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Weather Index Derivatives in Risk Transfer for Agricultural Natural Hazards

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Abstract

The article begins by briefly reviewing agricultural risk management strategies used by farm households and some of the unique problems associated with agricultural insurance. Especially, the experience of developed countries is highlighted to make the case for why such approaches cannot work well in lower-income countries. The article introduces innovations that use index-based insurance products, and gives a pricing model for weather index derivatives which is deduced with utility-based pricing, and then, the article reviews both the advantages and disadvantages of index-based agricultural insurance and its applicable scope.

Keywors: Risk transfer; Agricultural insurance; Weather index derivatives; Natural hazards

1. Introduction

The article begins by briefly reviewing agricultural risk management strategies used by farm households and some of the unique problems associated with agricultural insurance. Especially, the experience of developed countries is highlighted to make the case for why such approaches cannot work well in lower-income countries. The article introduces innovations that use index-based insurance products, and gives a pricing model for weather index derivatives which is deduced with utility-based pricing, and then, the article reviews both the advantages and disadvantages of index-based agricultural insurance and its applicable scope.

2. Agricultural risk management and insurance

The strategies of agricultural risk management generally can be categorized as risk mitigation, risk transfer, risk diversification, and management of retained risk. But these strategies all have drawback respectively. It is highly likely that risk management strategies also vary over time as a function of farm household experience, the regulatory environment and changing risk attitudes among other factors. These risk management strategies may be complementary, as seen in the US crop insurance experience (Glauber, 2004)[1], but in the absence of risk transfer,

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risk mitigation and risk coping strategies may potentially be overwhelmed by catastrophic loss events. Building systems whereby insurance transfers highly correlated and catastrophic losses out of the community, and banks and non-banking institutions facilitate savings and borrowing to assist in coping with more frequent and less severe events, is at the core of designing effective systems for agricultural output risk.

Insurance is a commonly used risk-transfer mechanism for property damage throughout the developed world, and in many lower-income countries. But many different insurance products applied in developed countries are not true for lower-income countries due to the transaction cost of delivering insurance products to economically small rural households is simply too great in lower-income countries.

Agricultural production losses, especially due to weather events, tend to be characterized by some degree of positive spatial correlation, 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. 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)[2][3]. In general, agricultural production losses are typically neither uncorrelated nor highly positively correlated (Skees and Barnett, 1999)[4].

Besides the lack of statistical independence, agricultural insurance is often plagued by high administrative costs which spatially correlated risk, moral hazard, adverse selection, and high administrative costs are all important reasons why agricultural insurance markets may fail. If consumers fail to recognize and plan for low-frequency, high-consequence events, the likelihood that an insurance market will emerge diminishes, so the consumer may have difficulty determining the value of the contract (Kunreuther and Pauly, 2001)[5]. The evaluation of probability assessments regarding future events is complex and often entails high search costs. On the other hand, insurers will typically load premium rates heavily for low-frequency, high-consequence events where considerable ambiguity surrounds the actual likelihood of the event (Schade et al., 2002; Kunreuther et al., 1995)[6][7]. A very common problem in lower-income countries is that uncertainty is further compounded when the historical data used to estimate probability distributions are incomplete or of poor quality.

Together, functioning private-sector markets may fail to materialize or, if they do materialize, they may cover only a small portion of the overall risk exposure (Pomareda, 1986)[8].

3. Innovation in managing production risk: weather index

Index insurance products offer some potential new solutions to help mitigate several aspects of the problems outlined above (Skees et al., 1999)[3]. Index products also facilitate risk transfer into financial markets where investors acquire index contracts as another investment in a diversified portfolio. A suitable index requires that the random variables measured meet these criteria: observable and easily measured; objective; Transparent; independently verifiable; reportable in a timely manner; and stable and sustainable over time.

Weather derivatives is a financial instrument for avoiding weather risk, and it spreads fast recently because of its' unique advantage of diversifying and transferring risk. Weather risk refers that drastic fluctuations of production cost and then the market demand which result from uncertain weather condition can lead an uncertain cash flow and profit. Disastrous weather can be led directly by typhoon, whirlwind, thunderstorm, and storm wind etc, and even weather change such as temperature, rainfall, sunshine and frost all could lead tremendous uncertainty of income of economic entity. Weather derivatives appeared in U.S.A at the earliest. At 1999, CME listed weather derivatives for transaction, and has gradually been developing several products, including HDD (Heating-Degree-Day) and CDD (Cooling-Degree-Day) and GDD (Growth- Degree-Day) etc. derivatives products so far. The market of weather derivatives has become the financial market which has the fastest speed of developing in EURO and Japan. In 2005, more than 360 hundred millions dollars come into CME and some company held under the contractual weather derivatives transaction volume of 80 ten thousands hands and the contract sum of 210 hundred millions dollars in 2006.

Temperature indicator is the most standard in all kinds of weather indicators, temperature risk is that too high or too low temperature can seriously influence the growth of all kinds of crop. So weather index is the most active in numerous weather derivatives products. The main weather index future is HDDs and CDDs. In American, the average temperature is 18.3°C, when temperature of a certain day is lower than it, there can be conducted HDDs, otherwise, there can be conducted CDDs, in a given period, we can hold the two index through following two functions:

$$y = \sum_{d=1}^{n} HDD \text{ and } y = \sum_{d=1}^{n} CDD . \tag{1}$$

Where the D is a given durative days. Naturally, all of crops need a given accumulated temperature which must achieve a certain level to meet certain quality and output.

The theory of expected utility which proposed by Von Newman is a specification of decision make under an uncertainty condition. The theory deems that if a decision maker chooses the best plan from some given alternatives subjects to utility axiom, he must choose the plan which has can give him the most utility. The article is to apply the method to price the weather index. Presuming an individual has a utility function as

$$U(x) = E(x) - \lambda \sigma^2(x) \tag{2}$$

Where the λ is coefficient of risk aversion and $\lambda > 0$. There are three kinds of assets could be invested by a peasant including riskless asset which return rate is r_f and risk asset which return rate is r and weather derivatives which price is $\pi^b(y)$. Further, the price of agricultural product is p, sales volume is q and the primary asset the peasant owns is w. The utility of the best strategy the peasant could make is

$$V_1^b = \underset{m}{Max}\, U[wr_f + m(r - r_f) + pq] \tag{3}$$

Where m is the amount of money the peasant invested in risk asset.

$$\begin{aligned} U[wr_f + m(r - r_f) + pq] &= E[wr_f + m(r - r_f) + pq] \\ &\quad - \lambda^b \sigma^2[wr_f + m(r - r_f) + pq] \\ &= wr_f + m(r - r_f) + E(pq) \\ &\quad - \lambda^b \sigma^2(r)m^2 - \lambda^b \sigma^2(pq) - 2\lambda^b mCOV(r, pq) \end{aligned} \tag{4}$$

So we could have the maximal anticipant utility the peasant desires:

$$V_1^b = wr_f + E(pq) - \lambda^2 \sigma^2(pq) + \frac{[E(r) - r_f - 2\lambda^b COV(r, pq)]^2}{4\lambda^b \sigma^2(r)} \tag{5}$$

But the anticipant return the peasant can hold when he buys weather derivatives is

$$V_2^b = \underset{m}{Max}\, U[(w - \delta\pi^b(y))r_f + m(r - r_f) + pq + \delta R(y)] \tag{6}$$

Where the variable δ is the amount of the weather derivatives the peasant has bought. Further,

$$\begin{aligned} &U[(w - \delta\pi^b(y))r_f + m(r - r_f) + pq + \delta R(y)] \\ &= w - \delta\pi^b(y)r_f + m(r - r_f) + E(pq) + \delta E[R(y)] \\ &\quad - \lambda^b m^2 \sigma^2(r) - \lambda^b \sigma^2(pq) - \lambda^b \delta^2 \sigma^2[R(y)] - 2\lambda^b mCOV(r, pq) \\ &\quad - 2\lambda^b \delta mCOV(r, R(y)), 2\lambda^b \delta COV(pq, R(y)) \end{aligned} \tag{7}$$

So, we can have the following equation:

$$\begin{aligned} V_2^b &= w - \delta\pi^b(y)r_f + E(pq) + \delta E[R(y)] - \lambda^b \sigma^2(pq) \\ &\quad - \lambda^2 \delta^2 \sigma^2[R(y)] - 2\lambda^b \delta COV(p\ qR(y)) \\ &\quad + \frac{[E(r) - r_f - 2\lambda^b COV(r, pq) - 2\lambda^b \delta COV(r, R(y))]^2}{4\lambda^b \sigma^2(r)} \\ &\quad + \frac{\lambda^b \delta COV(r, R(y))}{r_f \sigma^2(r)} \end{aligned} \tag{8}$$

We can hold the indifference price between the peasant buys the weather derivatives or not under the condition $V_1^b = V_2^b$,

$$\begin{aligned}\pi^b(y) = {} & \frac{E[R(y)] - \lambda^b \delta\sigma^2 R(y) - 2\lambda^b COV(pq, R(y))}{r_f} \\ & - \frac{COV(r, R(y))[E(r) - r_f - 2\lambda^b COV(r, pq)] - \lambda^b \delta COV^2(r, R(y))}{r_f \sigma^2(r)}\end{aligned} \tag{9}$$

Where $R(y)$ is the gain from the contract and it is equal to the contractual price minus the cost y. Considering a future about weather derivatives, we then have

$$\begin{aligned}\pi_f^b(y) = {} & \frac{K - E(y) - \lambda^b \delta\sigma^2(y) + 2\lambda^b COV(pq, y)}{r_f} \\ & + \frac{COV(r, y)[E(r) - r_f - 2\lambda^b COV(r, pq)] + \lambda^b \delta COV^2(r, R(y))}{r_f \sigma^2(r)} = 0\end{aligned} \tag{10}$$

Then the price of future is

$$\begin{aligned}F^b(y) = {} & E(y) + \lambda^b \delta\sigma^2(y) - 2\lambda^b COV(pq, y) \\ & - \frac{COV(r, y)[E(r) - r_f - 2\lambda^b COV(r, pq)] - \lambda^b \delta COV^2[r, R(y)]}{\sigma^2(r)}\end{aligned} \tag{11}$$

But we also can calculate the price of weather derivatives from the sellers' opinion. At first, we don't consider selling weather derivatives. Under the condition, the dominated strategy for the peasant is $V_1^s = \underset{m}{Max}\, U[wr_f + m(r - r_f)]$, where

$$\begin{aligned}U[wr_f + m(r - r_f)] &= E[wr_f + m(r - r_f)] - \lambda^s \sigma^2[wr_f + m(r - r_f)] \\ &= wr_f + m(r - r_f) - \lambda^s m^2 \sigma^2(r)\end{aligned} \tag{12}$$

So, we have $V_1^s = wr_f + \dfrac{[E(r) - r_f]^2}{4\lambda^s \sigma^2(r)}$. Otherwise, if the seller decides to sell the contract of weather derivatives, the dominated strategy is then $V_2^s = \underset{m}{Max}\, U[w + \delta\pi^s(y) r_f + m(r - r_f) - \delta R(y)]$. Then

$$\begin{aligned}& U[w + \delta\pi^s(y) r_f + m(r - r_f) - \delta R(y)] \\ & = w + \delta\pi^s(y) r_f + m(r - r_f) - \delta E[R(y)] - \lambda^s m^2 \sigma^2(r) \\ & \quad - \lambda^s \delta^2 \sigma^2(r)[R(y)] + 2\lambda^s \delta m COV(r, R(y))\end{aligned} \tag{13}$$

So we can hold the following equation:

$$\begin{aligned}V_2^s = {} & w + \delta\pi^s(y) r_f - \delta E[R(y)] - \lambda^2 \delta^2 \sigma^2(r)[R(y)] \\ & + \frac{[E(r) - r_f + 2\lambda^s \delta COV(r, R(y))]^2}{4\lambda^s \sigma^2(r)}\end{aligned} \tag{14}$$

We can hold the indifference price $\pi^s(y)$ for peasant as soon as $V_1^s = V_2^s$. Where

$$\pi^s(y) = \frac{E[R(y)] + \lambda^s \delta\sigma^2[R(y)]}{r_f} - \frac{COV(r, R(y))[E(r) - r_f] + \lambda^s \delta COV^2(r, R(y))}{r_f \sigma^2(r)} \tag{15}$$

If the contract is put option and the due price is K, then due payoff is R(y)=Max(K-y) and then the indifference price is

$$p^b(y) = \frac{E[\max(k-y,0] - l^s ds^2(r)\max(k-y,0)] - 2l^s COV(pq, \max(k-y,0))]}{r_f} - \frac{COV(r, \max(k-y,0))[E(r) - r_f - 2l^s COV(r, pq)] - l^s dCOV^2(r, \max(k-y,0))}{r_f s^2(r)} \tag{16}$$

4. Where index insurance is inappropriate

There are three aspects which could hinder and even lead to index insurance contracts not work well for all agricultural producers. In highly spatially heterogeneous production areas, basis risk will likely be so high that index insurance will not work. Over-fitting the data is another concern with index insurance. If one has a limited amount of crop yield data, fitting the statistical relationship between the index and that limited data can become problematic. Finally, when designing index insurance contracts, significant care must be taken to assure that the insured has no better information about the likelihood and magnitude of loss than does the insurer. Farmers' weather forecasts are quite often highly accurate. Potato farmers in Peru, using celestial observations and other indicators in nature, are able to forecast weather at least as well as many climate experts.

So it is the perquisite that insurance providers who venture into weather index insurance must know at least as much as farmers do about conditional weather forecasts because of that farmers have a vested interest in understanding the weather and climate. If not, inter-temporal adverse selection will render the index insurance product unsustainable.

5. Summary and conclusions

This article provides an overview of the traditional and the basic innovation approaches of agricultural insurance in risk transfer for natural hazards. Especially, the article mentions three aspects, at first, why traditional approaches to agricultural insurance are not appropriate for many lower-income countries that are dominated by a large number of small farms, then introduces innovations that use index-based insurance products, and gives a pricing model for weather index derivatives which is deduced with utility-based pricing, and then, the article reviews both the advantages and disadvantages of index-based agricultural insurance and its applicable scope.

Some progress is being made in the implementation of index-based agricultural insurance products. India has adopted a number of weather-based insurance products in recent years. Both the government agricultural insurer and private insurers are offering index insurance for weather risk in India. The World Bank and others are involved in a large number of feasibility studies to determine how such innovations can be introduced to ease the suffering and losses associated with weather related crop failure. A critical aspect of all of this thinking is the explicit recognition that many weather events impacted a large number of individuals at the same time creating larges losses. The need to transfer this type of correlated risk out of local communities is large. Index based weather insurance products can be a key ingredient in meeting that need. Nonetheless, in every case the adoption of these innovations must be put into a local context that explicitly recognizes the nature of the risk, the current risk-coping and risk management strategies of rural households, and the markets and institutions within the country.

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