at 80% coverage range between 0.2% and 15.0%, with the county risk rate at 5.3% (Figure 6.3). This example shows the variability of field-level yields relative to county yield and as a result, large differences in risk rates.

### LOSS ADJUSTMENT

Loss adjustment for MPCI determines actual yield per policyholder and is undertaken by trained professionals with loss adjustment manuals and a clearly defined methodology as to how yield is derived through sampling. To estimate actual yield at harvest, the minimum number of samples per field is determined in function of the average stage of growth and visible damage extent and the row distance established through measurement – for example, in the USA at least three samples are taken for fields ranging from 0.1 to 10 acres.

The determination of yield reduction as a function of plant density (row distances) and growth stages, shown in the example of corn in the USA, includes (i) stand reduction through relevant reduction curves, with an assessment of replanting from damage at early vegetative stages, (ii) maturity line weight for vegetation stages close to harvest, with weighing ear samples according to maturity and deriving yield, and (iii) weight method when kernels are fully developed at maturity in taking the weight of the sampled ears and deriving yield.[27]

## 6.6 REVENUE INSURANCE

RI covers producers against volatility in revenues, which are based on gross sales, i.e. the proceeds received by selling the harvested crop production at a certain price. RI is often an extension of existing MPCI-type products where shortfalls in the product of yield and price are insured. The basic version of RI indemnifies producers when actual revenue, as a combination of yield and commodity prices at harvest, is below planting price levels, which results in low revenue relative to the pre-agreed revenue guarantee. RI covers have been developed based on individual grower revenue histories and as products that use area-based revenues that are a function of area-yield and prices. In the USA, a special version of the basic form of RI, called revenue protection (RP), is used in that producers obtain a payout for revenues that result from any combination of low yields and/or the difference between harvest and planting prices, including the possibility that harvest prices are above prices at planting level.

### REVENUE INSURANCE MARKETS

RI products are implemented in Canada, the USA, Europe (Spain) and Brazil and are under discussion in several Asian countries.

#### Canada

RI was first implemented in several Canadian provinces as the Gross Revenue Insurance Program (GRIP) in 1991 and benefited from government premium subsidies to

[27] USDA, 2013: Corn Loss Adjustment Standards Handbook – 2014 and Succeeding Crop Years. FCIC Publication 25080, 104p.

guarantee a gross revenue target for grain and oilseed growers. For example, in Saskatchewan (Central Canada), GRIP offered a 70% guarantee of gross revenues that were based on observed yields and a 15-year indexed moving average of commodity prices. GRIP was discontinued in 1995 due to budget pressures.[28]

### USA

In the USA, numerous studies have tried to demonstrate that farm incomes could be stabilised and payments to growers could be substantially lower under RI than under price support policies.

*Revenue Protection*

In 1997, RI started in the USA in the form of crop revenue coverage (CRC) and revenue assurance (RA) as an initiative of the private sector and government approval and support. The RI products grew rapidly due to (i) a wider coverage compared with MPCI-type policies, (ii) the availability of substantial premium subsidies, and (iii) the 1996 Federal Agriculture Improvement and Reform Act, which cancelled the existing deficiency payments to compensate producers for commodity price variability.

In 2011, CRC and RA were revamped into (i) RP, which provides a grower with protection against revenue losses as a result of yield volatility from natural causes as well as pests and diseases and changes in the harvest price relative to a projected price from futures prices, and (ii) revenue protection with harvest price exclusion (RP-HPE), which operates like RP with the difference that the guaranteed revenue is based on projected prices, i.e. the guarantee is not increased in case the harvest price is greater than the projected price.[29] The periods during which the projected and harvest prices are determined vary by region. In 2017, 1.5 million RP policies were sold with a premium volume of US$7.6 billion and 9111 RP-HPE policies generated a premium income of US$32.2 million.

*Whole-Farm Revenue Protection (WFRP)*

WFRP was introduced in 2015 as a pilot programme in 45 US states, replacing adjusted gross revenue (AGR) and adjusted gross revenue lite (AGR-Lite).[30] WFRP was developed to cover specialty crop farmers who often produce many different fruit or vegetable commodities as it was not feasible to develop separate insurance products for each of these specialty commodities. WFRP provides a holistic safety net for low revenues from an unavoidable natural cause for (i) commodities that are produced during the insurance period, (ii) commodities that are bought for resale during the insurance

[28] Gray, A. et al., 1995: Farm level impacts of revenue assurance. *Rev. Agr. Econ.*, 17, 171–83.

[29] In the USA, options on futures contracts began trading in October 1984 for soybeans, in March 1985 for corn and in November 1986 for wheat on the Chicago Board of Trade (CBOT), which merged later with the CME Group. The *base price* for corn (soybeans) is the average of the December (November) CME Group daily futures contract prices during February (February). The *harvest price* for corn (soybeans) is the average of the December (November) CME Group daily futures contract prices during October (October), reflecting market conditions during harvest time.

[30] Risk Management Agency (RMS), 2015: Whole-Farm Revenue Protection Pilot Handbook. USDA/RMA Report FCIC-18160, 174p.

period, and (iii) all commodities on the farm except for timber, forest products, pets and sport/show animals. WFRP provides additional protection for replanting costs for up to a maximum of 20% of the expected revenue when at least 20% or 20 acres of the crop needs replanting.

The approved revenue is determined from the farm operation report and is the lower of the expected revenue or the whole-farm five-year historic average revenue from tax filings. In cases when farm operations have been growing, an indexation is used to account for growth in the approved revenue. The insured revenue is calculated by multiplying the approved revenue by the coverage level. The maximum insured revenue is set at US$8.5 million at a farm, out of which a maximum US$1 million can be generated from animals and animal products, a maximum of US$1 million from greenhouse and nursery products, and less than 50% of the total revenue from commodities purchased for resale. Special attention is given to expenses (as filed in the tax forms) and in cases where expenses are below 70% of the five-year average expenses, a downward adjustment of the insured revenue is undertaken based on the assumption that a change in the operation has led to lower expenses. Coverage levels range from 50% to 85% in 5% increments and are a function of the number of commodities produced at a farm, i.e. only highly diversified farms that produce at least three commodities qualify for 80% and 85% coverage.

Farm diversification, which reduces revenue risk, determines the level of government premium subsidies, with a maximum of 80% for farms that produce at least three commodities. The farm-level premium rate depends on (i) the location (county) of the farm, (ii) the types and total number of commodities produced, and (iii) the amount of farm revenue of each commodity produced. For farms that have a commodity that is insured under other approved insurance plans (e.g. RP), at least two further commodities must be grown on the farm to be eligible for WRFP while the WFRP premium rate is reduced due to the coverage provided by other policies.

A claim can be filed only once taxes have been filed for the period of insurance. An indemnity occurs when the gross adjusted revenue falls below the insured revenue. The gross revenue is established from the revenue filed for taxes and adjusted by (i) excluding inventory from commodities sold that were produced in previous years, and (ii) including the value of commodities produced that have not yet been harvested or sold. Losses for replanting are paid during the insurance period based on an assessment of the insurer.

WFRP allows a producer to insure a wide variety of crops and livestock products and includes coverage for higher-value specialty products (e.g. unique varieties, organic products, seeds, humanely produced livestock) that have not been insurable before. The experience with WFRP has shown implementation challenges, particularly for specialty crop growers, including (i) the need for extensive recordkeeping with at least five years of tax filing records, (ii) increased costs to transform cash-based farm accounting to accrual accounting, which is required for insurance, (iii) dramatic changes in farmed commodities in function of prices offered by processors, (iv) the need for farm-level yield or revenue distributions of each produced commodity to develop joint probability distributions, which is hardly feasible and led to the development of more pragmatic pricing approaches with the risk of inadequate premium rates, and (v) multiple harvest of certain specialty crops (e.g. vegetables), which can cause moral hazard. In 2017, 2845 WFRP policies were sold for a premium volume of US$145 million, with an average loss ratio of 86% (2015–2017).

### Europe

In Europe, RI was first proposed in the UK in 1999 but failed as a private sector initiative. Similarly, a pilot RI programme of potatoes and strawberries in Spain in 2000 was not successful and was discontinued, although it has been reconsidered for implementation since 2014.[31]

### Brazil

In Brazil, RI was developed by the private sector for agribusinesses as standard crop insurance products could not fulfil the needs of grain aggregators, processors and investment funds. As most Brazilian farmers use prices for CBOT, RI covers that use CBOT prices include a pre-agreed currency exchange rate of the Brazilian real against the US dollar to limit adverse currency rate developments.

### Asia-Pacific

RI was recently under discussion in India, but the concept was dropped, with a focus on increasing insurance penetration of area-yield index products. Similar discussions were held in China, where liquid commodity exchanges exist and where the ultimate goal seems to be to introduce RI once the current named-peril insurance products are changed to more MPCI-type yield insurance policies.[32] As Japan seeks to transform its government-run rice insurance scheme into a private–public partnership (Section 5.5), RI seems to be one of the most attractive propositions for rice farmers.

### Challenges of Revenue Insurance

As with MPCI, RI is most suited for large production units and main crop types (e.g. rice, wheat, corn, soybean, cotton) where reliable and longer time series of commodity prices exist, e.g. from future markets.

Pricing and underwriting of RI products is demanding in that farm or area-yields need to be simulated and price volatility modelled while performing joint yield-price simulations and preserving the correlations. Rating errors may reflect incorrect assumptions on yield and/or price distributions, data inconsistencies and the length of the combined yield-price time series as well as more fundamental issues with the rating methodology as such.

The implication of severe rating errors for RI products is inefficient insurance products that do not find support in the market. Difficulties in pricing yield and price volatility due to lack of reliable data and liquid markets and the relatively high premium rates often prevent the wider development of RI outside the USA.

In countries with government schemes that provide minimum commodity prices, RI will be an additional and relatively costly risk management measure and makes economic sense only if it can complement or replace existing government-supported price schemes. Depending on the size of an RI scheme and the number of crop types covered, the systemic exposure from yield volatility and even more so from price fluctuations creates large liabilities, which will require government-backed catastrophe protection.

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[31] Ahmed, O. and Serra, T., 2015: Economic analysis of the introduction of agricultural revenue insurance contracts in Spain using statistical copulas. *Agr. Econ.*, 46(1), 69–79.

[32] Cole, J.B. and Gibson, R., 2010: Analysis and feasibility of crop revenue insurance in China. *Agric. Agric. Sci. Procedia,* 1, 136–45.

## INSURANCE TERMS

RI which uses farm-based yields establishes the expected revenue before planting in multiplying an expected or average historical farm yield with an expected harvest price as the average of spot markets or futures contract prices. Area-based RI uses the same approach but with the difference that average or expected area-based yields are used.

Producers are usually allowed to select a coverage level, which is typically between 65% and 75% of the average historical farm yield when individual fields are insured and increases to 80–85% in the case of all fields being covered due to a diversification effect. Based on the expected revenue and a selected coverage level, the guaranteed revenue is calculated by multiplying the guaranteed yield with the expected harvest prices and the area insured, based on which premium amounts are determined. At harvest time, the final guaranteed revenue is established in function of the guaranteed yield and the actual harvest price, which is averaged over a pre-agreed time (e.g. 10 days spot market prices or 30 days futures contract prices) and multiplied by the area insured. At the same time, the actual revenue is calculated by multiplying the actual yield with the actual harvest price (or the difference of the base and harvest prices as under RP products in the USA) and the area insured. Actual yields are determined through on-site loss adjustments in same way us under MPCI-type policies. An indemnity is received in case the actual revenue is below the final guaranteed revenue.

However, as harvest prices are taken from regional or national commodity exchanges (spot markets and/or future contracts), these prices can differ greatly from local prices such as prices paid by grain elevators. These differences are known as basis and the variability of this basis over time is called basis risk. Basis risk results from the imperfect correlation of price indices with actual prices.

## PRICING

The pricing of RI products requires accurate crop yields at different geographical resolutions as well as historical and forward-looking commodity prices to establish expected and guaranteed revenues. The main challenge is to relate the distribution of crop yields to the distribution of prices while performing joint simulations so that correlations are preserved. An additional complexity arises when farm yields need to be related to area-based yields (e.g. a county) where longer times series are available, which in turn needs to be correlated to yields of areas for which commodity price information is available (e.g. a province or state).

The common pricing approach for RI involves four steps in (i) establishment of yield and price PDFs, (ii) estimation of correlations between yield and price distributions, (iii) joint simulation of correlated yield and price events, and (iv) computation of estimated losses at different geographical resolutions and coverage levels, through geographical downward adjustments.[33]

[33] Coble, K.H. et al., 2010: A comprehensive review of the RMA APH and combo rating methodology. Final report. Prepared by sumaria systems for the Risk Management Agency (RMA), 157p.

### Sources of Commodity Prices

RI mostly relies on forward-looking prices from futures markets; however, for crops that are not traded at futures markets, expected prices over the period of insurance have been derived from historical data. Historical price data are imperfect estimators of future expected price or price volatility, particularly in the presence of significant structural market changes (e.g. new trade agreements). Futures, options and spot-market prices are available from financial market platforms and terminals (e.g. Reuters, Bloomberg) but require a subscription. Some open source platforms provide access to agriculture commodity data from several exchanges and barchart markets.[34]

*Price Volatility Indices*

A reliable price volatility index needs to fulfil the following criteria: (i) standardisation, which refers to the need of the market participant to know that the underlying commodity, futures or products are consistent and to a large extent deliverable, (ii) verifiable pricing, where parties of the same trade are able to replicate and reasonably forecast price index values, (iii) frequent price dissemination to assure wide access, e.g. through the internet or bulletins, (iv) competitive price determination without manipulation of trading, delivery or input data that are used to compute the price index under free market conditions, and (v) value representation in the price index that largely reflects the underlying risk and general valuation while market participants accept that some inaccuracies exist.[35]

A key concern with agricultural commodities is that farmers sell production in function of expected prices and can store commodities to be sold later at optimal prices, which can lead to distortions in price volatility measures. Corn, soybean and spring wheat prices in the USA show that for periods early in the growing season, price distributions from options trades offer higher reliability than distributions based on historical futures trades.[36] Further, volatility in commodity prices of main crops has been shown to be higher than volatility in crop yield, e.g. for US corn, yield varies between 12% (state level) and 25% (farm level) and prices between 17% (state level) and 28% (farm level).[37] Generally, spatial disaggregation increases price and yield variability, while yield variability increases typically faster than price and revenue variability.

### Calculation of Yield Volatility

Crop yield data are examined for inconsistencies and outliers, after which the data are, if justified, detrended and deviations in percentages from the trend (residuals) computed, to which a suitable parametric or non-parametric PDF is fitted (Section 4.4). While parametric (e.g. beta) and non-parametric (e.g. kernel) functions are often used to establish yield densities, the most suitable distribution depends on the length of the data records

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[34] For example, www.quandl.com, which is a source of open, commercial and alternative data for investment professionals and includes soft commodity prices.

[35] Cole, J., 2002: Designing and pricing new instruments for insurance and weather risks, in *Risk Management: The State of the Art*, S. Figlewski and R. Levich (eds.), Kluwer Academic Publishers, 79–85.

[36] Buschena, D. and Ziegler, L., 1999: Reliability of options markets for crop revenue insurance rating. *J. Agr. Resource Econ.*, 24(2), 398–423.

[37] Coble, K.H. et al., 2007: Policy implications of crop yield and revenue variability at differing levels of disaggregation. In annual meeting of the American Agricultural Economics Association, Portland, USA, 29p.

and the presence of outliers. To avoid computational difficulty and complexity when yield PDFs are to be combined with price PDFs, yield PDFs in earlier RI products have been chosen to follow a censored normal distribution, which however violates some of the common characteristics of crop yield distributions such as heteroscedasticity and negative skewness (Section 4.4). Flexible multivariate models that can describe major data properties, higher-order moments, fat tails, co-extreme movement and tail dependence can combine any type of parametric or non-parametric PDFs of yields and prices.

#### Calculation of Price Volatility

To establish price volatility, percentage change from base prices at planting time to prices at harvest time are calculated. The measurement of price risk heavily depends on assumptions relative to the distribution of the underlying price movements. The main approaches to model price volatility include the Present Value Method (PVM), the Black–Scholes Option Pricing Method (BSOPM) and the Geometric Brownian Motion (GBM).

*Present Value Method*

The PVM is the most used method to value insurance contracts including price volatilities. PVM prices insurance contracts at present value of the expected indemnity and is straightforward in computation; however, it requires arbitrary assumption of discount rates. Under PVM, the price value at planting time of an RI contract based on a crop revenue index $Y_t$ that is realised and observed at harvest period $t$ when revenues are realised, and any insurance indemnities are paid, is written for a guarantee level ($G_t$) as:[38]

$$P_{t-1}\left(G_t\right) = \left(1+\gamma_t\right)\beta_t E_{t-1}\left[\max(G_t - Y_t, 0\right] = \left(1+\gamma_t\right)\beta_t \int_0^{G_t} \left(G_t - Y_t\right) h\left(Y_t\right) dY_t$$

with $\gamma_t$ as a loading factor that reflects costs of risk premium and the insurance transaction for the time period of $t-1$ to $t$; $\gamma_t$ is usually positive and a negative value signifies that the premium does not cover the present value of expected indemnities and a value of zero is equivalent to the actuarially fair premium rate, $\beta_t$ is a discount for the expected indemnity back to the planting time at a risk-free rate, $E_t$ is the expectation that is conditional on information available at a given time and $h\left(Y_t\right)$ is the PDF for $Y_t$ conditional on information available at $t-1$.

The RI contract is based on a contingent claim with a payout at harvest time $t$ over the difference between a guaranteed level of the revenue index, the level of guarantee ($G_t$) and the realised harvest value of the revenue index $Y_t$ when $Y_t < G_t$. The insurance indemnity is written as $\max\left(G_t - Y_t, 0\right)$ with a premium value of $P_{t-1}\left(G_t\right)$.

A key advantage of PVM is that it is highly flexible and can include any underlying PDF $h\left(Y_t\right)$ but it has the disadvantage that the loading factor $\gamma_t$ must be predetermined and can have a large impact on the premium value $P_{t-1}\left(G_t\right)$. Setting the loading factor at 0 is unrealistic because agricultural contracts typically involve non-diversifiable risk that must be priced. A simplified formula for the premium value has been developed in case $h\left(Y_t\right)$ is lognormal. Often, sensitivity analyses are undertaken to evaluate how the premium value changes with different loading factors.

[38] Myers, R.J. et al., 2005: How should we value agricultural insurance contracts. Paper prepared at the American Agricultural Economics Association Annual Meeting, Providence, Rhode Island, 24–27.

*Black–Scholes Method*

The BSOPM is the most used method to valuate financial derivatives using the contingent claim method. Under the BSOPM terminology, an RI contract provides a producer the right, but not the obligation, to claim a fixed amount in the event of an indemnifiable loss, while the probability of a loss is known only up to the observed distribution of both crop yield and commodity prices. RI products are similar to a European put option, which is a financial derivative and is mostly valuated through BSOPM assuming that prices are lognormally distributed.[39] BSOPM has been used to value crop RI insurance contracts[40] and assumes that prices are lognormally distributed, which was the case for the earlier RI products in the USA. Based on BSOPM, price changes from planting to harvest can be established based on a futures prices at planting time ($P_p$) and harvest prices of the same futures contracts ($P_h$) as:[41]

$$F(P_h) = \left(\sqrt{\pi\sigma}\right)^{-1} \exp\left[\frac{-0.5\left(\log\left(P_h - \mu\right)\right)}{\sigma^2}\right]$$

with $\mu$ as the mean and $\sigma$ as the standard deviation from the lognormal distribution estimated from option trades. The BSOPM contains several main assumptions that can cause potential problems for agricultural revenues in that (i) crop prices are not always lognormally distributed and lognormality suggests a proportional relationship between the variance and the mean of the observed data, which might not be the case for crops, (ii) stochastic processes[42] underlying revenues from agricultural commodities may not be completely continuous (as is often assumed) but rather show continuous as well as discrete components in the form of sudden jumps, (iii) farm revenues are not tradable and are not influenced by constant updating of buying and selling positions in the options market under non-arbitrage conditions, and (iv) a producer's revenue is often derived from more than one commodity. The evidence that agricultural commodity prices include sudden jumps due to shocks that are often driven by low yields has led to the use of pricing approaches that allow both continuous and discrete jumps.[43]

*Geometric Brownian Motion*

The GBM allows prices to be continuous and concrete through a continuous-time stochastic process where the logarithm of a randomly varying quantity follows the Brownian motion. The GBM is used in mathematical finance to model stock prices and incorporates components of the BSOPM to describe the movement of time series of asset prices. The GBM has two components in (i) a certain component, which represents

[39] Stokes, J.R. et al., 1997: The pricing of revenue assurance. *Amer. J. Agr. Econ.,* 79, 439–51.

[40] Turvey, C., 1992: Contingent claim pricing models implied by agricultural stabilization and insurance policies. *Can. J. Agr. Econ.*, 40, 183–98.

[41] Buschena, D. and Ziegler, L., 1999: Reliability of options markets for crop revenue insurance rating *J. Agr. Resource Econ.*, 24(2), 398–423.

[42] Any variable that shows a change in value over time in an uncertain way is said to follow a stochastic process. Stochastic processes can be discrete (value of the variable can change only at certain fixed points in time) or continuous (value of the variable changes at any time) with respect to time.

[43] Richards, T.J. and Manfredo, M.R., 2003: Infrequent shocks and rating revenue insurance: A contingent claims approach. *J. Agr. Resource Econ.,* 28(2), 233–51.

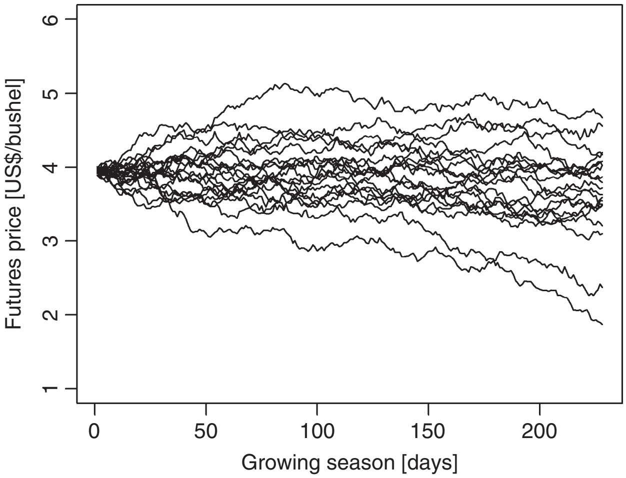


**FIGURE 6.4** Example of 20 realisations of futures prices using the Geometric Brownian Motion for corn futures prices in Illinois (USA), with a starting point of US$3.96/bushel and an implied volatility of 17.23% for 1 March to 15 October (228 days).
*Data source*: CBOT.

the return that a stock will earn over time, which is called drift of the stock, and (ii) an uncertain component, which is a stochastic process that includes stock volatility and an element of random volatility, called implied volatility.

The GBM has been used to model agricultural commodity prices[44] and to price crop RI products.[45] For the use of the GBM to price RI products, the drift is the expected return on capital over the period of insurance (i.e. the crop season) and the implied volatility is determined from capital markets or computed from the data (Figure 6.4).

#### Calculation of Yield-Price Correlations

In major production regions for commodities where production is a main part of the global market, or in markets that are protected from global markets, yield and prices tend to be negatively correlated in that with high production, prices decline and vice versa. In markets with production that is of lower importance at the domestic and global scale, yield and prices are typically unrelated. For example, negative yield-price correlations exist for corn and soybeans in the US Midwest, which is the dominant production region and of global importance; however, yield and prices are non-related for the same commodities in southern US states, which produce lower quantities.

Studies of yield-price correlations of US RI products have shown that strong correlations exist for certain crop types at farm as well as at national level.[46] As in many markets and main crop types, yields and prices can be related, joint yield-price simulations for RI products evolved from the initial additive approach to the use of copula functions (Table 6.6).

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[44] Hennessy, D.A. and Wahl, T.I., 1996: The effects of decision making on futures price volatility. *Amer. J. Agr. Econ.*, 78(3), 591–603.
[45] Richards, T.J. and Manfredo, M.R., 2003: Infrequent shocks and rating revenue insurance: A contingent claims approach. *J. Agr. Resource Econ.*, 28(2), 233–51.
[46] Coble, K. et al., 2000: Implications of crop yield and revenue insurance for producer hedging. *J. Agr. Resource Econ.*, 25(2), 432–52.

**TABLE 6.6** Overview of the main methods for pricing revenue insurance products.

| Method | Complexity | Yield Data | Price Data | Joint Simulation | Comments |
|---|---|---|---|---|---|
| Additive method | Low | Detrended observed or modelled yield (any PDF) | Observed or simulated price differentials (usually lognormal) | Adding price volatility to risk rates determined from yield volatility | Conservative approach as negative yield-price correlations are ignored |
| Simple simulation | Low | Detrended and modelled yield (censured normal or lognormal) | Modelled price differentials (lognormal) | Simulation that easily allows the combination of modelled yield (e.g. lognormal or censured normal) with modelled prices (lognormal) | Crop yields are rarely lognormal or normal distributed |
| Black–Scholes with copula functions | High | Detrended and modelled yield (any PDF) | Black–Scholes Option Pricing Model (BSOPM) with lognormally distributed price differentials | Copula functions to combine modelled yield (any PDF) with modelled price (lognormal) | BSOPM assumes continuous prices but soft commodity prices often show sudden jumps and farm revenues are not tradable |
| Geometric Brownian Motion with copula functions | High | Detrended and modelled yield (any PDF) | Geometric Brownian Motion (GBM) with simulations (random walks) of prices | Copula functions to combine modelled yield (any PDF) with modelled price (lognormal) | GBM allows continuous and discrete (jumps) price movements but requires determination of shift and implied volatility |

*Additive Methods and Simple Simulations*

The additive method simply assumes that yields and prices are independent, and RI covers are priced in adding the price volatility to the risk rates determined from yield volatility. This approach was initially used for the earlier US CRC products.[47] However, ignoring negative correlations between yield and price distributions implies that the risk from revenue shortfall is lower than the risk from price and yield shortfalls considered in isolation, which leads to conservatively priced RI products. An approach that respects yield-price correlations is to choose the PDFs of yield and prices in a way that allows simple simulations where price distributions are assumed to be lognormally distributed following the BSOPM approach and yield distributions are selected to follow a censored normal distribution.

*Copula Functions*

A more complex approach to develop joint yield-price series that allows joint simulations of any type of PDF for yields and prices are copula functions. Under copula functions, marginal distributions are linked to form a joint distribution. Copula functions are widely used by insurance actuaries to model multiple sources of risk at various degrees of correlation. One of the advantages of the copula approach is that the estimation and inference are based on standard maximum likelihood procedures, which allows efficient estimation of the assumed copula model. While mathematically complex, the copula methodology allows the development of joint distributions of a variety of underlying parametric and non-parametric PDFs. Copula functions facilitate the joint simulation of yield and prices under the BSOPM and the GBM and have been used to price RI products[48] as well as farm-income insurance policies.[49]

#### Geographical Downward Adjustments

As consistent yield data and commodity prices are typically available only at geographically aggregated levels (e.g. county for yield and province for prices), risk premium rates established at these resolutions need to be downward adjusted to farm level in relating farm-level yields to yields at aggregated levels. Often, a Monte Carlo simulation is used to compute RI losses over a range of different coverage levels, which is assumed to be constant for all producers in the administrative area (e.g. county).

#### Example of Revenue Insurance Pricing

As with the example of corn in Adams County (Illinois, USA), the following shows a step-by-step approach to pricing two types of revenue cover: (i) a payout in case the harvest price is lower than the base price at planting, called RP-HPE in the USA, and (ii) a payout of the higher of the base price and the harvest price, called revenue protection (RP) in the USA.

[47] Goodwin, B.K. et al., 2000: Measurement of price risk in revenue insurance: implications of distributional assumptions. *J. Agr. Resource Econ.,* 25(1), 195–214.
[48] Goodwin, B.K. and Hungerford, A., 2014: Copula-based models of systemic risk in US agriculture: implications for crop insurance and reinsurance contracts. *Amer. J. Agr. Econ.*, 97(3), 879–96.
[49] Zhu, Y. et al. 2008: Modeling dependence in the design of whole farm insurance contract – a Copula-based model approach. In Selected Paper prepared for presentation at the American Agricultural Economics Association Annual Meeting, Orlando, USA, 27–29.

*Pricing Yield Volatility*

First, county-level corn yields are linearly detrended for the period for which both yield and commodity price data are consistently available (1990–2015). Testing different PDFs, the logistic function produces the best fit for the detrended corn yield data and additionally, a normal distribution function is used to demonstrate the difference. The guaranteed yield is taken from the online *iFarm* Crop Insurance Premium Calculator for corn in Illinois at 154.89 bushels/acre, which compares to 139.17 bushels/acre as the historical average (1990–2015) and 156.74 bushels/acre from detrended yield data (1990–2015).

*Pricing Price Volatility*

For the RP cover, the base price (average of February prices) and harvest prices (average of October prices) from the December futures contracts (contract CZ17) of CBOT is established for the period of available data (1990–2015). In about one third of the years, harvest prices were above base prices, while in two thirds of the years, the opposite occurred (Figure 6.5). Price differentials show phases of continuity but include several discrete phases (jumps) in 2008 and in 2013 (Figure 6.5). For the RP-HPE cover, spot market prices for corn are used from CBOT at planting and harvest time. Price differentials for the RP and RP-HPE covers are simulated using a GBM with a shift factor of 0 and an implied volatility of 17.23% as calculated from the price data.

*Joint Yield-Price Simulations*

The analysis between the detrended corn yields and the corn price differentials reveals a strong negative correlation (–0.75) and implies that high yields result in most cases in lower prices and vice versa (Figure 6.5). This is not surprising given that Adams County is in the Corn Belt in the US Midwest, which is a major global corn-producing region. For pricing, a yield-price correlation coefficient of –0.75 is taken and to test the sensitivity, a coefficient of –0.3 is used additionally, assuming a more elastic market.

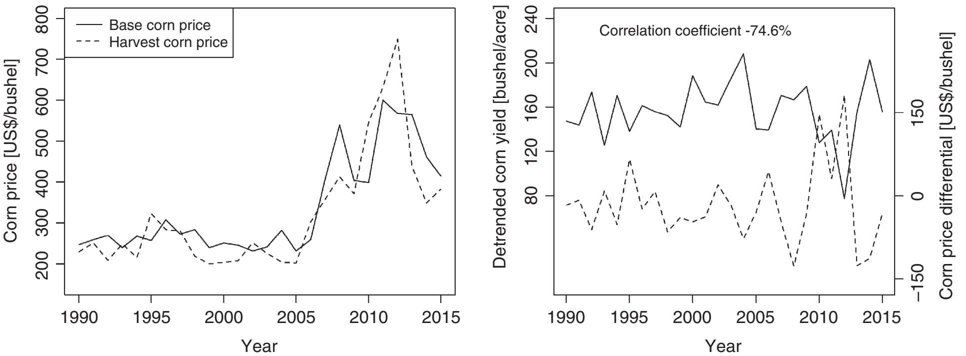


**FIGURE 6.5** Left: Base corn prices (averages of February) and harvest corn prices (averages of October) from the December futures contracts (CBOT contract CZ17), 1990–2015. Right: Detrended corn yield for Adams County (Illinois, USA, solid line) and corn price differentials from harvest and base prices (dotted line), 1990–2015.
*Data source*: NASS and CBOT.

**TABLE 6.7** Risk premium rates for the revenue protection (RP) and the revenue protection with harvest price exclusion (RP-HPE) products, with yield distributions following a logistic and a normal function and yield-price correlation coefficients of –0.75 (as observed) and –0.30.

| | | | Risk Premium Rates Per Coverage Level | | |
|---|---|---|---|---|---|
| **Product** | **Yield Distribution** | **Correlation** | **70%** | **80%** | **85%** |
| RP | Normal | –0.75 | 3.8% | 12.9% | 21.9% |
| RP | Logistic | –0.75 | 4.3% | 12.4% | 20.6% |
| RP | Normal | –0.30 | 5.6% | 16.2% | 26.1% |
| RP | Logistic | –0.30 | 5.7% | 14.4% | 24.7% |
| RP-HPE | Normal | –0.75 | 1.0% | 3.9% | 7.9% |
| RP-HPE | Logistic | –0.75 | 1.4% | 4.5% | 8.2% |
| RP-HPE | Normal | –0.30 | 3.7% | 10.6% | 17.5% |
| RP-HPE | Logistic | –0.30 | 4.0% | 10.7% | 17.3% |

For the combination of the yield distribution (logistic function) and the price differential distribution (simulated with GBM to be lognormal), a copula function is used to obtain the joint yield-price distribution. This joint distribution forms the basis for deriving risk premium rates for different coverage levels set at 70%, 80% and 85% (Table 6.7).

*Risk Premium Rates*

As expected, risk premium rates for the RP-HPE cover are lower than for the RP product as RP-HPE compensates for low revenues only in cases when harvest prices are below (and not below or above) base prices at planting. Risk premium rates that are based on normally distributed yields are considerably lower compared with the logistic function as the normal distribution assumes equal probabilities of low and high yields realtive to the mean yield (i.e. no skewness), which is not suitable for crop yields. Increasing coverage level (e.g. from 70% to 85%) largely increases the risk premium rates, which is necessary to compensate against more frequent shortfalls in revenues. The use of a lower yield-price negative correlation (–0.30) compared with the correlation of the observations (–0.75) results in higher risk premium rates. This example shows that risk premium rates of RI products are highly sensitive to the yield density distribution and the extent of the yield-price correlation.

## 6.7 INCOME INSURANCE

Income insurance provides coverage for volatility of farm income, which is determined by deducting expenses (e.g. for input supplies) from revenues and therefore differs from RI (Section 6.6) where low revenues are compensated. Income insurance covers covariate risks that cause low income from different farming activities that can include crop farming, livestock rearing and on some occasions timber and aquaculture production. As such, income insurance has the widest coverage of all agricultural insurance products and is based on the concept that pooling risks over different farm activities