Hedging Crop Risk with Yield Insurance Futures and Options

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Abstract

This paper analyses the optimal hedging decisions for risk-averse producers facing crop risk, assuming crop yield insurance futures and options can be used. The first-best optimal hedge requires a futures position or an option position proportionate to the individual beta depending on whether the financial markets are perceived unbiased or biased. Using yield data for a sample of wheat producers in France, the producers' hedge ratios are derived. These new hedging instruments are more effective to reduce farm yield variability than the individual yield contracts, except if the individual yield guarantee is at least equal to the individual average yield.

Key words: crop insurance, hedging position, incomplete markets.

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Introduction

The failure of Multiple Peril Crop Insurance (MPCI) programs, in which individual farm yields are used to measure yield loss, to meet policy marker's expectations in a large and diverse set of countries has been usually explained by the presence of informational asymmetries such as moral hazard and adverse selection (Chambers 1989, Quiggin 1994). Area yield insurance has been investigated as an alternative program where indemnification is based upon shortfalls below a trigger yield for a surrounding area, contributing to significantly reducing informational asymmetries and administrative costs (Halcrow 1949, Miranda 1991, Mahul 1999).

Nevertheless, the occurrences of unfavorable weather events which affect simultaneously a large number of farms, such as droughts, generate a significant correlation among individual crop risks. This systemic risk prevents crop insurers from achieving large gains from the pooling of individual risks. The cost of bearing this risk or the cost of transferring it on the reinsurance market can be so high that crop risks can become uninsurable. Contrary to the insurance and reinsurance industries, financial markets have resources to support the economic consequences of these natural hazards. Hence, the Chicago Board of Trade (CBOT) has launched in 1995 Crop Yield Insurance (CYI) futures and options. The underlying instrument of these quantity-based contracts is the official yield estimates released during the growing and harvesting season by the United States Department of Agriculture. These cash-based index contracts are offered at state and national levels. The unit of trading for the CYI contracts is the yield estimate in bushels times $100, contract months are September and January, and the tick size is 1/10 bushel per acre ($10 per contract). Financial markets thus offer producers, insurers and more generally operators who are affected by yield variability a new opportunity to spread systemic risk at a lower cost than the reinsurance market and, therefore, they contribute to making crop risk insurable. In counterpart, they offer investors

new opportunities of portfolio diversification since the CYI contracts are likely to be weakly correlated with standard financial assets.

The purpose of this paper is to analyze the problem of hedging crop risk with CYI futures and options. Its main originality is to use recent developments in the theory of crop insurance in incomplete markets to derive the first-best hedging position in the general expected utility model. Under a positive correlation between the individual yield and the area yield index, the optimal hedge requires a short futures position is markets are unbiased and a long put position if they are biased. These theoretical results are then applied empirically to the problem of hedging wheat production using French data. They allow us to stress the importance of the systemic component in the individual yield risk and to analyze how the risk reduction effectiveness of CYI and MPCI contracts varies among producers. The former turn out to be more effective than the latter, except if the individual yield guarantee is at least equal to the individual average yield.

Optimal Hedging Decisions

We consider a competitive farmer/producer who makes all hedging decisions at a single point in time. The producer's individual yield is affected by uncertain effects of weather and other natural phenomena. The output price is assumed certain and thus the producer only faces yield risk. He is able to manage the risk associated with production through CYI futures and options contracts proposed by the financial markets.

The farm's individual stochastic yield $\tilde{y}_i$ and the stochastic area yield index $\tilde{y}$ are not perfectly correlated. The producer is thus exposed to a yield basis risk. To model this imperfect hedging mechanism provided by the financial markets, we use the assumption of regressability introduced by Benninga, Eldor and Zilcha (1984):

(1) $$\tilde{y}_i - m_i = b_i(\tilde{y} - m) + \tilde{e}_i$$

where $b_i = \text{cov}(\tilde{y}_i, \tilde{y})/\text{var}(\tilde{y})$, $E\tilde{e}_i = 0$, $E\tilde{y}_i = \mathtt{m}_i$, $E\tilde{y} = \mathtt{m}$ and $\tilde{e}_i$ is independent of $\tilde{y}$. The coefficient b_i measures the sensitivity of farm yield to movements in area-yield index. Equation (1) thus decomposes total individual risk into a component that is perfectly correlated to the area yield index, namely the systemic risk, and a component $\tilde{e}_i$ that is uncorrelated with the area yield index, namely the specific risk.

Since any combination of futures, put and call contracts can be replicated by any two of these financial instruments, only futures and put markets are considered. Therefore, call options are ignored in the following analysis without precluding call-like solutions. Let x represent the producer's futures position: $x > (<) 0$ is short (long), i.e. he has sold (purchased) futures. Let z represent his put position: $z > (<) 0$ is long (short), i.e. he has purchased (sold) put options. The random profit of the producer is thus defined by:

(2) $$\tilde{p} = p\tilde{y}_i + \left[m(f - \tilde{y})x + m(\tilde{v} - r)z\right]$$

where p is the nonrandom output price, f is the futures yield at planting, $\tilde{v} \equiv \max(k - \tilde{y}, 0)$ is the payoff of the put option with a strike yield k, r is the put option price (premium), and m is a multiplier. In the case of CYI contracts proposed by the CBOT, m equals \$100 for each bushel per acre harvested. In addition, we assume that the premium r depends only upon the expected payoff: $r \equiv h(E\tilde{v})$ with $h(0) = 0$ and $h'(v) \geq 1$ for all v.

The hedging problem of the risk-averse producer with increasing and concave utility function u is to select x and z as well as f and k that maximize the expected utility of his final profit under the above-mentioned constraints. It should be noticed that, contrary to the standard literature on optimal hedging (see, for example, Moschini and Lapan 1995), the producer can choose freely not only the amount of contracts sold or bought but also the futures yield at planting and the strike yield in order to maximize the expected utility of his final wealth. The problem can thus be written as:

(3) $\underset{x,z,f,k}{Max}\, Eu(\tilde{p})$

subject to the above-mentioned conditions. It can be solved by deriving the first-order condition of the objective function with respect to the four decision variables. An alternative approach is to analyze this hedging problem in the general framework of the theory of insurance by stressing the similarity between option contracts and insurance policies. It is thus solved in two steps. First, the design of an optimal area yield crop insurance contract is characterized in the presence of an unhedgeable yield basis risk. Second, the optimal net indemnity payment is duplicated in order to derive the producer's hedging position in CYI futures and options markets.

The Pareto optimal insurance contract in which the indemnity is based upon an area yield index is obtained by finding the insurance premium P and the indemnity function I that maximize the producer's expected utility under the constraints that the indemnity function is nonnegative and the premium is a function of the expected indemnity. The couple $[I(.), P]$ is thus solution of the following maximization problem:

(4) $\underset{P,I(.)}{Max}\, Eu\left(p\tilde{y}_i + I(\tilde{y}) - P\right)$

subject to conditions (1), $P = h\left(EI(\tilde{y})\right)$ and $I(.) \geq 0$.

This problem of optimum insurance in the presence of an uninsurable and independent background risk was recently solved by Mahul (1999). He shows that the optimal form of the area yield insurance contract depends on the producer's beta coefficient. If this coefficient is positive, $b_i > 0$, the optimal indemnity function satisfies:

(5) $I^*(y) = pb_i \max[y_c - y, 0]$

with $y_c \in [0, y_{\max}]$ where $y_{\max}$ is the maximum area yield index. If the beta coefficient is negative, $b_i < 0$, the optimal indemnity function is:

(6) $I^*(y) = -pb_i \max[y - y_c', 0]$

with $y_c' \in [0, y_{\max}]$. Therefore, the insured producer with a positive (negative) beta coefficient receives a payoff if the realized area yield is lower (higher) than a trigger area yield index. He does not receive any indemnity payment if his beta coefficient is equal to zero, i.e. when the individual yield and the area yield are independent. Mahul (1999) shows also that, under a positive (negative) beta coefficient, the optimal trigger area yield equals the maximum (minimum) area yield $y_{\max}$ ($y_{\min} = 0$) if the insurance premium is actuarially fair, $P = EI(\tilde{y})$, and it is strictly lower (higher) than this maximum (minimum) if insurance is costly, $P > EI(\tilde{y})$. These results are used to characterize the optimal hedging position of the producer on the CYI futures and options markets.

First, suppose that the financial markets are unbiased. This means that the producer perceives options to be fairly priced, i.e. $r = E\tilde{v}$. It follows that the optimal trigger area yield is equal to the maximum or minimum area yield index depending upon whether b_i is positive or negative. Consequently, the first-best net indemnity payment is:

$$(7) \qquad I^*(y) - P = \begin{cases} pb_i(y_{\max} - y) - pb_i(y_{\max} - m) = (m - y)pb_i & \text{if } b_i > 0 \\ -pb_i y - (-pb_i m) = -(m - y)p(-b_i) & \text{if } b_i < 0 \end{cases}$$

From the comparison of equation (7) and the terms in brackets in equation (2), the first-best net indemnity payment can be duplicated by selecting a short (long) futures position equal to $\frac{p}{m}|b_i|$ at the futures yield at planting $f = m$ if the beta coefficient is positive (negative). All other hedging instruments, and especially options, are thus redundant under the unbiasedness assumption.

Second, suppose that the financial markets are biased. This means that the put option price is larger than its expected payoff, i.e. $h'(v) > 1$ for all v. The optimal trigger area yield is thus strictly lower than the maximum area yield index if b_i is positive, and it is strictly higher than

the minimum area yield index if b_i is negative. Hence, the first-best net indemnity payment is:

$$(8)\quad I^*(y)-P=\begin{cases} pb_i \max[y_c-y,0]-P=\left(\max[y_c-y,0]-r\right)pb_i & \text{if } b_i>0 \\ -pb_i \max[y-y_c',0]-P=-(y_c'-y)p(-b_i)+\left(\max[y_c'-y,0]-r\right)p(-b_i) & \text{if } b_i<0 \end{cases}$$

Comparing equation (8) and the terms in brackets in equation (2) yield that the first-best net indemnity payment can be duplicated with futures and puts as follows. If the beta coefficient is positive, the optimal hedge is a long put position equal to $\frac{p}{m}b_i$ with a strike yield $k=y_c<y_{\max}$. If the beta coefficient is negative, the optimal hedge requires a long call position equal to $\frac{p}{m}(-b_i)$ with $k=y_c'>0$. This hedging position can be duplicated by purchasing simultaneously $\frac{p}{m}(-b_i)$ futures with $f=y_c'>0$ and $\frac{p}{m}(-b_i)$ puts with $k=y_c'>0$. It should be noticed that these hedging strategies hold if futures and options with strike yields equal to y_c and y_c' are available.

Empirical Illustration

The producer is assumed to be mean-variance maximizer. The maximization problem (3) is thus rewritten:

$$(9)\qquad \underset{x,z,f,k}{Max}\, U\left(E\tilde{p},\operatorname{var}(\tilde{p})\right)$$

where the objective function U increases with the expected profit and decreases with its variance. Meyer (1987) has shown that these two-moment decision models are consistent with the expected utility maximization if the random attribute is a monotonic linear function of a single random variable, referred to as the location-scale condition. This condition is less restrictive than those that require that the producer's utility function is quadratic or that the random alternatives are normally distributed. This restriction holds if the futures markets are

only available, but the use of options means that the random variables are non-linearly related to the strike price and, therefore, leads to violation of the location-scale condition (Lapan, Moschini and Hanson 1991). Nevertheless, the mean-variance framework in the presence of options has been shown to provide close approximations of the expected utility model (Garcia, Adam and Hauser 1994).

The following hedging contract scenarios are examined. Financial markets offer futures in which the area yield index is based upon national yield (NYF) and upon regional yield (RYF). Put options are also offered at the national level (NYP) or at the regional one (RYP). The strike price of these put options is chosen equal to the expected area yield. For purpose of comparison, two individual yield insurance programs are also examined. The first one, denoted IYC1, restricts the farm's trigger yield to be 100 percent of its average yield, i.e. $a_{\max} = 1$. The second one, denoted IYC2, sets the maximum trigger yield to be 90 percent of its average yield, i.e. $a_{\max} = 0.9$.[1]

The financial markets are assumed unbiased and the insurance programs are assumed actuarially fair. This entails that the futures yield at planting equals the expected area yield, the put premium is equal to its expected payoff, $r = E\tilde{v}$, and the insurance premium is equal to the expected indemnity, $Q = E\max(a_i m_i - \tilde{y}_i, 0)$, where for the sake of simplicity the output price p and the multiplier m are normalized at unity.

Unbiaisedness implies that the mean-variance framework is equivalent to the variance minimizing criterion. Under the NYF scenario or the RYF scenario, the optimal hedge ratio is thus $x^* = b_i$, where b_i is the individual beta coefficient associated with the national yield or with the regional yield. Under the NYP scenario or the RYP scenario, the producer selects the hedge ratio which minimizes the profit variance. The optimal option ratio is thus

[1] In the U.S. Multiple Peril Crop Insurance program, the highest yield guarantee is equal to 75% of the individual average yield. As it will be shown, such a guarantee may turn out to be too low for French farmers because yield variability is lower in France than in the USA thanks to a more temperate climate.

$z^* = -b_i \operatorname{cov}(\tilde{y}, \tilde{v}) / \operatorname{var}(\tilde{v})$. Since we have $-\operatorname{cov}(\tilde{y}, \tilde{v}) > \operatorname{var}(\tilde{v}) > 0$ by definition of the payoff function v, the optimal amount of puts is higher than the beta coefficient, if it is positive. Therefore, the variance-minimizing producer responds to the existence of a constraint on the strike yield by selecting an hedge ratio higher than his positive beta coefficient, as it was previously mentioned by Miranda (1991). Under individual yield insurance programs, the producer would be induced to choose a trigger yield equal to the maximum individual yield since the premium is actuarially fair. Therefore, restricted trigger yields lead him to always choose the highest trigger individual yield which is available.

The risk reduction provided by the four financial contracts and the two insurance programs are illustrated with individual farm yield data for 124 French wheat producers located in four regions (28 wheat operations in Champagne-Ardennes, 35 wheat operations in Ile de France, 26 wheat operations in Nord Pas de Calais, and 35 wheat operations in Picardie). The associated regional yield data and the national yield data over the ten year period 1987-1996 are obtained from the French Accountancy Data Network.[2] These regions located in the northern part of France are characterized by highly fertile soils and temperate climates. Agriculture is dominated by cereals and oilseeds produced using intensive cropping technology. Regional yields are estimated from the individual yields of all the farmers located in each region and national yields are assessed using the yields of all the French wheat producers. This approach differs from previous works where area yield data were based upon the average yield of the sample (Miranda 1991, Smith, Chouinard and Baquet 1994).

Optimal hedge ratios and their associated fair premium rate are estimated for five selected producers of each region and for the four average farms. The latter are equal to the sum of the individual yields of the regional panel weighted by the proportion of the total acreage in the area planted by each producer. The notation is defined as follows: *Ca-n*, *Np-n*, *If-n* and *Pi-n*

are the *n*th producer in the region Champagne Ardennes, Nord Pas de Calais, Ile de France and Picardie, respectively, and the associated average farm of the region panel is noted *Ca-avg*, *Np-avg*, *If-avg* and *Pi-avg*, respectively.

The risk reduction, expressed in percentage variance reduction, generated by the optimal hedging strategies are presented in Table 1. When futures contracts are only available, we know from the above theoretical analysis that the producer is perfectly hedged against the systemic risk. He thus bears only his farm-specific risk. Consequently, the risk reduction provided by the NYF contract and the RYF contract can be interpreted as the fraction of the systemic component in the individual risk at the national and regional level, respectively. It is worth noticing that the risk reduction provided to the individual farms is sometimes greater when the hedging instrument is based on the national yield index rather than the regional on, like selected producers *Ca-21* or *Np-20*. This stresses the role of financial contracts based on national yields in addition with hedging tools based on regional yields.

Previous theoretical findings can be illustrated with the empirical results presented in Table 1. First, the RYF (NYF) contract is always preferred to the RYP (NYP) contract in which the strike yield is fixed since the futures were shown to generate a first-best systemic risk sharing when the financial markets are perceived unbiased. Second, if the insurance premium is actuarially fair, the producers always prefer the individual yield insurance program which provides the highest yield guarantee and, therefore, they always prefer the IYC1 policy to the IYC2 contract. Third, the IYC1 policy is always preferred by the risk-averse producers to the RYP contract and the NYP contract because it provides a trigger yield for the individual yields, whereas the put options provide a trigger yield for the regional or national yield. Consequently, the RYP or NYP contracts do not hedge the producers against the farm-specific risk, whereas the IYC1 policy hedges it partially.

[2] These yield data were adjusted for secular trends to reflect 1996 production levels. All estimates are derived directly from the empirical yield distributions.

The producers prefer the individual yield insurance policy to the futures contracts based on an area yield index if the individual risk reduction provided by the former is higher than the systemic risk reduction provided by the latter. The average farms unanimously prefer the RYF contract which allows them to eliminate totally the regional systemic risk, as shown in Table 1. However, some of selected producers prefer the NYF contract, like *Np-20* or *If-33*. Half of selected producers prefer the IYC1 policy which provides them a yield guarantee equal to their average yield. The IYC2 contract generates the lowest risk reduction for all selected producers. This means that the multiple-peril crop insurance program may be more efficient, in term of yield variance reduction, than the innovative hedging tools if the individual yield guarantee is equal to or higher than the individual average yield.

Conclusions and Policy Implications

The currents results tend to show that financial markets could play a central role in the management of crop risks in France. They could replace the reinsurance market which has turned to be unable to provide efficient risk spreading and the government which acts as an insurer in last resort. This issue is all the more reliable as the French government has recently decided to develop a private market for crop insurance. This paper thus contributes to bringing new elements in the debate about the feasibility of a crop insurance market in France through the development of hedging tools. Nevertheless, the decrease in commodity price guarantees generated by the successive reforms of the Common Agricultural Policy induces a higher price variability which could significantly affect the farmer's revenue. Consequently, the producer has to face both yield and price risk. Revenue insurance, which provides a revenue guarantee, appears to be an efficient hedging instrument. Further research should thus attempt to create hedging tools which would be based on an aggregate revenue index and to measure their efficiency to stabilize farmers' revenue.

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Farms	Normal Yield[1]	Yield Variance[2]	Percent Variance Reduction					
			NYF	RYF	NYP	RYP	IYC1	IYC2
Ca-2	85.30	45.37	59.41	70.32	41.36	44.76	66.95	11.17
Ca-3	91.01	87.21	78.65	84.86	54.75	54.02	75.25	30.23
Ca-11	81.02	116.04	37.37	47.33	26.01	30.13	48.15	6.13
Ca-16	84.86	45.01	68.34	85.92	47.58	54.69	55.83	13.20
Ca-21	88.07	90.12	64.05	56.75	44.59	36.12	86.81	50.53
Ca-avg	79.95	42.45	92.93	94.17	64.70	59.94	78.10	24.50
Np-1	75.57	39.10	47.41	68.20	33.00	43.02	71.93	14.49
Np-5	88.65	35.25	66.37	41.38	46.21	26.10	64.90	3.87
Np-13	100.31	87.04	41.04	47.08	28.57	29.69	52.63	13.68
Np-14	86.95	18.75	41.39	34.09	28.81	21.50	72.07	11.90
Np-20	76.21	22.42	83.66	68.79	58.24	43.39	74.82	8.10
Np-avg	86.94	34.11	48.74	93.53	33.93	58.99	66.38	11.75
If-1	85.69	68.55	42.05	61.28	29.28	34.13	67.43	19.94
If-6	66.25	126.44	66.11	76.27	46.02	42.48	71.16	47.56
If-9	92.49	67.66	68.59	64.94	47.75	36.17	75.22	29.12
If-18	69.84	22.43	51.34	62.08	35.74	34.57	73.62	16.44
If-33	70.99	42.90	83.28	64.35	57.97	35.83	69.07	28.46
If-avg	72.46	30.75	59.57	93.15	41.47	51.87	69.31	17.89
Pi-3	88.75	28.97	51.15	54.01	35.61	38.93	69.81	4.92
Pi-4	84.55	82.89	88.92	87.20	61.91	62.84	74.63	33.11
Pi-24	83.84	72.65	53.42	71.41	37.19	51.46	74.42	35.04
Pi-32	82.71	119.30	89.06	85.43	62.00	61.57	70.80	29.44
Pi-35	72.26	61.01	48.59	49.41	33.83	35.61	78.59	31.17
Pi-avg	84.82	51.53	85.44	89.46	59.48	64.47	77.28	23.70

[1] Average detrended yield, 1987-1996, quintal per hectare, 1996 equivalent.
[2] Variance measured in quintals per hectare squared.

Table 1. Yield Variance Reduction Under Crop Yield Insurance Futures and Put Options and Under Individual Yield Insurance Contracts, Selected Producers