm}}$ - CR)/CR$</em>{\text{norm}}$ &lt; 60%</td>
<td>25</td>
</tr>
<tr>
<td>1 &lt; $T_{\text{average}}$ - $T_{\text{norm}}$ &lt; 3</td>
<td>(CR$<em>{\text{norm}}$ - CR)/CR$</em>{\text{norm}}$ &lt; 50%</td>
<td>30</td>
</tr>
<tr>
<td>$T_{\text{average}}$ - $T_{\text{norm}}$ &gt; 3</td>
<td>60% &lt; (CR$<em>{\text{norm}}$ - CR)/CR$</em>{\text{norm}}$ &lt; 90%</td>
<td>30</td>
</tr>
<tr>
<td>$T_{\text{average}}$ - $T_{\text{norm}}$ &gt; 3</td>
<td>50% &lt; (CR$<em>{\text{norm}}$ - CR)/CR$</em>{\text{norm}}$ &lt; 60%</td>
<td>40</td>
</tr>
<tr>
<td>$T_{\text{average}}$ - $T_{\text{norm}}$ &gt; 3</td>
<td>40% &lt; (CR$<em>{\text{norm}}$ - CR)/CR$</em>{\text{norm}}$ &lt; 50%</td>
<td>50</td>
</tr>
<tr>
<td>$T_{\text{average}}$ - $T_{\text{norm}}$ &gt; 3</td>
<td>(CR$<em>{\text{norm}}$ - CR)/CR$</em>{\text{norm}}$ &lt; 40%</td>
<td>100</td>
</tr>
</tbody>
</table>

Source: Author, using data from Adamenko, 2004
In Table 2.2.4, $T_{\text{norm}}$ is defined as the 10-year average value of $T_{\text{average}}$ for Kherson weather station for the period April 15–June 14. $^{21}$ $CR_{\text{norm}}$ is defined as the 30-year average $CR$ value for Kherson weather station for the period April 15–June 14. A grower could therefore protect himself from moisture stress risk on his winter wheat crop by purchasing a weather contract whose payout characteristics reflected the expected yield losses estimated by the model results in Table 2.2.4.

General indexes, such as the Palmer Drought Severity Index (PDSI), have also become widely used drought assessment tools; the U.S. federal government and many U.S. state governments rely on the PDSI to trigger drought relief programs. The PDSI is based on more than just rainfall and uses temperature, latitude, available water holding capacity of the soil, as well as precipitation, to infer the supply and demand of the soil moisture at a location on a weekly basis throughout a growing season (Palmer, 1965). The value of the PDSI is reflective of the how the soil moisture, excess or deficit, compares with normal conditions. Such an index could be used as a general indicator of the severity of weather and growing conditions for the local area, rather than for a specific crop.

**Excess Rainfall**

Excessive moisture conditions, however, can also retard growth and affect the yield and quality of a harvest. Excess precipitation can cause flooding and waterlogging of the soil, which can restrict oxygen supply to root systems, reduce nutrient uptake, lead to nitrate leaching and an increase in the incidence of plant disease and pests. The effects are worse when combined with warmer than average temperatures which encourage pest development; warm water also contains less dissolved oxygen than cold water. Precipitation can impact the time and effectiveness of farming operations such as sowing, land preparation, and pesticide and fertilizer applications. Excessive rainfall at harvest time can also delay harvest and/or spoil standing crops. Daily rainfall amounts in excess of 4 mm (Adamenko, 2004) can make harvesting impossible—a grower could purchase weather protection for such an event or events that would cover the associated financial cost of a harvest delay (see Chapter 3, the Indian case study).

**Quantifying the Risk**

Once the index has been identified, it must be calibrated to capture the financial impact of the specified weather exposure as measured by the index. There can be two approaches to this stage: identifying the financial exposure per unit of the

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$^{21}$ There is a warming trend in the historical temperature data (see Section 2.4 for more information on dealing with such trends in data), therefore, a 10-year average baseline is used, rather than a 30-year climate average.
defined index, and/or establishing the limit, the total financial protection required per risk period, i.e., the maximum payout necessary in a worst-case scenario. The approach that is chosen depends on the nature of the underlying index and weather event. For example, if the weather exposure is event driven, such as a Category 5 hurricane hitting a particular location or a cold winterkill event destroying an entire wheat crop, the latter approach is more appropriate. If the weather exposure is of a cumulative nature, such as drought or Growing Degree Days, the former approach should be chosen. However, taking into consideration the maximum protection required per risk period can also inform the financial exposure per unit index.

**Unit Exposure**

Once weather indexes to capture the impact of adverse weather conditions on a specific crop’s yield have been developed it is straightforward to calculate the financial impact of these events for producers. In designing the index, expert scientific agro-meteorological assessments, either in conjunction with crop model output or with verification using historical yields, have been employed to construct an underlying index that best proxies the weather sensitivity of the crop in question. Having identified the index, $I$, the crop yield, $Y$, or volume, $V$, variability per unit of the defined index, can be defined

$$\Delta Y = \Delta V / H = a(I) \Delta I$$  \hspace{1cm} (2)

where $a(I)$ is some function of $I$ that relates the index to the yield $Y$; and $H$ is the planting area of the crop. In order to calibrate an appropriate weather contract, the variation in crop yield must now be converted into a financial equivalent that mirrors the producer’s exposure. This can be done, for example, by considering a producer’s production and input costs per hectare planted or by considering his expected revenue from the sale of the crop at harvest. Producers with fixed-price delivery contracts or those that use price risk management instruments to protect themselves from market fluctuations in the price of their crop at harvest time know the financial value of each kilogram or metric ton they produce and hence can quantify the financial cost of a shortfall in production. For example, if a grain producer knows he will receive $X per metric ton of crop, the following relationship must hold for his change in revenue:

$$\Delta \text{Revenue} = X \ast (\text{Actual Yield} – \text{Expected Yield}) \ast H = X \ast \Delta V$$

$$= \pm X \ast H \ast a(I) \ast \Delta I$$ \hspace{1cm} (3)

A good weather hedge must offset the negative $\Delta \text{Revenue}$ fluctuation in the event of a drop in yield from budgeted levels if a producer is to protect his earnings. In order to perfectly replicate his position, the farmer could enter into a weather contract with the following incremental payout $P$ per unit index:
\[ \Delta P = X \times H \times a(I) \times \Delta I \]  
(4)

Therefore his overall position would be

\[ \Delta \text{Revenue} + \Delta P = -X \times \Delta Y \times H + X \times H \times a(I) \times \Delta I = 0 \]  
(5)

Producers may have contractual obligations to deliver a pre-defined amount of their farmed product to a buyer at harvest time, with associated penalties if these obligations are not met. In such a situation, it would be straightforward to quantify and structure a hedging product to protect a producer from these contractual costs in the event of a weather-related shortfall in production (Box 2.2.2).

**Box 2.2.2 The Corn Grower’s Weather Hedge: Unit Exposure**

The grower is one of the few corn producers in the region and he has just won a contract to deliver 500,000 bushels of corn to a local buyer at harvest. However there are penalties in the contract associated with under-delivery. In the contract, the buyer has specified that the grower will receive $3 per bushel for the 500,000 bushels he is contracted to deliver, however the contract also stipulates that the grower will pay a penalty of $1 for every bushel under 500,000 that he fails to deliver. The grower is extremely happy with his contract. He knows on average he can expect to make $2.5 per bushel for his production by selling outside of his area, so $3 per bushel is a very good price for the grower as it does not include transportation costs. Additionally he also knows that he can sell his excess production, if any, at $2.5 per bushel. However he is concerned about the $1 per bushel penalty so he makes a table (Table B) of his overall revenue with and without the supply contract given different farm production scenarios.

**Table B: Farm Revenue under Different Total Production Scenarios**

<table>
<thead>
<tr>
<th>Total Farm Production (bushels)</th>
<th>Revenue w/ 500,000 bu Supply Contract ($)</th>
<th>Revenue w/out 500,000 bu Supply Contract ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>800,000</td>
<td>2,250,000</td>
<td>2,000,000</td>
</tr>
<tr>
<td>700,000</td>
<td>2,000,000</td>
<td>1,750,000</td>
</tr>
<tr>
<td>600,000</td>
<td>1,750,000</td>
<td>1,500,000</td>
</tr>
<tr>
<td>500,000</td>
<td>1,500,000</td>
<td>1,250,000</td>
</tr>
<tr>
<td>400,000</td>
<td>900,000</td>
<td>1,000,000</td>
</tr>
<tr>
<td>300,000</td>
<td>550,000</td>
<td>750,000</td>
</tr>
<tr>
<td>200,000</td>
<td>200,000</td>
<td>500,000</td>
</tr>
</tbody>
</table>

Source: Author
He is interested in purchasing a weather contract that duplicates the terms of his underlying corn supply contract so that in years where his production falls below the 500,000 bushel threshold he does not make less money than he would expect to make if he simply sold his produce outside of the region at $2.5 per bushel.

He can see that every 100,000 bushels below the 500,000-bushel threshold corresponds to a loss in revenue of $100,000. The grower would like to enter a contract that financially compensates him for such a loss in case there is a weather-related shortfall in production on his farm. The grower uses the postgraduate’s equation (b) to convert the total farm production in bushels to an equivalent cumulative MGDD:

$$MGDD = \frac{(Total \ Production \ / \ 3700 + 791.8)}{0.38} \quad (c)$$

He finds that 2436.5 MGDDs corresponds to 500,000 bushels of farm production according to the equation. For total farm production less than 500,000 he makes a net loss in revenue of $1 for each bushel less than the 500,000 bushel threshold, i.e.,

$$MGDD = \frac{($1 \ / \ 3700)}{0.38} = 0.00071 \quad (d)$$

Therefore for every MGDD less than 2436.5 MGDDs from May 6–September 15, he calculates that he can expect to lose $1,410 per MGDD in revenue (Table C).

<table>
<thead>
<tr>
<th>Total Farm Production (bushels)</th>
<th>Required MGDDs</th>
<th>Loss in Expected Revenue Associated with Entering Supply Contract ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>800,000</td>
<td>2649.3</td>
<td>0</td>
</tr>
<tr>
<td>700,000</td>
<td>2578.4</td>
<td>0</td>
</tr>
<tr>
<td>600,000</td>
<td>2507.4</td>
<td>0</td>
</tr>
<tr>
<td>500,000</td>
<td>2436.5</td>
<td>0</td>
</tr>
<tr>
<td>400,000</td>
<td>2365.6</td>
<td>-100,000</td>
</tr>
<tr>
<td>300,000</td>
<td>2294.7</td>
<td>-200,000</td>
</tr>
<tr>
<td>200,000</td>
<td>2223.8</td>
<td>-300,000</td>
</tr>
<tr>
<td>100,000</td>
<td>2152.8</td>
<td>-400,000</td>
</tr>
</tbody>
</table>

Source: Author
Often before a growing season, however, growers are uncertain as to the price $X$, at which they can sell their crop after harvest, rendering the quantification of risk more uncertain. Furthermore, commodity prices also often vary in response to extreme production shocks and it is often difficult to quantify the production (weather)-price correlation, particularly in emerging commodity markets where prices are not always stable. However estimates for the harvest-time price can be made, e.g., the futures price for harvest delivery contracts trading on a local commodities exchange, last year’s harvest price or the five-year average sales price could be used as a best estimate. Furthermore, historical sales price, marketing, and production data can be used to quantify the index-value interaction capturing the financial exposure of a producer. By performing, for example, a linear regression on historical commodity prices and farm production data, a producer can quantify how a variation in index and therefore, yield has related to a variation in sales price of the commodity in the past to estimate a value of $X$ for the future. Such an approach can also be used by an agrochemical producer to find the relationship between the historical values of an index designed to capture the development of a pest and the historical sales of pesticides, in order to quantify a hedge to protect against reduced sales arising from weather conditions that decrease pest development.

**The Limit**

Most weather contracts have a limit, which corresponds to the maximum financial payout or recovery from the contract in a worst-case scenario, such as a complete crop failure. The maximum payout can be set by either considering the value-at-risk for the producer in the event of a total crop failure or by looking at historical index, production, and sales data to find the worse case scenario historically in order to establish a limit. Alternatively a producer may simply want to insure his production and input costs in order to recover these outlays if the crop fails. If a producer’s production costs are $Z$ per hectare farmed, $Z$ will therefore correspond to the maximum payout, the limit of the weather contract, for each hectare the producer wishes to insure. The unit exposure $P$ will therefore be

$$\Delta P = ( - \Delta Y / \text{Expected Yield} ) * Z$$

$$= ( a(I) \Delta I / \text{Expected Yield} ) * Z, \text{ for } \Delta Y < 0$$

(6)

**Structuring the Product**

**Structure Type**

Once the index has been identified and calibrated, the next step is to structure a contract that pays when the specified adverse weather occurs in order to perform a hedging or risk-smoothing function for an agricultural grower or producer.
Derivative and insurance products form the mainstay of the weather risk management market. While the two instruments feature different regulatory, accounting, tax, and legal issues, the risk transfer characteristics and benefits are often the same. One of the drivers of market growth has been the flexibility between both instruments and the possibility to tailor risk management solutions to a client’s needs (Corbally and Dang, 2002). A risk management product can be

- A traditional insurance-style product—that is, risk transfer that results in downside protection in exchange for a premium, e.g., a call or put option structure;
- A risk-exchange derivative-based product—that is, giving away upside in good years or seasons to finance downside protection, e.g., a collar or swap structure.
- A risk-financing product to smooth risk over a longer time horizon—that is, using future income potential to guarantee the repayment for an insurance payout in the event of a bad year, e.g., a finite risk program.

**Call and Put Options**

A call option gives the buyer of the option the right, but not the obligation, to buy the underlying index at a pre-defined level at the maturity, or end date, of the contract. In exchange for this right, the buyer pays a premium to the seller. Similarly a put option gives the buyer the right, but not the obligation, to sell the underlying index at a pre-defined level at contract maturity; in exchange for this right, the buyer of the option pays a premium to the seller. Every option contract, and, in general, most weather contracts are defined by a set of standard specifications including

1. The reference index, I, and weather station(s)—complete specification of the index and data used to construct it;
2. The term, T—the risk protection period of the contract, including the start and end date of the contract;
3. A strike, K—also known as an attachment level, the level at which the weather protection begins;

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22 To be precise, this definition describes a European Option, an option that can only be exercised at the end of its life, at maturity. In general, this is the most appropriate type of option on an underlying weather index. Other types of options include American Option, an option that can be exercised at any time during its life; Bermudan Option, an option that can be exercised on specific dates during its life; and Asian Option, an option with a payout function that depends on the average value of the underlying index during a specified period.
4. The payout rate, $X$—the financial compensation per unit index deviation above (call) or below (put) the strike at maturity, defined as the unit exposure in the previous section;

5. The limit, $M$—the maximum payout per risk protection period.

The payout, $P_{\text{call}}$, of a call option can be defined by the following equation:

$$P_{\text{call}} = \min( \max(0, I - K) \times X, M) \quad (7)$$

The payout, $P_{\text{put}}$, of a put option can be defined as:

$$P_{\text{put}} = \min( \max(0, K - I) \times X, M) \quad (8)$$

The type of option purchased depends on the risk profile of the buyer. For example, assume a winter wheat grower loses 4 percent of his expected yield every day the maximum daily temperature is above 30°C in the months of May and June, incurring a cost of €16 per hectare of wheat cultivated every day the 30°C threshold is exceeded. The grower has 10,000 hectares of wheat under cultivation and is prepared to accept yield losses due to heat stress of up to €480,000, but wants protection for any losses in excess of that amount. In this case, the grower may consider purchasing a call option, either in derivative or insurance form, with the following specifications:

**Reference Weather Station (RWS):** Growerstown, ID No. 12345  
**Index:** Daily Tmax > 30°C, measured at RWS  
**Calculation Period:** May 1, 2005–June 30, 2005 (inclusive)  
**Call Strike:** 3 events  
**Payout Rate:** €160,000 per event above the strike  
**Limit:** €1,600,000

For securing such protection, the grower is required to pay a premium, but is allowed to recover €160,000 for each day in May and June that the daily maximum temperature exceeds 30°C in excess of the strike level. Figure 2.2.1 illustrates the impact of such hedging strategy on the revenues of the grower—his downside exposure is now limited to €480,000 by purchasing the call option, unless the number of heat events exceeds an unprecedented 13 during the calculation period.
Figure 2.2.1 Call Option Payout Structure and Wheat Grower’s Losses

![Graph showing Call Option Payout Structure and Wheat Grower's Losses](source: Author)

Modifications can obviously be made to this simplified example to better replicate the exposure of the grower—a more sophisticated product may be, for instance, based on an index that considers only consecutive days of excessive temperature, includes relative humidity or a non-linear payout rate that increases the compensation as the number of heat events during the calculation period increases. Alternatively, the grower many want to purchase a digital call option, an all-or-nothing structure that will pay the grower a lump sum, rather than incremental payout, if the heat stress reaches a critical level at which most of the crop will be lost. Similarly, an end user buying a put option would protect himself from events when the index drops below the strike level. An example of a put option application is given in Box 2.2.3.
Box 2.2.3 The Corn Grower’s Weather Hedge: Put Option

Having quantified his financial exposure as $1,410 per MGDD in the event of a cool summer, the corn grower decides that he should purchase a weather derivative contract that pays out when MGDDs accumulated at his local National Meteorological Service (NMS) weather station at Corn town Airport are low. In particular, given his analysis, he wants protection against years where the cumulative MGDDs, from May 6–September 15, are less than 2436. He decides a put-option structure is the best way to manage this risk and he develops a prototype weather contract with the following specifications:

**Reference Weather Station** Corntown, ID No. 56789 (RWS):
- **Index:** Daily Tmax > 30° C, measured at RWS
- **Calculation Period:** May 6, 2005–September 15, 2005 (inclusive)
- **Put Strike:** 2436
- **Payout Rate:** $1,410 per MGDD below the strike
- **Limit:** $400,000

The grower contacts his local derivatives broker to see whether the broker can get him a quote for the prototype contract he has developed.

**Collars and Swaps**

A business may be averse to paying an upfront premium for risk protection. An alternative is a contract where the business receives downside protection in return for sacrificing upside revenue in the event of weather that is beneficial for the business. In essence, the business can forego a proportion of profit to offset the cost of reduced revenues by selling a put option and then buying a call option from the provider, or vice versa. A collar, therefore, combines both a call and put option, but does not involve an exchange of premium from the end user to the provider. A collar is a means by which two parties can exchange risk, hence collars may often be structured with asymmetric call and put options in order to make the risk exchange of equal value to both parties. This approach may not be applicable to all weather risk management problems in agriculture. Furthermore, businesses may be averse to giving up profits in a good year. However, a very simple example of a possible application can be found by considering a local agrochemical company whose sales of a particular pesticide vary depending on the number of pest growing degree days (PGDDs) recorded in their sales region during the winter. When the recorded PGDDs are high, pest attack incidents increase and pesticide sales increase accordingly. When PGDDs are low, demand for their product drops and pesticide sales are low. The company has quantified this risk and finds that on average it loses or gains $12,000 per PGDD from their budgeted revenues if the accumulated PGDD are below or above the 1700
PGDDs expected in a normal winter in the region. The company may be interested in a collar, as not only is it costless to enter into a collar agreement, but it also reduces the company’s revenue volatility caused by weather. In this case, the company may consider purchasing a collar with the following specifications:

**Reference Weather Station (RWS):** Growerstown, ID No. 12345  
**Index:** Cumulative PGDDs measured at RWS  
**Calculation Period:** November 1, 2005—March 31, 2006 (inclusive)  
**Call Strike:** 1800 PGDDs  
**Put Strike:** 1600 PGDDs  
**Payout Rate:** $12,000 per PGDD above/below strikes  
**Limit:** $2,400,000

**Figure 2.2.2 Collar Payout Structure and Agrochemical Company’s Deviation from Budgeted Revenue**

The historical distribution of November–March PGDDs in Growerstown is found to be symmetric around the 1700 PGDD average with a standard deviation of 100 PGDDs; hence, the call and put options have strikes equidistant of the average to create a zero-cost collar. Figure 2.2.2 illustrates the impact of such hedging strategy on the revenues of the company—the collar reduces a potential two standard deviation fluctuation in revenues for the company from +/- $2,400,000 to +/- $1,200,000.
A swap is a contract in which a buyer makes a payment to the seller when a weather index rises above a pre-defined strike level and entitles the buyer to receive a payment from the seller when the index falls below the same level. Essentially a swap is a put and a call option with the same strike, payment rate, and limit, which, like a collar, is costless to enter. In the example above, instead of using a collar contract the local agrochemical company could “sell” a swap contract to a provider with a strike of 1700 PGDDs and a payout rate of $12,000 per PGDD. This would ensure that the business achieves no more or less than its budgeted revenue. Swaps are derivative OTC contracts that are commonly traded in the secondary derivative weather risk market and, outside the energy industry, are not often used by end users as they do not always offer the best correlation to the underlying risk. Swaps are only available in derivative form (Raspe, 2002).

**Exotic Structures**

In theory, a weather risk management solution can take any form or combination of options, swaps, triggers, and indexes. Possible exotic combinations include knock-in or knock-out options, which grant the buyer a standard call or put option if a particular knock-in or knock-out threshold is breached, either on the same or even a different index—for example, a heat stress call option for wheat that is only triggered if precipitation during the same calculation period drops below a critical level; compound options, known as “an option on an option,” that grants the buyer to right to purchase an underlying option at some future date—for example, a multi-year structure that gives the buyer an option to buy an option on the weather conditions for the next growing season at the end of the current season; structures with a variable start date depending on the timing of a pre-specified event—such a structure may be appropriate for crops with variable planting dates that can be associated with cumulative rainfall or growing degree day totals.

Reference indexes may also include non-weather variables. For example, temperature contingent commodity call options that give a purchaser the right but not an obligation to buy an underlying commodity at a pre-specified price and volume only if certain temperature, i.e., growing conditions, have been met. Such exotic structures could potentially provide total revenue insurance for agricultural producers whose revenues depend on both the price at which they sell their produce and the volume that they produce. Such contracts exist and are traded in the OTC energy derivatives markets.

**Finite Risk Solutions**

Finite risk products are becoming another accepted risk management mechanism, often popular with corporate end users. Finite risk solutions seek to spread the risks for an insurance policyholder over time and shift the main value proposition from traditional risk transfer towards risk financing for the client. Products are
designed specifically to the needs of the customers, and in contrast to traditional annual-renewal insurance policies, they are typically multi-year contracts that smooth the year-to-year volatility of insurance claims and premium payments—and consequently earnings—over a long time horizon therefore limiting the overall risk transfer during the contract period. Finite risk programs involve either pre-funded (prospective) structures—where the client pays an annual or single premiums into a fund account that earns a contractually agreed investment return; these funds are then used to make loss payments to the customer—or post-funded (retrospective) structures, where the client pays back the claims payments of the insurer over a defined period of time. Such a risk management mechanism can also be used to finance weather risk.

Exchange-Traded Products
The CME lists weather futures and options on futures, with over US$4 billion dollars of trading notional value in 2004/2005. These are standardized exchange-traded derivatives that reflect monthly and seasonal temperatures of 15 U.S. cities, five European cities, and two Japanese cities, measured according to specific indexes and weather stations. The contracts are specifically tailored for the energy industry. Weather contracts for winter months are classified according to an index of cumulative HDD values, days in which energy is used for heating. Weather contracts for summer months in the United States are classified according to an index of cumulative CDD values (days in which energy is used for air conditioning), and in Europe, according to an index of cumulative average temperature. All futures and option contracts on the CME can be bought and sold through an exchange broker, with terms and conditions set forth in agreements provided by the CME. However, due to the standardized nature of the contract they may have limited appeal to the agricultural industry.

Risk Retention and Premium
It is clear that an important aspect to consider when structuring an index-based solution is the retention of risk by the party seeking protection, this means defining the index trigger level when the weather protection begins. The strike determines the level of risk retention of the insured party and is the key to pricing and success in transferring the risk. A strike very close to the mean of the index indicates a low level of risk retention by the end user and a contract that will pay out with high probability. This implicitly means a large premium, as well as the possibility of inspiring little interest from the weather market if the location or nature of the risk is outside the main liquid trading hubs or variables. A strike further away from the mean reduces the probability of a payout and hence the premium of the contract as the entity is retaining the more frequent, near-the-mean risk internally, and transferring less to the market. The level of risk retention will depend on the risk appetite and business imperatives of the
end user in question and the sensitivity to the premium associated with entering into a contract. For instance, to reduce the premium payment, the wheat grower in the call option example above could increase the strike for heat stress events. By retaining more risk, all things being equal, it would reduce the premium of the contract. Alternatively, the grower could reduce the payment rate to partially, instead of fully, hedge its exposure. Premium payment terms must be defined before entering a weather contract and an overview of how such contracts are priced by weather market providers is given in the following section.

### Execution

**The Market Providers**

The main providers of risk capacity, product structuring, and/or pricing for end user customers in the current weather risk market can be categorized into three main groups:

- Insurance and reinsurance companies that view non-catastrophic weather insurance as a natural extension to their traditional business and given analysis capabilities. Examples include ACE, AXA, Munich Re, Partner Re, Swiss Re, Tokio Marine and Fire Insurance, and XL Capital. Most of these entities can also offer derivative products and, although some may choose to retain the risk by dealing in a large amount of diversified end user business, several are some of the most active portfolio managers in the secondary market, using financial derivatives contracts to manage their weather risk portfolios, of both high- and low-frequency risk.

- Banks that structure weather risk solutions to fit the needs of their clients. Examples include ABN AMRO, Calyon, Deutsche Bank, Goldman Sachs, Merrill Lynch, and Rabobank. Banks have a large potential client base for weather derivative products and may find many marketing and cross-selling opportunities in many different sectors of business. Banks generally do not have as much risk capacity as the (re)insurers, often passing positions of their end user customers to other market providers or actively hedging positions in the secondary OTC and exchange-traded derivatives market.

- Specialized hybrid companies or funds such as Coriolis Capital (formerly Société Générale) and Guaranteed Weather Trading Ltd., have been established specifically to trade and invest in weather risk. Such hybrid entities are able to deal in weather derivatives and reinsurance and offer weather risk solution products to customers.

Brokers, who facilitate transactions between buyers and sellers of weather protection, are an independent point of contact for customers seeking a
counterparty in the weather market. A broker’s role is to allow for price discovery while ensuring confidentiality until final negotiations are concluded. Brokers have in-depth knowledge of the market with some offering risk solution structuring services. Derivative brokers, dealing primarily with the secondary OTC and exchange-traded market include: Tradition Financial Services (TFS), Intercapital (ICAP), GFI, and Evolution. Insurance brokers, that provide weather insurance broking services, include Marsh, Aon, and Willis Group.

The energy companies responsible for the birth of the marketplace, Enron, Aquila, Southern Company, and Entergy Koch (now Merrill Lynch) are no longer active in the weather market. Although the market is still predominantly driven by energy related weather risk—with energy companies and several banks hedging their energy portfolios with weather derivatives—the major source of secondary market liquidity is now driven by the three predominant types of counter-party outlined above, either through the hedging of end user deals or the taking of speculative positions.

Regulatory Issues

Depending on the jurisdiction, weather risk management products can be classified as financial (derivative), insurance, or gaming contracts. Depending on their classification, these contracts are subject to specific tax and accounting treatments, which can render one form more optimal than another for an end user’s purposes and business. Interested parties are strongly advised to contact their local financial services authority, insurance regulator, or a professional specializing in insurance law to find out how weather contracts are treated in their jurisdiction and the legal and financial implications associated with each.

In Europe, individual countries currently have their own regulatory standpoint. In the United Kingdom, for example, OTC weather derivatives are considered to be investment or financial contracts, “contracts for differences,” and are therefore regulated by the U.K. Financial Services Authority along with other financial contracts. Entities trading in weather derivatives must either be licensed or authorized to trade derivative contracts or be exempt from obtaining a license, such as end users or those dealing in weather mitigation products on their own account (Raspe, 2002). The International Swaps and Derivatives Association (ISDA, www.isda.org) Master Agreement confirmations and credit support provisions are used for the documentation for OTC weather derivatives in the United Kingdom and various countries in Continental Europe have also adopted this documentation (Raspe, 2002). Germany, France and The Netherlands have a

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23 Comments and advice from Claude Brown, Clifford Chance.
similar regulatory approach as the United Kingdom; in other European countries the classification of such contracts has not yet been clarified, e.g., Italy.

However, the new EU Investment Services Directive (ISD2) on financial instruments markets may bring weather derivatives into the regulatory framework that applies to other derivative contracts and give an EU-wide “passport” for trading OTC weather derivatives (Clifford Chance, 2004). Member states have until early 2007 to bring their national laws and regulations into line with the new rules. However, they will not be able to finalize their national implementation programs until the European Commission concludes its discussions, including if weather derivatives should be treated as financial instruments subject to the ISD2, or as an asset class outside the scope of regulation. If the directive is extended to cover weather derivatives, then member states will be required to adjust and apply their licensing and other financial regulatory rules accordingly. The proposal to extend the scope of regulation to cover weather derivatives will have several benefits and disadvantages for market participants (Clifford Chance, 2004), however there are some exemptions included in the directive, in particular for market players that currently can operate without a financial services license, such as end users of weather derivatives products.

In the United States, OTC weather derivatives are also treated as financial contracts, and most market participants use an ISDA Master Agreement to document their weather derivative transactions, although weather derivatives are excluded from the regulatory scope of the Commodity Exchange Act (Raspe, 2002); Exchange-traded contracts are regulated by the Commodity Futures Trading Commission.  

If a company wishes to purchase weather insurance to mitigate its weather risk, it must do so from an insurance provider licensed in its jurisdiction, who in turn must draft an insurance policy that must meet the definitions of “insurance” in the jurisdiction where the policy is to be written. In comparison to financial contracts, insurance is highly regulated and must comply with strict criteria. Regulators define the elements of an insurance policy to ensure supervision and compliance with the law. While definitions vary from jurisdiction to jurisdiction, the following six common elements can be extracted (WRMA, 2004):

---

24 The federal agency created by U.S. Congress in 1975 to regulate futures and options trading through its administration of the Commodities Exchange Act, a federal act which regulates the futures and options industries, requiring all futures and options to be traded on organized exchanges.
1. The process of insurance involves a contract between two parties, which runs for a specified term of “cover.”

2. Under the terms of this contract, one party (the “insurer”) must promise to pay a sum of money or provide a corresponding benefit to the other (the “insured”), should a specified future contingent event occur during the term of cover of the contract.

3. The insured must make a payment of money or money’s worth—the premium, in a lump sum or installments—to the insurer in consideration of the insurer’s promise of the point above.

4. There must be uncertainty as to the occurrence or the timing of the specified future contingent event.

5. There must be an “insurable interest” for the insured party. In other words, the insured must have an economic interest in the subject matter of the contract and have an interest in the subject matter that is lawful.

6. The insured must suffer a loss of a financial nature in relation to his insurable interest and the amount payable must be a reasonable recovery for the loss experienced.

The Weather Risk Management Association (2004) further illustrates point 6:

In many cases the amount payable by the [insurer] may be quantified by the actual financial loss suffered by the insured if the specified uncertain future event occurs and causes damage to the subject matter of the contract; this is in the nature of an indemnity. However, the amount payable by the [insurer] may also be predetermined and may be more or less than the loss suffered by the insured. That said, these “valued” policies or those that have fixed or formulaic payments are employed in order to expedite the claim settlement process. Whilst they do not provide a full correlation between the loss suffered by the insured and the amount paid by the insurer, the sums are not entirely unconnected. In these contracts, the amount payable upon a contingency must represent a genuine attempt to pre-estimate, or reflect, the loss that the insured might be expected to suffer, should the contingency occur. The amount payable cannot be wildly divergent from the loss experienced. The essential feature of this element of insurance remains that the insured does suffer a loss.

Although a weather derivative is consistent with point 1 and may share—although does not have to—some similarities with points 2-4 above, such an instrument does not need by law to exhibit any elements of insurance outlined by
points 5 and 6. For example, the New York State Insurance Department based its conclusion that a weather derivative is not insurance by noting, "The issuer is obligated to pay the purchaser whether or not that purchaser suffers a loss. Neither the amount of the payment nor the trigger itself in the weather derivative bears a relationship to the purchaser's loss. Absent such obligations, the instrument is not an insurance contract." (WRMA, 2004)

In the context of agriculture, the elements of weather insurance are that the insured party must have an insurable interest and needs to suffer a loss in respect of that interest, and the insurance payment must indemnify the insured party for the loss. For example, if a grower wants to purchase weather insurance for his wheat crop, he must: 1) be growing wheat; 2) purchase an insurance contract based on an index that correlates closely to his wheat yield; and 3) purchase insurance whose payout is related to the actual financial loss experienced. For instance the grower cannot buy insurance for more hectares of wheat than the number of hectares he is currently farming, nor can he purchase a contract where the sum insured (the limit) or the payout rate exceeds a reasonable value for the crop—for example, he cannot buy insurance with a limit of $10,000 per hectare when a reasonable estimate of the value of the crop, under current market prices or contractual obligations, is $1,000 per hectare. An end user and the insurer must be clear that the contract into which they enter satisfies the elements of insurance outlined by their jurisdiction, either by conducting a correlation analysis between the end user’s economics and variations in the weather in the application process and/or requiring the insured party to represent and warrant in the claim form that the recovery is a reasonable estimate of economic loss. In jurisdictions where weather risk protection can be obtained in both insurance and derivative form, such as in the United States or United Kingdom, these contracts are subject to distinct tax and accounting treatments.

2.3 VALUING WEATHER RISK

Pricing Overview

The premium of an index-based weather contract is determined actuarially, by conducting a rigorous analysis of the historical weather in order to understand the statistical properties and distribution of the defined weather index and therefore the payouts of the insurance or derivative contract. Such an analysis includes 1) cleaning and quality controlling the data, i.e., using statistical methods to infill missing data and/or to account for significant changes, if any, as a result of instrumentation or station location changes; 2) checking the cleaned data for significant trends and detrending to current levels if appropriate—this is particularly pertinent for temperature data which, in general, exhibit a strong
warming trend in the Northern Hemisphere; and 3) performing a statistical analysis on the cleaned and detrended data and/or a Monte Carlo simulation, using a model calibrated by the data, to determine the distribution of the defined weather index and therefore payouts of the contract. By determining the frequency and severity of weather events specified by the index, an appropriate premium can be calculated.

It should be noted that the premium charged by the providers in the weather market may depend on several factors, not all as objective as the underlying statistical analysis of the weather data. Institutions charge different risk margins, or discounts, over the expected value or fair price to potential buyers; these choices are driven by the risk appetite, business imperatives, and operational costs of the provider (Henderson, 2002). An overview of pricing is given in this section and the implications of the premium charged for the end user will also be discussed. The data issues associated with points 1 and 2 will be covered in Section 2.4.

Expected Loss and Risk Margin

To illustrate the pricing process, an index-based weather contract is structured as a call option (Section 2). The payout, \( P \), of the contract is determined by the following equation:

\[
P = \min\{ \max(0, I-K) \times X, M \}
\]

where \( K \) is the strike, \( I \) is the index measured during the calculation period, \( X \) is the payout rate per unit index and \( M \) is the limit of the contract. To calculate the premium for the contract one must determine the following parameters:

4. The expected loss of the contract, \( E(P) \), i.e., the average or expected payout of the structure each year;
5. The standard deviation of the payouts of the contract, \( \sigma(P) \), i.e., a measure of the variability of the contract payouts;
6. The xth-percentile of the payouts, i.e., a measure of the Value-at-Risk (VaR) of the contract for the seller, \( \text{VaR}_X(P) \). For example, the 99 percent VaR represents the economic loss for the provider that is expected to be exceeded with 1 percent probability at the end of the calculation period of the contract.

These three parameters quantify the expected (1) and variable (2, 3) payouts of the contract and must be determined from the historical weather data, either by using the historical index values from the available cleaned and detrended dataset or by using the data to calibrate a Monte Carlo simulation model to generate thousands of possible realizations of \( I \) in order to fill out the distribution of payouts and to determine better estimates of \( E(P) \), \( \sigma(P) \) and \( \text{VaR}_X(P) \).
complete description of the various methods for determining these payout statistics are beyond the scope of this chapter, but an overview of possible approaches is given in the following subsection. It is clear, however, that \( E(P) \), \( \sigma(P) \) and \( \text{VaR}_{99}(P) \) will vary with the strike, payout rate and limit.

Having established values for the expected and variable payout parameters, the price of a contract is then determined by the risk preferences of the (re)insurance company or financial institution that is providing the risk protection: that is, how they measure the cost of risk with respect to return for the purposes of pricing, risk management, and capital allocation (Henderson, 2002). As a result this is the most subjective aspect to the risk pricing process as it is largely driven by the institutional constraints and risk appetite of the provider. However it is clear that the provider will charge \( E(P) \) plus an additional risk margin for taking the weather risk from the end user, i.e.,

\[
\text{Premium} = E(P) + \text{Risk Margin} \tag{10}
\]

There are many methods for measuring risk and hence determining the risk margin of a risk taker. Two examples of simple methods that have been suggested (Henderson, 2002) for the weather market are the Sharpe Ratio and the Return on VaR methods—both measure expected excess return in terms of some measure of risk and hence determine the “cost of risk” for the contract seller:

\[
\text{Sharpe Ratio, } \alpha = \frac{[\text{Premium} - E(P)]}{\sigma(P)} \\
\text{Premium} = E(P) + \alpha \sigma(P) \tag{11}
\]

\[
\text{Return on VaR (99%), } \beta = \frac{[\text{Premium} - E(P)]}{[\text{VaR}_{99}(P) - E(P)]} \\
\text{Premium} = E(P) + \beta [\text{VaR}_{99}(P) - E(P)] \tag{12}
\]

The Sharpe Ratio uses standard deviation as the underlying measure of risk and therefore \( \alpha \) represents the “cost of standard deviation” as determined by the seller’s risk preferences. One of the benefits relating risk with the standard deviation of payouts is that it is an easy parameter to estimate, however, it is a symmetric measure of risk capturing the mean width of the payout distribution, and, for traditional risk exchange products, the payout distribution is often not symmetric but has a long tail. The Return on VaR method uses \( \text{VaR}(99\%) \) as the underlying measure of risk and therefore \( \beta \) represents the “cost of VaR.” Value-at-Risk (VaR) is a term that has become widely used by insurers, corporate treasurers, and financial institutions to summarize the total risk of portfolios. Central bank regulators, for example, use VaR in determining the capital a bank is required to reflect the market risks it is bearing. A VaR calculation is aimed at determining the loss that will not be exceeded as some specified confidence, often set at the 99% confidence level, over a given time horizon (Hull, 2000). The advantage of \( \text{VaR}_{99} \) is that it is computed from the loss side of the payout
distribution, where loss is defined with respect to the expected payout $E(P)$, and therefore captures the potential financial loss to the seller. Using the Return on VaR method is more appropriate for pricing structures that protect against low-frequency/high-severity risk, that have highly asymmetric payout distributions. However $VaR_{99}$ is a harder parameter to estimate, particularly for strike levels set far away from the mean, and is usually established through Monte Carlo simulation. The worst-case recorded historically can often be used as a cross check for VaR. In both methods outlined above, $\alpha$ and $\beta$ quantify the risk loading appropriate for the risk preferences of the provider.

It is also worth noting that weather market participants can often enter into financial derivatives contracts to manage their weather risk portfolios and actively hedge positions in the secondary OTC and exchange-traded derivatives market. This is particularly true if the end user risk is in a location that is included or positively correlated to the locations that are commonly traded in the market. Moreover, even if a market provider chooses to retain the risk internally, a new potential contract may look attractive in comparison to the overall portfolio of the risk-taker, i.e., it may be a contract that, like hedging, will reduce the relative $\sigma$ and $VaR_{99}$ parameters and hence the overall risk position of the portfolio. The cost of the chosen hedging strategy (if any) may affect the expected loss and the variability of payouts making the payout a function of the hedging strategy $H$, $P(H)$ (see Market Pricing subsection below)—hence a more general representation of the premium, given Equations 10 and 12, is

$$
Premium = E(P(H)) + \alpha \left( \sigma(P(H), C) - \sigma(C) \right)
$$

(13)

where $\sigma(P(H), C)$ can be expressed as:

$$
\sigma(P(H), C) = \sqrt{\sigma(P(H))^2 + \sigma(C)^2 + 2\rho(P(H), C)\sigma(P(H))\sigma(C)}
$$

(14)

$\sigma(P(H))$ and $\sigma(C)$ are the standard deviations of the contract payout and the current portfolio position $C$ over the same time horizon respectively; $\sigma(P(H), C)$ is the overall standard deviation of the new portfolio with the contract included; $\rho(P(H), C)$ is the correlation between the contract payouts and the position of the current portfolio over the time horizon of the contract. As the correlation can be negative or positive the new contract can decrease or increase the overall risk of the portfolio, as can the relative magnitudes of $\sigma(P(H))$ and $\sigma(C)$, and hence reduce or increase the premium while maintaining the same cost of risk, $\alpha$. Alternatively the premium can be expressed as:

$$
Premium = E(P(H)) + \beta \left( VaR_{99}(P(H), C) - VaR_{99}(C) - E(P(H)) \right)
$$

(15)

---

25 Equations 13 and 14 (Henderson, 2002).
where \( \text{VaR}_{99}(P(H)) \) and \( \text{VaR}_{99}(C) \) are the VaR(99\%) for the contract payout and the current portfolio position \( C \) over the same time horizon respectively, and \( \text{VaR}_{99}(P(H), C) \) is the VaR(99\%) of the new portfolio with the contract included. As VaR(99\%) may express the 99\% confidence level of a non-normal distribution of payouts, it is difficult to express \( \text{VaR}_{99}(P(H), C) \) mathematically, estimates are usually taken from simulation results. A well-diversified book of contracts will reduce the relative \( \sigma \) and \( \text{VaR}_{99} \) parameters and hence the overall risk position of the portfolio of a provider.

A reasonable estimate for \( \alpha, \beta \) given prices in the weather market are \( \alpha = 15 \text{–} 30\% \) and \( \beta = 5 \text{–} 10\% \).

**Approaches to Pricing Weather Risk**

In order to price a weather contract, given the overview above, the parameters that quantify the expected \( (E(P)) \) and variable \( (\text{VaR}_{99}(P), \sigma(P)) \) payouts of the contract must be determined. This section briefly outlines three possible approaches with varying degrees of difficulty, and efforts that are commonly used by weather market participants. In general, providers may use several or all of these methods to crosscheck results and compute a contract price.

**Historical Burn Analysis**

Historical Burn Analysis (HBA) is the simplest method of weather contract pricing. It involves taking historical values of the index, which may be based on raw, cleaned, and possibly detrended weather data, and applying the contract in question to them. Assuming the data used to calculate the historical indexes are of good quality for the risk analysis, HBA can give a useful and intuitive first indication of the mean and range of possible payouts of a weather contract from which parameters such as \( E(P) \) and \( \sigma(P) \) can be calculated (Box 2.3.1).
Box 2.3.1 The Corn Grower’s Weather Hedge: Historical Burn Analysis

On receiving the grower’s price request, the broker contacts a company that he knows actively sells weather risk management products. The company already has historical weather data for Corntown Airport from the NMS going back for 30 years, although it is not a station on which they have written a weather contract on before. The data from the Corntown Airport are good, with no gaps or obvious discontinuities (Section 2.4). The weather structurer at the company computes the cumulative MGDDs from May 6–September 15—as specified by the broker—for each year in the historical data set. The structurer observes that there is a significant warming trend in the data—recent MGDD values have been higher than values in the past—and therefore detrends the 30 MGDD index values to make the older data consistent with today’s warmer temperatures (Box 2.4.1). The average value of the MGDD index using 30 years of detrended data is $E(I) = 2567$ with a standard deviation of $s(I) = 131$.

The structurer then applies the weather insurance contract to each of the 30 detrended MGDD index values to create an historical time series of contract payouts. He finds the average payout of the contract is $E(P) = \$21,303$ with a standard deviation $s(P) = \$54,666$. He takes $a = 25\%$ and therefore calculates a premium:

$$\text{Premium} = \$21,303 + 0.25 * \$54,666 = \$34,970$$

He decides to quote the broker a price of $\$34,970$ for the contract. (See Equations 16 and 17 in the Historical Distribution Analysis subsection for an alternative approach to pricing the corn grower’s contract.)

The method is simple and can be easily done in a spreadsheet. The disadvantage of HBA is that it gives a limited view of possible index outcomes: it may not capture the possible extremes and may be overly influenced by individual years in the historical dataset. Estimates of parameters such as $VaR_{99}(P)$ therefore become very difficult, although the largest historical value is always a good reality check when considering the possible variability of payouts. Additionally, the confidence level that can be attached to averages and standard deviation calculated from historical data is limited by the number of years of data available. The standard error in the average decreases as the number of years included in the average increases however, although weather stations often have 30–40 years of historical data, the representative nature of older data for today’s weather and climate should also be questioned (Section 2.4).

Historical Distribution Analysis

Much can be gained in understanding the statistical properties of the underlying index. If index values are calculated from historical meteorological data, then
looking at the distribution of these index values and ascertaining the probability
distribution function of the index can give a better estimate of the parameters
necessary to specify that function—and therefore, the expected and variable
payouts of the contract. Historical Distribution Analysis (HDA) involves
determining the probability distribution that best fits the historical (possibly
detrended) index data. The process is very much one of trial and error and
various standard tests and goodness-of-fit statistics, each with their strengths and
weaknesses, can be used to pick the best distribution from a potential selection,
such as Quantile-Quantile plots, calculation of moments and statistical tests such
as chi-squared, Kolmgorov-Smirnov, Anderson-Darling, root-mean squared error
and maximum likelihood methods.26 By determining the distribution and
therefore, the parameters necessary to define it, such as the mean and standard
deviation, the $E(P)$ and $\sigma(P)$ $VaR_{99}(P)$ can be calculated either by simulation
from the distribution (see below) or analytically, depending on the type of
distribution chosen and the underlying complexity of the contract to be priced.
For example in the case of a normally distributed index, closed-form expressions
can be found for $E(P)$, $\sigma(P)$ and $VaR_{99}(P)$ for simple structures such as call and
put options (McIntyre, 1999; Jewson, 2003a, 2003b). For a weather call option
with strike $K$, payout rate $X$ and limit $M$, the expected payout, i.e., the expected
loss of the contract $E(P)$ is given by:

$$E(P) = X(\mu - K)N\left(\frac{\mu - K}{\sigma}\right) + \sigma XN\left(\frac{\mu - M}{\sigma}\right) - X(\mu - M)N\left(\frac{\mu - M}{\sigma}\right) - \sigma XN\left(\frac{\mu - M}{\sigma}\right)$$

where $N$ is the cumulative normal distribution and $\mu$ and $s$ are the mean and
standard deviation defined by the historical mean and standard deviation of the
index data. The standard deviation of the contract $\sigma(P)$ is given by:

$$\sigma^2(P) = N\left(\frac{\mu - K}{\sigma}\right)X^2\left(2\sigma (\mu - K) + \sigma^2\left(\frac{K - \mu}{\sigma}\right)\right) - N\left(\frac{\mu - M}{\sigma}\right)X^2\left(2\sigma (\mu - K) + \sigma^2\left(\frac{M - \mu}{\sigma}\right)\right)$$

$$- N\left(\frac{K - \mu}{\sigma}\right)X^2\left((\mu - K)^2 + \sigma^2\right) + N\left(\frac{M - \mu}{\sigma}\right)X^2\left((\mu - K)^2 + \sigma^2\right) - M^2 + M^2 - E(P)^2$$

26 See Groebner and Shannon, 1993; Walpole and Myers, 1993, and Law and Kelton,
1991; for information about distribution fitting.

27 Equations 16 and 17 (Jewson, 2003b).
For example, if the GDD index considered in Box 2.3.1 is normally distributed with $\mu = 2567$ and $s = 131$, taking $a = 25\%$ the premium of the call option given the closed form solution above and using Equation 11 is

$$\text{Premium} = E(P) + 0.25 \times \sigma(P) = 15,350 + 0.25 \times 138,895 = 50,074^{28}$$

Closed form solutions can also be derived for call and put options using different underlying distributions, such as the kernel density (Jewson, 2004b) and Gamma distribution (Jewson, 2003a). Although the HDA method is more accurate than HBA for computing expected and variable payouts (Henderson, 2002; Jewson 2004a), and is often simpler due to the availability of analytical formulas, it assumes the underlying distribution is a correct representation of the data. Fitting and putting too much emphasis on a distribution that does not capture the higher moments of variability, for example, can lead to underestimate of variability and therefore premium.

Monte Carlo Simulation

Index Simulation. Once a distribution is identified to represent an index, constraints associated with the length of the historical data records are no longer valid and thousands of realizations of the index can be simulated, to estimate the contract statistics to any arbitrary degree of statistical accuracy, by using the distribution to make Monte-Carlo simulations. The Index Simulation (IS) method is a very common method for pricing weather contracts. Index values can be simulated statistically by drawing samples from the chosen distribution to generate large numbers (years) of artificial index values. The weather contract structure is applied to each of these values to create a range of payout outcomes that can be used to calculate the price of the contract. The IS method is particularly good for cumulative contracts, such as GDDs, or contracts that depend on several weather variables and where the correlation between these variables can be included in the simulation process. An additional advantage of the IS and HDA methods is that weather forecasts can be incorporated in the pricing process though the $E(P)$ and possibly $\sigma(P)$ terms by their dependence on $E(I)$ and $\sigma(I)$. The weather market actively follows forecast information and will

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28 The premium is significantly higher than the premium calculated in Box 2.3.1 using the simple HBA method. The closed-form solution implicitly takes into account the distribution of the underlying index and the possibility of the contract payout reaching the $400,000 limit. The HBA method can only take into account what has happen historically—the maximum payout of the contract using the detrended MGDD data is only $221,700$—therefore the latter method will under-estimate the variability of the index, assuming the normal distribution adequately represents the detrended MGDD data. This is one of the limitations of the HBA method.
modify its estimates of $E(I)$ and $\sigma(I)$ from historical information if necessary (Jewson, 2004d).

**Daily Simulation.** Daily Simulation (DS) methods are one of the most complex ways to price weather contracts. A statistical model is built for daily meteorological variables and is used to create thousands of years of artificial daily data. Index values can be calculated from these data, the weather contract can be applied to each simulated index value to create thousands of simulated payouts from which the expected and variable payout statistics can be calculated. Building daily simulation models that correctly capture the physical relationships between many meteorological variables at many sites poses significant scientific, mathematical and programming challenges (Brody et al., 2002) and should only need to be used for path-dependent contracts, e.g., knock-in or knock-out options or exotic or non-linear structures that depend on several variables or critical daily values. As these models involve manipulating daily data, they tend to be much slower than the other methods outlined above and, if built correctly, do not offer more accuracy that the IS method for simpler structures such as cumulative rainfall or GDD contracts (Jewson, 2004e).

**Market Pricing**
Finally, for completeness, if underlying indexes are the same or well-correlated to indexes that trade frequently in the secondary over-the-counter and exchange-based derivative market, the prevailing market price of traded contracts can influence the cost of the end user contract through the terms $E(P)$ or $\sigma(P)$. For example, if November–March GDDs correlate strongly with November–March HDDs measured at the same station, then a market provider could use the market-based HDD contract to hedge an end user GDD structure. If so, the provider will want to account for the market price of the HDD index in the pricing of the end user structure by adjusting the theoretical structure cost by any extra costs or benefits incurred by hedging (Henderson, 2002). This can be done by making the structure price independent of model based estimates of $\mu$ and $\sigma$ and allowing the market price of the underlying HDD swap ($\mu_{\text{market}}$) and the implied standard deviation from the prices of HDD option contracts ($s_{\text{market}}$) to be used instead for the parameters of the index $I$ when calculating $E(P)$ or $\sigma(P)$ via HDA or IS methods. In other words, replacing the model estimates of $\mu$ with $\mu_{\text{market}}$ and $s$ with $s_{\text{market}}$, where $?$ is the appropriate conversion factor from cumulative HDDs to cumulative GDDs, as measured at the station. Using the market as a benchmark also has an advantage as the traded weather market incorporates weather forecast into its prices. They therefore offer an indicator of how price estimates using historical data could be modified to reflect forecast information (Dischel, 2000).
End User Perspective

On receiving a price quotation for a weather risk management solution from a market provider, an agricultural grower or producer must decide if, given the price, such a solution is the best strategy for the business to manage its weather risk. Some of the advantages and disadvantages of using a market-based risk management tool are highlighted below for an end user to consider. There are many technical and practical measures a grower can take to make his crops more resilient to the vagaries of the weather with better irrigation systems, new strains of seed, or new farming technologies. Likewise, an agricultural product sales company, for example, may choose to diversify into other products in order to reduce their overall exposure to a particular weather event. Although such strategies will not be covered in this chapter, the relative cost and efficiency of choosing such approaches over an insurance or derivative weather-based solution must also be considered by the end user. Ideally the end user should focus on the most cost-efficient and effective means for dealing with weather risk by determining the optimal interaction of risk retention, risk transfer, and potential operational strategies, to create a comprehensive risk management solution.

Revenue Volatility and Value-at-Risk

From an agricultural end user’s perspective, the cost of $E(P)$ is essentially already embedded in the business—it is the average annual cost (loss) of weather inherent in running the business in question, be it farming a crop in a particular region or selling a specific agrochemical product. In other words, without protection the grower or producer can expect to lose this amount on average each year. Therefore the premium the grower or producer ultimately pays for weather risk management product is only the risk margin charged by the provider over the expected loss, illustrated by Figure 2.3.1.
By purchasing a tailored weather hedge, an end user receives a reduction of revenue volatility due to weather, but at a cost—the risk margin. However, reducing the volatility at an appropriate cost increases the return per unit risk, or the quality of earnings of the end user (Box 2.3.2).

Box 2.3.2 The Corn Grower’s Weather Hedge: Revenue Volatility

The grower receives the quote from the broker for $34,970 for the weather contract. He considers how this will impact the overall revenue performance of his business and asks the postgraduate student from the local agricultural university, who helped him construct the MGDD index, to assist him with the analysis. They study his past seven years of yield data (Table D) and the corresponding MGDDs values for each of those years (Figure B). They then apply the grower’s corn supply contract specifications and the weather hedge to each year to see what would have happened.
Table D: Corn Grower’s Expect Revenue With and Without Weather Contract

<table>
<thead>
<tr>
<th>Year</th>
<th>Yield (bu/hct)</th>
<th>MGDDs</th>
<th>Total Farm Production (bu)</th>
<th>Hedge Payout ($)</th>
<th>Net Revenue without Hedge ($)</th>
<th>Net Revenue with Hedge ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1998</td>
<td>263.4</td>
<td>2551</td>
<td>395,100</td>
<td>-34,970</td>
<td>882,850</td>
<td>847,880</td>
</tr>
<tr>
<td>1999</td>
<td>455.2</td>
<td>2651</td>
<td>682,800</td>
<td>-34,970</td>
<td>1,957,000</td>
<td>1,922,030</td>
</tr>
<tr>
<td>2000</td>
<td>145.5</td>
<td>2249</td>
<td>218,250</td>
<td>228,700</td>
<td>263,875</td>
<td>492,575</td>
</tr>
<tr>
<td>2001</td>
<td>510.5</td>
<td>2602</td>
<td>765,750</td>
<td>-34,970</td>
<td>2,164,375</td>
<td>2,129,405</td>
</tr>
<tr>
<td>2002</td>
<td>317.1</td>
<td>2399</td>
<td>475,650</td>
<td>17,200</td>
<td>1,164,775</td>
<td>1,181,975</td>
</tr>
<tr>
<td>2003</td>
<td>580.2</td>
<td>2649</td>
<td>870,300</td>
<td>-34,970</td>
<td>2,425,750</td>
<td>2,390,780</td>
</tr>
<tr>
<td>2004</td>
<td>481.6</td>
<td>2550</td>
<td>722,400</td>
<td>-34,970</td>
<td>2,056,000</td>
<td>2,021,030</td>
</tr>
</tbody>
</table>

Source: Author

Figure B: Historical Contract Payouts and Farm Yields

They decide to ignore 1998, where farm production was low but the hedge didn’t payout as they know there were other factors that contributed to the low yield on the grower’s farm that year, that were not temperature related. They
compute the average revenue expected from both strategies using data from 1999–2004: on average the grower expects to make $1,671,963 when not weather hedging and $1,689,633 when hedging, despite paying an annual premium of $34,970. They then study the deviations from the expected revenue level for both strategies (Table E).

<table>
<thead>
<tr>
<th>Year</th>
<th>Deviation from Expected without Hedge ($)</th>
<th>Deviation from Expected with Hedge ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1999</td>
<td>285,038</td>
<td>232,398</td>
</tr>
<tr>
<td>2000</td>
<td>-1,408,088</td>
<td>-1,197,058</td>
</tr>
<tr>
<td>2001</td>
<td>492,413</td>
<td>439,773</td>
</tr>
<tr>
<td>2002</td>
<td>-507,188</td>
<td>-507,658</td>
</tr>
<tr>
<td>2003</td>
<td>753,788</td>
<td>701,148</td>
</tr>
<tr>
<td>2004</td>
<td>384,038</td>
<td>331,398</td>
</tr>
<tr>
<td>Expected Revenue</td>
<td>1,671,963</td>
<td>1,689,633</td>
</tr>
<tr>
<td>Worst Case Revenue</td>
<td>263,875</td>
<td>492,575</td>
</tr>
<tr>
<td>Value-at-Risk</td>
<td>1,408,088</td>
<td>1,197,058</td>
</tr>
<tr>
<td>Expected Revenue/VaR</td>
<td>119%</td>
<td>141%</td>
</tr>
</tbody>
</table>

Source: Author

The grower is further encouraged when he sees the superior risk/return characteristics of the weather hedging strategy over the unhedged strategy. By entering into a weather contract for the past six years the grower would have reduced his Value-at-Risk, which he defines to be the difference between his expected revenue and his worst case year, by over $200,000, resulting in a 32% increase in the risk-reward ratio, i.e., his business would have generated a higher return for less risk under the weather hedging strategy. Although he knows the MGDD index does not correlate perfectly with his risk, he is satisfied with the performance of the index as a base for hedging his corn production in the past six years.

However, the postgraduate is not happy with this analysis and decides to investigate the impact of weather on the grower’s revenues further. He looks at all 30 years of historical cumulative MGDD values for May 6–September 15 at Corntown Airport weather station and notices that there is a warming trend in the data, making farming of corn more difficult in the past due to cool summer temperature conditions. The postgraduate decides to detrend the historical MGDD data by using a linear least squares regression to adjust the older data and bring them in line with current warmer levels. Although he does not have
actual production data for the grower’s farm for 30 years, he is satisfied with the cumulative MGDD-yield relationship he established earlier and uses the detrended MGDD data and Equation (b), to infer the yields the grower would have expected to produce on his farm in the past 30 years given the weather conditions in those years and his current farming techniques. The postgraduate then applies the grower’s corn supply contract specifications and the weather hedge to each detrended year to see what would have happened and compares the statistics for both strategies over the 30 scenarios. He calculates the average revenue, standard deviation of revenue and Value-at-Risk for both strategies and makes a table of the results to show the grower (Table F).

**Table F: Revenue Statistics Under Two Weather Risk Management Strategies**

<table>
<thead>
<tr>
<th>Statistics</th>
<th>Without Hedge ($)</th>
<th>With Hedge ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Expected Revenue</td>
<td>2,199,991</td>
<td>2,186,324</td>
</tr>
<tr>
<td>Worst Case</td>
<td>471,457</td>
<td>658,188</td>
</tr>
<tr>
<td>Value-at-Risk</td>
<td>1,728,534</td>
<td>1,528,136</td>
</tr>
<tr>
<td>Standard Deviation in Revenue</td>
<td>862,411</td>
<td>824,954</td>
</tr>
<tr>
<td>Expected Revenue/VaR</td>
<td>127%</td>
<td>143%</td>
</tr>
</tbody>
</table>

Source: Author

The grower sees that the expected revenue is less for the strategy where he hedges his business risk but the postgraduate explains that this is because he pays an annual premium of $34,970 to the insurance company each year for the weather hedge. The grower understands that the company must be charging more for the contract than the expected or fair value. However, the grower notices that his worst-case revenue year is almost $200,000 less under the weather hedging strategy and that the standard deviation in his revenues under that strategy is also reduced. He also notes the superior risk/return characteristics of his business portfolio—a 16% increase in the risk-reward ratio—under the weather hedging strategy as compared to the unhedged strategy (Figure C). Given these benefits the grower chooses to hedge his weather exposure with the weather derivative contract.
Obviously, the end user must also consider the efficacy of the weather hedge and decide whether the risk management contract offers adequate protection, particularly in a worst-case scenario, for his business. This can, to a certain extent, be quantified with historical information. The relevant question the end user should consider is whether the payout from a risk management contract based on a weather index effectively reduces the end user’s VaR, in other words, whether it reduces the potential economic loss of the end user business expected to be exceeded with a given probability within a given time horizon (Hull, 2000).

A grower or producer VaR is an effective measure of the overall vulnerability of the business to external shocks, be it price movements or fluctuations in supply and demand for their product. Weather protection that limits the potential downside revenue exposure of a business reduces the end user’s overall VaR. Minimizing VaR also has the associated cost—the risk margin—but it raises the question as to whether a business could withstand extreme systematic shocks and their ramifications without protection, limiting losses in catastrophic years.

The birth of the weather market has created an opportunity for a business to protect itself from the impact of non-catastrophic weather variations on its
income statement. Previously, traditional insurance products dealt primarily with losses that impacted the balance sheet, through the protection of physical assets from damage due to catastrophic weather. A business that protects its revenues and, as a result, has a less volatile revenue stream may benefit by receiving, for example, a lower cost of debt or increased access to credit and, for public companies, potentially improved stock valuations or stronger credit ratings (Malinow, 2002). Eliminating the uncertainty associated with non-catastrophic weather-related risk allows an operation to concentrate on its core business and focus on controllable targets and growth. These benefits associated with reducing revenue volatility and VaR, in relation to the effective cost of hedging, are considerations for the end user. Just like the weather market providers, an end user must also decide how it values risk in relation to return in the context of its business. It must define how much risk it is willing to hold and the budgeted cost at which it is willing to do so.

Basis Risk

A major concern with index-based weather risk management products is basis risk—the potential mismatch between contract payouts and the actual loss experienced. On considering weather-index insurance as a product for growers, Skees (2003) writes, “The effectiveness of index insurance as a risk management tool depends on how positively correlated farm-yield losses are with the underlying area-yield or weather index.” As with the regulatory concerns regarding the definition of insurance (Section 2.2), this statement relates to the question of whether insurance based on a weather index can substitute for a traditional crop insurance policy and indemnify the grower for his losses.

Basis risk is a concern for all weather variables but it is particularly important for rainfall, which exhibits a high degree of spatial and temporal variability. For example a weather station on which a weather contract is based may not experience the same rainfall patterns or totals during the calculation period as the locations an end user wishes to protect. For this reason, contracts based on hail are not products that are offered by weather market providers; hail is a highly localized meteorological phenomenon, although it can be indexed to an observing weather station, it may not be an effective risk management strategy for an end user. Although historically an index and losses may correlate strongly—showing than an index could be used as an underlying trigger to indemnify losses in an insurance contract (Section 2.2)—a good correlation is not a guarantee that the underlying contract payout will match the actual loss experienced. Basis risk therefore—which can often be minimized by effective or intuitive structuring and by using local stations (Hess and Syroka, 2005)—is always an issue when dealing with an index-based risk management solution. A potential basis risk outcome can be quantified by using historical data; however,
the key point to consider, as outlined above, is the efficacy of the hedge and the effective reduction the insured party’s overall operational VaR (Hess, 2003).

2.4 WEATHER DATA

Data Requirements

In order to implement a successful weather risk management program, the data used to construct the underlying weather indexes must adhere to strict quality requirements, including:

1. Reliable and trustworthy on-going daily collection and reporting procedures.
2. Daily quality control and cleaning.
3. An independent source of data for verification, e.g., GTS (Global Telecommunication System) weather stations.
4. A long, clean, and internally consistent historical record to allow for a proper actuarial analysis of the weather risks involved—at least 30 years of daily data are Ideally required.

The premium associated with weather risk management strategies is based on a sound actuarial analysis of the underlying risk. An appropriate premium given the probability and severity of specific weather events will be charged by the commercial risk-taker, hence the quality of historical and on-going weather data is paramount. Nearly all weather contracts are written on data collected from official National Meteorological Service (NMS) weather stations; ideally, these are automated stations that report daily to the World Meteorological Organization (WMO) GTS—in internationally recognized standard format—and then undergo standard WMO-established quality control procedures.

In addition to defining financial or insurance terms, all weather contracts must also include instructions on how to determine and adjust weather data, for example, in the event that weather data are not recorded or unavailable from the specified source during the calculation period. Financial contracts that trade in the secondary OTC weather market are usually subject to fallback methodology specifications,29 which identify a nearby “fallback” station to be used in the event of missing data from the primary reference weather station (RWS) and detail

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29 The Weather Risk Management Association (WRMA) provides a standard of operation and business practices in the form of Standardized Contracts/Confirms for weather derivatives and has developed Exposure Calculation and Fallback language to include in financial contracts (www.wrma.org).
exactly how fallback station data will be adjusted to infer and infill the missing data from the RWS. In cases where fallback stations are not available, other methodologies or provisions must be outlined in the contract terms.

End users without access to weather data satisfying the above criteria, or when the spatial coverage of a NMS weather station network may not be sufficient to fully represent an end user’s weather risk profile, may not able to benefit from weather risk management solutions.

**Data Sources**

Weather Stations

All contracts traded in the active secondary OTC derivative market are based on climatic weather data collected and published by the NMS of the country in question. Each weather station in the global NMS network has a unique WMO ID number, which is used for international identification, as well as a reference latitude, longitude and elevation. Stations are generally manned by NMS staff or volunteers who are trained by the NMS and whose equipment is certified and maintained by the NMS to WMO standards. NMS weather stations produce SYNOP reports, observations that are made at internationally agreed times by all meteorological observers. The regulations and practices are set by the WMO and adhered to by all NMSs. SYNOP reports—covering elements such as temperature, wind speed, rainfall, sunshine hours, humidity and atmospheric pressure—are generally made at 3 hourly intervals to monitor real-time conditions. NMSs then communicate these data from specific stations in their observing network to the GTS, for dissemination to the global weather observing and forecasting community. There are well over 8000 SYNOP stations reporting from sites around the world.

Historical climate and SYNOP data, and daily updates, can be purchased from each NMS, a list of which can be found on the WMO website ([www.meteo.org/wmo](http://www.meteo.org/wmo)). For example, in the United States the primary source of weather data is the National Climatic Data Center; in United Kingdom, weather data can be purchased from Weatherexchange ([www.weatherxchange.com](http://www.weatherxchange.com)), a joint venture with the U.K. Meteorological Office set up to support the European weather derivatives market. Weatherexchange provides quality-controlled historical climate and SYNOP datasets across the United Kingdom, and has distribution rights to data from several NMS across Europe including Germany, Italy, France, Netherlands, Austria, and Spain. Data can also be purchased from private data vendors, such as Risk Management Solutions/EarthSat ([www.rms.com](http://www.rms.com), [www.earthsat.com](http://www.earthsat.com)), and Applied Insurance Research (AIR; [www.air.com](http://www.air.com)). Private vendors often offer additional value-added services such as data cleaning and adjusting (see below).
Reanalysis and Satellite Products

Other weather datasets exist that could potentially be used for certain weather risk management products and contracts if weather station data are not available or not representative of the risk.

**NCEP-NCAR Reanalysis**

The NCEP-NCAR Reanalysis (Kalnay, et al., 1996) is a joint project between the U.S. National Center for Environmental Prediction (NCEP) and the National Center for Atmospheric Research (NCAR) to produce a 40-year record of global atmospheric analyses using a data assimilation system that is kept unchanged over the reanalysis period 1958–1997. An identical Climate Data Assimilation System using the same frozen analysis/forecast system has been used to continue to perform data assimilation to date, to ensure the continuation of the analysis. The reanalysis has a horizontal resolution of approximately 210km, with 28 vertical levels, and is a complete, consistent, and continuous gridded daily global dataset of all atmospheric variables (surface and air temperature, precipitation, wind speed, pressure, and humidity) from 1958. The data are available for free download from NCEP-NCAR, and although it has a low-resolution, it may be appropriate for large-area weather exposures that are not covered by a weather station network. The European Center for Medium Range Forecasting (ECMWF) has recently produced a higher resolution 40-year reanalysis, although it is not yet updated on an ongoing basis. The use of a constant and consistent data assimilation system implies the dataset would be an ideal base for pricing weather contracts; however, the low resolution makes the reanalysis inappropriate for small-scale, localized risk.

**Satellite Data**

Another alternative to weather-based indexes is to use satellite-based products to measure the pertinent weather parameters traditionally measured using ground observatories. Two strong candidates for agriculture include satellite-derived precipitation estimates and Normalized Difference Vegetative Index (NDVI) satellite readings. Current satellites offer high-resolution, albeit, expensive data; NDVI data, for instance, could be used to monitor crop “greenness” and therefore crop development and biomass. However, satellite-based products are not often used in the weather market due to their short and inconsistent historical data lengths; the first generation of earth observing satellites were launched in 1979, however calibrating older low-resolution data—through the generations of improved versions—to data from the current satellites is not straightforward.

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31 [http://www.ecmwf.int/research/era/](http://www.ecmwf.int/research/era/)
Nonetheless, both Spain and Alberta, Canada (see Appendix) have recently launched drought insurance programs for forage based on NDVI indexes (Saunderson, 2004). Risk management products against tropical cyclones—whose strength and location are measured and monitored using real-time satellite data—are also available in the weather insurance industry. The use of satellite data has also been recently discussed in the broader context of traditional agricultural insurance products (Aon, 2005).

Cleaning and Adjusting Data

Despite the NMS quality control procedures, data from some meteorological observing stations may still have missing and erroneous values. Stations may also have undergone instrumentation and/or station location changes, which can introduce systematic changes to an historical dataset. For instance, if a station was moved from a rural to an urban location it may be several degrees warmer in the new location and therefore, there will be an artificial jump in the station’s historical temperature record. Records of station or instrumentation changes are usually kept by the NMS for each weather station. Therefore, in order for data to be used for pricing weather risk management products, the raw data should be cleaned to correct for errors and missing values, and checked and perhaps adjusted for non-climatic inhomogeneities that could make the historical data unrepresentative of current values. The methods of cleaning and adjusting data often involve statistical procedures beyond the scope of this chapter. However, an awareness of the possible need for cleaning and adjusting of data is recommended and the approaches used are briefly outlined below. Cleaned and adjusted datasets can also be purchased from private vendors with proprietary data estimation models like Risk Management Solutions and Applied Insurance Research.

Cleaned Data

Creating cleaned datasets involves identifying and correcting erroneous values in historical weather datasets and infilling missing data with realistic values using appropriate statistical techniques where necessary. The first steps are the same as the NMS quality control procedures outlined above: all observations are screened for physical inconsistencies and erroneous values by comparing the data against itself and against alternative data sources (e.g., SYNOP, hourly data, climate reports, station climatology, and surrounding stations). If missing data cannot be recovered (e.g., from SYNOP data) or if data are found to be erroneous, the value is flagged and filled with an estimated value. A common method used to construct an estimate is to employ regression equations calculated from periods of overlapping data with the $n$ best-correlated neighbor stations. A weighted average of the estimates is used to calculate the missing data value at the target location.
station. The weights are set according to the correlation coefficient between the target station and the surrounding neighbors. This method can be used to both clean data and to extend data records. Sometimes SYNOP or hourly data can also be used to reconstruct missing or erroneous values.

**Adjusted Data**
Raw meteorological observations sometimes exhibit non-climatic jumps in the historical record due to movements in the measurement station, changes in the time of measurement, or changes in the equipment used to make the measurements. Often such discontinuities do not significantly affect the historical record but in some cases discontinuities can introduce artificial trends to the data or impact the variance or the average value of readings. Statistical procedures based on neighboring stations exist to identify significant discontinuities and account for these changes in cleaned meteorological data records (Jewson, et al., 2003; Boissonnade, et al., 2002; Henderson, et al., 2002). The challenge in these methods is to correct for the artificial discontinuity without altering the natural weather variability measured by the station.

**Detrending Data**
Meteorological data often contain trends that arise either due to natural climate variability, urban heating effects, or the impact of global warming. Irrespective of the cause, in some circumstances it may be useful to be able to remove such trends from the data. Such a procedure is known as detrending. The aim of detrending data for pricing weather risk is to obtain better estimates or forecasts of $E(I)$, $s(I)$ and $\text{VaR}_X(I)$ from the historical data for pricing weather contracts. Warming trends, for instance, can significantly impact the defining parameters of the underlying data. By not accounting for such trends, $E(I)$ may be significantly underestimated and $s(I)$ overestimated, which can lead to mispricing of contracts which settle on future data. Many different mathematical methods exist for detrending data, each based on a different set of assumptions.

As well as choosing the method there are two further points to consider when detrending data. Firstly, the underlying data must be prepared in a selected format: daily, monthly, or annual averages of a meteorological parameter can be detrended and then the new detrended historical values of an index can be computed; or the historical values of the index itself can be detrended. Secondly, the number of years of historical data or index values to be considered in the detrending process must be selected (Jewson, 2004c). Detrending data using the same method but a different number of years (for example, 30 years versus 40 years) can lead to significantly different results.
In essence, the aim of detrending is to statistically model the underlying process by decomposing a dataset into a deterministic trend and a stochastic noise term around the trend:

\[ D(t) = Y(t) + e(t), \quad e(t) \sim \mathcal{N}(0,s^2) \]  

(18)

where \( D(t) \) is the process represented by the dataset, \( Y(t) \) is the deterministic and therefore predictable component, \( e(t) \) is a normally distributed noise component with a mean of zero and standard deviation \( s \) and \( t \) is unit time. Determining how much of the historical data variability is attributed to \( Y(t) \) gives an indication of how well a particular model represents the underlying data. The method and approach chosen for detrending data can be highly subjective and the decision to detrend or not to detrend should be informed by some underlying criteria (Jewson and Penzer, 2004). For example, choosing a detrending method that is better at predicting future data values than another method, or than not doing anything at all, is preferable to a method that increases the uncertainty in predicting future values. The performance of different methods can be compared by considering characteristics of the distribution of errors in the predictions they make. By using the historical data to back-test various detrending methods and approaches, estimates of the uncertainty around the trend can be found which can inform the error associated with a particular method for estimating future values.

However, identifying trends and their cause is itself a subjective process and care should always be taken to check the sensitivity of detrending results to the underlying method used. Crosschecking several detrending methods and approaches and visually checking the data are always recommended. The weather market often uses the 10-year average of an index as a quick first-guess estimate for \( E(I) \). The simplest and most commonly used method for detrending data is polynomial detrending.

**Polynomial Detrending**

The aim of this method is to fit a polynomial function of time to a meteorological dataset. The polynomial function is defined as:

\[ Y(t) = m_0 + m_1 \ t + m_2 \ t^2 + m_3 \ t^3 + \ldots + m_p \ t^p \]  

(19)

where \( t \) is time. For example, if the underlying dataset is composed of 40 historical index values from 40 years of weather data, \( t \) will be in years. The constants \( m_i \) are chosen to minimize the root mean squared error \( R^2 \) of the vertical deviation of \( n \) meteorological data points from the trend line, where \( R^2 \) is given by.\(^{32}\)

\(^{32}\) Weisstein, 2002.
Risk Management in Agriculture for Natural Hazards
Chapter 2 Weather Risk Management for Agriculture
Joanna Syroka

\[ R^2 = \sum_{i=1}^{n} (D(t_i) - Y(t_i))^2 \]  \hspace{1cm} (20)

The simplest polynomial trend is when \( p = 1 \), a linear trend which fits a straight line through a set of data points:

\[ Y(t) = m_0 + m_1 t \]  \hspace{1cm} (21)

The intercept and slope \( m_0 \) and \( m_1 \) are estimated by the intercept and slope of the least-squares regression line.

The standard error (SE) in the estimated slope parameter \( m_1 \) and intercept parameter \( m_0 \) from the least-squares regression line are given by:

\[ SE_{m_1} = \frac{s}{\sqrt{\sum (t_i - \bar{t})^2}} \]  \hspace{1cm} (22)

\[ SE_{m_0} = s \sqrt{\frac{1}{n} + \frac{\bar{t}^2}{\sum (t_i - \bar{t})^2}} \]  \hspace{1cm} (23)

where \( i = 1, \ldots, n \), \( n \) is the number of years of historical data included in the regression and \( s \) is an estimate of \( s \), the standard deviation of the noise term in Equation 18, given by:

\[ s = \sqrt{\frac{\sum (D(t_i) - Y(t_i))^2}{n-2}} \]  \hspace{1cm} (24)

The standard error of the linear model predicting an individual value \( D(t_X) \) at a time \( t_X \), for example in year \( n+1 \), is given by:

\[ SE_y = s \sqrt{1 + \frac{1}{n} + \frac{(t_X - \bar{t})^2}{\sum (t_i - \bar{t})^2}} \]  \hspace{1cm} (25)

The t-statistic of the linear slope term \( m_1 \) can be used to determine whether or not the linear trend is statistically significant and is defined as:

\[ t_{statistic_{m_1}} = \frac{m_1}{SE_{m_1}} \]  \hspace{1cm} (26)

---

33 Equations 22, 23, and 25 (Von Storch and Zwiers, 1999).
The t-statistic (Von Storch and Zwiers, 1999) for that coefficient is the ratio of the coefficient to its standard error. The t-statistic can be tested against a Student’s t-distribution with \( n-2 \) degrees of freedom to determine how probable it is that the true value of the coefficient is zero and thus how significant the fit is. The \( r^2 \) value is the fraction of the total squared error that is explained by the linear model and is an indicator of the predicative power of the model. The \( r^2 \) value is calculated as follows:

\[
r^2 = \left( \frac{n \sum Y(t_i) t_i - \sum Y(t_i) \sum t_i}{\sqrt{n \sum Y(t_i)^2 - (\sum Y(t_i))^2} \left[ n \sum t_i^2 - (\sum t_i)^2 \right]} \right)^2
\]

(27)

and is the square of the correlation coefficient, \( r \), between the linear model predictions and actual data observations. A simple method to test the null hypothesis that the correlation coefficient is zero can be obtained by using a Student’s t-test with \( n-2 \) degrees of freedom on the t-statistic:

\[
t_{\text{statistic}, r} = r \cdot \frac{\sqrt{n-2}}{\sqrt{1-r^2}}
\]

(28)

where \( n \) is the number of years of historical data considered. By comparing values for \( SE_r \), \( r^2 \) and the statistical significance of \( m \), for a given confidence level, decisions can be made as to whether a linear trend actually describes the data well and the optimal number of years of data \( n \) to be considered in the calculation. The detrended historical dataset, \( D(t) \), will then used to calculate new values of the index \( I \) and therefore to calculate revised estimates of \( E(I), s(I) \) and \( VaR_x(I) \) for pricing. Values of \( D(t) \) are given by:

\[
D(t_i) = D(t_i) - Y(t_i) + Y(t_n), \quad i = 1 \ldots n
\]

(29)

for all \( n \) years that are included in the detrending calculation, where \( n \) is the most recent year (Box 2.4.1).
Box 2.4.1 The Corn Grower’s Weather Hedge: Detrending the Data

On analyzing the historical MGDD record from Corntown Airport weather station the structurer at the company responsible for pricing the request from the broker realizes that there is a strong warming trend in the data (Figure D).

**Figure D: MGDDs at Corntown Airport Weather Station**

Source: Author

Temperatures were cooler and hence cumulative MGDD values were lower in the 1970s compared to the late 1990s and early 2000s. Therefore in order to get a better estimate of the weather insurance contract payout statistics, the structurer decides to detrend the raw MGDD record, $D(t_i)$. He chooses a first-order polynomial function, $Y(t)$, to model the trend in the MGDDs:

$$Y(t) = m_0 + m_1 t \quad (e)$$

He fits a least-squares regression line to the data that minimize the root mean squared error of the data points around the trend line. The intercept and slope, $m_0$ and $m_1$, are estimated by the intercept and slope of the least-squares regression line and are found to be $m_0 = -12346$ $m_1 = 7.4413$. The $r^2$ of the fit is 20.1%, which implies that the linear trend explains 20% of the overall interannual variability of the MGDD index. He computes standard error in the $m_1$ estimate and therefore, the t-statistics for the coefficient $m_1$:

$$t_{statistic} m_1 = \frac{7.4413}{2.808} = 2.65$$

The t-statistic is tested against a Student’s t-distribution with n-1 degree of
freedom to determine how probable it is that the true value of the coefficient is greater than zero. The t-statistic is significant at the 99.3% confidence level, i.e., the probability that the true value of the coefficient is zero is 0.7%. Therefore the structurer is happy to use the linear model to detrend the historical MGDD data.

The detrended dataset \( D(t_i) \) is constructed by adjusting each historical value by the amount predicted by the linear trend model, i.e.:

\[
D(t_i) = D(t_i) - Y(t_i) + Y(t_{2004}), \quad i = 1975 \ldots 2004 \quad (f)
\]

for all 30 years that are included in calculation. The average value of the MGDD index, using 30 years of raw historical data, is \( E(I) = 2459 \) with a standard deviation of \( s(I) = 146 \). The average value of the MGDD index, using 30 years of detrended data, is \( E(I) = 2567 \) with a standard deviation of \( s(I) = 131 \). The structurer then applies the weather insurance contract to each of the 30 detrended MGDD index values to create an historical time series of contract payouts. He finds the average payout of the contract is \( E(P) = $21,303 \) with a standard deviation \( s(P) = $54,666 \). He takes \( a = 25\% \) and therefore calculates a premium to be:

\[
\text{Premium} = $21,303 + 0.25 \times $54,666 = $34,970
\]

He compares this to what the premium would have been if he had not adjusted for the warming trend in the data. He finds the average payout of the contract, based on raw MGDD values, is \( E(P) = $69,068 \) with a standard deviation \( s(P) = $114,809 \) which would imply a premium of:

\[
\text{Premium} = $69,068 + 0.25 \times $114,809 = $97,770
\]

The warming trend at Corntown Airport is decreasing the risk of cool summers in the area and hence is reducing the premium of a weather hedge designed to protect against this risk for the grower.

Often increasing the parameter \( p \) creates a better data fit, as higher order polynomials capture higher frequency variations in the data. However over-fitting data is a potential danger of all trend-fitting techniques. By arbitrarily increasing \( p \), high-frequency fluctuations, essentially the noise in the underlying historical data record, can be reproduced by the model, which will have little predictive power for future data. The underlying physical nature of a higher-order polynomial should also be questioned and therefore it is often best to fit a simple linear trend to the data instead of assuming higher-order processes. Examples of other detrending techniques include the moving average (Henderson et al., 2002), LOESS (Cleveland, 1979), and low-pass filter (Von Storch and Zwiers, 1999) methods.
2.5 FURTHER READING

The emerging weather risk market clearly offers new risk management tools and opportunities for agriculture. The aim of this chapter is to briefly illustrate how an end user in the agricultural industry could use a market-based solution to mitigate the financial impact of weather on its business operations. The key steps for designing a weather risk management program outlined above involve identifying and quantifying the weather risk, structuring a weather risk management solution that best protects the end user, and executing a contract in optimal form given the local regulatory framework. These processes necessitate obtaining, analyzing and possibly cleaning, adjusting and/or detrending historical weather data to understand the nature of the underlying weather risk and its financial impact on a business in order to structure an appropriate risk-transfer or risk-smoothing solution.


Information on weather risk management in the developing world can be found at [http://www.itf-commrisk.org](http://www.itf-commrisk.org).
CHAPTER 3

CASE STUDIES FOR AGRICULTURAL WEATHER RISK MANAGEMENT

HECTOR IBARRA AND JOANNA SYROKA

Chapter 2 introduced the concept of weather risk and weather risk management in the context of agriculture and reviewed the existing literature on the subject, with particular emphasis on how weather risk management products and solutions can be designed for the agricultural sector. The aim of this chapter is to present four case studies of where weather risk management insurance and derivative products have been successfully applied to end users in agriculture. Index-based weather insurance is a relatively new product and the use of weather risk management products in the agricultural sector is still in its infancy, with very few publicized transactions in the U.S. and Europe. However there have been a number of agricultural transactions outside of these regions that have been made public, most notably in Canada, Mexico, and India.

The objective of this chapter is to expand on issues and ideas raised in Chapter 2 with real-world examples of situations where weather risk management solutions have actually been applied to agriculture. Part 1 of this chapter will focus on the Agriculture Financial Services Corporation (AFSC), the Canadian financial crown corporation of Alberta that has been offering Growing Degree Day products to maize farmers in the province since 2000. Part 2 presents the case of Agroasemex, the Mexican agricultural reinsurance company that has been using weather derivatives to manage agricultural portfolio risk since 2001. Part 3 will present two case studies from the recent work of the World Bank’s Commodity Risk Management Group on weather insurance in the developing world. As mentioned in Chapter 2, weather insurance is one potential alternative to traditional crop insurance programs for smallholder farmers in the emerging markets. Part 3 will focus on the developing agricultural weather risk markets in India and Ukraine. The Appendix will briefly outline the principles of the AFSC program to insure grassland for pasture on an index basis using satellite imagery and the grassland insurance program in Spain.
3.1 INDEXED-BASED INSURANCE FOR FARMERS IN ALBERTA, CANADA: THE (AFSC) CASE STUDY

Introduction to AFSC

All levels of government in Canada (federal, provincial and local) use crown, or government owned corporations, to pursue economic and social objectives such as controlling the distribution, use and price of certain goods and services. Crown corporations are also used as financing vehicles for development and capital projects because of their independent access to financial markets. Crown corporations that provide goods and services to the public can either compete with private enterprises (for example, in the transportation and housing sector) or operate as a monopoly (for example, in electricity and natural gas supply). The government has conceptualized and implemented this type of institutional framework to ensure the provision of goods and services that are too expensive or risky for the private sector to undertake alone. The corporations include agricultural and industrial development corporations, financing corporations and many transportation systems and facilities.

Agriculture Financial Services Corporation (AFSC) is a provincial crown corporation of the government of Alberta, with a private sector Board of Directors that provides farmers, agribusinesses, and other small businesses loans, crop insurance, and farm income disaster assistance. AFSC is closely linked with, and partly funded by, government but also works closely with many private sector companies through key business alliances. AFSC reports to Alberta's Minister of Agriculture, Food, and Rural Development (AFRD). The Board comprises agriculture business owners, entrepreneurs, and professionals who have extensive experience in the agriculture and business sectors. The Board has 11 members, including the Deputy Minister of the Ministry of Agriculture, Food and Rural Development, and the AFSC President and Managing Director.

AFSC has provided Alberta farmers with hail insurance for over 60 years, and has grown into a diverse corporation with several core businesses: crop insurance, farm loans, commercial loans and farm income disaster assistance. The menu of available traditional crop-yield insurance products is fairly extensive; the AFSC also provides a variable price option for customers, with variations from market price that range from 10 percent to 50 percent for some crops.

Corn Heat Unit Insurance

The Corn Heat Unit insurance program is a weather index-based insurance product offered by the AFSC to protect farmers against the financial impact of
negative variations in yield for irrigated grain and silage corn. The contract is designed to insure against lack of Corn Heat Units (CHU) over the growing season. It has been offered on a pilot basis since 2000 and a thorough evaluation of the results is scheduled to assess the impact of the program.

The index has been designed to indemnify the policyholder against annual CHU being less than a Threshold Corn Heat Unit (TCHU) level at the specified weather station. The CHU is a Growing Degree Day type index, as discussed briefly in Chapter 2, which represents the energy available for the development of corn. Given the small window for agricultural production in Canada, the availability of enough solar energy is vital for the development of this crop. The CHU is estimated from daily maximum and minimum temperature, beginning on May 15 of each year. The Celsius-based formula used to calculate daily CHUs is defined as follows (Brown and Bootsma, 1993):

\[
CHU = 0.5 Y_{\text{min}} + 0.5 Y_{\text{max}} \quad (1a)
\]

\[
Y_{\text{min}} = \frac{9}{5} (T_{\text{min}} - 4.4) \quad (1b)
\]

\[
Y_{\text{max}} = 3.33 (T_{\text{max}} - 10.0) - 0.084 (T_{\text{max}} - 10)^2 \quad (1c)
\]

where \( T_{\text{min}} \) and \( T_{\text{max}} \) are the daily minimum and maximum temperatures respectively. The daily CHU values are calculated from these temperatures. The daytime relationship involving \( T_{\text{max}} \), uses 10°C as the base temperature (if \( T_{\text{max}} \) is less than 10 its value is set at 10) and 30°C as the optimum temperature, as warm-season crops do not develop when daytime temperatures fall below 10°C and develop at a maximum rate at around 30°C. The nighttime relationship involving \( T_{\text{min}} \), uses 4.4°C as the base temperature below which daily crop development stops (if \( T_{\text{min}} \) is less than 4.4 its value is set at 4.4). The CHU value is calculated by taking into account the functional relationship between daytime and nighttime temperatures and the daily rate of crop development, as shown in Figure 3.1.1.
The nighttime relationship is a straight line (Equation 1b), while the daytime relationship is given by a curve that records greater CHUs at 30°C than at higher or lower temperatures (Equation 1c). The accumulation of CHU stops on the first day on which a minimum temperature of minus 2 degrees Celsius or less is recorded, after 700 CHU have been accumulated. This means the accumulation continues until the first killing frost hits the crop. An early frost setback is also built into the AFSC calculation.

The weather data for settlement of the contracts are provided by the federal and provincial weather stations and compiled by the Irrigation Branch of the Alberta Government. The end user of the contract can select a weather station for the settlement of its contract from the federal and provincial stations available. Producers choose a weather station that best represents the temperatures on their farm. Weather stations used for CHU insurance are divided into three groupings based on similar historical accumulations of heat (see Table 3.1.1). Weather stations within each grouping have similar threshold options, premium rates, and loss payment functions.

Information is not available for public disclosure.
Table 3.1.1 Weather Station Groupings for the CHU Program

<table>
<thead>
<tr>
<th>Group</th>
<th>Weather Station</th>
<th>Weather Station Affiliation</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Bow Island</td>
<td>AAFRD Irrigation Branch</td>
</tr>
<tr>
<td></td>
<td>Seven Persons</td>
<td>AAFRD Irrigation Branch</td>
</tr>
<tr>
<td>B</td>
<td>Brooks</td>
<td>AAFRD CDC South</td>
</tr>
<tr>
<td></td>
<td>Echant</td>
<td>AAFRD Irrigation Branch</td>
</tr>
<tr>
<td></td>
<td>Vauxhall</td>
<td>AAFC Lethbridge Research Substation</td>
</tr>
<tr>
<td>C</td>
<td>Fincastle</td>
<td>AAFRD Irrigation Branch</td>
</tr>
<tr>
<td></td>
<td>Iron Springs</td>
<td>AAFRD Irrigation Branch</td>
</tr>
<tr>
<td></td>
<td>Lethbridge</td>
<td>AAFRD Irrigation Branch</td>
</tr>
<tr>
<td></td>
<td>Picture Butte</td>
<td>Environment Canada</td>
</tr>
</tbody>
</table>

Source: Ibarra, 2003

Coverage is available in $25 Canadian Dollar (CD) increments per acre with the limits outlined in Table 3.1.2.

Table 3.1.2 Coverage Limits for CHU Insurance

<table>
<thead>
<tr>
<th>Crop</th>
<th>Minimum Per Acre (CD$)</th>
<th>Maximum Per Acre (CD$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grain Corn</td>
<td>100</td>
<td>225</td>
</tr>
<tr>
<td>Silage Corn</td>
<td>100</td>
<td>300</td>
</tr>
</tbody>
</table>

Source: Ibarra, 2003

Farmers can buy the insurance product until April 30 of the year to be covered for that year’s growing season. When buying the insurance policy the farmer must elect the dollar coverage per acre, the selected weather station for settlement purposes, and indicate if they prefer a hail endorsement to the contract or the variable price benefit.

To be eligible for insurance, the farmer must insure all the seeded acres of eligible corn and must insure a minimum of five acres for each crop: grain and silage crops are considered separate for the purposes of referring to a specific insurance contract. Only producers growing grain or silage corn on irrigated land in AFSC designated areas are eligible to buy CHU insurance contracts. The
farmer must complete seeding by May 31, and must declare the final number of seeded acres and a legal description for the location of each crop no later than June 1. The insurable crop shall be grown within the risk area boundaries as determined solely by AFSC. Furthermore, the AFSC is responsible for controlling the use of these contracts to ensure that they are only used for insurance purposes. For control and product evaluation purposes, the farmer is required to present a harvested production report, stating the production of all insured crops, no later than fifteen days after completion of the harvest, but no later than December 15 of each calendar year.

The premium payable under the CHU contract is due upon receipt of the contract by the farmer. A table of premium rates and payment rates for grain and silage corn is made available to the farmers and indicates the base premium rate and the percentage payment triggered depending on the heat unit level recorded at the station chosen. The formula to calculate the indemnity for each insurable crop is given by the following equation:

\[
\text{Indemnity} = \text{Dollar Coverage per Acre} \times \text{Payment Rate} \times \text{Number of Insured Acres}
\]

For example, if a farmer chose to insure 100 acres at $225 per acre, and the accumulated CHU payment rate was 30 percent of the expected level, a claim of $6,750 dollars would result. The maximum indemnity payable shall be 100 percent of the Dollar Coverage per Acre (including the additional dollar coverage if the Variable Price Benefit is activated) multiplied by the number of insured acres.

Producers can choose between two CHU insurance deductibles or threshold options (High and Low “Trigger”)—see Table 3.1.3. Payments begin sooner under the high threshold option so the cost of this choice is more than for the low threshold option.

---

35 The actual premium and payment rates are not available for public disclosure and are omitted from this paper. Since the lack of heat units affects the end use of grain corn more than it does silage corn, the table of premium and payment rates is different for the two types of crops.
Table 3.1.3 Options for CHU Contracts

<table>
<thead>
<tr>
<th>Station Grouping</th>
<th>Long-Term Normal</th>
<th>Low Option*</th>
<th>High Option**</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>2,505</td>
<td>2,260</td>
<td>2,380</td>
</tr>
<tr>
<td>B</td>
<td>2,387</td>
<td>2,160</td>
<td>2,280</td>
</tr>
<tr>
<td>C</td>
<td>2,332</td>
<td>2,100</td>
<td>2,220</td>
</tr>
</tbody>
</table>

*Approximately 90 percent of long-term CHU normal

**Approximately 95 percent of long-term CHU normal

Source: Ibarra, 2003

Claims are based on accumulated CHUs calculated using the temperature data recorded at the selected weather station. CHUs accumulated before the killing frost are compared to the threshold chosen by the producer at the weather station. If the annual CHUs are less than the chosen threshold, the insurance program starts to make payments according to a predetermined table. The further the annual CHUs are below the threshold, the greater the insurance payment.

The main peril is lack of heat during the growing season. However this insurance plan also includes a provision for late spring frost. A late spring frost can set back corn plant growth and impact production. To trigger this provision a temperature of less than zero degrees Celsius has to be recorded 1) on or after June 1 and; 2) prior to 700 CHUs being recorded at the weather station. If both these conditions are met, 50 CHUs will be deducted from the accumulated total CHUs at the end of the year for the first day. An additional 15 CHUs will be deducted for every other day between June 1 and the day the frost in question occurred.

As a reference of the indemnity rates, Table 3.1.4 summarizes the payments for stations in grouping A.
## Table 3.1.4 Payment Rates for Contract Based in Station Grouping A

### Station Grouping A: Bow Island, Seven Persons

<table>
<thead>
<tr>
<th>CHU Threshold Option</th>
<th>Silage Corn</th>
<th>Grain Corn</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low 2260 CHUs</td>
<td>Low 2260 CHUs</td>
</tr>
<tr>
<td>Threshold Level</td>
<td></td>
<td></td>
</tr>
<tr>
<td>≥ 2380</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2360 = CHU &lt; 2380</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>2340 = CHU &lt; 2360</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>2320 = CHU &lt; 2340</td>
<td>0</td>
<td>9</td>
</tr>
<tr>
<td>2300 = CHU &lt; 2320</td>
<td>0</td>
<td>12</td>
</tr>
<tr>
<td>2280 = CHU &lt; 2300</td>
<td>0</td>
<td>15</td>
</tr>
<tr>
<td>2260 = CHU &lt; 2280</td>
<td>0</td>
<td>18</td>
</tr>
<tr>
<td>2240 = CHU &lt; 2260</td>
<td>3</td>
<td>21</td>
</tr>
<tr>
<td>2220 = CHU &lt; 2240</td>
<td>6</td>
<td>24</td>
</tr>
<tr>
<td>2200 = CHU &lt; 2220</td>
<td>9</td>
<td>27</td>
</tr>
<tr>
<td>2180 = CHU &lt; 2200</td>
<td>12</td>
<td>30</td>
</tr>
<tr>
<td>2160 = CHU &lt; 2180</td>
<td>15</td>
<td>33</td>
</tr>
<tr>
<td>2140 = CHU &lt; 2160</td>
<td>18</td>
<td>36</td>
</tr>
<tr>
<td>2120 = CHU &lt; 2140</td>
<td>21</td>
<td>39</td>
</tr>
<tr>
<td>2100 = CHU &lt; 2120</td>
<td>24</td>
<td>42</td>
</tr>
<tr>
<td>2080 = CHU &lt; 2100</td>
<td>27</td>
<td>45</td>
</tr>
<tr>
<td>2060 = CHU &lt; 2080</td>
<td>30</td>
<td>48</td>
</tr>
<tr>
<td>2040 = CHU &lt; 2060</td>
<td>33</td>
<td>52</td>
</tr>
<tr>
<td>2020 = CHU &lt; 2040</td>
<td>36</td>
<td>56</td>
</tr>
<tr>
<td>2000 = CHU &lt; 2020</td>
<td>39</td>
<td>60</td>
</tr>
<tr>
<td>1980 = CHU &lt; 2000</td>
<td>42</td>
<td>64</td>
</tr>
<tr>
<td>1960 = CHU &lt; 1980</td>
<td>45</td>
<td>68</td>
</tr>
<tr>
<td>1940 = CHU &lt; 1960</td>
<td>48</td>
<td>72</td>
</tr>
<tr>
<td>1920 = CHU &lt; 1940</td>
<td>52</td>
<td>76</td>
</tr>
<tr>
<td>1900 = CHU &lt; 1920</td>
<td>56</td>
<td>80</td>
</tr>
<tr>
<td>1880 = CHU &lt; 1900</td>
<td>60</td>
<td>80</td>
</tr>
<tr>
<td>1860 = CHU &lt; 1880</td>
<td>64</td>
<td>80</td>
</tr>
<tr>
<td>1840 = CHU &lt; 1860</td>
<td>68</td>
<td>80</td>
</tr>
<tr>
<td>1820 = CHU &lt; 1840</td>
<td>72</td>
<td>80</td>
</tr>
<tr>
<td>1800 = CHU &lt; 1820</td>
<td>76</td>
<td>80</td>
</tr>
<tr>
<td>CHU &lt; 1800</td>
<td>80**</td>
<td>80**</td>
</tr>
</tbody>
</table>

*The CHUs in the table are after adjustments for late spring frost (if required);
**For CHUs in this range or below, producers may be eligible for a larger payment if indicated by inspection.

Source: Ibarra, 2003
It is important to point out that the CHU contract with the hail endorsement is designed to protect corn against two major perils, lack of heat and hail. The grain and silage corn farmers are also eligible for traditional crop insurance contracts based on individual records; nevertheless the premiums are lower for the CHU contract because of the reduced transaction costs for AFSC. It should also be noted that the premiums paid by the farmers for the CHU contract are subsidized by approximately 55 percent, so that the farmer pays only 45 percent of the cost of the contract. The subsidy is 40 percent for the hail endorsement. The federal and provincial governments co-share the financial burden of the program and they subsidize all the administration costs for AFSC.

### 3.2 ALTERNATIVE INSURANCE THROUGH WEATHER INDEXES IN MEXICO: THE AGROASEMEX CASE STUDY

#### Introduction to Agroasemex

Agroasemex is a Mexican government-owned reinsurance company operating exclusively in agricultural insurance. The company was created in 1990 as a direct insurer, with the responsibility of promoting the insurance participation of private institutions such as private companies and cooperatives (*fondos de aseguramiento*). In 2001 the Mexican Government decided to transform Agroasemex completely into a reinsurance company, in order to continue promoting the development of the agricultural insurance market through private institutions.

Agroasemex operates in the Mexican market as a regulated insurance institution; therefore it complies with all the regulatory requirements of the insurance sector and follows sound risk management practices, including the management of its portfolio risk. From creation, as a direct insurer, Agroasemex relied heavily on the traditional reinsurance market to protect its agricultural portfolio from inordinate losses. Reinsurance supply in Mexico is affected by several factors, such as the macroeconomic situation prevailing in the countries where reinsurance capacity is offered (including relevant regulatory and fiscal issues), as well as microeconomic factors within Mexico related to the suppliers of insurance, the technical infrastructure, and the historical stability of the insurance programs. However, the cession of risks through reinsurance contracts between reinsurance companies is classified as retrocession; hence risk transfer arrangements for the Agroasemex portfolio, following the transformation in 2001, were no longer considered as traditional reinsurance agreements. This issue brought with it difficulties for Agroasemex when looking for open markets.
to place their reinsurance program, as retrocession markets have reduced dramatically in the last decade.

As a consequence of the company transformation in 2001 and the inherited industry-wide restrictions associated with this transformation, the price of an equivalent stop loss reinsurance program for Agroasemex increased by approximately 70 percent—the financial cost of transferring portfolio risk became very expensive. This posed a significant threat to the financial equilibrium of Agroasemex and motivated the company to look for alternative markets for the transfer of its portfolio risk. The search for new alternatives led Agroasemex to analyze the comparative efficiency of the weather derivatives market.

The purpose of this case study is to present the background, design, and guiding principles behind the weather derivative structure that was ultimately used as a hedge for the Agroasemex agricultural portfolio. It is worthy to note that the institution’s weather derivative transaction in 2001 was the first of its kind in the developing world. The simplified case study will outline the approach and thought process behind the structuring of the Agroasemex weather risk-transfer program.

Designing a Weather Risk Transfer Solution for the Agroasemex Agricultural Portfolio

Selection of Risks
There are two agricultural production cycles in Mexico: spring-summer and autumn-winter. The former is primarily a rainfed production cycle, while the latter is generally irrigated. The Agroasemex weather risk transfer program is specifically designed for the autumn-winter cycle, 2001–2002. The main weather risks for agriculture during this cycle are potentially large negative deviations in temperature and excess rainfall. For some areas, where irrigation is not used, lack of rainfall is also an important risk. The percentages of crops distributed in 5 states are included in the weather risk transfer program.

The crops and risks that were included in the weather risk transfer program are listed in Table 3.2.1.

The crops and weather risks were selected by the following criteria:

1. The relative historical importance of the crop, in terms of acreage and insurance penetration, for the autumn-winter production cycle;
2. Crops with a significant portion of the investment cost insurance scheme were selected. Historically, over 90 percent of agricultural insurance in Mexico has been related to the investment cost for producers (seed,
fertilizers, etc.). Historical information on investment cost insurance schemes was available for 10 years to inform this selection process;

3. Strong and consistent results in the numerical analysis between negative deviations in the agricultural portfolio and the protection provided by the proposed weather derivative structure;

4. Availability of consistent and high-quality historical weather data.

Based on the original risk profile and business plan report for the autumn-winter cycle of 2001–2002, the total liability for the crops and risks selected for the weather risk transfer program were as follows (Table 3.2.2):

**Table 3.2.1 Crops and Risks Selected for the Design of the Weather Risk Transfer Program**

<table>
<thead>
<tr>
<th>State</th>
<th>Crop</th>
<th>Risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nayarit</td>
<td>Tobacco</td>
<td>Low Temperature</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Excess Humidity</td>
</tr>
<tr>
<td>Sinaloa</td>
<td>Beans</td>
<td>Low Temperature and Frost</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Excess Humidity</td>
</tr>
<tr>
<td></td>
<td>Chickpeas</td>
<td>Excess Humidity</td>
</tr>
<tr>
<td>Tamaulipas</td>
<td>Sorghum</td>
<td>Drought</td>
</tr>
<tr>
<td>Sinaloa–Sonora</td>
<td>Maize</td>
<td>Low Temperature and Frost</td>
</tr>
</tbody>
</table>

Source: Ibarra, 2003

**Table 3.2.2 Total Liability Factored into the Agroasemex Business Plan for Autumn–Winter 2001/2002 that Served for the Design of the Weather Derivative Contract**

<table>
<thead>
<tr>
<th>State</th>
<th>Crop</th>
<th>Total Liability (US$ Million)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nayarit</td>
<td>Tobacco</td>
<td>22.4</td>
</tr>
<tr>
<td>Sinaloa</td>
<td>Beans</td>
<td>0.19</td>
</tr>
<tr>
<td>Sinaloa</td>
<td>Chickpeas</td>
<td>0.46</td>
</tr>
<tr>
<td>Tamaulipas</td>
<td>Sorghum</td>
<td>1.82</td>
</tr>
<tr>
<td>Sinaloa—Sonora</td>
<td>Maize</td>
<td>2.02</td>
</tr>
</tbody>
</table>

Source: Ibarra, 2003
The total expected traditional reinsurance premium for the entire Agroasemex portfolio was estimated to be US$1,917,422. The subset in Table 3.2.1 represents approximately 10 percent of the risk in the entire portfolio for 2001/2002.

Transforming Weather Indexes into the Expected Indemnities of the Agroasemex Agricultural Portfolio

The main difference between traditional reinsurance and a weather derivative transaction to transfer portfolio risk, is that a weather derivative transaction allows for the transfer of risk related to the potential deviation (as measured by a probability distribution) in the behavior of certain weather variable, while a reinsurance contract covers deviations in the actual losses of a given portfolio that result from that deviation in the weather variable if it occurs. Therefore, in order to use a weather derivative contract as an alternative portfolio hedge to a traditional reinsurance contract, it is important to determine that the underlying variables considered in a weather derivative design are also an important risk factor for the portfolio if covered by reinsurance contracts.

The following method was used to establish the relationship between weather indexes and the expected indemnities of the Agroasemex agricultural portfolio. Firstly, a severity index was created for each crop in the portfolio in order to understand, at the portfolio level, how important this crop risk is when a given weather phenomenon, as captured by an index, occurs. A very simple severity index (SI) is defined as follows:\^36

\[ SI = \left( \frac{Indemnities}{TotalLiability} \right)_{it} \quad (1) \]

\[ t = 1991/92, 1992/93 \ldots 1999/2000 ; \text{ Autumn-Winter Cycles} \]

\[ i = \text{Crop} \]

Once the severity index was calculated for each crop, the next step was to find a mathematical relationship between the SI and the weather index most relevant to the crop. Agroasemex performed linear least square regressions for each crop severity index to establish the SI-weather index relationship:

\[ y_t = m_0 + m_1 x_t + \epsilon_i \quad (2) \]
where,
\[ y_i = \left( \frac{\text{Indemnities}}{\text{TotalLiability}} \right)_i; \quad (3) \]

\[ x_i = FCDD_i, \] where FCDD (Factores Climaticos Dañinos Diarios)—damage degree days or periods—that represent the index that captures the critical weather risk of each crop in the portfolio outlined in Table 3.3.1 (see following section); \( \epsilon_1 \) is a normally distributed noise term and; the estimators for the linear gradient and intercept, \( m_1 \) and \( m_0 \), were calculated from the least squares regression as:

\[
\hat{m}_1 = \frac{\sum_{i=1}^{n} (x_i y_i) - n \sum_{i=1}^{n} (x_i) \sum_{i=1}^{n} (y_i)}{\sum_{i=1}^{n} (x_i^2) - n \left( \sum_{i=1}^{n} (x_i) \right)^2} \quad (4)
\]

\[
\hat{m}_0 = \frac{\sum_{i=1}^{n} (y_i) \sum_{i=1}^{n} (x_i^2) - \sum_{i=1}^{n} (x_i) \sum_{i=1}^{n} (x_i y_i)}{\sum_{i=1}^{n} (x_i^2) - n \left( \sum_{i=1}^{n} (x_i) \right)^2} \quad (5)
\]

where \( n = 9 \), corresponding to the nine autumn-winter cycles 1991/1992–1999/2000 for which there was historical portfolio information. The gradient estimator for \( m_1 \), in particular, is very important as it establishes the relationship between the individual severity indexes and the relevant weather indexes. Once all the linear regressions for each crop are performed and all the linear estimators are calculated, the expected indemnities (in monetary terms) for each severity index, given a certain weather index (FCDD) and total liability, can be calculated as follows:

\[
\left( \text{Indemnities} \right)_i = \left( \text{TotalLiability} \right)_i \times FCDD_i \times \hat{m}_1 \quad (6)
\]

**FCDDs: The Weather Indexes**

The FCDD terms for each crop in the preceding section, represents the weather index, or indexes, that best captures the weather risk for that crop. For example, if we are analyzing the exposure of beans to low temperatures, the FCDD index could be defined as the number of days that the daily minimum temperature drops below a specified daily threshold during the growing season. In order to
construct the appropriate weather indexes for the Agroasemex portfolio shown above in Table 3.2.2, the relevant weather historical information was collected: five Mexican weather stations on the Pacific Ocean coast were chosen to represent the western area of the country (Sonora, Sinaloa, and Nayarit), while two U.S. airport stations (McAllen and Brownsville) were used to represent the northeastern area (Tamaulipas; see Figure 3.2.1).

It is important to note that even though each severity index, as defined above, is a seasonal aggregate, the types of risks that are relevant for an agricultural portfolio of crops can occur over very short periods of time, for example crop damage due to frost can occur in just one day. Therefore the selection of the individual weather indexes for each crop was based on two criteria: first and primarily, on the agronomical surveys and experience of the technical personnel of Agroasemex and second, on the strength of the mathematical relationship obtained when comparing the available data on indemnities for the crop in question, with the weather index (Equation 2)—this was done on both a daily (data on indemnities were available in daily resolution) and seasonal basis.

To demonstrate how each individual FCDD was estimated, consider the example for the weather index chosen for tobacco in Nayarit, DDD-12. Low temperature is the greatest risk for tobacco crops in Nayarit; when the daily minimum
temperature drops below 12ºC the expected tobacco yields will be below average. Hence 12ºC is the minimum temperature threshold level for tobacco crop damage—DDD-12 represents Damage Degree Days with a 12ºC threshold. The DDD-12 index is defined as follows:

\[
DDD-12 = \sum \max(0, 12 - T_{min})
\]

where the DDD-12 summation is over each day in the growing period of tobacco, November 1–March 31 of the following year. Daily minimum temperature, \(T_{min}\), is measured at a single weather station, Capomal, in Santiago Ixcuintla, Nayarit. Tables 3.2.3 and 3.2.4 show the DDD-12 index values by month and season from 1991–2000:

**Table 3.2.3 Monthly and Seasonal Accumulated DDD-12 in Nayarit from 1991 to 2000**

<table>
<thead>
<tr>
<th>Year</th>
<th>January</th>
<th>February</th>
<th>March</th>
<th>November</th>
<th>December</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1991</td>
<td>3</td>
<td>5.5</td>
<td>8</td>
<td>0</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td>1992</td>
<td>0</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>1993</td>
<td>0</td>
<td>0</td>
<td>6</td>
<td>0</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>1994</td>
<td>1</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>1995</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1996</td>
<td>4</td>
<td>0</td>
<td>1.5</td>
<td>0</td>
<td>0</td>
<td>5.5</td>
</tr>
<tr>
<td>1997</td>
<td>23.5</td>
<td>15</td>
<td>8</td>
<td>0</td>
<td>8</td>
<td>46.5</td>
</tr>
<tr>
<td>1998</td>
<td>3.5</td>
<td>14</td>
<td>1.5</td>
<td>0</td>
<td>0</td>
<td>27</td>
</tr>
<tr>
<td>1999</td>
<td>0</td>
<td>4</td>
<td>1.5</td>
<td>0</td>
<td>0</td>
<td>5.5</td>
</tr>
<tr>
<td>2000</td>
<td>2.5</td>
<td>1</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>5.5</td>
</tr>
</tbody>
</table>

Source: Ibarra, 2003

It is clear that 1996/97, the strongest El Niño event on record, was the worst year, in terms of cold temperatures, for tobacco production in Nayarit. In total, eleven independent FCDDs were designed to represent the exposure of the crops and risks selected in Table 3.2.1 (see Table 3.2.4).
Table 3.2.4 Summary of the 11 FCDD Indexes for the Crops and Risks Selected to be Included in the Weather Derivative

<table>
<thead>
<tr>
<th>State</th>
<th>Crop</th>
<th>Risk</th>
<th>FCDD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nayarit</td>
<td>Tobacco</td>
<td>Low Temperature</td>
<td>DDD-12</td>
</tr>
<tr>
<td>Nayarit</td>
<td>Tobacco</td>
<td>Excess Humidity</td>
<td>EMNF</td>
</tr>
<tr>
<td>Nayarit</td>
<td>Tobacco</td>
<td>Excess Humidity</td>
<td>EMMA</td>
</tr>
<tr>
<td>Sinaloa</td>
<td>Beans</td>
<td>Low Temperature and Frost</td>
<td>DDD-5</td>
</tr>
<tr>
<td>Sinaloa</td>
<td>Beans</td>
<td>Low Temperature and Frost</td>
<td>DDD-3</td>
</tr>
<tr>
<td>Sinaloa</td>
<td>Beans</td>
<td>Excess Humidity</td>
<td>EMF</td>
</tr>
<tr>
<td>Sinaloa</td>
<td>Beans</td>
<td>Excess Humidity</td>
<td>MAX-5</td>
</tr>
<tr>
<td>Sinaloa</td>
<td>Chickpeas</td>
<td>Excess Humidity</td>
<td>EMG</td>
</tr>
<tr>
<td>Tamaulipas</td>
<td>Sorghum</td>
<td>Drought</td>
<td>MAXPS</td>
</tr>
<tr>
<td>Sinaloa-Sonora</td>
<td>Maize</td>
<td>Low Temperature and Frost</td>
<td>DDD-5</td>
</tr>
<tr>
<td>Sinaloa-Sonora</td>
<td>Maize</td>
<td>Low Temperature and Frost</td>
<td>DDD-3</td>
</tr>
</tbody>
</table>

Source: Ibarra, 2003

The FCDD calculation methodologies using daily weather data are presented in Table 3.2.5 for all crops in the portfolio.
### Table 3.2.5 Summary of the Methodology to Calculate the 11 FCDD Indexes

<table>
<thead>
<tr>
<th>State</th>
<th>Crop</th>
<th>FCDD</th>
<th>Weather Station</th>
<th>FCDD Calculation Methodology (In mm and deg Celsius)</th>
<th>Calc. Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nayarit</td>
<td>Tobacco</td>
<td>DDD-12</td>
<td>Capomal</td>
<td>DDD-12 = Sum Daily [\max(0, 12 - T_{\text{min}})]</td>
<td>Dec 1–Mar 31</td>
</tr>
<tr>
<td></td>
<td></td>
<td>EMNF</td>
<td>1 Capomal</td>
<td>EMNF = Sum Daily [\text{Rainfall Station 1}] + \text{Sum Daily} [\text{Rainfall Station 2}]</td>
<td>Nov 1–Feb 28</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2 La Concha</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>EMMA</td>
<td>1 Capomal</td>
<td>EMNF = Sum Daily [\text{Rainfall Station 1}] + \text{Sum Daily} [\text{Rainfall Station 2}]</td>
<td>Mar 1–Apr 30</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2 La Concha</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sinaloa</td>
<td>Beans</td>
<td>DDD-5</td>
<td>Sanalona</td>
<td>DDD-5 = Sum Daily [\max(0, 5 - T_{\text{min}})]</td>
<td>Oct 1–Apr 30</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DDD-3</td>
<td>Sanalona</td>
<td>DDD-3 = Sum Daily [\max(0, 3 - T_{\text{min}})]</td>
<td>Dec 1–Dec 31</td>
</tr>
<tr>
<td></td>
<td></td>
<td>EMF</td>
<td>1 Sanalona</td>
<td>EMF = Sum Daily [\text{Rainfall Station 1}] + \text{Sum Daily} [\text{Rainfall Station 2}] + \text{Sum Daily} [\text{Rainfall Station 3}]</td>
<td>Nov 1–Mar 31</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2 El Fuerte</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3 Jaina</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>MAX-5</td>
<td>1 Sanalona</td>
<td>MAX-5 = \max( MP - 200, 0 ); MP = \max \text{Sum 5-day D3} - \max \text{rainfall for a consecutive period of 5 days, where}</td>
<td>Nov 1–Mar 31</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2 El Fuerte</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3 Jaina</td>
<td>D3 = \text{Daily Rainfall Station 1} + \text{Daily Rainfall Station 2} + \text{Daily Rainfall Station 3}</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Chickpeas</td>
<td>EMG = Sum [\max(\text{Daily Rainfall - 55}, 0)]</td>
<td>Nov 1–Apr 30</td>
</tr>
<tr>
<td></td>
<td>EMG</td>
<td>Sanalona</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tamaulipas</td>
<td>Sorghum</td>
<td>MAXPS</td>
<td>1 Brownsville</td>
<td>PS = \text{Sum} [\max(250 - \text{CMP1}, 0)] + 2*\text{Sum} [\max(250 - \text{CMP2}, 0)]</td>
<td>Oct 1–May 31</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2 McAllen</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sinaloa</td>
<td>Maize</td>
<td>DDD-5</td>
<td>Sanalona</td>
<td>DDD-5 = \max[D5 - 22, 0]; D5 = Sum Daily [\max(0, 5 - T_{\text{min}})]</td>
<td>Oct 1–Apr 30</td>
</tr>
<tr>
<td>Sonora</td>
<td></td>
<td>DDD-3</td>
<td>Sanalona</td>
<td>DDD-3 = Sum Daily [\max(0, 3 - T_{\text{min}})]</td>
<td>Dec 1–Dec 31</td>
</tr>
</tbody>
</table>

Source: Ibarra, 2003
Using Equations 2–6, the mathematical relationship between each FCDD index and the indemnities for the corresponding crop in the Agroasemex portfolio was established, in so doing defining a means of converting FCDD indexes into expected indemnities in monetary terms. By combining this information the basket of all the expected indemnity indexes was used to replicate the overall weather exposure of the agricultural portfolio (Table 3.2.6).

This “combined index”—essentially the sum of all the expected crop indemnity indexes given by Equation 6—was used as an underlying proxy and therefore hedge for the weather exposure of a portfolio (Table 3.2.6). A derivative structure based on this combined index, such as a call option, is therefore conceptually the same as a stop loss reinsurance strategy for the portfolio, as weather is the greatest risk to Agroasemex.

**Table 3.2.6 Summary of the Individual Equations that Constitute the Basket of Indexes of the Weather Derivative**

<table>
<thead>
<tr>
<th>State</th>
<th>Crop</th>
<th>Risk</th>
<th>Total Liability ($US Million)</th>
<th>Total Indemnities Estimated by FCDD ($US)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nayarit</td>
<td>Tobacco</td>
<td>Low Temperature</td>
<td>22.4</td>
<td>1 = 22.4*(922.18*DDD-12)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Excess Humidity</td>
<td>22.4</td>
<td>2 = 22.4*((81.34<em>EMNF) + (210.63</em>EMMA))</td>
</tr>
<tr>
<td>Sinaloa</td>
<td>Beans</td>
<td>Low Temperature</td>
<td>0.1917</td>
<td>3 = 0.1917*((23350.52<em>DDD-3) + (4791.55</em>DDD-5))</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Excess Humidity</td>
<td>0.1917</td>
<td>4 = 0.1917*((422.07<em>MAX-5) + (68.28</em>EMF))</td>
</tr>
<tr>
<td></td>
<td>Chickpeas</td>
<td>Excess Humidity</td>
<td>0.46</td>
<td>5 = 0.46*(1316*EMG)</td>
</tr>
<tr>
<td>Tamaulipas</td>
<td>Sorghum</td>
<td>Drought</td>
<td>1.82</td>
<td>6 = 1.82<em>max[(MAXPS</em>254.53)-1178375, 0]</td>
</tr>
<tr>
<td>Sinaloa-Sonora</td>
<td>Maize</td>
<td>Low Temperature</td>
<td>2.019</td>
<td>7 = 2.019*((12426.51<em>DDD-3) + (1594</em>DDD-5))</td>
</tr>
</tbody>
</table>

Total Indemnities Estimated by Model = 1 + 2 + 3 + 4 + 5 + 6 + 7

Source: Ibarra, 2003
Historical Back-Testing

The strength of the approach outlined above—to establish a basket of indexes that best captures the weather exposure of the Agroasemex agricultural portfolio—was back-tested by using annual historical indemnity and total liability information from the Agroasemex direct insurance operations, 1990–2001. The historical portfolio indemnity records were compared to the estimated indemnities, given the total liability observed for that year and using the FCDD-indemnity relationships established in Table 3.2.6. The results are given in Table 3.2.7.

Table 3.2.7 Comparative Analysis Between the Real Indemnities and the Estimated Indemnities for the Agroasemex Portfolio (Figures in US$)

<table>
<thead>
<tr>
<th>Cycle</th>
<th>Model (1)</th>
<th>Actual (2)</th>
<th>Difference (1)-(2)</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>91–92</td>
<td>1,434,845</td>
<td>958,025</td>
<td>476,820</td>
<td>33.23</td>
</tr>
<tr>
<td>92–93</td>
<td>477,213</td>
<td>443,550</td>
<td>33,663</td>
<td>7.05</td>
</tr>
<tr>
<td>93–94</td>
<td>660,098</td>
<td>498,567</td>
<td>161,531</td>
<td>24.47</td>
</tr>
<tr>
<td>94–95</td>
<td>727,205</td>
<td>806,625</td>
<td>-79,420</td>
<td>-10.92</td>
</tr>
<tr>
<td>95–96</td>
<td>556,794</td>
<td>569,859</td>
<td>-13,065</td>
<td>-2.35</td>
</tr>
<tr>
<td>96–97</td>
<td>2,930,648</td>
<td>2,811,334</td>
<td>119,314</td>
<td>4.07</td>
</tr>
<tr>
<td>97–98</td>
<td>6,262,201</td>
<td>6,599,068</td>
<td>-336,867</td>
<td>-5.38</td>
</tr>
<tr>
<td>98–99</td>
<td>1,709,067</td>
<td>2,080,705</td>
<td>-371,638</td>
<td>-21.75</td>
</tr>
<tr>
<td>99–00</td>
<td>699,972</td>
<td>480,383</td>
<td>219,589</td>
<td>31.37</td>
</tr>
</tbody>
</table>

Source: Ibarra, 2003

The results showed that the combined weather index established for the Agroasemex portfolio had an acceptable predictive power, mainly because it captured the large historical deviations in the portfolio. The values of the severity index for each crop were calculated using both the historical and the modeled (Table 3.2.6) data for comparison; the results are shown in Table 3.2.8.

Table 3.2.8 includes the correlation coefficient ($r$), and the $r^2$ value for the different crops individually and for the portfolio overall. The results demonstrate that the combined weather index model explains around 93 percent of the variability demonstrated by the empirical data. It is important to note that in order to evaluate the stability of the combined index model; alternative scenarios
were run with +/- 20 percent variations for the thresholds that determined the FCDD indexes. The correlation coefficient remained within the 70 percent level.

**Table 3.2.8 Comparative Analysis Between the Observed Historical Severity Indexes (Indemnities/Total Liability) and the Estimated Severity Indexes for the Crops and Risks Selected (Figures in Decimals)**

<table>
<thead>
<tr>
<th>Tobacco</th>
<th>Beans</th>
<th>Chickpeas</th>
<th>Sorghum</th>
<th>Maize</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.052</td>
<td>0.060</td>
<td>0.000</td>
<td>0.086</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0.017</td>
<td>0.019</td>
<td>0.020</td>
<td>0.018</td>
<td>0.003</td>
<td>0</td>
</tr>
<tr>
<td>0.004</td>
<td>0.009</td>
<td>0.027</td>
<td>0.043</td>
<td>0</td>
<td>0.015</td>
</tr>
<tr>
<td>0.007</td>
<td>0.002</td>
<td>0.109</td>
<td>0.113</td>
<td>0.043</td>
<td>0.042</td>
</tr>
<tr>
<td>0.009</td>
<td>0.006</td>
<td>0.059</td>
<td>0.047</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0.067</td>
<td>0.068</td>
<td>0.164</td>
<td>0.178</td>
<td>0.117</td>
<td>0.126</td>
</tr>
<tr>
<td>0.052</td>
<td>0.046</td>
<td>0.403</td>
<td>0.407</td>
<td>0.117</td>
<td>0.104</td>
</tr>
<tr>
<td>0.008</td>
<td>0.006</td>
<td>0.167</td>
<td>0.140</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0.007</td>
<td>0.006</td>
<td>0.099</td>
<td>0.115</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

\[ r = 0.985 \quad r = 0.968 \quad R = 0.988 \quad r = 0.702 \quad r = 0.999 \quad r = 0.970 \]
\[ r^2 = 0.971 \quad r^2 = 0.936 \quad R^2 = 0.976 \quad R^2 = 0.492 \quad r^2 = 0.999 \quad r^2 = 0.939 \]

Source: Ibarra, 2003

---

**Valuation of the Weather Derivative Structure and the Agroasemex Transaction**

Monte Carlo simulation, as described in Chapter 2, was used to generate an estimate of the distribution of the possible results of the combined weather index and therefore the maximum liability of the Agroasemex portfolio (see Figure 3.2.2).\(^{37}\) The jagged line in Figure 3.2.2 is constructed using only historical information, while the darker, smoother line is established from the stochastic Monte Carlo simulation analysis of the underlying weather variables. It is clear that the historical payout of the Agroasemex portfolio has never exceeded

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\(^{37}\) The weather information for the Mexican transaction was reviewed directly by Risk Management Solutions (RMS—[www.rms.com](http://www.rms.com)) who determined that there were no significant trends, particularly in the temperature data, in the information used to construct the weather derivative structure. Therefore the following pricing exercise does not include any “detrending” procedures like those described in Chapter 2.
US$1.65 million, while the simulation analysis generates more extreme results, exceeding the US$2.5 million level.

**Figure 3.2.2  Comparative Accumulated Distribution Probability Function Based on a “Probability of Exceedence Curve” for the Historical and Modeled Results (Payouts in US$)**

The original analysis performed by Agroasemex focused on four possible call options derivative structures, which varied in strike price and limit of payout that could be used as an alternative to a traditional stop loss reinsurance contract to manage the portfolio risk (Table 3.2.9):

**Table 3.2.9 Specifications of Call Option Structures Considered by Agroasemex**

<table>
<thead>
<tr>
<th>Structure</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strike Price (US$)</td>
<td>1,000,000</td>
<td>1,100,000</td>
<td>1,200,000</td>
<td>1,300,000</td>
</tr>
<tr>
<td>Payout Limit (US$)</td>
<td>1,200,000</td>
<td>1,100,000</td>
<td>1,000,000</td>
<td>900,000</td>
</tr>
</tbody>
</table>

Source: Ibarra, 2003

The historical results and the stochastic analysis for the actuarial fair value of risk for each call option structure (average and standard deviation) are summarized in Table 3.2.10.
Table 3.2.10 Actuarial Fair Value Price Based on Historical Burn and Simulation Analysis (in US$).

<table>
<thead>
<tr>
<th>Analysis and Statistics</th>
<th>Structure A</th>
<th>Structure B</th>
<th>Structure C</th>
<th>Structure D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Last 10-yr HBA(^{38})</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average Payout</td>
<td>181,447</td>
<td>151,447</td>
<td>121,447</td>
<td>91,447</td>
</tr>
<tr>
<td>Standard Dev. of Payouts</td>
<td>277,908</td>
<td>232,229</td>
<td>186,622</td>
<td>141,157</td>
</tr>
<tr>
<td>Last 20-yr HBA</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average Payout</td>
<td>153,901</td>
<td>118,394</td>
<td>87,416</td>
<td>61,198</td>
</tr>
<tr>
<td>Standard Dev. of Payouts</td>
<td>238,018</td>
<td>170,405</td>
<td>157,762</td>
<td>118,390</td>
</tr>
<tr>
<td>Last 30-yr HBA</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average Payout</td>
<td>111,061</td>
<td>84,394</td>
<td>60,071</td>
<td>40,798</td>
</tr>
<tr>
<td>Standard Dev. of Payouts</td>
<td>208,258</td>
<td>170,405</td>
<td>134,815</td>
<td>100,878</td>
</tr>
<tr>
<td>Last 37-yr HBA</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average Payout</td>
<td>124,195</td>
<td>95,668</td>
<td>70,541</td>
<td>49,509</td>
</tr>
<tr>
<td>Standard Dev. of Payouts</td>
<td>222,632</td>
<td>184,167</td>
<td>146,729</td>
<td>110,300</td>
</tr>
<tr>
<td>Simulation Analysis</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average Payout</td>
<td>133,460</td>
<td>104,291</td>
<td>80,252</td>
<td>60,528</td>
</tr>
<tr>
<td>Standard Dev. of Payouts</td>
<td>267,471</td>
<td>234,087</td>
<td>202,127</td>
<td>172,112</td>
</tr>
</tbody>
</table>

Source: Ibarra, 2003

As described in Chapter 2, the premium charged is a combination of the expected or fair value of the risk—the pure risk premium—and an additional risk margin. Considering market standards at the time,\(^{39}\) the following risk loadings above the expected value were considered:

\(^{38}\) Historical Burn Analysis—see Chapter 2.

\(^{39}\) According to Risk Management Solutions (RMS) who worked with Agroasemex on the initial project, [www.rms.com](http://www.rms.com).
1. Loading Based on Standard Deviation. Market standards 20–40 percent. An intermediate loading of 30 percent was considered by Agroasemex.

2. Loading Based on the Uncertainty due to Gaps in the Historical Weather Data: When missing data exceed 1 percent of data points, market players usually design a sensitivity analysis to estimate the impact of using alternative infilling methods (see Chapter 2) and charge for the uncertainty that arises as a result of such gaps in the historical record. There is no established method for calculating this uncertainty loading in the market, which generally depends on the risk appetite of the individual weather risk taker.

3. Loading for Administrative Expenses: 15 percent was added as a margin. The weather stations used for the project in Mexico were carefully selected. Nevertheless, missing data ranged from 2.70 percent to 9.20 percent. The weather data gaps were infilled by Risk Management Solutions (RMS) on a monthly basis, based on data collected from neighboring weather stations. In order to quantify the sensitivity and robustness of the infilling method, instead of filling gaps with data inferred from the most correlated stations, the gaps were also infilled with the most extreme observations from a sample of stations that had acceptable correlations to the station with the missing data points, both for temperature and rainfall. The uncertainty loading due to missing data was estimated to be 50 percent of the resulting change in the average payout, as a result of this sensitivity analysis, plus 50 percent of the change in the standard deviation observed. The results were aggregated to complete the analysis—Table 3.2.11 shows the estimated commercial premium (expected value plus risk margin) calculated for the four weather derivative structures.

Despite the risk loading, Agroasemex eventually bought structure D from the market. The main motivations for this choice were the following:

- The four derivative structures were designed to hedge what in reinsurance are called working layers, which are usually the most cost-inefficient in the market. Actually the probability of attachment of the four structures ranged from one-third to one-sixth.
- The transaction included the donation of three automated weather stations as fallback stations, worth approximately US$36,000. Taking this cost into account, the ratio of the commercial price of the derivative to the pure risk premium was the lowest for structure D—1.57 versus 1.62 for the nearest structure.

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40 The Sharpe Ratio method is presented in Chapter 2, Section 3.
To establish credibility and brand recognition for future weather transactions.

- To set a market reference for the risk margin, so that future, larger deals could be negotiated under more narrow risk margins.

Table 3.2.11  Estimated Commercial Premium for Weather Derivative Structures (in US$)

<table>
<thead>
<tr>
<th>Analysis and Statistics</th>
<th>Structure A</th>
<th>Structure B</th>
<th>Structure C</th>
<th>Structure D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Last 10-yr HBA</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pure Risk Premium</td>
<td>181,447</td>
<td>151,447</td>
<td>121,447</td>
<td>91,447</td>
</tr>
<tr>
<td>Standard Deviation Loading</td>
<td>83,372</td>
<td>69,669</td>
<td>55,987</td>
<td>42,347</td>
</tr>
<tr>
<td>15% Margin</td>
<td>46,733</td>
<td>39,020</td>
<td>31,312</td>
<td>23,611</td>
</tr>
<tr>
<td>Full Price</td>
<td>311,552</td>
<td>232,229</td>
<td>186,622</td>
<td>141,157</td>
</tr>
<tr>
<td>Simulation Analysis</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pure Risk Premium</td>
<td>133,460</td>
<td>104,291</td>
<td>80,252</td>
<td>60,528</td>
</tr>
<tr>
<td>Standard Deviation Loading</td>
<td>80,241</td>
<td>70,226</td>
<td>60,638</td>
<td>51,634</td>
</tr>
<tr>
<td>Data Uncertainty Loading</td>
<td>31,750</td>
<td>27,584</td>
<td>23,693</td>
<td>20,136</td>
</tr>
<tr>
<td>15% Margin</td>
<td>43,315</td>
<td>30,797</td>
<td>24,863</td>
<td>19,793</td>
</tr>
<tr>
<td>Full Price</td>
<td>288,766</td>
<td>232,898</td>
<td>189,447</td>
<td>152,091</td>
</tr>
</tbody>
</table>

Source: Ibarra, 2003

Developments Since 2001

Since the initial weather derivative transaction presented above, Agroasemex devoted its institutional efforts and experience to developing a local weather risk market. These activities included: a thorough review of the weather data; further improvements to the weather observing infrastructure, in conjunction with the Mexican National Weather Service; and training and education for potential end users within Mexico. The greatest interest generated by the 2001 transaction was from the Mexican government regarding their catastrophic weather exposure: Since 2001 Agroasemex has sold weather index insurance to three Mexican states, to cover the states’ catastrophic exposure related to agriculture. In turn, Agroasemex has bought protection for this risk, on a quota share basis, in the
international weather derivatives market. The three transactions together have an approximate notional value of US$15 million, with several other states in the pipeline. There are unofficial reports that the international market has also closed several transactions with the private industry in Mexico as a result of this first weather derivative transaction.

### 3.3 WEATHER INSURANCE FOR FARMERS IN THE DEVELOPING WORLD: CASE STUDIES FROM INDIA AND UKRAINE

#### The Importance of Weather Risk in the Developing World

Agriculture employs nearly one-half of the labor force in the developing world. As inclement weather is one of the greatest risks to agricultural production, this reliance on agriculture in developing countries leaves the livelihoods of many millions of people dependent on the vagaries of the weather. In the past, traditional crop insurance programs have been used to manage this risk, but these programs have several problems when they are translated from the developed to the developing countries. Most notably the high unit administration costs, high entry barriers for farmers and difficulties of control make traditional crop insurance schemes neither practical nor cost effective in small-farmer economies (Hazell et al., 1986). Traditional crop insurance relies on costly on-farm assessments and field inspections to determine the actual yield losses in order to make payouts to farmers. In addition, farmers often need to provide historical yield data for their farm to qualify for more comprehensive (multi-peril) crop insurance (Skees et al., 2000). Furthermore, these programs contain systematic catastrophic yield risk components—usually due to weather—and hence need reinsurance.

As traditional crop insurance has been unable to penetrate developing country markets, weather-indexed insurance has been suggested as a potential alternative to the traditional crop insurance programs for smallholder farmers in the developing world (Skees et al., 2001). As introduced in Chapters 1 and 2, index-based weather insurance, instead of measuring actual damage on each farm, simply uses a weather-index measured at the local weather station as a proxy measurement of losses. Some of the clear benefits of this approach in small-farmer economies include: lower administration and monitoring costs, elimination of anti-selection and moral hazard, the objective and timely nature of the product and its reinsurability in the international weather market. These new weather risk management insurance instruments provide a viable alternative to
traditional insurance instruments, and offer advantages to households, companies, and governments in developing countries.

The Commodity Risk Management Group (CRMG) at the World Bank started working on pilot weather risk management projects in 2003. The CRMG was involved in its first index-based weather risk management contract in India in June, 2003. Since then, the number of projects has grown. CRMG is currently working on pilot projects for smallholders in India as well as projects in Peru, Nicaragua, Ethiopia, Thailand, Malawi, and Ukraine. Providers in the global weather risk market are extremely interested in such new transactions that diversify their weather portfolios through new locations and risks, and offer opportunities for business growth and expansion.

To illustrate some of the CRMG work in this new area, two case studies are presented. The first case study will focus on the developing weather market in India and the recent work of the Mumbai-based insurance company ICICI Lombard General Insurance Company Ltd. and Hyderabad-based microfinance institution BASIX in making weather insurance available to smallholder farmers in Andhra Pradesh. This case study provides an example of the role of insurance in access to finance for farmers exposed to weather risk. The second case study will focus on an upcoming weather insurance pilot program for winter wheat farmers in the southern oblast of Kherson in Ukraine.

**Weather Insurance for Agriculture in India**

In 1991 a household survey addressing rural access to finance revealed that barely one-sixth of rural households in India had loans from formal rural finance institutions and that only 35–37 percent of the actual credit needs of the rural poor were met through these formal channels (Hess, 2003). These findings implied that over a half of all rural household debt was to informal sources, such as moneylenders charging annual interest rates ranging from 40–120 percent. A survey based on the Economic Census of 1998 (Hess, 2003) showed that India’s formal financial intermediaries reportedly met only 2.5 percent of the credit needs of the unorganized sector through commercial lending programs.  

Farmers respond to the lack of formal financial services by turning to moneylenders; reducing inputs in farming; over capitalizing and internalizing risk; and/or by over diversifying their activities which leads to sub-optimal asset allocation.

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41 The unorganized sector corresponds to the informal or *submerged* economy, such as small-scale non-registered businesses in India, particularly found in the rural areas.
The combined effect of these coping strategies is a poverty trap. Smallholders cannot risk investing in fixed capital or concentrating on the most profitable activities and crops, because they cannot leverage the start-up capital and they face systemic risks that could wipe out their livelihoods at any point in time. The challenge for banks is to innovate a low-cost way of reaching farmers and helping them better manage risk. (Hess, 2003)

In this context, the CRMG, in collaboration with Hyderabad-based microfinance institution BASIX and Indian insurance company ICICI Lombard, a subsidiary of ICICI Bank, initiated a project to explore the feasibility of weather insurance for Indian farmers and to determine if, by reducing exposure to weather risk, it would be possible to extend the reach of financial services to the rural sector.

BASIX—Weather Insurance for Groundnut and Castor Farmers

Established in 1996, BASIX has emerged as one of the leading microfinance institutions in India. It has systematically addressed the issues of risk mitigation and cost reduction with the twin aim of attracting investment from the mainstream capital markets while maintaining and expanding its lending in rural areas, including lending for agriculture in drought-prone geographies (Hubka, 2005).

BASIX is the umbrella name used to denote a group of companies focused on the provision of microcredit and investment services as well as improving the livelihoods of its clients and borrowers. To date, BASIX has approximately 150,000 borrowers and 8,600 savers in 7,800 villages in 10 Indian states, disbursing US$37 million in loans since 1996; currently 49 percent of loans are for non-farm activities (Hubka, 2005). Its goal is to impact one million livelihoods by 2010—500,000 directly through financial services, and another 500,000 through indirect means. BASIX thinks of itself not as a microfinance institution, but as “a new generation livelihood promotion institution,” implying credit alone is not the solution for rural areas.

BASIX manages its risk at two levels: firstly by managing its own, institutional-level risk—through customer selection and lending practices and partnerships with other institutions—and secondly by helping its borrowing customers to reduce their risk (Hubka, 2005). By helping customers to mitigate and manage their own risk, and hence the risk of default on their loans, BASIX in turn protects the quality of its own portfolio. In 2003 in order to further extend the risk management offerings it provides its clients, BASIX joined forces with

42 www.basixindia.com
ICICI Lombard to design, develop, and pilot a weather insurance product for small and medium farmers in Andhra Pradesh with technical support from CRMG.

BASIX recognized that in many areas farmers’ yields depend critically on rainfall and that its loan default rates were highly correlated to drought. Furthermore, BASIX found that the loss sustained by individual farmers, due to below average rainfall, was on account of several factors not only the direct impacts on yields (KBS LAB, 2004). In addition to weather-related yield loss affecting an individual farmer’s ability to meet credit repayments—with credit default disrupting the next season’s loan disbursal and hence his agricultural cycle—the systematic nature of drought leads to areawide production drops, resulting in local price inflation and harder credit terms for the next growing season for all producers.

The government-sponsored area-yield indexed crop insurance scheme offered by the National Agricultural Insurance Company (NAIC) is compulsory for all crop-loan borrowers from Indian banks and the only crop insurance option available to BASIX customers. However, BASIX, as others (Skees and Hess, 2003), found a number of inefficiencies in the federal program in relation to drought (Table 3.3.1).

<table>
<thead>
<tr>
<th>NAIC Crop Insurance</th>
<th>Weather (Monsoon) Insurance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coverage for floods and droughts—extreme situations</td>
<td>Coverage against a shortfall in a pre-determined rainfall index—compensation for economic losses due to below-average rainfall index</td>
</tr>
<tr>
<td>Based on drought declaration—politically motivated, not transparent</td>
<td>Calculation of rainfall index is transparent and fully objective</td>
</tr>
<tr>
<td>Claim payout after a lag of 2–3 years</td>
<td>Immediate claim settlements</td>
</tr>
<tr>
<td>Claim payouts based on minimum prices</td>
<td>Claim payouts based on fair estimated market price</td>
</tr>
</tbody>
</table>

Source: KBS LAB, 2004

In particular, they noted that the NAIC program only led to recovery in extreme situations, following a drought declaration for the district by the state government, with these declarations often the result of political maneuvering rather than objective criteria. Furthermore, in the NAIC program recovery was based on minimum crop prices and in general occurred two to three years after the failed harvest. By comparison, index-based weather insurance offered the
potential of a transparent, objective, and timely settlement process for economic losses associated with non-catastrophic weather risk, with recovery based on fair market price estimates. With the requirements of farmers in rain-sensitive regions in mind, BASIX considered these to be compelling reasons to launch a pilot weather insurance program.

*First Pilot Program: 2003*
The initial pilot launched by BASIX and ICICI Lombard was based in the Mahabubnagar district of Andhra Pradesh, with an objective of selling weather insurance policies to 200 groundnut and castor farmers through Krishna Bhima Samruddhi Local Area Bank (KBS LAB), a BASIX subsidiary that is a Reserve Bank of India licensed bank providing microcredit and savings services in three districts.43 The farmers selected for the initial pilot were members of a Bore Well Users’ Association (BUA)44 in four BUA villages in the Mahabubnagar district: Kodur, Pamireddypally, Utkoor and Ippalapaddy. For example, in 1999 the BUA in Pamireddypally received an agricultural loan from BASIX. With a 100 percent repayment rate, and therefore good BASIX credit history and standing, they were planning to borrow a further amount for the financial year 2003–04. Based on this strong customer relationship, BASIX launched the weather insurance pilot in Pamireddypally and the other three villages. In particular, by linking the new insurance pilot to farmers who had accessed finance, BASIX would form a base from which they could begin understand the interaction between such a product, credit repayment and ultimately their crop-loan portfolio default rates.

*The Weather Insurance Contract Design*
Groundnut is the primary rainfed crop grown in the Mahabubnagar district during the June–September monsoon, or khariff season, followed by castor. While most of the cultivation of groundnut and castor is during the khariff, crops are also cultivated in the winter, or rabi growing season, in pockets of irrigated land. The economics of cultivating groundnut and castor per acre during the khariff and rabi seasons were established through interactions with the BUA members in feedback sessions and workshops organized by KBS LAB and ICICI Lombard (Tables 3.3.2 and 3.3.3).


44 The BUA is a project of the Andhra Pradesh Government which subsidizes 85 percent of the cost of community bore wells dug for irrigation of lands belonging to multiple households from villages. The remaining 15 percent of the bore well cost is met by the individual BUA members, in proportion to the land they irrigate.
Table 3.3.2 Economics of Groundnut, Per Acre of Cultivation

<table>
<thead>
<tr>
<th>Investment</th>
<th>Khariff (Rain-fed) May–October</th>
<th>Rabi (Irrigated) December–March</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seed (80 kg pods = 55 kg of kernels) @ Rs.1,800 per quintal</td>
<td>Rs.1,500</td>
<td>Rs.1,500</td>
</tr>
<tr>
<td>Fertilizer</td>
<td>Rs.1,000</td>
<td>Rs.1,500</td>
</tr>
<tr>
<td>Pesticide—3 sprays</td>
<td>Rs.1,000</td>
<td>Rs.1,000</td>
</tr>
<tr>
<td>Labor—60 man days @ Rs.50 per day</td>
<td>Rs.3,000</td>
<td>Rs.2,000</td>
</tr>
<tr>
<td>Total Expenses</td>
<td>Rs.6,500</td>
<td>Rs.6,000</td>
</tr>
<tr>
<td>Expected Yield and Average Sales Price</td>
<td>6 quintals @ 1500 per quintal = Rs.9,000</td>
<td>10 quintals @ 1500 per quintal = Rs.15,000</td>
</tr>
<tr>
<td>Surplus over Expenses</td>
<td>Rs.2,500</td>
<td>Rs.9,000</td>
</tr>
</tbody>
</table>

Source: Davikonda Sattaiah, Head of Insurance, BASIX, India, Private Communication, February, 2004

Table 3.3.3 Economics of Castor, Per Acre of Cultivation

<table>
<thead>
<tr>
<th>Investment Season</th>
<th>Khariff (Rain-fed) May–October</th>
<th>Rabi (Irrigated) December–March</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seed 6 kg @ Rs.50 per kg</td>
<td>Rs.300</td>
<td>Rs.300</td>
</tr>
<tr>
<td>Fertilizer—Urea and DAP</td>
<td>Rs.600</td>
<td>Rs.1,200</td>
</tr>
<tr>
<td>Pesticide—3 Sprays</td>
<td>Rs.1,000</td>
<td>Rs.1,000</td>
</tr>
<tr>
<td>Labor—22 women days @ Rs.50 per day = Rs.1,100</td>
<td>@ Rs.30 per day = Rs.660</td>
<td></td>
</tr>
<tr>
<td>Total Expenses</td>
<td>Rs.3,000</td>
<td>Rs.3,100</td>
</tr>
<tr>
<td>Expected Yield and Average Sales Price</td>
<td>4 quintals @ 1,800 = Rs.7,200</td>
<td>8 quintals @ 1,800 = Rs.14,400</td>
</tr>
<tr>
<td>Surplus over Expenses</td>
<td>Rs.4,200</td>
<td>Rs.11,300</td>
</tr>
</tbody>
</table>

Source: Davikonda Sattaiah, Head of Insurance, BASIX, India, Private Communication, February, 2004
The aim of the pilot program in 2003 was to design weather insurance contracts to insurce these input and production costs for the farmer. The initial weather insurance contracts designed for the castor and groundnut farmers were based on a weighted rainfall index of rainfall collected and record at the Indian Meteorological Department (IMD) official district weather station in the district capital town, Mahabubnagar. High-yield rainfall correlations were measured for khariff crops in the area, nevertheless agronomic information was used to enhance and strengthen the yield-rainfall relationship for the contract structures. For example, in the case of groundnut, the most critical periods, when groundnut is most vulnerable to low rainfall and therefore water stress, are the emergence periods immediately after sowing and the flowering and pod-filling phase 2-3 months after emergence (Narahari Rao et al., 2000). On the basis of farmer interviews, agro-meteorological studies (Gadgil, et al., 2002), local yield information, and models such as the United Nations Food and Agriculture Organization (FAO) water satisfaction index (FAO, 2005), a groundnut-specific rainfall index was developed. The index was defined as a weighted sum of cumulative rainfall during May 11–October 17, the average calendar dates for the growing season of groundnut. Individual weights were assigned to consecutive 10-day periods of the growing season so that the index gave more weight to the critical periods during the crop’s evolution when groundnut is most vulnerable to rainfall variability. Furthermore, a 10-day cap on rainfall of 200mm was introduced to the index to address the fact that excessive rain does not contribute to plant growth. The individual weights were determined by groundnut water requirements, as advised by local agro-meteorologists, that maximized correlation between district groundnut yields and the rainfall index (Figure 3.3.1), but that defined homogenous rainfall periods making the contract understandable and more marketable to the farmers and less susceptible to basis risk (see Chapter 2).
The 10-day cumulative rainfall weightings are given in Table 3.3.4. A similar index was designed specifically for castor. More information on the index construction can be found in Hess (2003).

The average or reference weighted index value for groundnut and castor at Mahahubnagar weather station were determined to be 653mm and 439mm, respectively. These reference-weighted index values represent the expected growing conditions in the region for these crops that produce satisfactory yields for the farmers. The weather insurance contracts were designed so that payouts started at 95 percent of this reference level. Farmers participating in the program received a payment if the index fell below the predetermined threshold, indicating the insured should be granted an indemnity to cover lost production and input costs as a result of lower than expected yields. The initial pilot limited how much insurance a farmer could purchase by offering three different fixed contracts depending on the type of farmer wanting to buy the insurance (Table 3.3.5). The payout schedule as a function of index for small, medium, and large farmers is given in Figure 3.3.2.
### Table 3.3.4 10-day Cumulative Rainfall Weighting for Groundnut Rainfall Index

<table>
<thead>
<tr>
<th>Sub-Periods</th>
<th>Weighting Factor (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commencing</td>
<td>Ending</td>
</tr>
<tr>
<td>May 11</td>
<td>May 20</td>
</tr>
<tr>
<td>May 21</td>
<td>May 30</td>
</tr>
<tr>
<td>May 31</td>
<td>June 9</td>
</tr>
<tr>
<td>June 10</td>
<td>June 19</td>
</tr>
<tr>
<td>June 20</td>
<td>June 29</td>
</tr>
<tr>
<td>June 30</td>
<td>July 9</td>
</tr>
<tr>
<td>July 10</td>
<td>July 19</td>
</tr>
<tr>
<td>July 20</td>
<td>July 29</td>
</tr>
<tr>
<td>July 30</td>
<td>August 8</td>
</tr>
<tr>
<td>August 9</td>
<td>August 18</td>
</tr>
<tr>
<td>August 19</td>
<td>August 28</td>
</tr>
<tr>
<td>August 29</td>
<td>September 7</td>
</tr>
<tr>
<td>September 8</td>
<td>September 17</td>
</tr>
<tr>
<td>September 18</td>
<td>September 27</td>
</tr>
<tr>
<td>September 28</td>
<td>October 7</td>
</tr>
<tr>
<td>October 8</td>
<td>October 17</td>
</tr>
</tbody>
</table>

Source: Ulrich Hess, The World Bank
Table 3.3.5 Weather Insurance Contracts Offered to Groundnut and Castor Farmers

<table>
<thead>
<tr>
<th>Category</th>
<th>Premium (Rs)</th>
<th>Farmer Eligibility</th>
<th>Sum Insured (Rs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Groundnut</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Small</td>
<td>450</td>
<td>&lt; 2.5 acres land holding</td>
<td>14,000</td>
</tr>
<tr>
<td>Medium</td>
<td>600</td>
<td>2.5–5 acres land holding</td>
<td>20,000</td>
</tr>
<tr>
<td>Large</td>
<td>900</td>
<td>&gt; 5 acre land holding</td>
<td>30,000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Category</th>
<th>Premium (Rs)</th>
<th>Farmer Eligibility</th>
<th>Sum Insured (Rs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Castor</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Small</td>
<td>255</td>
<td>&lt; 2.5 acre land holding</td>
<td>8,000</td>
</tr>
<tr>
<td>Medium</td>
<td>395</td>
<td>&gt; 2.5 acre land holding</td>
<td>18,000</td>
</tr>
</tbody>
</table>

Source: Ulrich Hess, The World Bank

Figure 3.3.2 Payout Structure of Groundnut Weather Insurance Policy for Small, Medium, and Large Farmers

Source: Authors
The Marketing and Sales Campaign
The products were marketed and sold by KBS LAB extension officers to the four villages through workshops and meetings with the BUA members. The sales period ended on April 30, 2003. In total, 230 farmers bought the insurance: 154 groundnut farmers and 76 castor farmers, most falling into the small farmer category. Of the 154 groundnut farmers, 102 were women who belonged to Velugu (light) self-help groups. Velugu works with four hundred thousand poor women organized into self-help groups in Andhra Pradesh. Funded by the World Bank, Velugu is implemented by the Society for Elimination of Rural Poverty (SERP), an autonomous society set up by the government of Andhra Pradesh to fulfill its poverty alleviation objectives. The women were keen to purchase protection against the vagaries of the monsoon, as all their households and most of their fellow villagers grew groundnut. These fellow villagers were the primary customers of the women in the self-help groups and therefore these women felt the additional impacts of a poor monsoon season through drops in sales and purchases of their services, and wanted to protect themselves also.

The entire portfolio of weather insurance contracts sold by BASIX was insured by ICICI Lombard, with reinsurance through one of the leading international reinsurance companies. ICICI Lombard filed all the necessary forms and terms of insurance with the Indian insurance regulator, registering their products before the program was launched. The number of contracts sold is presented in Table 3.3.6. An example of a farmer crop insurance policy for castor is shown in Figure 3.3.3.

Table 3.3.6 Number of Contracts Sold

<table>
<thead>
<tr>
<th>Farmer Categories</th>
<th>Groundnut Insurance Contracts Sold</th>
<th>Castor Insurance Contracts Sold</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>BASIX borrowers</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Small (&lt;2.5 acre land holding)</td>
<td>38</td>
<td>51</td>
<td>38</td>
</tr>
<tr>
<td>Medium (2.5 to 5 acres)</td>
<td>13</td>
<td>25</td>
<td>13</td>
</tr>
<tr>
<td>Large (&gt;5 acres)</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>52</td>
<td>76</td>
<td>128</td>
</tr>
<tr>
<td>SERP beneficiaries</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Small (&lt;2.5 acre land holding)</td>
<td>102</td>
<td>0</td>
<td>102</td>
</tr>
<tr>
<td>Medium (2.5 to 5 acres)</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>102</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>Grand Total</strong></td>
<td><strong>154</strong></td>
<td><strong>76</strong></td>
<td><strong>230</strong></td>
</tr>
</tbody>
</table>

Source: Davikonda Sattaiah, Head of Insurance, BASIX, India, Private Communication, February, 2004
At the end of the contract term the final values of the weighted indexes at Mahahbubnagar weather station were calculated by multiplying the cumulative rainfall totals, in each 10-day period from May 11—October 17, 2003 by the specific weight assigned to that period. The weighted rainfall indexes for groundnut and castor were calculated to be 516mm and 490mm, respectively, for khariff 2003, triggering a payout for groundnut farmers and no payout for castor farmers. Small, medium, and large groundnut farmers recovered Rs 320, Rs 400, and Rs 480, respectively, within two weeks of the end date of the contract, after the rainfall data were collected and crosschecked by the IMD.

Farmer Feedback
The overall farmer feedback from the first pilot was positive; the farmers welcomed the new product and appreciated the objective nature of the weather insurance contracts and the timely payment of claims. In particular, groundnut farmers received a timely recovery from the policies they purchased, even though the Mahahbubnagar district was not declared a drought area by the government of Andhra Pradesh in 2003 and, as a result, there was no payment from the government’s crop insurance program. The following positive aspects
of the pilot, as reported by KBS LAB from feedback sessions with the BUA members in Pamireddypally in January, 2004, were given:

- Farmers had the opportunity to reflect on rainfall shortages and the economic losses associated with them and to learn about the concept and process of rainfall insurance;
- Farmers were happy that they could buy rainfall insurance to protect themselves from the most critical risk to their farming operations;
- The product was introduced through KBS LAB, a credible source of services and facilities for the farmers;
- Claims were paid in a timely manner.

However, there were perceived shortfalls of the product design, in particular, the farmers expected that more weight would be given to the initial sowing period of groundnut. Moisture stress at sowing was associated with the greatest financial risk for farmers, as the farmers invest most of their production costs at sowing time. If the plants do not germinate and survive the establishment period, the entire crop will be lost along with the investment costs and a farmer will have to re-sow, incurring further input and production expenditures. For example, in 2003 the groundnut farmers expected a greater payout than the amount recovered, as the rains during sowing were delayed and not optimal. The farmers felt the index did not properly reflect the fact that most of the investment into the crop was made at the beginning of the growing season and therefore more emphasis should have been given to this phase. Other shortfalls, as reported by KBS LAB after feedback sessions with the BUA members in January, 2004, included:

- Rainfall data were collected at Mahahbubnagar weather station, the farmers felt the station did not represent the rainfall of their village well.
- Claim calculation criteria were not clearly communicated to the farmers during the sales and marketing campaign, in particular:
  i. The farmers were more comfortable with indexing claims in millimeters rather than in percentile points.
  ii. The farmers did not understand the non-linear payout function of the insurance contract and were expecting a linear relationship between the rainfall index and the claim amount. For example, in 2003 there was a 22 percent shortfall in the rainfall index, hence the farmers expected Rs 2,800 as the claim amount—22 percent of the Rs14,000 sum insured for small farmers.
- Farmers felt that the product should offer phase-wise payouts for each growing phase, subject to the maximum limits, so that it would be clear how the weights and therefore payouts related to each growing stage.
The farmers also requested that in the future the insurance company send a progress report on the rainfall for each of the crop phases in order to facilitate a better understanding for the farming community.

- Farmers noted that excess rainfall at harvest could result in severe crop losses and requested that risk of excess rainfall protection be offered under the weather insurance product.

Despite the high-expectations of the farmers, with fine-tuning and adjustment to the comments above, most were happy to buy the product again in the following year. Despite the administration costs incurred by the KBS LAB office, BASIX was happy with the product and the initial pilot and were keen to refine it for the following year (see Table 3.3.7). ICICI Lombard was also happy to expand the pilot in the following Khariff season.

**Table 3.3.7 Pilot Statistics, 2003**

<table>
<thead>
<tr>
<th></th>
<th>Groundnut</th>
<th>Castor</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Number of Farmers Insured</td>
<td>154</td>
<td>76</td>
<td>230</td>
</tr>
<tr>
<td>Aggregate Value of Insurance (Rs)</td>
<td>2,250,000</td>
<td>858,000</td>
<td>3,108,000</td>
</tr>
<tr>
<td>Aggregate Premium Paid (Rs)</td>
<td>71,700</td>
<td>22,880</td>
<td>94,580</td>
</tr>
<tr>
<td>Aggregate Amount of Claims (Rs)</td>
<td>50,417</td>
<td>0</td>
<td>50,417</td>
</tr>
<tr>
<td>Net Incurred Claim to Net Premium Earned (%)</td>
<td>70.3</td>
<td>0</td>
<td>53.3</td>
</tr>
</tbody>
</table>

Source: Davikonda Sattaiah, Head of Insurance, BASIX, India, Private Communication, February, 2004

**Second Pilot Program: 2004**

The second pilot program in khariff 2004 introduced significant changes to the 2003 design. The program was extended to four new weather reference station locations, in two additional districts in Andhra Pradesh: Khammam and Anantapur. The weather insurance contracts were offered to both BASIX borrowers and non-borrowers, and marketed and sold through KBS LAB in Khammam and Mahahubnagar districts and Bhartiya Samruddhi Finance Ltd. (BSFL)\(^{45}\) in Anantapur district through village meetings, farmer workshops, and feedback sessions in the month leading up to the groundnut and castor growing season. A portion of the weather insurance contracts was written on local rain gauges monitored by the government of Andhra Pradesh, rather than the district

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\(^{45}\) BSFL is another BASIX subsidiary company. Launched in 1998, BSFL is the “flagship” company of the group and is a Reserve Bank of India registered non-bank financial company, engaged in microcredit and retailing insurance and providing technical assistance. Source: [www.basixindia.com](http://www.basixindia.com)
IMD stations. Because 60 percent of agriculture in Andhra Pradesh is rainfed, the government of Andhra Pradesh maintains a network of 1108 rain gauges throughout the state. This monitoring is done at the smallest administrative unit in the state, known as a mandal, which is a grouping of approximately 15 villages. In Andhra Pradesh, there are 40–50 mandals in each district and each mandal has one rain gauge: 232 of the rain gauges are owned by the IMD and all conform to World Meteorological Organization specifications. Records begin in 1956 and historical data can be purchased from the Government Bureau of Statistics and Economics in Hyderabad. The second pilot used these rain gauges and, as a result, in general all rain gauges were 10 km away from the farming villages involved in the scheme. This limited the basis risk to farmers, because the gauges were closer to their actual farms, but made it more difficult and indeed impossible to find international reinsurance for the final portfolio of weather insurance contracts sold by BASIX and insured by ICICI Lombard. In 2004 therefore, ICICI Lombard chose to keep the risk without international reinsurance support.

However, the biggest difference in 2004 was the design of the weather insurance contracts. In light of the farmer feedback from khariff 2003, the drought protection products for 2004 were structured by dividing the growing season of groundnut and castor into three phases which correspond to the three critical growing periods: Establishment and Vegetative Growth, Flowering and Pod Formation, Pod Filling and Maturity. With a departure from the weighted index design, the new contracts specified a cumulative rainfall trigger for each of the three phases, with an individual payout rate and limit for each phase. For example, for Narayanpet mandal in Mahahbubnagar district the groundnut drought insurance policy offered to farmers is structured in Table 3.3.8.

<table>
<thead>
<tr>
<th>Phase</th>
<th>Dates</th>
<th>Strike (mm)</th>
<th>Limit (mm)</th>
<th>Payout Rate (Rs)</th>
<th>Limit (Rs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Establishment and Vegetative Growth</td>
<td>June 10–July 14</td>
<td>75</td>
<td>20</td>
<td>15</td>
<td>3,000</td>
</tr>
<tr>
<td>Flowering and Pod Formation</td>
<td>July 15–August 28</td>
<td>110</td>
<td>40</td>
<td>10</td>
<td>2,000</td>
</tr>
<tr>
<td>Pod Filling and Maturity</td>
<td>August 29–October 2</td>
<td>75</td>
<td>10</td>
<td>5</td>
<td>1,000</td>
</tr>
</tbody>
</table>

Source: Authors
Trigger levels and payout rates were determined in consultation with local agro-meteorologists and farmers, and with reference to local yield data as in 2003. Premiums and threshold levels vary by weather station, depending on the risk profile of each individual location. This simplified design was introduced to give clarity to the recovery process by clearly associating each critical growth phase with an individual deficit rainfall protection structure. If the rainfall deficit reached the lower limit in each phase, the total payout limit for that phase would be triggered to indemnify farmers for the severe corresponding crop losses associated with the lack of rainfall. Figure 3.3.4 shows the contract payout structure. In a further departure from the 2003 pilot, the contracts were designed to be sold per acre.

**Figure 3.3.4 Payout Structure of Groundnut Weather Insurance Policy for Narayanpet Mandal, Mahabubnagar District, 2004**

Source: Authors

A farmer could buy as many acres of protection as he wished provided he actually cultivated that many acres of the crop to be insured. The premium associated with the product in Table 3.3.8 is Rs 250 per acre insured, for a sum insured of Rs 6,000 per acre. New contracts were also offered for cotton farmers in Khammam district and an excess rainfall product for harvest was offered to all castor and groundnut farmers with the structure shown in Table 3.3.9.

151
Table 3.3.9 Payout Structure Per Acre for Castor and Groundnut Excess Rainfall Weather Insurance Policy for Narayanpet, Mahahbubnagar

<table>
<thead>
<tr>
<th>Dates</th>
<th>September 1—October 10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rainy Day Index</td>
<td>Daily Rainfall Greater Than or Equal to 10 mm</td>
</tr>
<tr>
<td>Premium</td>
<td>Rs200 Per Acre Insured</td>
</tr>
<tr>
<td>Limit</td>
<td>Rs6,000 Per Acre Insured</td>
</tr>
</tbody>
</table>

Excess Rainfall Payout Structure

<table>
<thead>
<tr>
<th>Number of Consecutive Rainy Days</th>
<th>Claim Amount (Rs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>1,500</td>
</tr>
<tr>
<td>5</td>
<td>1,500</td>
</tr>
<tr>
<td>6</td>
<td>3,000</td>
</tr>
<tr>
<td>≥ 7</td>
<td>6,000</td>
</tr>
</tbody>
</table>

Source: Authors

In total, over 400 farmers bought insurance through BASIX in 2004 and a further 320 groundnut farmers, members of a Velugu self-help group organization in Anantapur district, bought insurance directly from ICICI Lombard. Several farmers were repeat customers from the 2003 pilot. The breakdown of risk insured by ICICI Lombard, who insured the entire BASIX weather insurance portfolio of contracts sold to farmers, and corresponding payouts in 2004 are given in Table 3.3.10.

In contrast to 2003, ICICI Lombard did not seek reinsurance for the BASIX farmer weather insurance portfolio in 2004. As in 2003, all contracts were settled promptly, within 30 days of the end of the calculation period. An example of the marketing leaflet developed by KBS LAB and ICICI Lombard detailing the weather insurance contracts for castor, groundnut, and excess rainfall for Narayanpet mandal are shown in Figure 3.3.5. For example, in kharif 2004, the rainfall in Narayanpet mandal was not good for groundnut farmers. The rainfall recorded at the local mandal rain gauge measured 12mm for Phase 1, and 84.2mm for Phase 2; rainfall during Phase 3 was above average at 112mm. Farmers who bought this policy received a payout of Rs 3,258 per acre insured on September 22, 2004.
### Table 3.3.10 Breakdown of all Weather Insurance Contracts sold by ICICI Lombard in Andhra Pradesh through BASIX for Khariff 2004

<table>
<thead>
<tr>
<th>Client</th>
<th>Location</th>
<th>Crop</th>
<th>Data Source</th>
<th>Peril</th>
<th>Acres Insured</th>
<th>Farmers</th>
<th>Total Premium (Rs.)</th>
<th>Total Risk (Rs.)</th>
<th>Total Claims (Rs.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>KBS LAB</td>
<td>Atmakur, M’bubnagar</td>
<td>Ground nut</td>
<td>Mandal Station</td>
<td>Deficit Rainfall</td>
<td>43</td>
<td>26</td>
<td>10750</td>
<td>258000</td>
<td>8428</td>
</tr>
<tr>
<td>KBS LAB</td>
<td>Narayanpet, M’bubnagar</td>
<td>Ground nut</td>
<td>Mandal Station</td>
<td>Deficit Rainfall</td>
<td>49</td>
<td>37</td>
<td>12150</td>
<td>294000</td>
<td>159642</td>
</tr>
<tr>
<td>KBS LAB</td>
<td>M’bubnagar</td>
<td>Ground nut</td>
<td>IMD</td>
<td>Deficit Rainfall</td>
<td>0.5</td>
<td>1</td>
<td>125</td>
<td>3000</td>
<td>325</td>
</tr>
<tr>
<td>KBS LAB</td>
<td>Atmakur, M’bubnagar</td>
<td>Castor</td>
<td>Mandal Station</td>
<td>Deficit Rainfall</td>
<td>40</td>
<td>24</td>
<td>10000</td>
<td>240000</td>
<td>5760</td>
</tr>
<tr>
<td>KBS LAB</td>
<td>Narayanpet, M’bubnagar</td>
<td>Castor</td>
<td>Mandal Station</td>
<td>Deficit Rainfall</td>
<td>105</td>
<td>73</td>
<td>21000</td>
<td>630000</td>
<td>182385</td>
</tr>
<tr>
<td>KBS LAB</td>
<td>M’bubnagar</td>
<td>Castor</td>
<td>IMD</td>
<td>Deficit Rainfall</td>
<td>127.5</td>
<td>74</td>
<td>19125</td>
<td>765000</td>
<td>44625</td>
</tr>
<tr>
<td>KBS LAB</td>
<td>Atmakur, M’bubnagar</td>
<td>Castor</td>
<td>Mandal Station</td>
<td>Excess Rainfall</td>
<td>16</td>
<td>14</td>
<td>3200</td>
<td>960000</td>
<td>24000</td>
</tr>
<tr>
<td>BSFL</td>
<td>Khammam</td>
<td>Cotton</td>
<td>IMD</td>
<td>Deficit Rainfall</td>
<td>42</td>
<td>25</td>
<td>8820</td>
<td>315000</td>
<td>18270</td>
</tr>
<tr>
<td>BSFL</td>
<td>Hindupur, Anantapur</td>
<td>Ground nut</td>
<td>Mandal Station</td>
<td>Deficit Rainfall</td>
<td>160</td>
<td>83</td>
<td>44000</td>
<td>960000</td>
<td>0</td>
</tr>
<tr>
<td>KBS LAB</td>
<td>Narayanpet, M’bubnagar</td>
<td>Castor</td>
<td>Mandal Station</td>
<td>Deficit Rainfall</td>
<td>45</td>
<td>45</td>
<td>12375</td>
<td>270000</td>
<td>31050</td>
</tr>
<tr>
<td>SERP</td>
<td>Hindupur, Anantapur</td>
<td>Ground nut</td>
<td>Mandal Station</td>
<td>Deficit Rainfall</td>
<td>408.5</td>
<td>320</td>
<td>114380</td>
<td>2451000</td>
<td>0</td>
</tr>
</tbody>
</table>

Source: Virat Divyakirti, Manager of Weather Products, ICICI Lombard, Mumbai
In autumn 2004 CRMG commissioned a baseline survey to be conducted for the World Bank by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) in Hyderabad to ascertain the overall farmer feedback of the first two years of weather insurance. The survey involving 600 farmers, some of whom have been involved in both pilot programs, will be used as base from which the impact, efficiency, and acceptability of the weather insurance concept can be measured. The results expected in early 2006 are anticipated to give strong guidelines and direction for future weather insurance programs in India, particularly regarding the issues of scalability and sustainability of such initiatives. The results are also expected to give an indication of how these new products play a role in the overall rural finance framework, with particular emphasis on access to credit and credit repayment by farmers.

The Future for BASIX Weather Insurance
In 2004 a number of other transactions also took place within the Indian private sector in response to the 2003 pilot. In 2004 for the first time, BASIX bought a crop loan portfolio insurance policy based on weather indexes. BASIX used this protection to cover their own risk and passed neither the cost nor the benefits to their farmers. The protection allowed BASIX to keep lending to drought-prone
areas by mitigating default risk through the insurance policy claims in extreme drought years. BASIX bought a policy to cover three business locations, which was insured by ICICI Lombard and then reinsured into the international weather market.

In 2005 BASIX scaled-up the weather insurance program for farmers, extending the projects to all of their branches in seven Indian states for kharif 2005, with a sales target of ten thousand policies. In the end BASIX sold 7,685 policies to 6,703 customers in 36 locations in six Indian states during the 2005 monsoon season. The new policies featured a dynamic contract start date determined by a rainfall trigger and minimum and maximum limits to the rainfall counted (for example, rainfall below two millimeters per day is not counted). In addition, BASIX simplified and largely automated the underwriting process, which is why BASIX could roll out weather insurance to every branch. Intense training sessions with loan officers, who became literally one-stop-shop, full customer service agents, allowed BASIX to service a large array of rainfall insurance products. At the same time, the policies became more general “monsoon failure” policies, meaning they were area-specific rather than crop-specific products, targeting general livelihood losses of farmers that have diversified agricultural portfolios at risk to weather, rather than losses associated with yield variations of a specific crop. For the first time BASIX also worked with another insurance provider, NAIC, as well as ICICI Lombard, to sell weather insurance policies in some locations. In 2005 over 70 new automated weather stations were installed throughout India by private company Delhi-based National Collateral Management Services Limited (NCMSL) in partnership with ICICI Lombard, on which weather insurance contracts were written, including many BASIX contracts. By establishing stations closer to the farmers, BASIX had more reliable automatic stations as settlement bases for their contracts and more accurate products for their farmers. NCMSL plans to scale-up their installations throughout the country with more insurance provider partners in 2006, which will benefit end users like BASIX in subsequent seasons.

The ultimate goal of BASIX is to offer weather-indexed loans to their borrowers. For example, BASIX can package a loan and a weather insurance contract (Hess, 2003), based on the drought indexes described above, into one product—a weather-indexed groundnut production loan, for instance. The farmer would enter into a loan agreement with a higher interest rate that accounts for the weather insurance premium that BASIX would pay to the insurer. In return, the farmer will not repay all the dues in case of a drought as defined by the index. In case of a moderate drought, instead of paying the loan principal and interest, the farmer would repay the principal only; in the case of a severe drought he would only need to repay part of the principal. BASIX is also interested in making the
insurance available to landless laborers and self-help group women in its operating regions, whose livelihoods also suffer from the vagaries of the monsoon. In 2004, 300 women already bought a weather insurance policy from ICICI Lombard directly, traveling by train to Hyderabad.

During 2004 and 2005, not only did BASIX expand their weather insurance program, a number of other institutions, including the originator ICICI Lombard, began expanding the market for weather insurance in India. IFCCO-Tokio, a joint venture insurance company, launched weather insurance contracts similar to the 2003 contracts in 2004, selling over three thousand policies to farmers throughout India in 2004 and over sixteen thousand in 2005. In conjunction with ICICI Lombard, the government of Rajasthan launched a weather insurance program for farmers for the 2004 growing seasons, insuring 783 orange farmers from insufficient rainfall in kharif 2004 and 1036 coriander farmers in rabi 2004; this was scaled up to include more crops and farmers in 2005. The NAIC, responsible for the government-sponsored area-yield indexed crop insurance scheme, also launched a pilot weather insurance scheme for twenty districts throughout the country in 2004, reaching nearly 13,000 farmers; the scheme was even mentioned in the government of India budget for the financial year 2004 to 2005. In 2005, NAIC sold weather insurance to approximately 125,000 farmers throughout India. In the same year ICICI Lombard scaled up its agricultural weather insurance sales, reaching approximately 100,000 farmers, and expanded into other economic sectors. New insurance providers such as HDFC Chubb also entered the market in 2005. In total it is estimated that during kharif 2005 250,000 farmers bought weather insurance throughout the country. Given this strong level of interest and the potential size of the end user market, agriculture weather risk management in India is set to grow (Divyakirti, 2004).

Weather Insurance for Agriculture in Ukraine

Historically known as a breadbasket for millions, the Ukraine has a large agriculture sector with almost 40,000 private farmers and 16,100 commercial farms producing a variety of products, including cereals, corn, beets, oilseeds and livestock products. Ukraine is one of the biggest grain and oilseed producers in the world and the agricultural sector is of great importance for the national economy: agriculture accounts for 14 percent of the country’s GDP. For their production Ukrainian farmers face multiple perils, such as drought, excess rain, and frost, which make their incomes unpredictable and limit their access to credit.

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46 This section on Ukraine is from Hess et al., 2005.

47 As of 2003; Source: World Development Indicators database, August, 2004.
The International Finance Corporation\(^{48}\) Partnership Enterprise Projects (IFC-PEP) in Kiev has been working in southern oblast\(^{49}\) of Kherson since March, 2001, as part of their Agribusiness Development Project in Ukraine. Farmers, agribusinesses, and finance institutions working with IFC-PEP indicate that the largest risk to crop production in the oblast is weather, namely drought in spring and summer, and low temperatures in winter. Traditional multi-peril products offered by local insurance companies somewhat addressed winter risks, but drought cover was excluded from the insurance products that were available to farmers. In addition, the insurance companies did not have the professional staff with the agricultural expertise nor the infrastructure necessary to offer comprehensive agricultural insurance products. Consequently the farmers did not trust the insurance companies and the policies offered. High administrative costs and asymmetry of information further compounded these problems, rendering the agricultural insurance system in the country ineffective.

In 2001 the World Bank introduced the concept of index-based weather insurance to Ukraine in collaboration with IFC-PEP. The concept of weather insurance appeared particularly feasible in Ukraine because of a widespread system of 187 weather stations, eight in Kherson, and the excellent quality of data. After extensive consultations with the farmers, local authorities, and agricultural scientists, IFC-PEP decided to investigate the feasibility of weather insurance in the southern oblast of Kherson. In order to reach the acceptable volume of contract sales, IFC-PEP decided that the weather pilot project should concentrate on the most important crops to farmers in the region that are susceptible to weather risk. Potential crops included winter wheat, spring barley, sunflower, and corn. Of these, winter wheat has the biggest planted area and considerable value at risk, 1.5–2 million tons is produced in the oblast annually with an approximate crop value of US$200 million, and, in addition, most of this crop is cultivated without irrigation. Furthermore, financial institutions in the oblast had recently started to accept standing crops of grain as security for agricultural loans despite concerns over lack of sufficient insurance protection.

With this basis in 2004, the CRMG together with IFC-PEP Agribusiness Development Project agreed to run a small pilot project for the Kherson oblast in spring 2005.

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\(^{48}\) The IFC is part of the World Bank Group.

\(^{49}\) An oblast is an administrative territorial division within Russia and other former Soviet republics, including Ukraine.
The Kherson Oblast

The Kherson oblast is situated in the southern steppe of Ukraine. The climate of the southern steppe belongs to the Atlantic continental climate and is distinguished by its drastic continentality and dryness vis-à-vis other zones of Ukraine.

Winter wheat is one of the dominant grain crops in the region and the main grain crop in the country. The life cycle of winter wheat consists of the following phenological stages: germination, sprouting, bushing, leaf-tube formation, earing, flowering, and ripening (milk, wax, and full ripeness). Each development phase is connected to morphological changes in the plant physiology and has its own weather requirements for optimum growth. In several years, the agro-climatic resources of the Kherson oblast fall short of these requirements. A cursory glance at winter wheat yield data for the Kherson oblast shows that there is significant interannual variability in yield in the region (Figure 3.3.5), which reflects the agro-climatic risk inherent to the oblast.

Informal interviews with winter wheat farmers in the region indicate the greatest perceived risk for wheat production is drought followed, in order of importance, by frost, storm/hail, and finally fire. Pest attack is considered a manageable risk.
by most farmers. Hence, it is clear there is potential for an index-based weather insurance pilot in the region.

**Designing the Index**

It is generally accepted that the reported yield data, available from the Ukrainian Statistics Office, differ significantly from actual yields collected by farmers throughout the country. There are significant political and economic incentives for both farmers and officials to under- or over-report production and planting data, particularly since independence in the early 1990s. Therefore historical yield data for Kherson are unreliable (not reported accurately) for the purposes of index construction, as it does not faithfully represent the actual production in the rayons (sub-regions) of the oblast. In order to design an effective weather risk management instrument, key weather factors will need to be discussed with experts, such as agro-meteorologists and farmers, and crop models that use weather variables as inputs for yield estimates must be used. To this end, a report (Adamenko, 2004) was commissioned by the CRMG and ICF-PEP from the Ukrainian Hydrometeorological Center (UHC) in Kiev to assess the agro-climatic conditions and weather risks for growing winter wheat in the Kherson oblast. In the absence of reliable yield data, the results from the report based on the UHC oblast-specific crop model and expert assessment will be used as the basis for constructing an appropriate weather index for winter wheat in Kherson.

**Identified Weather Risks**

According to the UHC report (Adamenko, 2004) the most significant weather risks for the growing of winter wheat in the Kherson oblast are: 1) Winterkill during the crop’s hibernation period from December to March; 2) Moisture stress during the vegetative growth period from mid-April to June.

Winter wheat yields at harvest depend to a great extent on how well the plants survive the winter and the hibernation period. In the territory of Kherson, winter wheat winter crops die primarily as a result of air temperature and therefore soil temperatures falling below a critical level for one day or longer. These winterkill events cause damage and death of the plants’ tillering node. Snow cover considerably improves conditions of winter wheat hibernation, as the difference between air and soil temperature increase by 0.5 to 1.1°C per each centimeter of snow cover. The crop usually dies in years with no snow cover or where the stable snow cover appears late in winter, such as in 2003.

The other main limiting factor for high winter wheat yields in the Kherson oblast is moisture. Lack of moisture in the soil and air during the vegetative growth period are the main causes of low winter wheat yields. In particular, all five rayons of the oblast are subject to frequent droughts; the probability of a severe and medium drought (defined subsequently) during the vegetative period in the
region is 15–20 percent and 40–50 percent, respectively. The first critical period in which winter wheat yield formation is highly susceptible to moisture stress is the leaf-tube formation to earing phase. According to the climatic conditions of the region this period lasts from April 15 to May 25. The water requirements for winter wheat during this stage, when compared to the climatic conditions for this period for the oblast, are estimated to be 80 percent of the optimum by the UHC. During the most recent years in 50 percent of cases moisture conditions during this period were close to optimum (1998, 1999, 2001) while in the other 50 percent of cases they were insufficient (in 2000, 2002, and 2003). The second critical period for winter wheat is the earing to milk ripeness stage, which is the kernel formation phase and lasts, on average, from May 22 to June 14, but can extend later into June. Lack of moisture during this period directly decreases the number of kernels in a wheatear and leads to excessive drying of the kernels. The water requirements for winter wheat during this stage, when compared to the climatic conditions for this period for the oblast, are estimated by the UHC to be 90 percent of the optimum.

These findings indicate that two products must be available in order to sufficiently protect winter wheat farmers purchasing weather insurance in the Kherson oblast. As mentioned previously, during the growing season 2004/2005, winterkill insurance (based on traditional methods of loss adjustment) was offered in the oblast by several insurance companies. This is a welcomed development by the farmers; however, drought protection is still not available. Therefore an index to capture drought risk from mid-April to June must be designed in order to address the disparity between the products currently offered and identified production risks faced by the farmers. An example of a product that has been suggested for Kherson oblast is outlined below.

The Selyaninov Hydrothermal Ratio Index (SHRI)\textsuperscript{50}

There are two types of agricultural drought: air drought and soil drought. Air drought describes conditions where precipitation is low and high air temperature persists against the background of low relative air humidity. It leads to unfavorable conditions for plant vegetation and drastically reduces crop yields. Soil drought describes the excessive dryness of soil, resulting in a scarce supply of moisture available for crop growth and development. Air drought, which is characterized by long rainless period, high air temperature, and low air humidity, is often characterized by using the Selyaninov Hydrothermal Ratio (SHR). For the vegetative growth period for winter wheat in Kherson, April 15–June 30, the SHR is defined as follows:

\textsuperscript{50} Information on SHR is from Adamenko, 2004.
\[
SHR = \frac{\sum_{15\text{ April-June}}\text{Daily Rainfall}}{0.1 \times \sum_{15\text{ April-June}}\text{Average Daily Temperature}}
\]

It holds for periods when daily averages temperatures are consistently above +10°C. This period on average begins from April 15 in the Kherson oblast. The SHR does not always serve as a reliable criterion of agricultural drought because it does not take soil moisture into account, but because generally this is not an observed variable, while rainfall and average temperature are, it is the only objective indicator that can be used to capture drought risk during the vegetative period.

Conditions for obtaining the best harvest are when the SHR = 1.0–1.4. When the SHR is greater than or equal to 1.6, plant yields will be depressed by excessive moisture. When the SHR is less than or equal to 0.6, plants are depressed by drought conditions. In general, the isoline SHR = 0.5 coincides with regions of semi-desert climate conditions. Results from the UHC crop model (Adamenko, 2004) that suggest the impact of SHR during the vegetative growth stage April 15–June 30 on yields are defined in Table 3.3.11.

<table>
<thead>
<tr>
<th>SHR</th>
<th>Description</th>
<th>Yield Loss (%)</th>
<th>SHR</th>
<th>Description</th>
<th>Yield Loss (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.6</td>
<td>Excessive Humidity</td>
<td>30+</td>
<td>&lt; 0.7</td>
<td>Drought Conditions</td>
<td>-</td>
</tr>
<tr>
<td>1.3–1.6</td>
<td>Damp</td>
<td>-</td>
<td>0.5–0.6</td>
<td>Medium Drought</td>
<td>20</td>
</tr>
<tr>
<td>1.2–1.0</td>
<td>Sufficient Humidity</td>
<td>-</td>
<td>0.4–0.5</td>
<td>Severe Drought</td>
<td>20–50</td>
</tr>
<tr>
<td>0.9–0.7</td>
<td>Dry</td>
<td>-</td>
<td>&lt; 0.4</td>
<td>Extreme Drought</td>
<td>50 +</td>
</tr>
</tbody>
</table>

Source: Adamenko, 2004

Therefore the SHR can be used as an index to monitor the impact of air drought on winter wheat crop yields.

Quantifying the Impact of Weather

In order to calibrate an indexed-based weather insurance contract to the financial losses experienced by a farmer as a result of weather, there are two aspects that need to be quantified: 1) The limit, also called the sum insured, of the contract, i.e., the maximum protection required per risk period; and 2) The payout rate, i.e., the farmer’s weather exposure per unit of the defined index.
There are two possible levels for weather insurance protection that can identify the appropriate limit for a weather insurance contract: 1) Production Costs, 2) Expected Revenue. The former, in general, is more appropriate for catastrophic weather risks earlier in the growing season, such as winterkill, when the farmer has an opportunity to re-sow another crop for summer harvest if his winter wheat crop is completely destroyed. The latter is, in general, more appropriate for weather risks later in the growing season, when there is no opportunity for re-sowing, yet when yield can vary significantly from the expected levels, for example, as a result of April–June drought. However, the choice depends on the preferences of the farmer. Informal interviews with farmers in the oblast indicate that farmers are less concerned with winterkill risk than with drought risk, despite that fact it can potentially cause complete damage, because of the re-sowing potential.

Winter wheat farmers spend a maximum of (Ukrainian Hryvna) UAH 1000 per hectare in production and inputs costs during the entire growing season of the crop. The limit of a mid-April–June drought insurance contract to cover production and input costs should by set at UAH 1000 per hectare insured. For example, in the event of total crop failure as a result of a very extreme drought (e.g., a SHR < 0.15 event) the farmer would be indemnified for UAH 1000 per hectare insured to compensate for the loss of the investment. The payout rate of the insurance contract can be determined from the information in the UHC report and are summarized in Table 3.3.12.

### Table 3.3.12 Relationship Between SHR and Financial Losses Associated with Winter Wheat Yield Fluctuations

<table>
<thead>
<tr>
<th>SHR</th>
<th>Payout per Hectare</th>
<th>SHR</th>
<th>Payout per Hectare</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.6–0.51</td>
<td>UAH 200 (20% loss)</td>
<td>0.3–0.26</td>
<td>UAH 700 (70% loss)</td>
</tr>
<tr>
<td>0.5–0.46</td>
<td>UAH 300 (30% loss)</td>
<td>0.25–0.21</td>
<td>UAH 800 (80% loss)</td>
</tr>
<tr>
<td>0.45–0.41</td>
<td>UAH 400 (40% loss)</td>
<td>0.2–0.16</td>
<td>UAH 900 (90% loss)</td>
</tr>
<tr>
<td>0.4–0.36</td>
<td>UAH 500 (50% loss)</td>
<td>&lt; 0.15</td>
<td>UAH 1000 (100% loss)</td>
</tr>
<tr>
<td>0.35–0.31</td>
<td>UAH 600 (60% loss)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: Adamenko, 2004

For example in the event of a partial crop failure as a result of a bad drought (e.g., a SHR = 0.39 event) the farmer would be indemnified for 500 UAH per hectare insured to compensate for the 50 percent loss in yield and hence his investment. In the event of an extreme drought (e.g., a SHR = 0.2 event), the farmer would be indemnified for 900 UAH per hectare insured to compensate for the 90 percent loss in yield.
Calculating the limit and payout rate for a contract to protect farmer revenue is a little more difficult as harvest-time commodity prices are not known in advance when the insurance is purchased. Furthermore, commodity prices also often vary in response to extreme production shocks and it is often difficult to quantify the production (weather) price correlation. However, estimates for the harvest-time price can be made, e.g., last year’s harvest-price or the five-year average of the September price from the local commodities exchange could be used as a best estimate, or the government minimum support price could be used as a lower-bound for the selling price.

For example, if a fair estimate of the September price is 700 UAH per ton based on prices in previous years and if a farmer’s expected yield is 3.5 tons per hectare, then as profit he expects to make approximately 2450 UAH per hectare less his production costs at harvest, or 1450 UAH per hectare profit. Therefore, in order to protect this profit, a farmer could buy a weather insurance contract in March for a sum insured of 1450 UAH per hectare. Based on discussions with farmers however most would be interested in buying weather insurance contracts to cover their production and input costs in the first year of the pilot.

Structuring a Weather Insurance Contract

The Sum Insured
In order to ensure that the insurance product has some relationship with the true risk exposure of the farmer, the limit of the insurance contract is negotiable with the farmer; however, it cannot exceed a maximum estimated by the potential insured loss to the farmer as outlined in above. For example, if production/input costs are 1000 UAH per hectare at the end of the growing season a farmer cannot insure himself for 2000 UAH per hectare to cover these costs. Furthermore, the farmer cannot buy winter wheat insurance for more hectares than he farms. In the design of the contract, an upper limit on the risk volume per client will be set at the total area of the crop planted multiplied by the expected selling price, determined as mentioned above by either last year’s selling price according to records, the five year average, or the government’s minimum support price. One way the insurer can do this is to ask for a copy of the State Statistics Agriculture Report No. 29 that all the farmers should provide to the Statistics Service. This document is also used for allocating government subsidies to farmers and can be used as a basis to consider index contracts valid and sufficient for the regulator from supervisory point of view. The farmer and insurer should be liable for correctness of the reported hectarage of the crop.

Contract Specifications
As outlined in Chapter 2, in addition to defining the index, the buyer/seller information (names, crop, and hectarage insured), limit, and tick size, an index-based weather insurance contract must also include the following information:
Risk Management in Agriculture for Natural Hazards
Chapter 3  Case Studies for Agricultural Weather Risk Management
Hector Ibarra and Joanna Syroka

• Location—the weather station at which the weather variables used to construct the index are measured and recorded
• Calculation period—the risk protection period of the contract
• Strike—the index level at which weather protection is triggered
• Premium—the cost of the insurance per hectare insured

In the case of Ukraine, index-based insurance contracts must be written on the nearest UHC weather station to the farmer’s land in order to provide the best possible coverage for the farmer client. Indeed, the extent of the UHC weather observation network may be a limiting factor for the applicability of this type of insurance in regions that do not have a UHC station. The correlation coefficients for the interannual variation in cumulative rainfall, cumulative average temperature and SHR for April 15–June 30 from 1973–2002 for five weather stations in the oblast are given in Table 3.3.13.

Table 3.3.13 Correlation Coefficients for the Interannual Variability of Cumulative Rainfall, Average Temperature, and the SHR Index Measured at Five UHC Weather Stations in Kherson Oblast

<table>
<thead>
<tr>
<th>Station Name</th>
<th>Behtery</th>
<th>Genichesk</th>
<th>Kherson</th>
<th>N Kahowka</th>
<th>N Sirogozy</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Behtery</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>46°15′ N 32°18′ E</td>
</tr>
<tr>
<td>Genichesk</td>
<td>0.72</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td>46°10′ N 34°49′ E</td>
</tr>
<tr>
<td>Kherson</td>
<td>0.74</td>
<td>0.59</td>
<td>1</td>
<td></td>
<td></td>
<td>46°38′ N 32°34′ E</td>
</tr>
<tr>
<td>N Kahowka</td>
<td>0.70</td>
<td>0.41</td>
<td>0.65</td>
<td>1</td>
<td></td>
<td>46°49′ N 33°29′ E</td>
</tr>
<tr>
<td>N Sirogozy</td>
<td>0.35</td>
<td>0.54</td>
<td>0.39</td>
<td>0.50</td>
<td>1</td>
<td>46°51′ N 34°24′ E</td>
</tr>
<tr>
<td>Behtery</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>46°15′ N 32°18′ E</td>
</tr>
<tr>
<td>Genichesk</td>
<td>0.93</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td>46°10′ N 34°49′ E</td>
</tr>
<tr>
<td>Kherson</td>
<td>0.98</td>
<td>0.93</td>
<td>1</td>
<td></td>
<td></td>
<td>46°38′ N 32°34′ E</td>
</tr>
<tr>
<td>N Kahowka</td>
<td>0.98</td>
<td>0.95</td>
<td>0.99</td>
<td>1</td>
<td></td>
<td>46°49′ N 33°29′ E</td>
</tr>
<tr>
<td>N Sirogozy</td>
<td>0.95</td>
<td>0.95</td>
<td>0.98</td>
<td>0.98</td>
<td>1</td>
<td>46°51′ N 34°24′ E</td>
</tr>
</tbody>
</table>

(Continued)
Table 3.3.13 Correlation Coefficients for the Interannual Variability of Cumulative Rainfall, Average Temperature, and the SHR Index Measured at Five UHC Weather Stations in Kherson Oblast

<table>
<thead>
<tr>
<th>Station Name</th>
<th>Behtery</th>
<th>Genichesk</th>
<th>Kherson</th>
<th>N Kahowka</th>
<th>N Sirogozy</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Behtery</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>46°15′ N 32°18′ E</td>
</tr>
<tr>
<td>Genichesk</td>
<td>0.72</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td>46°10′ N 34°49′ E</td>
</tr>
<tr>
<td>Kherson</td>
<td>0.74</td>
<td>0.59</td>
<td>1</td>
<td></td>
<td></td>
<td>46°38′ N 32°34′ E</td>
</tr>
<tr>
<td>N Kahowka</td>
<td>0.74</td>
<td>0.44</td>
<td>0.68</td>
<td>1</td>
<td></td>
<td>46°49′ N 33°29′ E</td>
</tr>
<tr>
<td>N Sirogozy</td>
<td>0.38</td>
<td>0.58</td>
<td>0.42</td>
<td>0.50</td>
<td>1</td>
<td>46°51′ N 34°24′ E</td>
</tr>
</tbody>
</table>

Source: Authors

A very loose rule-of-thumb is that farmers living within a 30km radius of the weather stations are able to purchase weather insurance for that station. Temperature exhibits less spatial variability than rainfall. The benefit of the SHR index is that by combining cumulative rainfall with temperature, the spatial variability of the index, in comparison to cumulative rainfall alone, is slightly reduced.

In this example, the calculation period for the SHR drought insurance contract is April 15–June 30 to cover the leaf-tubing to kernel formation growth period of winter wheat. Final settlement of the weather insurance contracts typically would occur up to 45 days after the end of the calculation period, once the collected weather data have been crosschecked and quality controlled by the UHC. The strike would be set at a predefined SHR level, appropriate to the weather station under consideration. A pricing example for winter wheat drought risk is given below for Behtery weather station.

Example: Pricing Drought Risk as Measured by the SHR Index

In Behtery, droughts of varying intensity happen quite frequently. Although irrigation is partially used by farmers in this area, farmers have expressed an interested in products that protect against extreme drought. Figure 3.3.6 shows the cumulative average temperature and cumulative daily rainfall measured at the Behtery station from April 15–June 30, 1973–2002.
The temperature data exhibit strong trends, hence the data must be detrended in order to make the historical data consistent with the recent warmer conditions, which may make severe drought events more frequent in Behtery now than 30 years ago. The weather data from the UHC are of high quality and do not need to be cleaned or quality controlled prior to analysis. The data are detrended by fitting and removing a best-fit least mean square linear trend to the cumulative average temperature totals for April 15–June 30 (see Chapter 2, Section 4). Figure 3.3.7 shows the corresponding SHR index: medium droughts (SHR < 0.6) have occurred nine times in the past 30 years and severe droughts (SHR < 0.4) two times. The driest conditions occurred in 1996 with SHR = 0.21.
The payout of a SHR index insurance contract at Behtery is determined by the following equation:

\[ Payout = \min(\max(0, K - SHR) \times X, M) \]

where \( K \) is the strike, \( SHR \) is the SHR index measured during the calculation period, \( X \) is the payout rate, determined by the structure of the contract and \( M \) is the limit of the contract. A reasonable estimate for the risk loading factors \( \alpha \), \( \beta \) given prices in the weather market are \( \alpha = 25\% \) and \( \beta = 5\% \). By simply taking the 30 years of payouts in Figure 3.3.7, the payout statistics for a weather insurance contract with a strike level of \( SHR = 0.4 \), can be calculated: \( E(SHR) = UAH 70 \), \( \sigma(SHR) = UAH 220 \) and \( VaR_{0.97}(SHR) = UAH 800 \). Therefore, a first-order estimate of an appropriate premium to charge a farmer for an insurance contract with a strike level of \( SHR = 0.4 \) at Behtery weather station is between UAH 110–125 per hectare for a sum insured of UAH 1000.\(^{51}\) (See Figure 3.3.8 for an example of prototype contract for Behtery).

\(^{51}\) See Chapter 1, Section 3 for details regarding the pricing of weather insurance contracts.
### Figure 3.3.8 Sample Contract for Behtery Weather Station

| **Buyer:** | Farmer Z  
1 Wheat Street, Behtery, Kherson, UA |
| **Seller:** | ABC Insurance Company |
| **Hectares of Winter Wheat Insured:** | 100 Hectares |
| **Calculation Period:** | April 15, 2005–June 30, 2005 (inclusive) |
| **Location:** | Behtery Weather Station |
| **Index, SHR:** | SHR = Index 1 / (Index 2 * Scaling Factor)  
*Where:*
- **Index 1** = Cumulative Capped Daily Rainfall measured during the Calculation Period at Location. Measuring Unit: mm  
- **Index 2** = Cumulative Daily Average Temperature measured during the Calculation Period at Location. Measuring Unit: Degrees Celsius  
- **Scaling Factor** = 0.1 |
| **Capped Daily Rainfall:** | Capped Daily Rainfall = min(50, Daily Rainfall Total)  
Measuring Unit: mm |
| **Strike, K:** | 0.4 |
| **Maximum Payout, M:** | UAH 1000 per Hectare Insured |
| **Settlement Calculation:** | 1) If the Index SHR is greater than the Strike K no payment is made.  
2) If the Index SHR is less than or equal to the Strike K the Buyer receives a payout X per hectare insured from the Seller according to the following Settlement Calculation:  
   - If $0.36 < \text{max}(K - \text{SHR}, 0) < 0.41$, $X = \text{UAH} 500$  
   - If $0.31 < \text{max}(K - \text{SHR}, 0) < 0.36$, $X = \text{UAH} 600$  
   - If $0.26 < \text{max}(K - \text{SHR}, 0) < 0.31$, $X = \text{UAH} 700$  
   - If $0.21 < \text{max}(K - \text{SHR}, 0) < 0.26$, $X = \text{UAH} 800$  
   - If $0.16 < \text{max}(K - \text{SHR}, 0) < 0.21$, $X = \text{UAH} 900$  
   - If $\text{max}(K - \text{SHR}, 0) < 0.16$, $X = \text{UAH} 1000$ |
| **Maximum Settlement:** | The maximum payment that can be made from the Seller to the Buyer is UAH 100,000. |
| **Premium:** | The Buyer will pay the Seller a premium of UAH 12,000 for the weather protection outlined above. |
| **Settlement Data:** | Ukrainian Hydrometeorological Center, Kiev |
| **Settlement Date:** | Within 45 days of the end of the Calculation Period. |

Source: Authors
The 2005 Pilot in Kherson

According to Ukrainian legislation, in order to be able to introduce a new product, such as index-based weather insurance, to the market the participating company (or companies) must design and register the rules of insurance with the state regulatory body. Although the law on insurance—the leading document regulating the insurance industry—does not specifically reference "index" insurance, other legislative documents introduce index-based products in relation to agricultural applications, for example relating to agricultural insurance and state finance support of the agricultural sector. As a result there was no direct legislative barrier prohibiting the use of index-based products in Ukraine and in April, 2005 the regulator agreed to register rules of insurance that permit the development of different types of index-based insurance products for agribusiness applications.

The insurance company partner, Kiev-based Credo Classic, working with IFC-PEP and CRMG submitted the necessary package of documents to the regulator in Kiev, in doing so drafting and registering the rules of insurance for index-based weather insurance products with the regulating body. The rules of insurance were accepted at the beginning of April, 2005, clearing the way for the first weather insurance pilot in Ukraine. The regulator confirmed that given the nature of the product the insurer is not required to carry out field checks and loss adjustments, despite the potential of basis risk. The regulator further stated that the insured area must not be greater than the seeded area and, for the purpose of this product, a farmer report declaring the seeded area should be sufficient proof of the maximum possible area for insurance.

The weather insurance contract designs and marketing materials for the proposed pilot program in Kherson were finalized following the State Regulator approval of the rules of weather index insurance for agricultural applications. IFC-PEP worked with the insurance partner in Kherson oblast to target groups—including farmers, agribusinesses and financial institutions—who could benefit from the new insurance products through feedback and workshop sessions. Only two weather insurance contracts protecting against drought were sold during the brief marketing period, primarily due to the timing of the pilot and late regulatory approval. The protection period for the first pilot ended in July, 2005. The results of the small first pilot have been communicated to the public to raise awareness about index insurance and the pilot experience: the concept and methodologies developed have been made publicly available. At the present time the insurance company leading the pilot in Kherson is already providing consultations to other markets players in Ukraine on designing index-based products in-house and drafting the rules of insurance for these new products. There are also plans to scale up weather insurance activities to more crops and more regions in 2006.
APPENDIX

GRASSLAND INDEX INSURANCE USING SATELLITE IMAGERY

This appendix will discuss the use of satellite imagery in creating useful indexes to insure grassland following a parametric and objective procedure, presenting two of the most relevant experiences in the world dealing with this kind of parametric insurance: Canada and Spain.

Extensive livestock production relies very heavily on the availability of grassland to feed the cattle. Whenever grassland is not available in sufficient quality and quantity, livestock producers are forced to buy supplementary industrialized fodder for feeding the cattle. This increase in inputs can create a considerable differential in their cost structure and therefore can pose some threat to the profitability of the business when adverse weather decreases the availability of grassland.

Technically speaking, any product of insurance offering coverage for deviations in availability of grassland is an agriculture insurance program. The main challenge relies on the fact that traditional statistical information related to historical yields is very scarce (if not non-existent in most places) and therefore there is difficulty in evaluating the actual yield for insurance purposes. Therefore the design of an insurance program for grassland faces important challenges on several fronts: design, pricing, loss, and evaluation.

Given the importance of the livestock sector in agrarian economies, several initiatives have been tested at the international level with limited impact and very high transaction costs involved. Some of the experiences include the use of “in-field” yield clippings at selected sites, through the use of metal cages that were set up to exclude cattle grazing. The undisturbed pasture was “clipped” by field inspectors at the end of the growing season. Under this scheme, the clipped pasture samples from each site were bagged, identified, and sent for dry matter analysis at a laboratory facility. Results from each cage site were averaged within a nine-township block area to determine annual production. These were then compared to normal production estimates for the same area. If annual production was less than a set percentage of normal production, insurance payments would be made to insured farmers. Nevertheless, the procedure was considered too complicated for farmers and the payment schedule was considered nontransparent.
Additionally, there have been other interesting experiences in grassland insurance. During the 1980s, the crown financial corporation in Alberta (Canada) operated an insurance product based on a numeric model that estimated the actual growth of grassland based on measurements of rainfall, temperature, and hours of sunlight (measured by the weather service). If the annual production of pasture calculated at a township level fell below the 25-year normal level, a payment would be made to the insured farmers relative to the severity of the production loss. Several attempts were done to upgrade the scheme but it was finally cancelled in 1990 based on high losses and on the perception of complexity from the farmers, as well as their perception that the model results did not reflect their on-farm pasture production.

In recent times, the availability of new technology, like satellite imagery has sparked the introduction of new initiatives to insure grasslands. The most common technical justifications for the adoption of satellite imagery (SI), as the principle of area yield type of insurance, are the following: 1) SI can measure pasture health and growth and represents a multi-peril insurance approach; 2) SI can economically reduce the size of the area on which pasture growth and potential insurance payments are based, thereby reducing basis risk compared with other approaches (i.e., cage clipping alternative), 3) SI can assess pasture conditions throughout the growing season and thereby lends itself to “intra-seasonal coverage options.” This appendix will discuss the use of satellite imagery in creating useful indexes to insure grassland following a parametric and objective procedure. In addition, this appendix will discuss two of the most relevant experiences in the world dealing with this kind of parametric insurance: Canada and Spain.

**Use of the Normalized Difference Vegetation Index (Ndvi) for Insurance Purposes**

One of the satellite networks with more information available for these purposes comes from the NOAA satellite. The NOAA satellite has blue, green, red, infrared, and thermal sensors and takes one image per day for every 1km by 1km segment of the earth’s surface. The NDVI is a type of vegetative index based on the relationship between red light and near-infrared light. Healthy vegetation absorbs the red light from the sun and uses it for photosynthesis while reflecting near-infrared light from the sun. The formula used to calculate the NDVI is given by:

\[
NDVI = \frac{(NIR - \text{“Red”})}{(NIR + \text{“Red”})} \quad (1)
\]

where NIR is near-infrared light and “Red” is red light. The more red light that is absorbed by the plants, the smaller the amount of red light that is in turn reflected.
by the plant and recorded by the satellite and therefore the larger the NDVI value.

Another important input for the use of NDVI as index insurance is the design of an appropriate mask. A mask is simply a set of geo-referenced information that identifies specific land features that can be laid over the satellite imagery information. The overlaying of this information allows some of the satellite imagery to be extracted from the information file prior to making production assessments.

**Grassland Insurance in Alberta (AFSC Operated)**

In 2001 Alberta launched a pilot project using satellite imagery to define an historical “benchmark” production and assess annual pasture production. The pilot was limited to a geographical area of the province where pasture is the predominant land cover. An NDVI, scaled appropriately to reflect native pasture production, was calculated for each township in the pilot area. Insured farmers received payments according to a pre-determined payment schedule when the annual township NDVI fell below the historical benchmark NDVI for the township. The program was expanded slightly in 2002 to the portion of the province in which the 1km x 1km resolution (pixel image) of the NOAA satellite system was considered practical for pasture.

The mask used for the project selects only information that is known to be at least 85 percent native or improved pasture at a quarter-section level (160 acres). In the pilot area where satellite imagery insurance operated, a significant percentage, 80–90 percent, of the land is native pasture. However, there are areas of crop irrigation and some bush land that need to be extracted or they could significantly influence the program outcome. If a quarter section of land has irrigation, it is removed from the program dataset.

The process for calculating a township NDVI is given as follows:

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52 The information for this section is from AFSC, 2005.

53 The NOAA satellite system was used because historical satellite images were readily available. However, to be effective, any non-pastureland had to be excluded from the satellite images. With the 1km x 1km resolution of the satellite image, pastureland outside the pilot area is situated in smaller land parcels and within other crop and treed land. Moving beyond the pilot area, with this resolution, would dictate the exclusion of many pixels that do not meet the minimum pasture content criteria. Without a minimum number of pixel images, the sample size for a township production estimate is not credible.
The satellite(s)\textsuperscript{54} takes images once every day during the growing season;
An NDVI is calculated for each 1km x 1km image, with cloud cover removed, and scaled to identify variations in pasture observations to generate a pasture vegetative index (PVI);\textsuperscript{55}
The highest weekly PVI value for defined pasture land represents the 1km x 1km “pixel image” for the week;
All weekly “pixel image” PVI values within a township are averaged to get the weekly township PVI value.\textsuperscript{56} Both the “normal” township PVI value (the long-term production estimate)\textsuperscript{57} and the annual PVI value are calculated in this manner.

While there were ample data to calculate the PVI, there was little accurate “in-field” pasture information to judge whether the PVI actually correlated to pasture growth. Pasture production is not an accurately recorded crop—neither farmers nor AFSC have a good measuring technique to gauge absolute pasture growth. However, AFSC had operated in the past a cage clipping system that allowed them to obtain estimates of production. The availability of information allowed pursuing a statistical procedure to assess the efficiency of the index indicator to reflect the variations in volume of grassland, basically by comparing historical PVI values to pasture production trends over time and confirm any correlation with farmers.

The pasture production data were available for correlation comparisons from 1991 to 1999, from the cage clippings at designated and consistent sites. In

\textsuperscript{54} The NOAA satellite system comprises at least two satellites that are upgraded from time to time. Sensors are calibrated on the satellites to ensure consistent readings of light reflection from the earth’s surface.

\textsuperscript{55} The original NDVI values are scaled twice in order that variations in pasture production can be more readily identified. First, Statistics Canada uses the formula \(\frac{(A-B)}{A+B} + 1\) x 10,000 to provide the highest weekly township NDVI value to AFSC. Then AFSC applies a second scale to each weekly value to determine a weekly PVI value. The scale used to establish the “pasture vegetative index” or PVI is the scaled NDVI value minus (0.80 x the “normal” scaled NDVI).

\textsuperscript{56} A minimum of six pixels is required to determine a reliable township PVI. If this minimum is not available a PVI from the surrounding three-square township block, centered on the township without the minimum pixels, is used for the township with limited pixel information.

\textsuperscript{57} The “normal” township PVI value for 2003 is the simple the average of the annual township PVI values from 1987 to 2002.
addition, AFSC personnel compared satellite imagery to trends in precipitation measured at select Environment Canada weather stations. However, correlation results were not good (approximately \( r = 0.65 \)). Through a series of client meetings, AFSC asked farmers to identify their two best and two worst pasture production years in the last 15-year time period. Since a PVI value could be calculated for each township from 1987 to 2000, farmers could see whether the extreme PVI values compared to their recollections of historical pasture production trends. Production shortfalls due to drought and cool early season temperatures appeared to be identified in the historical PVI values. Geographical differences among township PVI values corresponded to the anecdotal production perceptions of farmers surveyed.

To augment the information acquired by satellite imagery, AFSC developed research plots throughout the pilot pasture area to measure rainfall, the growth of pasture under cages and to note changing pasture conditions over the growing season throughout the pilot area. In 2001, 30 research sites were selected. Rainfall, sub-soil moisture, and pasture growth under cages were measured monthly throughout the growing season. In addition, field personnel described the pasture conditions at each site with a species identification survey. Table 3.A.1 shows the results of correlation between satellite information and yields from cage clipping at research sites for 2002 and 2003.

**Table A.1 Correlation Coefficients \( (r) \) Between Clipped Yield and PVI Analyzed by Month and Region for 2001 and 2002**

<table>
<thead>
<tr>
<th>Region</th>
<th>2001</th>
<th>2002</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>May</td>
<td>June</td>
</tr>
<tr>
<td>Southeast</td>
<td>.582</td>
<td>.782</td>
</tr>
<tr>
<td>(n=11)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>East</td>
<td>.375</td>
<td>.526</td>
</tr>
<tr>
<td>(n=10)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Northeast</td>
<td>No data</td>
<td>.507</td>
</tr>
<tr>
<td>Southwest</td>
<td>No 2001 data</td>
<td></td>
</tr>
<tr>
<td>All</td>
<td>.503</td>
<td>.755</td>
</tr>
<tr>
<td>(n=31)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Pasture insurance is sold in the spring of each year, but farmers must make their purchasing decisions by the end of February. Farmers must insure all the acres of pasture within the same category—native, improved, or bush pasture—but a lower than normal PVI value in one township is not offset by a higher than normal PVI in another. Coverage and premium are expressed in dollars and derived by multiplying the pounds of pasture production expected in each forage risk area, as determined by AFSC, by 80 percent of one of the four price options available to the farmer. The premium rate for the 2003 native pasture insurance program was 21 percent. However, throughout Canada, premium for agriculture insurance programs is cost-shared by governments; the farmer pays approximately 40 percent of the total premium cost.

**Grassland Insurance in Spain**

The parametric insurance scheme in Spain was engineered mainly to cover farmers from droughts affecting the pasture areas. The index utilized is also the NDVI (estimated from NOAA images). The product has been offered since 2001 for all the farms performing extensive livestock production, specifically on the following species: cattle, sheep, horses, and goats. The insurance product is designed to cover the farmers experiencing more than 30 dry days (defined as based on the average historical information on pasture).

In contrast to the previous case study, the insurable index is based only on pure imagery, i.e., no verification with actual yields was performed. Therefore the index is constructed using an historical evolution of the pixels to create a curve, and the indemnity is defined when the actual observations in a particular year are located below the average curve, which is based on 18 years of data.

Also in contrast to the weekly NDVI values, this scheme is based on a 10-day period NDVI index. A Maximum Value Composite Index (MVCI) is estimated for each 10-day period in order to eliminate the effect of the clouds. The reference curves built from the MVCI are smoothed using different algorithms, and are defined as beginning on the first 10-day period of October and finalized on the last 10-day period of September of the next calendar year. Whenever information is not available for a particular period, a linear interpolation method is used to fill the missing gaps.

The mask in this scheme is based on the Corine Land Cover (CLC-90), which is used to discriminate between areas with and without grassland production. The deductible is calculated from the 10-day period and is defined as the historic average MVCI for each area, minus 1.25 standard deviations from the average MVCI. The second item of the deductible is related to the amount of 10-day periods below the individual deductible for each time window. The time...
deductible is three periods below the reference threshold for every 10-day period, which is equivalent to 30 days with dry vegetative indicators.
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