The Design of Index-based Flood Insurance

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Workshop on "Enhancing the benefits of Remote Sensing Data and Flood Hazard Modelling in Index-based Flood Insurance (IBFI)"

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Contents

1. Farm Management Group
2. Agricultural Insurance Products
3. Development of Index-based Flood Insurance
4. Identification of Pilot Location
5. Conclusion
Farm Management Group

Team

- Head: Prof. Dr. Martin Odening
- Researchers: Dr. Matthias Ritter, Dr. Günter Filler, Dr. Zhiwei Shen
- Research Expertise: Risk management, especially climate risks, Investment and finance, Structural change in Agriculture

Related Research Projects and Publications

- Weather Risk Management (DFG), INKA-BB: insurance and climate change
  - Management of Climate Risks in Agriculture (Applied Economics)
  - Pricing Rainfall Futures at the CME. (Journal of Banking and Finance)
  - Can Expert Knowledge Compensate for Data Scarcity in Crop Insurance Pricing? (ERAE)
- Risk Management Tools for Wind Power Industry
  - Designing an Index for Assessing Wind Energy Potential. (Renewable Energy)
Weather Risk

Germany 2013

USA 2012
## Rainfall Index Insurance

### Table: Rainfall insurance for wheat producers in Brandenburg, Germany (ha)

<table>
<thead>
<tr>
<th></th>
<th>Option 1</th>
<th>Option 2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Rainfall index</strong></td>
<td>Cumulative rainfall</td>
<td>Rainfall deficit</td>
</tr>
<tr>
<td><strong>Accumulation</strong></td>
<td>June</td>
<td>April-June</td>
</tr>
<tr>
<td><strong>Calculation</strong></td>
<td>( I^c = \sum_{t=1}^{30} R_t )</td>
<td>( I^d = \sum_{\tau=1}^{13} \min(0, \sum_{t=(\tau-1)\cdot7+1}^{\tau\cdot7} R_t - 7.4) )</td>
</tr>
<tr>
<td><strong>Strike level</strong> ( S )</td>
<td>144.3mm</td>
<td>-29.4mm</td>
</tr>
<tr>
<td><strong>Tick size</strong> ( V )</td>
<td>1.4( )€/ index point</td>
<td>13.5( )€/ index point</td>
</tr>
<tr>
<td><strong>Payoff</strong> ( P )</td>
<td>( \max(144.3 - I^c, 0) \cdot 1.4 )</td>
<td>( \max(-29.4 - I^d, 0) \cdot 13.5 )</td>
</tr>
</tbody>
</table>
Wind Index
Agricultural Insurance Products

Indemnity-based Insurance
- Named Peril Crop Insurance: Hail, Fire
- Multiple Peril Crop Insurance (MPCI)

Index-based Insurance
- Weather-index Insurance
- Area Yield Insurance
- Price Index Insurance
- Revenue Insurance (price × yield)
Concept: Indemnity payments are based upon actual losses incurred.

**Named peril crop insurance: Hail Insurance**

- Perils: hail, fire (suited to localized, independent perils)
- Measure % damage in field; pre-agreed sum insured; operated in private sector; generally unsubsidised.
- Benefits: transparent loss assessment, manageable adverse selection and moral hazard
- Challenges: individual loss assessment; assessment cost in small farmers; not suited to complex perils.
Indemnity-based Insurance

Concept: Indemnity payments are based upon actual losses incurred.

Multiple peril crop insurance

- Perils: a wide list of perils
- Measure yield loss compared to a % of average yield; highly subsidised; public-private-partnership (PPP).
- Benefits: easy to understand; limited technical adaptation required for different crops; indemnifies each farmer based on yield.
- Challenges: individual farmer loss assessment; adverse selection and moral hazard; poor data for yield history; high administrative cost; not suited where farms are small.
Agricultural Insurance Products

Indemnity-based Insurance
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Index-based Insurance
- Weather-index Insurance
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- Revenue Insurance (price $\times$ yield)
Index-based Insurance

Concept: Indemnity payments are based on objectively observable indices.

Weather-index Insurance

- Perils: rainfall deficit and excess; high or low temperatures
- Payouts based on weather station measurement
- No adverse selection and moral hazard; no individual loss adjustment; transparent, objective data
- Challenge: Basis risk; setting up index is complex; need good meteorological and agronomic data as well as crop modelling;
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2 Agricultural Insurance Products
3 Development of Index-based Flood Insurance
   Theoretical model
   Example of rainfall index insurance
   Designing flood index insurance
4 Identification of Pilot Location
5 Conclusion
Index-based Flood Insurance

The index insurance framework:

- Find an flood index \( I \): cumulative rainfall, inundated area, flood duration, depths, water level (e.g. Sirajganj flood insurance) or combined index.

- Relation between crop yield and index

\[
y = g(I) + \epsilon
\]

\( y \): crop yields; \( g(\cdot) \): a function estimating the relation between yield and index; \( \epsilon \): error term indicating the basis risk.

- Payoff function

\[
P(I) = V \cdot \max\{0, S - I\}
\]

\( I \): index; \( P \): insurance payout; \( S \): strike level; \( V \): tick size.
Design Index-based Flood Insurance

Estimating yield-index relation $g(\cdot)$

- Index form:
  - Single index: cumulative rainfall or excessive water level
  - Combined or transformed index to best fit the yield; e.g.,

$$Y_{\text{corn}} = \alpha_0 + \alpha_1 R + \alpha_2 T + \alpha_3 R^2 + \alpha_4 T^2 + \alpha_5 RT + \epsilon$$

- Wind speed-Wind power
  $$f(WS; a, b, c, d, g) = d + \frac{a - d}{(1 + (\frac{WS}{c})^b)^g} + \epsilon$$

- Estimation technique
  - Standard Ordinary Least Squares
  - Bayesian estimation
  - Extreme theory e.g., quantile regression
The distribution of the index $I$ is crucial to the assessment of insurance product. Its distribution influences the revenue distribution through the payoffs and also determines the cost of insurance. i.e., the price ($F$).

- **Burn Analysis**
  
  \[
  F = \exp(-r \cdot T) \cdot \left[ \frac{1}{n} \cdot \sum_{t=1}^{n} P(I_t) \right]
  \]

  → based on empirical distribution of index

- **Index Value Simulation**

  Statistical model for index
  → Parameters of distribution can be estimated from historical data
  → Index are randomly drawn to determine the price.

- **Daily Value Simulation**

  → A statistical model for stochastic process of the underlying variable (e.g. daily rainfall or water level)
Rainfall index insurance for grain producers in Northeast Germany:

- **Specification of Rainfall Index:**
  - **Rainfall sum:**
    \[ I^c = \sum_{t=1}^{T} R_t \]
  - **Rainfall deficit:**
    \[ I^d = \sum_{t=1}^{T} \min(0, \sum_{\tau=(t-1)s+1}^{\tau\cdot s} R_t - R^{\text{min}}) \]

This index measures the shortfall of the rainfall sum in an \( s \)–days relative to a reference level \( R^{\text{min}} \).
Rainfall Index Insurance

- Estimation of Yield-index Relation $g(\cdot)$
  A linear-limitational (Leontief) production function to specify the relationship between rainfall index and wheat yield:

  $$g(I) = \begin{cases} a_0 + a_1 \cdot I + \epsilon & \text{if } I < a_2 \\ a_3 + \epsilon & \text{Otherwise} \end{cases}, \quad \epsilon \sim N(0, \sigma_\epsilon)$$

- Maximum likelihood estimation to determine the parameter estimates. Best fit (highest $R^2$) leads to favour rainfall deficit index for April to June.
Rainfall Index Insurance

- Pricing index
  - Burn analysis (historical empirical data)
  - Index value simulation: Daily rainfall model

\[ R_t = r_t \cdot X_t \]

\[ X_t = \begin{cases} 
0 & \text{if no rain} \\
1 & \text{if rain} 
\end{cases} \]

Transition probabilities:
\[ p_t^{01} = \Pr\{X_t = 1|X_{t-1} = 0\} \]
\[ p_t^{11} = \Pr\{X_t = 1|X_{t-1} = 1\} \]

Rainfall amount \( r_t \) follows mixed exponential distribution:
\[ f[r_t] = \frac{\alpha_t}{\beta_t} \exp\left[-\frac{r_t}{\beta_t}\right] + \frac{1 - \alpha_t}{\gamma_t} \exp\left[-\frac{r_t}{\gamma_t}\right] \]
Theoretical model

Example of rainfall index insurance

Development of Index-based Flood Insurance

Identification of Pilot Location

Conclusion

Designing flood index insurance

Diagram of Pricing Index-based Flood Insurance

Data

- Historical flood damage, crop yield data and flood hazard parameter index

Relationship

- Regress crop yields with flood hazard parameter index

Flood Index

- Based on relationship, derive flood index representing crop yields properly

Parameter Estimation

- Determination of model and distribution type of flood index
  - Bayesian estimation for data scarcity
  - Quantile estimation for extremes
  - Multivariate distribution for systemic risk

Simulation

- Simulated flood index from determined flood index model

Insurance Premium

- Determine trigger value and calculate insurance premium
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Exposure of Floods

Average Rainfall Amount and Inundated Area

Cumulated Rainfall: Blue bars
Inundated Area: Orange bars

### C. Rainfall
- Bhagalpur, East Cham., Katihar, Supaul, and West Cham.

### I. Area
- Patna, Samastipur, Saran, Muzaffarpur, Bhagalpur

### Both
- Muzaffarpur, Bhagalpur
## Exposure of Floods

### Average Days of Rainfall and Inundation

<table>
<thead>
<tr>
<th>Location</th>
<th>Rainfall Days</th>
<th>Inundation Days</th>
</tr>
</thead>
<tbody>
<tr>
<td>Begusarai</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>Bhojpur</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>Buxar</td>
<td>55</td>
<td>55</td>
</tr>
<tr>
<td>Darbhanga</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>East Champaran</td>
<td>55</td>
<td>55</td>
</tr>
<tr>
<td>Katihar</td>
<td>70</td>
<td>70</td>
</tr>
<tr>
<td>Khagaria</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>Madhubani</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>Munger</td>
<td>55</td>
<td>55</td>
</tr>
<tr>
<td>Muzaffarpur</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>Nalanda</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>Patna</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>Saharsa</td>
<td>55</td>
<td>55</td>
</tr>
<tr>
<td>Samastipur</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>Saran</td>
<td>55</td>
<td>55</td>
</tr>
<tr>
<td>Supaul</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>Vaishali</td>
<td>55</td>
<td>55</td>
</tr>
<tr>
<td>West Champaran</td>
<td>60</td>
<td>60</td>
</tr>
</tbody>
</table>

**Rainfall Days**
- No significant difference; East Cham., Katihar, Supaul

**Inundation Days**
- Katihar, Patna, Samastipur, Saran, Bhagalpur

**Both**
- Katihar
Potential Insurance Demand

Affected Crop Area and People

<table>
<thead>
<tr>
<th>Affected Crop Area</th>
<th>Madhubani, East Cham., Darbhanga, Katihar, Vaishali</th>
</tr>
</thead>
<tbody>
<tr>
<td>Affected People</td>
<td>Darbhanga, East Cham., Muzaffarpur, Samastipur</td>
</tr>
<tr>
<td>Both</td>
<td>Darbhanga, East Cham.</td>
</tr>
</tbody>
</table>
Potential Insurance Demand

Rice Production and Crop Loss

<table>
<thead>
<tr>
<th>Rice Production</th>
<th>Katihar, East Cham., West Cham., Muzaffarpur</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crop Loss</td>
<td>Samastipur, Madhepura, East Cham., Muzaffarpur, Darbhanga, Muzaffarpur</td>
</tr>
<tr>
<td>Both</td>
<td>East Cham., West Cham., Muzaffarpur</td>
</tr>
</tbody>
</table>
Identification of Pilot Location

Potential pilot locations: Muzaffarpur, East Champaran, Katihar, The following reasons:

- High exposure to flood risk
- High potential rice insurance demand given high rice production
- Better data quality
- Accessibility to farmers and fields

<table>
<thead>
<tr>
<th></th>
<th>Muzaffarpur</th>
<th>East Champaran</th>
<th>Katihar</th>
</tr>
</thead>
<tbody>
<tr>
<td>R. Area (km$^2$)</td>
<td>mean 1070.7</td>
<td>mean 1237.5</td>
<td>mean 1277.5</td>
</tr>
<tr>
<td></td>
<td>std. 338.6</td>
<td>std. 297.2</td>
<td>std. 253.5</td>
</tr>
<tr>
<td>I. Area (km$^2$)</td>
<td>1750.2</td>
<td>1138</td>
<td>1611.2</td>
</tr>
<tr>
<td></td>
<td>1530.4</td>
<td>702.8</td>
<td>367.2</td>
</tr>
<tr>
<td>Crop loss (M. Rs.)</td>
<td>216.9</td>
<td>382.5</td>
<td>62.5</td>
</tr>
<tr>
<td></td>
<td>343.6</td>
<td>254.9</td>
<td>61.6</td>
</tr>
</tbody>
</table>
Conclusion

- **Agricultural Insurance Products**
  - Indemnity-based Insurance
  - *Index-based Insurance* for special risk and small households

- **Design of Index-based Flood Insurance**
  - Estimating yield-index relation
  - Modelling the index

- **Identification of Pilot Location**
  - *Muzaffarpur*, East Champaran, Katihar
Questions? Comments?

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