Self-Insurance and the Utility of Standard Risk Management Contracts

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Abstract
This paper analyzes the potential trade-offs and complementarities that exist between intra-year strategies employing annual price and yield risk contracts and inter-year self-insurance strategies involving intertemporal consumption substitution and borrowing, and explores whether standard crop insurance contracts can be made more useful to farmers if offered with a multiple-year horizon.

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Optimal response to income risk involves self insurance through savings and borrowings and/or spreading risk through standard risk management contracts (SRM) including insurance and options and futures contracts. Many agricultural risk management studies examine the benefits of using crop insurance, options, futures and forward contracts to mitigate farm-level harvest-time income risk. Typically, these studies focus on income risk within a single growing season, rather than across successive growing seasons, ignoring the potential benefits of alternative dynamic self-insurance strategies involving savings, borrowing, and intertemporal consumption substitution.

In this study, we examine optimal farm income risk management in a dynamic, multi-year stochastic framework. Our primary goal is to better understand the potential tradeoffs and complementarities that may exist between intra-year strategies employing short-lived price and yield risk contracts and inter-year self-insurance strategies involving savings, borrowing, and intertemporal consumption substitution. We intend to determine the optimal risk management strategy(ies) when crop insurance, options and futures contracts and savings (borrowings) are allowed simultaneously. Our secondary goal is to examine whether standard crop yield risk insurance contracts can be made more useful to farmers if offered with a longer, multiple-year horizon.

This paper incorporates several important characteristics of farming households, their risk management strategies, and crop insurance market that were ignored in the past literature. First,
farmers adopt a portfolio of strategies to mitigate risk. Farmers self insure through savings, buy crop insurance, and/or buy options and futures contracts. Saving and borrowing are inter-year or intertemporal choices as they affect both current and future incomes, while crop insurance contracts and futures contracts are generally intra-year. Second, the model pools risks over time. The agriculture sector poses a special problem where crop losses or drought conditions, for example, could be geographically widespread. That is, random factors generating uncertain farm incomes are likely to be correlated across farmers in a given region. However, events (good and bad) are stochastic (\textit{iid}) over time, making it attractive to design policies that would pool risks over time. Third, since saving is inherently intertemporal, a dynamic model is used. Finally, yield and prices are exogenous and uncertain at the time of risk management decision.

Risk averse farmers may choose a general risk-reducing strategy that contains a portfolio of options, depending on the relative costs and benefits of each option. It follows that changes in the costs and benefits of one strategy will affect how other strategies are used, and these interactions may be important in designing public policy. Past studies on risk management, however, have focused narrowly on one strategy at a time, thus significantly undermining the applicability of findings for policy purposes. We allow for savings and borrowings, yield and revenue insurance, and options and futures contracts in our study.

\textbf{Self Insurance}

Savings and borrowings are an important form of self insurance to mitigate consumption and income risks. In an economy with well developed capital markets, farmers’ ability to save and borrow is a significant factor in reducing consumption and income risk. For example, studies have shown that individuals would manage their savings and investment patterns to minimize the
adverse effects of variable income (Deaton 1991 and 1992). Savings are desirable at least for two reasons: First, savings generate a positive return, and, second, reducing insurance coverage is profitable because insurance is costly. However, the objectives of insurance and savings could be conflicting in the short-run because protecting against large crop losses may involve hefty premium costs which would reduce the funds otherwise used to build up savings (Gollier 1994). Most studies in crop insurance use static models, thereby excluding possibilities for savings and borrowings, while very few dynamic models of precautionary savings have included insurance as an option for smoothing consumption.

**Standard Risk Management Contracts**

The standard intra-year risk management contracts are based on the principle of risk spreading/sharing. The most commonly used strategies include yield and revenue insurance contracts and options and futures contracts. The crop insurance program provides yield and price risk protection to farmers through indemnity payments whenever yield falls below a predetermined level. Under a program like Multiple-Peril Crop Insurance (MPCI), farmers may select a guaranteed yield level (between 50 and 75% of their insurable yield) and an elected price level determined as a percentage of USDA forecasts of expected prices. If the yield falls below the guaranteed yield level, the farmer receives an indemnity payment equal to the product of the elected price coverage and yield shortfall.

More recently, there has been considerable interest in revenue insurance among farmers and private insurance companies. Under the revenue insurance program, farmers would be protected from shortfalls in revenue below the guaranteed level. It would include revenue shortfalls caused by low yields, low prices, or both. Similarly, options and futures contracts
provide farmers with further flexibility in managing risks. Forward contracts allows farmers to lock in price for a given quantity well ahead of harvest. Yield futures in combination with price futures can substantially reduce revenue risk to farmers.

Multi-year Insurance Contracts

Farm income is inherently uncertain, caused largely by uncertain yields and notoriously volatile agricultural prices. In addition, the agricultural sector poses a special problem where crop losses caused by drought conditions, floods, pests and diseases, etc., could be geographically widespread and induce significant correlation among individual farm-level yields. The lack of stochastic independence among individual yields reduces insurers’ ability to pool crop loss risk across farms. In a recent study, Miranda and Glauber (1997) argued that systemic risk in crop yields is large in agriculture and poses a pervasive problem for the provision of crop insurance by the private sector. Their results indicate that U.S. crop insurer portfolios are twenty to fifty times riskier than they otherwise would be if crop-yield losses were independent across farms. This supports the call for spreading risks over time instead of space in agriculture and offering multi-year crop insurance contracts.

Next, we develop a formal stochastic multi-year optimization model of a representative risk-averse farmer who faces exogenous annual price and production risks. The farmer is assumed to maximize expected discounted utility of wealth over his or her life time through the optimal use of futures, options, forward contracts, insurance, and credit contracts. The optimal portfolio of risk and credit contracts and the optimal consumption-savings allocation are derived jointly under alternative assumptions regarding the wealth of the farmer, the costs and availability of credit, the farmer’s level of risk aversion, the farmer’s discount factor, the degree of price and
yield risk, the correlation between prices and yields, the transactions costs associated with price and yield risk contracts, and the subsidy embedded in the crop insurance premium.

The Model

A typical farm household begins each period (crop year) with wealth \( w_t \), defined as the sum of revenue from current sales (current production \( q_t \) times current market price \( p_t \)), savings from the previous period \( s_{t-1} \), interest income from last year’s savings \( r s_{t-1} \) and indemnity payments \( \Upsilon_t \) from SRM contracts, if any:

\[
(1) \quad w_t = q_t p_t + (1+r)s_{t-1} + \Upsilon_t
\]

where \( r \) is the annual interest rate. The decision problem facing the farm household is to decide how much to spend on consumption (which would include production expenses for the next period), how much to save, and how much insurance to purchase. Therefore, endowment \( w_t \) is allocated to consumption \( c_t \), savings \( s_t \), and to pay for insurance premium \( \pi_t \):

\[
(2) \quad w_t = c_t + s_t + \pi_t
\]

**Objective function.** A typical risk averse rational farmer chooses consumption, savings, and insurance in order to maximize expected discounted utility of wealth over time:

\[
(3) \quad \text{MAX} \quad E_t \sum_{k=0}^{T} \delta^k U_{w_{t+k}}
\]

subject to

\[
(1) \quad w_t = q_t p_t + (1+r)s_{t-1} + \Upsilon_t
\]

\[
(2) \quad w_t = c_t + s_t + \pi_t
\]

\[
q_t > 0; \quad p_t > 0; \quad r > 0; \quad \delta > 0
\]

where \( c_t \) is the consumption expenditure (including production expenses for the next period), \( \delta = (1+\lambda)^1 \) is the annual discount rate, \( \lambda \) is the time preference rate or opportunity cost, and \( w_t \) is the wealth in period \( t \). (Risk neutral producers would maximize expected wealth instead of expected utility of wealth). The utility function \( U(\cdot) \) is assumed to be increasing, strictly concave, and
differentiable. The concavity of $U(\cdot)$ characterizes farmers’ attitude towards risk.

**Production.** The current production ($q_t$) equals the acreage allocated times a random per acre yield ($y_{it}$). Acreage allocation is assumed to be inelastic (normalized to one for simplicity), while yield is assumed to be random with a known probability distribution (mean $y^\mu$ and variance $y^\sigma$) and is bounded by minimum ($y^{\min}$) and maximum ($y^{\max}$) yield levels. The yield distribution is independently and identically distributed ($iid$) through time.

**Price.** Farmers face an exogenous random Price ($p_t$) for their produce. The price distribution is assumed to be $iid$ with known mean $p^\mu$ and variance $p^\sigma$ and is bounded by $p^{\min}$ and $p^{\max}$.

**Saving and borrowing.** Farmers choose a level of net saving $s_t$ (borrowing would be negative net saving). The risk-free saving would earn an annual fixed interest rate of $r$. There is no limit on savings, but there is a limit on borrowing. $s_t \geq -b$ where $b$ is the limit on borrowing. If the interest rate is negative, some limit on borrowing is required (infinite borrowing). If the interest rate is strictly positive, this assumption is less restrictive.

**Insurance Decision ($I_t$).** Farmers have the opportunity to purchase crop insurance contracts by paying a premium. Individual farmers’ decision to buy crop insurance is influenced by her/his risk attitudes and perceptions. When making the participation choice, a risk averse producer compares expected utility of wealth with insurance $E_t U_I (w_t)$ to expected utility of wealth without insurance $E_t U_N (w_t)$. A farmer would purchase crop insurance if $E_t U_I (w_t)$ is greater than $E_t U_N (w_t)$. If farmers are risk neutral, they would compare expected wealth with insurance $E_t (w_t)$ to expected wealth without insurance $E_N (w_t)$.

Consider a farm household which buys revenue insurance with a minimum guaranteed
revenue level of $g$ dollars at a price of $z$ dollars per dollar of guarantee. The insurance premium that farmer will pay is given by

\begin{equation}
\pi_r = (1+k_r) z g
\end{equation}

\begin{equation}
g = P^g y^g
\end{equation}

where $(1+k)$ is the loading factor that reflects the administrative and selling costs of the insurance, $P^g$ is the guaranteed price, and $y^g$ is the guaranteed yield coverage\(^3\).

The guaranteed yield level $y^g$ is a certain fixed proportion of the average expected yield $y^e$, usually based on previous records (APH yields) on the same farm:

\[ y^g = \theta y^e, \quad \forall \theta = (0.50, 0.55, 0.60, 0.65, 0.70, 0.75) \]

where $\theta$ is the percentage of yield insured, which range from 50 percent to 75 percent at an increment of 5 percent.

**Indemnity ($\Upsilon_r$)** is the payment from the insurance company to farmers when the actual income falls below the guaranteed level:

\begin{equation}
\Upsilon_r = MAX \{ (g - P^m y^a), 0 \}
\end{equation}

where $P^m$ is the market price at the time of harvest, $y^a$ is the actual or realized yield, and $g$ is the minimum guarantee revenue level. Using equations (4), (5), and (6), an actuarially fair premium is obtained as

\begin{equation}
\pi_r = (1+k_r) E MAX \{ (g - P^m y^a), 0 \}
\end{equation}

**Futures and Options Contract.** The structure of payoffs from buying futures or options contracts is similar to that of buying crop insurance. For example, if the farmer buys a price option, the net payoffs ($\Upsilon_p$) are given by

\begin{equation}
\Upsilon_p = MAX \{ (p^r - P^m, 0) \} y^F - \pi_p
\end{equation}
where \( p^* \) is the strike price, \( y^\text{f} \) is the contracted yield (or production), and \( \pi_p \) is the (fair) cost of contract, which is given by

\[
\pi_p = (1 + k_p) \mathbb{E} \max\{p^* - p, 0\} y^\text{f}.
\]

**Bellman’s Equation:** Let \( V_t(w_i) \) be the optimal value function for the farmer with endowment \( w_i \). This function is the unique solution to the following Bellman’s equation:

\[
V_t(w_i) = \max s_i \left\{ U_i(w_i - s_i) + \delta \mathbb{E} V_{t+1}(w_{t+1}) \right\}
\]

subject to

\[
w_{t+1} = \tilde{y}_{t+1} p_{t+1} + (1 + r) s_i + \alpha \left[ \mathbb{E} \max\{p^* - p, 0\} y^\text{f} - \pi_p \right]
\]

\[
+ \beta \left[ \mathbb{E} \max\{g - p^m y^a, 0\} - \pi_r \right]
\]

\[
\pi_p = (1 + k_p) \mathbb{E} \max\{p^* - p, 0\} y^\text{f}
\]

\[
\pi_r = (1 + k_r) \mathbb{E} \max\{g - p^m y^a, 0\}
\]

\[
\delta = (1 + \lambda)^{-1} ; \quad g = p^m y^a ; \quad w_t = c_i + s_i
\]

\[
q_t > 0 ; \quad p_t > 0 ; \quad r_t > 0 ; \quad \delta_t > 0 ; \quad -b \leq s_i \leq w_t
\]

The value function \( V_t(w_i) \) represents the maximum expected discounted sum of rewards from period \( t \) onward. The Chebychev orthogonal polynomial projection and collocation method is used to solve for the optimal values of savings, yield/revenue insurance and options/futures contracts (Miranda and Glauber 1993, 1995; Makki, Miranda and Tweeten). We parameterized the prototype model to capture the nature of relationship that exist between self insurance and SRM contracts.

In this prototype model, a typical farm household has the option to either self insure through savings, or to purchase SRM contract, either a yield/revenue insurance contract or options/futures contract, against income risk. Willingness to pay for an SRM contract is
calculated by taking difference between the value functions with and without a SRM contract and dividing that difference by the average of shadow prices obtained with and without a SRM contracts. The shadow price represents the value of the marginal unit of wealth to the farmer.

**Results**

Our preliminary analysis indicates that self-insurance via intertemporal consumption substitution and borrowing play significant roles in optimal farm risk management. Self insurance through savings and borrowing enable the farm household to spread the effects of income shocks across time, thereby offering an attractive alternative to the use of standard harvest-time price and yield risk contracts. Self-insurance becomes more attractive relative to standard risk contracts if the cost of credit, the subjective discount rate, and the degree of risk aversion are low.

Figure 1 indicates that the willingness to pay for standard risk management contracts decreases as the level of wealth increases. Results imply that at higher levels of wealth individuals prefer self insurance over other risk management strategies including yield/revenue contracts or options/futures contracts. Results also indicate that younger individuals are willing to pay more for standard risk management contracts if they are available to them in perpetuity.

Counter-factual simulations with alternative interest rates and production variabilities also reveal strong interactions between inter-year self insurance and intra-year standard risk management contracts (Figure 1). As the interest rate increases, farmers substitute SRM contracts with greater self insurance. Self-insurance also becomes more attractive if standard price and yield risk contract transactions costs are high. On the other hand, as production variability increases, farmers’ willingness to pay for SRM contracts increases (Figure 1).

If income risk is insurable, then the farm household can insure and need not take income risk into account in choosing savings\(^3\). Savings enables a farm household to stabilize consumption
income flows across time, but the level of consumption or income depends on the state of nature realized in each period. Therefore, farmer is still exposed to uncertainty in the levels of income realized, requiring the use of more than one strategy.

**Policy Implications**

Indeed, time and uncertainty are intimately connected and there is a strong relationship between attitude towards intertemporal substitution and attitude towards risk (Deaton 1992). Correspondingly, the choices of savings and insurance are interrelated and insurance strategy may not dominate over savings as protection against income risk. Farm households will weigh the options of either self insure through savings or purchase standard intra-year risk management contracts against income risk.

This model can easily be extended to explore the benefits of multi-year crop insurance policies to farmers compared to single year policies. Multi-year policies facilitate the transfer of yield risk across years by effectively allowing good yield years to subsidize the poor ones. Multi-year crop insurance policies provide farmers greater protection against bankruptcy for the same discounted premium than a series of one-year policies. Multi-year policies also mitigate against intertemporal adverse selection among farmers and provide a richer and more reliable actuarial data base to insurers, thereby reducing their cost of providing crop yield risk coverage and lowering its cost.
Endnotes

1. In a typical automobile or health insurance markets risk pooling invokes the law of large numbers for independent and identically distributed \((iid\) events to ensure that total indemnity paid will not exceed total premium amount collected.

2. Under CRC, for example, the minimum guarantee coverage level is given by

\[
g = 0.95 \left( \text{MAX} \{p^g, p^h\} \right) \left( \theta y^{\text{APH}} \right),
\]

where \(p^h\) is the harvest price and \(y^{\text{APH}}\) is the APH yield.

3. In theory, insurance should be able to eliminate all uncertainty, if the premium rates are actuarially fair. In reality, however, premium rates are not always actuarially sound for various reasons. First, there likely exists asymmetric information between farmers (insured) and insurance firms (insurer). For example, several studies have recognized the presence of moral hazard and adverse selection problems in crop insurance (Knight and Coble 1997). Second, administrative costs including book keeping cost, commission payments, and processing fee are non trivial. Finally, random factors generating uncertain farm incomes are likely to be correlated across farmers in a given region making the operation of crop insurance market less efficient relative to automobile or health insurance markets.
Figure 1. Willingness to Pay for Standard Risk Management Contracts
References


Willingness to Pay for Standard Risk Management Contract

- $r=0.05; \text{cv}=0.20$
- $r=0.05; \text{cv}=0.30$
- $r=0.10; \text{cv}=0.20$