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Risk Sharing and Incentives with External Equity Financing and Crop Insurance

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Risk Sharing and Incentives with External Equity Financing and Crop Insurance

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Special Note: This paper is in the process of being revised for resubmission to the *Journal of Agricultural and Resource Economics* and is far from complete. This version was prepared for the Applied Economics Seminar in the Department of Agricultural and Applied Economics at the University of Wisconsin-Madison. In particular, the conceptual model will change to include endogenization of crop acreage and the empirical section requires substantial updating.

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Risk Sharing and Incentives with External Equity Financing and Crop Insurance

Abstract

We develop a principal agent model to examine how the optimal contract between a farmer and an external equity investor is altered by the presence of crop insurance. The contract uses both fixed compensation and variable compensation varying with realized revenue to induce high farmer effort. All remaining surplus is divided between the farmer and investor. The optimal contract with crop insurance relies more on the variable compensation and less on the fixed compensation than when crop insurance is unavailable. This compensation scheme requires the investor to share more risk with the farmer to induce higher effort while still enticing the farmer's participation in the contract. Empirical analysis finds that the variable compensation increase is not substantial, but the fixed compensation decrease ranges 1% to 73% depending on the acreage allocation between crops.

Key words: risk sharing, incentives, crop insurance, equity financing, principal agent model.

Risk Sharing and Incentives with External Equity Financing and Crop Insurance

Introduction

Most farming operations are sole proprietorships using debt financing for their equity needs (Gloy and LaDue). Though farmers rarely use external equity (equity from outside the farm, not including retained earnings, off-farm income, and inheritance), existing research has shown the desirability of investment in farm assets as part of a well diversified, efficient portfolio (Irwin, Forster, and Sherrick; Kaplan; Crisostomo and Featherstone). Furthermore, the feasibility, benefits, and potential demand for external equity financing for farmers has generated considerable discussion (Collins and Bourn; Crane and Leatham 1993, 1995; Fiske, Batte, and Lee; Lowenberg-DeBoer, Featherstone, and Leatham; Mathews and Harrington; Raup; Wang, Leatham, and Chaisantikulawat). Partnerships and corporations, crop share agreements, and vertical coordination are traditional channels through which farmers obtain external equity (Lowenberg-DeBoer, Featherstone, and Leatham).

Sole proprietorships commonly use crop share leases to share input costs and yields with investors/landlords (Allen and Leuck). Using 1996 and 1998 data from a national survey, Hoppe reports 42% of cash grain farms share rent, while 64% of share renters are cash grain farms. Using Illinois data from the 1990's, Sotomayor, Ellinger, and Barry report substantial share leasing (about two-thirds of all leased cropland), though cash rental arrangements have grown in importance. Parcell, Massey, and Reinbott found in a 1999 survey in Missouri that on average, over half the acres respondents operated were share leased, commonly including sharing of input costs. The characteristics of these farm landlords are little studied. In a 1988 survey, Hoppe, Green, and Wunderlich found that only 12% of farm landlords were farming or working at farm-related jobs; the majority (52%) were retired, evenly split between those retired from farm-related and non-farm-related jobs. Sotomayor, Ellinger, and Barry report 36% of landlords in Illinois were either passive investors or trust companies. Hence, farmers commonly use share leases to obtain external equity.

Production contracts to improve vertical coordination in the supply chain also provide external equity to farmers. These contracts typically specify production practices and provide some of the inputs, often giving farmers access to genetics or technology that they would not otherwise be able to obtain (Ahearn, Korb, and Banker; Hueth and Ligon; Preckel et al.; Vukina). Production contracts are well established for producing broilers and hybrid seed corn and have rapidly increased for production of pork, beef, fruits, and vegetables (Calvin et al.; MacDonald et al.). Surveys of contracting farmers generally find that risk reduction is an important consideration when contracting, yet little research exists on the interactions between production contracts and government programs such as subsidized crop insurance (MacDonald et al.).

Little documentation exists concerning the extent of external equity financing among agricultural partnerships and corporations, but anecdotally, external equity arrangements exist (Klinefelter). For example, a Midwest joint venture includes ten investors and two operating managers (farmers) who also are investors. The farmers choose the crops to produce and each receives fixed compensation of $60,000 per year, plus variable compensation of 5% for prices and yields exceeding county averages. After payment to these operating farmers, investors share profit according to the share of the 12,000 total acres they contribute (Klinefelter).

Passage of the Agricultural Risk Protection Act (ARPA) in 2000 greatly expanded the availability of crop insurance to farmers. Not only have premium subsidies increased, but also the types of policies available and the crops that can be insured. As a result, total insured acres increased from 182 million in 1998 to 216 million in 2002, with total liability increasing from

$28 billion to $37 billion (USDA-RMA). Farmers purchasing crop insurance change their risks, which can affect production decisions (Ahsan, Ali, and Kurian). Most studies have focused on how crop insurance changes the optimal land allocation and variable input use (Chavas and Holt; Wu; Babcock and Hennessey; Horowitz and Lichtenberg; Smith and Goodwin; Goodwin and Smith). Those examining both decisions find that crop insurance generally has a larger effect on land allocation (Seo, Mitchell, and Leatham; Wu).

Investors (e.g., landlords, partners, or integrators) may want to adjust contracts to reflect farmer decisions and changes in risk induced by crop insurance. Indeed, some contracts may require crop insurance or even specify a certain level of coverage in the contract (Leatham, McCarl, and Richardson; Goodwin; Smith and Baquet). Optimal contracts will account for the optimizing behavior of both the farmer and the investor under crop insurance, plus specify risk sharing and provide economic incentives to induce optimal farmer effort and contract participation. However, because interactions between crop insurance and external equity contracts remain largely unexamined, to better understand these interactions, we develop a principal-agent model of the external equity contract when a farmer can purchase crop insurance.

Principal-agent models of sharecropping and crop insurance have largely focused on adverse selection and/or moral hazard (Ahsan, Ali, and Kurian; Allen and Lueck; Braverman and Stiglitz; Canjels and Volz; Chambers; Nelson and Loehman; Raviv; Skees and Reed; Stiglitz). Existing principal-agent models of debt and equity financing contracts have not incorporated the use of risk management tools such as insurance (Gale and Hellwig; Santos), even those focused on farmers (Wang, Leatham, and Chaisantikulawat). In general, little research exists regarding the effect of crop insurance on agricultural production contracts such as crop share arrangements, though risk reduction is often cited as a major concern as to why farmers choose to use a production contract (Allen and Lueck, p. 9; MacDonald et al., p. 64).

This study analytically examines how the optimal contract between an external equity investor and a farmer changes when crop insurance is available. The optimal contract accounts for the change in the variance of revenue and acreage reallocation as a result of crop insurance. This paper first describes an external equity financing contract and derives the optimal contract specifications and farmer decisions. The conceptual model uses assumptions so that analytical solutions can be determined to remove the need for numerical solutions to obtain comparative static results. Next, the conceptual model is modified to include crop insurance, and then the optimal contract specifications and farmer decisions are again derived. Comparative static analysis examines the effect of key parameters on the optimal contract and farmer decisions. The conceptual model is parameterized using data and published studies, and then empirical analysis indicates the likely magnitude and economic relevance of the different effects identified.

Conceptual Framework of External Equity Financing Contract

An investor and a farmer share investment costs for total acres M using external equity and owner equity. The farmer's share is δ and the investor provides the remaining share $(1 - \delta)$, where $0 < \delta < 1$. There are two crops, a risky crop and a safe crop. Without loss of generality, the safe crop is assumed to be risk free (Ashan, Ali, and Kurian). This assumption will be relaxed by introducing a relatively less risky crop in the empirical section. Denote investment in the risky crop without crop insurance as the acreage A_0, so that investment in the safe crop is $M - A_0$. Following Ashan, Ali, and Kurian, farm revenue without crop insurance is:

$$R_0 = R_S + R_R, \tag{1}$$

where R_S is revenue from the safe crop and R_R is random revenue from the risky crop.

The safe crop generates per acre revenue r (less than expected per acre revenue for the risky crop), so that $R_S = r(M - A_0)$. Following Spremann's linear-exponential-normal model, random revenue for the risky crop depends linearly on farmer effort $e \geq 0$, a nonrandom, continuous choice variable, so that

$$R_R = R_{R0} + e. \tag{2}$$

R_{R0} is stochastic revenue for the risky crop when the farmer exerts no extra effort ($e = 0$) and depends on A_0, acreage of the risky crop. Assuming an interior solution, a risk averse farmer chooses optimal acreage for the risky crop less than the total acreage: $A_0^* < M$. Next, let per acre revenue for the risky crop have a normal distribution with mean μ and variance σ^2, so that revenue R_{R0} has a normal distribution with a mean $\mu_0=\mu A_0$ and variance $\sigma_0^2 = \sigma^2 A_0^2$ and revenue R_R for the risky crop also has a normal distribution with mean $\mu_R = \mu_0 + e$ and variance σ_0^2.[1] An implication of this model is that the expected values μ_0 and μ_R and the variance σ_0^2 increase with the acreage in the risky crop: $\frac{\partial \mu_0}{\partial A_0} = \mu > 0$, $\frac{\partial \mu_R}{\partial A_0} = \mu > 0$, and $\frac{\partial \sigma_0^2}{\partial A_0} = 2\sigma_0^2 A_0 > 0$.

Moral Hazard

Following standard assumptions for moral hazard models (e.g., Laffont and Martimort, p. 149), risky crop revenue R_R is observable, but it is difficult or prohibitively costly for a third party to accurately determine the separate contributions of random revenue R_{R0} and farmer effort e, so that effort is non-contractible. The hidden information possessed by the farmer creates a classic moral hazard problem, which in this context could include the farmer underreporting crop yield or crop quality, input use, or contributed management or labor time. However, the investor

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[1] Variance of crop revenue is largely due to uncontrollable random events (Spremann; Allen and Lueck, p. 97) such as price shocks, pests, and natural disasters. Farmer effort may change the variance of crop revenue, but because allowing this possibility substantially complicates the model with little benefit, we assume farmer effort does not affect the variance of crop revenue.

knows the effect that farmer effort has on the distribution of revenue from the risky crop, namely that increasing effort increases mean revenue from the risky crop without changing its variance. Specifically, let $f(R_R|e)$ denote the probability density function for R_R (revenue from the risky crop) conditional on farmer effort e. For the assumed linear-exponential-normal model, this normal conditional density is $f(R_R|e) = \exp\left(-(R_R - \mu_0 - e)^2 / 2\sigma_0^2\right) / \sqrt{2\pi\sigma_0^2}$.

Exerting effort causes the farmer disutility so that the farmer is willing to tradeoff effort and the associated shift in the revenue distribution. However, the investor prefers that the farmer exert higher effort than the farmer would choose, since effort increases expected revenue without changing its variance and has no direct cost to the investor. The investor must design a contract that motivates the farmer to exert the higher level of effort the investor desires, but the contract can only compensate the farmer based on observable revenue from crop production (R_0), not on the farmer's unobservable effort. Denote this compensation as $t(R_0)$, where $R_0 = R_S + R_{R0} + e$ is observable farm revenue, which shows its dependence on farmer effort e, random revenue R_{R0} from the risky crop, and non-random revenue R_S from the safe crop.

Observed contracts for many relationships involving the potential for moral hazard are commonly linear (Holmstrom and Milgrom; Huffman and Just). For example, labor contracts typically pay employees a fixed hourly wage or a piece rate, while contracts for sales staff often include a fixed salary and a commission rate. Hence, we assume the compensation offered by the equity investor is linear as well, specifically

$$t(R_0) = w + bR_0. \tag{3}$$

Note that w can be positive or negative. If w is positive, the equity investor offers the farmer an extra bonus or provides up-front capital to entice the farmer to accept the contract. Alternatively, a negative w implies that in addition to an investment share, the farmer must make some initial expenditure as a show of good faith to the investor. However, b must be positive; otherwise the farmer has no incentive to exert effort. A traditional cash rent contract implies $w < 0$ and $b = 0$, while a crop share lease implies $w = 0$ and $b > 0$. Cash rent itself does not affect risk sharing because it is determined in advance regardless of crop revenue. However, the change in crop revenue variability caused by crop insurance may affect the risk premium that works as a compensation for farmers when taking a contract with risky crop revenue without crop insurance. Thus by putting these compensation variables together in a model as in equation (3), more generalized implications for the risk sharing in a contract can be obtained.

Profit and Utility

The investor and the farmer share all revenue remaining after the farmer receives compensation $t(R_0)$. Thus profits for the investor and the farmer without crop insurance are

$$\Pi_0^p = (1-\delta)\left(R_0 - t(R_0)\right), \tag{4}$$

$$\Pi_0^a = \delta\left(R_0 - t(R_0)\right) + t(R_0), \tag{5}$$

where the superscripts p and a denote the investor (principal) and the farmer (agent). Profit for the investor is the investor's equity share $(1 - \delta)$ of revenue remaining after paying the farmer $t(R_0)$, while profit for the farmer is the farmer's equity share δ of revenue remaining after paying the farmer $t(R_0)$, plus the farmer's compensation $t(R_0)$. Note that because revenue R_0 has a normal distribution and compensation $t(R_0)$ is linear in R_0, profit for both the investor and the farmer also have normal distributions. Using the definitions of profits in equations (4) and (5) and farmer compensation in equation (3), it can be shown that the mean and variance of profits in terms of the compensation parameters w and b are:

$$\mathrm{E}[\Pi_0^p] = (1-\delta)\left((1-b)\mathrm{E}[R_0] - w\right), \tag{6}$$

(7) $$\mathrm{Var}(\Pi_0^p) = (1-\delta)^2(1-b)^2\sigma_0^2\,,$$

(8) $$\mathrm{E}[\Pi_0^a] = \big(\delta + (1-\delta)b\big)\,\mathrm{E}[R_0] + (1-\delta)w\,,$$

(9) $$\mathrm{Var}(\Pi_0^a) = (\delta + (1-\delta)b)^2\sigma_0^2\,,$$

where $\mathrm{E}[R_0] = R_S + \mu_0 + e$.

The investor and the farmer respectively obtain utility $v(\Pi)$ and $u(\Pi)$ from profit, where Π is general for profit either with or without crop insurance. Following Spremann's linear-exponential-normal model, we assume constant absolute risk aversion (CARA) utility, which, when combined with the normal distribution of profits, implies analytically tractable solutions for the optimal contract and allows determinination of the qualitative effects of crop insurance and their relative magnitudes without resorting to numerical procedures. More general utility functions and distributions could be used, but would typically require numerical procedures to solve for the optimal contract. Indeed, theoretical analyses of contracts commonly assume CARA utility and often normality for the resulting analytical tractability (Huffman and Just; Gibbons and Murphy; Wang, Leatham, and Chaisantikulawat; Schattler and Sung).

In addition to obtaining utility from profit, the farmer also has a cost for effort. Denote this effort cost as $c(e)$, which has standard cost function properties ($c' > 0$ and $c'' > 0$). For simplicity and tractability, we follow Huffman and Just and use $c(e) = e^2$. Following standard assumptions (Laffont and Martimort, p. 149), we assume the farmer's effort cost is additively separable from $u(\Pi)$, the farmer's utility from profit. Thus the farmer's total utility is $U(\Pi,e) = u(\Pi) - c(e) = 1 - \exp(-\alpha_a\Pi) - e^2$, where α_a is the farmer's coefficient of absolute risk aversion.

With this specification, expected utility for the investor and the farmer are $\mathrm{E}[v(\Pi_0^p)] = \mathrm{E}[\Pi_0^p] - \tfrac{1}{2}\alpha_p\mathrm{Var}(\Pi_0^p)$ and $\mathrm{E}[U(\Pi_0^a,e)] = \mathrm{E}[\Pi_0^a] - \tfrac{1}{2}\alpha_a\mathrm{Var}(\Pi_0^a) - e^2$, where α_p and α_a are the coefficients of absolute risk aversion for the investor and the farmer. Making substitutions using equations (6)-(9) and $E[R_0] = R_S + \mu_0 + e$ gives:

(10) $$E[v(\Pi_0^p)] = (1 - \delta)((1 - b)(R_S + \mu_0 + e) - w) - ½\alpha_p(1 - \delta)^2(1 - b)^2\sigma_0^2,$$

(11) $$E[U(\Pi_0^a, e)] = (\delta + (1 - \delta)b)(R_S + \mu_0 + e) + (1 - \delta)w - ½\alpha_a(\delta + (1 - \delta)b)^2\sigma_0^2 - e^2.$$

The investor chooses compensation parameters b and w to maximize expected utility defined by equation (10) with constraints based on the farmer's expected utility defined by equation (11).

Optimal External Equity Financing Contract without Crop Insurance

The optimal external equity financing contract will satisfy two conditions—the participation constraint and incentive compatibility constraint. First, for the farmer to accept the contract, the investor must offer a contract such that the farmer's expected utility with the contract equals or exceeds his reservation utility U_r, the expected utility from his next best option. This participation constraint can be expressed generally as $\int_{R_R} U(\Pi_0^a, e) f(R_R \mid e) dR_R \geq U_r$, but in terms of equation (11), the participation constraint is

(12) $$(\delta + (1 - \delta)b)(R_S + \mu_0 + e) + (1 - \delta)w - ½\alpha_a(\delta + (1 - \delta)b)^2\sigma_0^2 - e^2 \geq U_r.$$

Second, since the farmer's effort is non-contractible, the investor must ensure that the contract creates the incentive for the farmer to exert the investor-desired effort. This incentive compatibility constraint requires that when the farmer accepts the contract, his expected utility when exerting the desired effort equals or exceeds his expected utility with any other effort level. Mathematically, this incentive compatibility constraint can be expressed generally as $\arg\max_e \int_{R_R} U(\Pi_0^a, e) f(R_R \mid e) dR_R$. For the specified model, this arg max problem simplifies, since expected utility in equation (11) can be directly maximized with respect to farmer effort e., giving optimal farmer effort *e* as a function of the contract parameter *b* (the optimal *e* generally depends on *w* as well, but not for the specified model):

$$e(b) = (\delta + (1 - \delta)b)/2. \tag{13}$$

In general, without crop insurance, the investor maximizes the expected utility of profit $E[v(\Pi_0^p)]$ by choosing the compensation $t(R_0)$ and farmer effort level *e*, subject to the farmer's participation constraint and incentive compatibility constraint. For the specified model, the linear compensation $t(R_0) = w + bR_0$ implies that the investor chooses *w*, *b*, and effort *e* to maximize expected utility defined by equation (10), subject to the participation constraint (12) and the incentive compatibility constraint implied by equation (13). Substituting $e(b)$ defined by equation (13) into the investor's objective and the farmer's participation constraint leaves only *w* and *b* as the investor's choice variables. Skipping the algebraic details, the solution is:

$$w^* = \frac{1}{1-\delta}\left[U_r - \left(\frac{1+2\alpha_p\sigma_0^2}{1+2(\alpha_a+\alpha_p)\sigma_0^2}\right)\mathrm{E}[R_0'] - 0.25\left(\frac{1+2\alpha_p\sigma_0^2}{1+2(\alpha_a+\alpha_p)\sigma_0^2}\right)^2\left(1-2\alpha_a\sigma_0^2\right)\right], \tag{14}$$

$$b^* = \frac{1}{1-\delta}\left[\frac{1+2\alpha_p\sigma_0^2}{1+2(\alpha_a+\alpha_p)\sigma_0^2} - \delta\right], \tag{15}$$

$$e^* = 0.5\left[\frac{1+2\alpha_p\sigma_0^2}{1+2(\alpha_a+\alpha_p)\sigma_0^2}\right], \tag{16}$$

where total expected revenue $\mathrm{E}[R_0'] = R_S + \mu_0$. Because the risky crop has higher expected per acre revenue than the safe crop, $\mathrm{E}[R_0']$ increases in A_0^*: $\frac{\partial \mathrm{E}[R_0']}{\partial A_0^*} > 0$.

Equations (14)-(16) generate several comparative static results that can largely be understood in terms of risk sharing. Any parameter change that reduces the farmer's risk or relative willingness to bear risk requires shifting more of the business risk to the investor. A shift of this sort requires decreasing the variable compensation rate b^* and farmer effort e^* and increasing the fixed compensation w^*. Decreasing the variable compensation rate decreases the farmer's risk because his earnings are less responsive to random revenue from the risky crop.

Farmer effort directly increases expected revenue from the risky crop, as equation (2) indicates. However, the farmer does not capture all the benefit from increased effort, since the share of realized revenue from the risky crop the farmer earns is determined by the variable compensation rate b (and the sharing parameter δ). Thus, if the variable compensation rate decreases to reduce risk, the optimal effort will also decrease. Hence, shifting more of the business risk to the investor also requires reducing optimal farmer effort e^*. Equation (13) captures this positive relationship between optimal effort and the variable compensation rate.

Finally, shifting more of the business risk to the investor also requires increasing the fixed compensation w^*. Reducing the farmer's risk by decreasing the variable compensation rate and farmer effort both reduce the farmer's expected income from participating in the contract. Hence, to ensure that the farmer will take the contract, the investor must increase the fixed compensation to increase the farmer's expected return to satisfy the participation constraint (12).

Given this intuition, if the farmer becomes more risk averse (α_a increases), the investor becomes less risk averse (α_p decreases), revenue from the risky crop becomes riskier (σ_0^2 increases), or the farmer's share of residual revenue increases (δ increases), the optimal contract responds by reducing the farmer's risk as just described. The only remaining comparative static results are the effect of expected revenue without farmer effort ($E[R_0'] = R_S + \mu_0$) and the farmer's reservation utility U_r. Both do not affect business risk, only the farmer's participation, and as a result, only the fixed compensation w^* responds to changes in either parameter. If expected revenue without farmer effort ($E[R_0']$) increases, the farmer's expected returns from participation increase, and so the investor compensates by reducing the fixed compensation to leave the farmer just indifferent to participation. Alternatively, if the return from the farmer's outside options (U_r) increase, the investor must compensate by increasing the fixed compensation to ensure the farmer's participation. No reallocation of the business risk is required, however, since both the investor and farmer have constant absolute risk aversion.

These comparative static results indicate the general effect that any change in the business environment will have on the optimal external equity contract when crop insurance is not used. At first pass, it might seem that adding crop insurance would reduce the revenue risk for the farm operation, and so the optimal contract would then require reallocating more risk to the farmer to maintain incentives for exerting high effort, which would be achieved by increasing the variable compensation rate and decreasing the fixed compensation rate.[2] However, this simple analysis ignores the endogenous nature of the business risk. Specifically, the availability of crop insurance likely makes acreage reallocation optimal, generally shifting the optimum to riskier crops (Goodwin and Smith; Wu). As a result, the overall level of income risk (as measured by the variance of revenue) can actually increase with crop insurance as a result of these acreage shifts (Seo, Mitchell, and Leatham). Hence, the effect of crop insurance on the optimal external equity contract is not certain.

Optimal External Equity Financing Contract with Crop Insurance

Because crop insurance changes the level of risk, the farmer's optimal acreage allocation may also change. Ahsan, Ali, and Kurian demonstrate that a risk averse farmer with actuarially fair

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[2] In terms of traditional arrangements, the risk premium given to the farmer as compensation for taking a contract with risky revenue would decrease with crop insurance, implying increased cash rent. Increasing the variable compensation rate with crop insurance enhances the farmer's incentive to do his/her best in production by having the farmer's reward rely more on the revenue outcome, which implies increasing the farmer's share in a crop share arrangement compared to the case without crop insurance. Finally, this summary assumes that farmers would still accept a contract with less revenue risk when crop insurance is used.

insurance and full coverage (i.e., no deductible) allocates more acreage to the risky crop than with actuarially fair insurance and less than full coverage, and allocates more acreage to the risky crop with actuarially fair insurance and less than full coverage than with no insurance. As a result of acreage changes due to insurance, we analyze the effects of crop insurance on the optimal contract in two steps. First, we derive the effect of actuarially fair crop insurance on the optimal contract while holding the crop acreage allocation fixed at the same level as optimal without insurance (i.e., crop acreage is not endogenized). Second, we show that if the acreage allocation is endogenized, the same comparative static results are obtained for the effect of crop insurance on the optimal contract, but with different implications. Finally, we briefly describe results if the insurance is less than actuarially fair (i.e., the premium is subsidized).

Optimal Contract with Fixed Acreage

Revenue with actuarially fair crop insurance with the acreage allocation fixed at the same level as without crop insurance (subscript *FA* for fixed acreage) is

$$R_{FA} = R_S + R_R + I - P, \tag{17}$$

where R_R and R_S are the revenue for the risky crop and safe crop as previously defined, I is the random insurance indemnity, and P is the non-random premium. The indemnity is $I(R_g, R_{R0}) = \max[R_g - R_{R0}, 0]$, where $R_g = g\mu_0$ is the revenue guarantee, g is the coverage level ($0 \leq g \leq 1$), R_{R0} is stochastic revenue with crop insurance (the same as without crop insurance since acreage is unchanged), and $\mu_0 = \mathrm{E}[R_{R0}] = \mu A_0$ is expected revenue, and μ is per acre expected revenue for the risky crop. With actuarially fair insurance, the premium equals the expected indemnity, or $P(R_g) = \mathrm{E}[I(R_g, R_{R0})] = \int_{-\infty}^{R_g} (R_g - R_{R0}) f(R_{R0}) dR_{R0}$.

Given previous assumptions, revenue from the risky crop with crop insurance and a fixed acreage allocation has a normal distribution censored from below at R_g with a mean of μ_0 and a variance of σ_{FA}^2. For this censored normal distribution, $\sigma_{FA}^2 = \sigma_0^2 K(g,\mu_0,\sigma_0)$, where σ_0^2 is the revenue variance without censoring (i.e., without crop insurance), $K(g,\mu_0,\sigma_0) =$ $(1-\Phi(q))[1-\lambda(q)^2+\lambda(q)q+(q-\lambda(q))^2\Phi(q)]$, and, since the censoring limit $R_g = g\mu_0$, $q = -(1-g)\mu_0/\sigma_0$ (Greene, p. 907). $K(g,\mu_0,\sigma_0)$ is a factor between zero and one that proportionally reduces the uncensored variance σ_0^2, with the reduction determined by q, the normalized mean of the censored normal variable. The function $\lambda(q) = \phi(q)/[1-\Phi(q)]$ is the inverse Mills ratio or the hazard function, $\phi(\cdot)$ is the standard normal probability density function, and $\Phi(\cdot)$ is the standard normal cumulative distribution function. As long as the coverage level g is strictly positive ($K < 1$), the revenue variance with crop insurance is less than without crop insurance ($\sigma_{FA}^2 < \sigma_0^2$). Also, as the insurance coverage level g increases, the guaranteed revenue $R_g = g\mu_0$ does as well, and so the variance decreases ($\frac{\partial\sigma_{FA}^2}{\partial g} < 0$), because $\frac{\partial R_g}{\partial g} > 0$ and $\frac{\partial K}{\partial \mu_g} < 0$.

With fair insurance and a fixed acreage allocation, the compensation function is $t(R_{FA}) = w + bR_{FA}$, profits for the investor and the farmer are $\Pi_{FA}^p = (1-\delta)\left(R_{FA} - t(R_{FA})\right)$ and $\Pi_{FA}^a = \delta\left(R_{FA} - t(R_{FA})\right) + t(R_{FA})$, and expected utilities are:

$$\text{(18)}\qquad E[v(\Pi_{FA}^p)] = (1-\delta)((1-b)(R_S+\mu_0+e)-w) - \tfrac{1}{2}\alpha_p(1-\delta)^2(1-b)^2\sigma_{FA}^2,$$

$$\text{(19)}\qquad E[U(\Pi_{FA}^a, e)] = (\delta+(1-\delta)b)(R_S+\mu_0+e) + (1-\delta)w - \tfrac{1}{2}\alpha_a(\delta+(1-\delta)b)^2\sigma_{FA}^2 - e^2.$$

Maximizing the investor's expected utility (18) with respect to farmer effort e and compensation parameters w and b, subject to the participation and incentive compatibility constraints (12) and

(13) gives the same functional forms as reported in equations (14)-(16), except that σ_0^2 is replaced by $\sigma_{FA}^2 < \sigma_0^2$. The solutions without crop insurance and for fair crop insurance with acreage held fixed have the same general functional forms because the expected indemnity and premium cancel. However, because the revenue variance with crop insurance and fixed acreage is less than without crop insurance, the magnitudes of the optimal solutions for the contract parameters will differ with and without crop insurance.

Assuming the risk aversion parameters α_p and α_a and investment share δ are the same with and without crop insurance, the variance reduction due to crop insurance increases the optimal variable compensation rate b^* and the optimal effort level e^*. Crop insurance partially insulates the farmer from incentives to exert high effort, and so the investor compensates by increasing the variable compensation rate b^* to increase the farmer's share in the risk. Furthermore, we know that the variable compensation rate and effort level increase with an increase in the insurance coverage level, $\frac{\partial b^*}{\partial g} > 0$ and $\frac{\partial e^*}{\partial g} > 0$, because $\frac{\partial \sigma_{FA}^2}{\partial g} < 0$, $\frac{\partial b^*}{\partial \sigma_{FA}^2} < 0$, and $\frac{\partial e^*}{\partial \sigma_{FA}^2} < 0$. In other words, as insurance coverage increases and so further insulates the farmer from risk, the investor adjusts the optimal contract to increase the farmer's share in the risk and to induce high effort.

The variance reduction from crop insurance decreases the optimal fixed compensation w^*. Greater business risk requires a higher fixed compensation to entice the farmer's participation. Because crop insurance reduces business risk, the investor reduces the fixed compensation because the larger compensation is no longer needed to entice participation, which implies that the cash rent in a traditional rental contract increases with crop insurance because the lower business risk caused by crop insurance reduces the risk premium given to farmers as compensation for undertaking the risky business venture. The fixed compensation w^* also decreases with the insurance coverage level for the same reason: $\frac{\partial w^*}{\partial g} < 0$ because $\frac{\partial \sigma_{FA}^2}{\partial g} < 0$ and $\frac{\partial w^*}{\partial \sigma_{FA}^2} > 0$. Finally, crop insurance increases the optimal level of effort by increasing the variable compensation and decreasing the fixed compensation. Thus, when holding acreage fixed, fair crop insurance induces a reallocation of risk from the investor to the farmer.

Optimal Contract with Endogenous Acreage

Because crop insurance decreases the variance of revenue from the risky crop, when crop insurance is available and the acreage allocation is endogenous, acreage devoted to the risky crop will increase relative to the acreage without crop insurance or with crop insurance and the acreage held fixed at the no insurance level: $A_{EA} > A_0 = A_{FA}$ (the subscript EA is for endogenous acreage). As a result, expected revenue increases relative to the case with insurance and acreage held fixed at the no insurance level: $\mu_{EA} > \mu_0 = \mu_{FA}$. However, the relative magnitude of the revenue variance when crop acreage is endogenous (σ_{EA}^2) compared to the revenue variance with insurance and acreage held fixed at the no insurance level (σ_{FA}^2) cannot be determined analytically because of offsetting effects. Specifically, $\sigma_{FA}^2 = \sigma_0^2 K(g, \mu_0, \sigma_0)$ and $\sigma_{EA}^2 = \tilde{\sigma}_{EA}^2 K(g, \mu_{EA}, \tilde{\sigma}_{EA})$, where $\tilde{\sigma}_{EA}^2$ is the uncensored variance of revenue with endogenous acreage when acreage of the risky crop is increased from A_0 to A_{EA}. Because acreage devoted to the risky crop increases, then the uncensored variance of revenue must increase: $\tilde{\sigma}_{EA}^2 > \sigma_0^2$. However, because $K(\cdot)$ also depends on $\tilde{\sigma}_{EA}$ and $\partial K / \partial \tilde{\sigma}_{EA} < 0$, the net effect of increasing the uncensored variance from σ_0^2 to $\tilde{\sigma}_{EA}^2$ is unclear. The effect of endogenizing acreage is further complicated because $K(\cdot)$ also depends on expected revenue which increases from μ_0 to μ_{EA} and $\partial K/\partial\mu_{EA} > 0$. Thus, the effect of crop insurance on revenue variance cannot be determined analytically, but rather empirical analysis is needed.

Solving for the optimal contract again gives the same functional forms as reported in equations (14)-(16), except that total expected revenue $E[R_0']$ is replaced by $E[R'_{EA}] = R_S + \mu_{EA}$ and σ_0^2 by σ_{EA}^2. Again, even though the functional forms are the same, the actual magnitudes differ depending on the effect of the acreage allocation change on $E[R'_{EA}]$ and the revenue variance σ_{EA}^2. Hence, the comparison between crop insurance with endogenous acreage and without crop insurance cannot be made analytically because the effect of crop insurance on revenue variance is ambiguous. If the revenue variance under crop insurance with endogenous crop acreage is less than the variance without crop insurance ($\sigma_{EA}^2 < \sigma_0^2$), then the optimal variable compensation rate b^* and effort e^* increase because the investor must increase the incentive to induce the farmer's effort; otherwise the opposite results occur. However, because the optimal fixed compensation w^* depends on both the mean and variance of revenue, the effect of crop insurance on it is more complicated because, even though expected revenue increases, the effect of crop insurance on revenue variance is uncertain. If the variance decreases, then the fixed compensation decreases—the investor must reduce the fixed compensation and increase the variable compensation to entice the farmer's participation. But if the revenue variance increases, then the crop insurance effect on the fixed compensation is inconclusive since both the mean and variance of returns increase.

If the premium is subsidized so the premium is less than actuarially fair, which is how the current U.S. crop insurance program is structured, determining the effect of crop insurance remains analytically ambiguous as was the case with fair insurance. The ambiguity remains because the effect of crop insurance on revenue variance is confounded due to the farmer's ability to reallocate crop acreage to adjust risk, just as for fair insurance. As a result, empirical analysis is required to understand the effect of crop insurance on the terms of the optimal external equity contract.

Empirical Analysis

This discussion has not been updated to reflect the new empirical results reported in tables 1-3.

For empirical analysis to quantify the effect of crop insurance on the optimal contract, we develop a representative farm based on the results of Seo, Mitchell and Leatham. Their methodology combined mathematical programming and Monte Carlo simulation to endogenize crop acreage and crop insurance participation for a representative farm in San Patricio County, Texas (near Corpus Christi). Their representative farm consisted of 1,700 acres growing cotton and grain sorghum, where cotton is riskier crop than sorghum in terms of net revenue variability.[3] Cotton has mean net revenue of \$60.00/ac with a standard deviation of \$142.90/ac and sorghum has mean net revenue of \$29.30/ac with a standard deviation of \$40.60/ac (Seo, Mitchell, and Leatham).[4] The farmer is assumed a reservation utility of \$60,000/year (in terms of certainty equivalent) and the share δ is assumed to be 50%. Seo, Mitchell, and Leatham report

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[3] Contrary to the analytical model with a risk free crop and a risky crop as assumed from the beginning, we introduce two risky crops to reflect the real world. This doesn't change the comparative statics and implications derived from the analytical model.

[4] These values were obtained using data from 1997 to 2000 by testing trends and considering correlation between yields and prices from 1980 to 2001.

(their table 3) that a moderately risk averse farmer would allocate 743 acres to cotton and 957 acres to sorghum when crop insurance is unavailable. Once crop revenue coverage (CRC) revenue insurance is available, the optimal coverage level is 70% for both crops and the optimal acreage allocation changes to 850 acres for both crops.

Using these values for the representative farm, table 1 reports optimal values for effort e^*, variable compensation rate b^*, and fixed compensation rate w^* for the three cases examined in the conceptual model. When the investor's risk aversion increases, the variable compensation increases while the fixed compensation decreases. The effort level that is tied to the variable compensation also increases. The changes in the variable compensation and the fixed compensation are substantial in our example, implying that the risk averse investor wants to share more risk with the farmer. The magnitude of changes is similar in all cases except the fixed compensation (66% change) in crop insurance with acreage change, reflecting the increased risk caused by acreage change. When the farmer's risk aversion parameter increases, the opposite results, in which the changes in the variable compensation and the fixed compensation are also substantial, are obtained compared to the change of the investor's risk aversion parameter.

When the insurance coverage level increases, the variable compensation increases and the fixed compensation decreases. Insurance coverage effect on risk sharing and farmer participation is not substantial regardless of acreage change. However, crop insurance still increases the farm capacity to bear more risk and the incentive to moral hazard so that the higher coverage level increases the variable compensation and decreases the fixed compensation. Thus the risk averse investor increases the variable compensation to share more risk with the farmer and to reduce moral hazard when the farmer buys crop insurance.

When the investment share of the farmer increases, the variable compensation decreases and the fixed compensation increases. This is because the higher the investment share of the farmer, the farmer is willing to effort to secure his portion of investment. Thus the investor does not need to give a high incentive but secure the farmer's reward from the investment by guaranteeing high fixed compensation.

As the reservation utility increases, the investor increases only the fixed compensation. The changes caused by reservation utility are substantial regardless of crop insurance but the magnitude of the change is higher in crop insurance regardless of acreage change. This implies that the investor is more sensitive to the change in the reservation utility when crop insurance is available to the farmer.

In addition to the effect of parameter change on the variable compensation and the fixed compensation, the effect of crop insurance on them can also be obtained. In the table 1, given the base parameters, we know that crop insurance increases the variable compensation regardless of acreage change. The increment (0.39 percentage point in crop insurance without acreage change and 0.11 percentage point in crop insurance with acreage change) is lower when the acreage change is allowed than when it is not because it is counteracted by the increase of risky crop. However, the magnitude in both is not substantial compared to the case of parameter change. These small increments from crop insurance also occur even when parameter changes in risk aversions and investment share are considered regardless of acreage change. Also, crop insurance increases the farmer's effort level that is tied to the variable compensation rate.

Crop insurance, however, decreases the fixed compensation regardless of production change in our example. The magnitude is substantial when acreage change is allowed while it is not when acreage change is not allowed. This is because the increased expected yield further decreases the fixed compensation in the former case.

In summery, crop insurance increases the variable compensation and thus the farmer's effort level and decreases the fixed compensation. And its effect gets higher as the insurance coverage level and the investor's risk aversion parameter increase and investment share and reservation utility decrease. From this result, we get an important implication for cash rental arrangement common in the U.S. in that crop insurance requires less incentive for farmers to participate in a contract compared with no insurance. This implies that crop insurance increases cash rent fee because a risk averse farmer prefers less risky contract with crop insurance and is willing to pay a higher cash rent fee by reducing risk premium required for the risky contract without crop insurance. Even though cash rent arrangement is not relevant to the risk sharing of farming, an implication from our model is obtained by linking lower fixed compensation rate to higher cash rent fee.

Conclusion (requires updating)

Subsidized crop insurance is a widely adopted risk management tool in the United States. By purchasing crop insurance, the farmer changes the risk faced and production behavior. Thus, an investor who provides external equity to a farmer also may want to adjust the investment contract design to reflect farmer's production and risk changes induced by the availability of crop insurance.

To better understand these relationships, we developed a principal-agent model of the contract between the agricultural investor and the farmer when the farmer can purchase crop insurance. The model examines how the optimal contract design that induces the best effort and contract participation from the farmer using a variable compensation rate and a fixed compensation rate is altered by the presence of crop insurance.

The results show that the investor's optimal contract with crop insurance employs a larger variable compensation rate and smaller fixed compensation rate than it does without insurance. This is because crop insurance reduces the risk farmers faced, thus allowing the farmer to bear more risk and to participate in the contract with more willingness, and gives an incentive for moral hazard. Thus the larger variable compensation rate gives more incentive for the farmer to exert higher effort.

Our empirical results show that the variable compensation that is tied to effort increases but not substantial in the presence of crop insurance. However, the fixed compensation decreases substantially depending on production decision and parameter change, implying that more emphasis needs to be given to the fixed compensation when crop insurance is available to the farmer because the farmer with crop insurance readily participates in contract compared to the farmer without crop insurance.

In summary, by making the compensation scheme depend more on variable compensation and less on fixed compensation when crop insurance is used, the investor may share more risk with the farmer, thus inducing more effort from the farmer, and entice the farmer's participation in the contract.

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Table 1. With no crop insurance available, effect of farmer risk aversion on optimal contract values and expected profit, profit standard deviation, and certainty equivalent for the principal and farmer.[a]

	Optimal Contract Values				Principal's			Farmer's[c]	
Farmer Risk Aversion[b]	Risky Crop Acres	Effort e	Variable Payment b	Fixed Payment w	Expected Profit	Profit St. Dev.	Certainty Equivalent	Expected Profit	Profit St. Dev.
6.00	111	0.167	-0.333	66,460	20,463	11,109	20,278	60,093	5,558
5.00	119	0.188	-0.250	59,758	20,482	11,109	20,296	60,111	6,669
4.00	130	0.214	-0.143	51,133	20,509	11,109	20,324	60,139	8,335
3.00	148	0.250	0.000	39,616	20,556	11,109	20,371	60,185	11,113
2.00	185	0.300	0.200	23,436	20,648	11,110	20,463	60,278	16,668
1.50	222	0.333	0.333	12,587	20,741	11,110	20,556	60,371	22,223
1.30	245	0.349	0.395	7,513	20,798	11,110	20,613	60,428	25,642
1.20	259	0.357	0.429	4,785	20,834	11,110	20,648	60,463	27,779
1.00	296	0.375	0.500	-1,114	20,926	11,110	20,741	60,556	33,334
0.80	352	0.395	0.579	-7,707	21,065	11,111	20,880	60,695	41,667
0.50	519	0.429	0.714	-19,366	21,482	11,111	21,297	61,111	66,667
0.30	815	0.455	0.818	-29,159	22,222	11,111	22,037	61,852	111,111
0.20	1185	0.469	0.875	-35,556	23,148	11,111	22,963	62,778	166,667
0.15	1556	0.476	0.905	-39,789	24,074	11,111	23,889	63,704	222,222

[a] Reported results use risk aversion coefficient of $\alpha_p = 0.000003$, total crop acres $M = 2{,}000$, net return for safe crop of \$40/ac, mean return for the risky crop of \$45/ac with a standard deviation of \$150/ac, farmer reservation utility $U_r =$ \$60,000, and share $\delta = 0.5$.

[b] Risk aversion coefficient α_a multiplied by 1,000,000.

[c] Farmer's certainty equivalent equals the reservation utility of $U_r =$ \$60,000.

Table 2. With actuarially fair crop insurance available, effect of farmer risk aversion on optimal contract values and expected profit, profit standard deviation, and certainty equivalent for the principal and farmer.[a]

	Optimal Contract Values				Principal's			Farmer's[c]	
Farmer Risk Aversion[b]	Risky Crop Acres	Effort e	Variable Payment b	Fixed Payment w	Expected Profit	Profit St. Dev.	Certainty Equivalent	Expected Profit	Profit St. Dev.
6.00	806	0.167	-0.333	65,320	23,359	29,928	22,016	60,672	14,965
5.00	860	0.188	-0.250	58,385	23,494	29,928	22,150	60,806	17,958
4.00	941	0.214	-0.143	49,411	23,695	29,928	22,352	61,008	22,448
3.00	1075	0.250	0.000	37,311	24,031	29,928	22,687	61,344	29,930
2.00	1344	0.300	0.200	19,968	24,703	29,929	23,359	62,016	44,894
1.50	1612	0.333	0.333	7,958	25,375	29,929	24,031	62,687	59,859
1.30	1778	0.349	0.395	2,170	25,788	29,929	24,445	63,101	69,067
1.20	1881	0.357	0.429	-1,005	26,047	29,929	24,703	63,359	74,823
1.00	2000	0.375	0.500	-8,023	26,512	27,843	25,349	63,489	83,531
0.80	2000	0.395	0.579	-15,921	26,908	23,447	26,083	63,093	87,927
0.50	2000	0.429	0.714	-29,730	27,722	15,910	27,342	62,279	95,464
0.30	2000	0.455	0.818	-40,562	28,463	10,125	28,309	61,538	101,250
0.20	2000	0.469	0.875	-46,570	28,910	6,961	28,837	61,090	104,414
0.15	2000	0.476	0.905	-49,741	29,156	5,303	29,114	60,844	106,071

[a] Reported results use risk aversion coefficient of $\alpha_p = 0.000003$, total crop acres $M = 2{,}000$, net return for safe crop of \$40/ac, mean return for the risky crop of \$45/ac with a standard deviation of \$150/ac, farmer reservation utility $U_r =$ \$60,000, share $\delta = 0.5$, and crop insurance coverage level of 75%.

[b] Risk aversion coefficient α_a multiplied by 1,000,000.

[c] Farmer's certainty equivalent equals the reservation utility of $U_r =$ \$60,000.

Table 3. With subsidized crop insurance available, effect of farmer risk aversion on optimal contract values and expected profit, profit standard deviation, and certainty equivalent for the principal and farmer.[a]

	Optimal Contract Values				Principal's			Farmer's[c]	
Farmer Risk Aversion[b]	Risky Crop Acres	Effort e	Variable Payment b	Fixed Payment w	Expected Profit	Profit St. Dev.	Certainty Equivalent	Expected Profit	Profit St. Dev.
6.00	2000	0.167	-0.333	28,387	85,688	74,249	77,419	64,135	37,125
5.00	2000	0.188	-0.250	16,354	85,462	69,609	78,194	64,361	41,766
4.00	2000	0.214	-0.143	693	85,266	63,642	79,191	64,557	47,732
3.00	2000	0.250	0.000	-20,521	85,172	55,687	80,520	64,652	55,688
2.00	2000	0.300	0.200	-50,858	85,358	44,549	82,381	64,466	66,825
1.50	2000	0.333	0.333	-71,496	85,688	37,124	83,621	64,135	74,250
1.30	2000	0.349	0.395	-81,207	85,899	33,671	84,198	63,925	77,703
1.20	2000	0.357	0.429	-86,439	86,026	31,821	84,507	63,797	79,553
1.00	2000	0.375	0.500	-97,758	86,335	27,843	85,172	63,489	83,531
0.80	2000	0.395	0.579	-110,379	86,731	23,447	85,906	63,093	87,927
0.50	2000	0.429	0.714	-132,284	87,545	15,910	87,165	62,279	95,464
0.30	2000	0.455	0.818	-149,331	88,286	10,125	88,132	61,538	101,250
0.20	2000	0.469	0.875	-158,738	88,733	6,961	88,660	61,090	104,414
0.15	2000	0.476	0.905	-163,690	88,979	5,303	88,937	60,844	106,071

[a] Reported results use risk aversion coefficient of $\alpha_p = 0.000003$, total crop acres $M = 2{,}000$, net return for safe crop of $40/ac, mean return for the risky crop of $45/ac with a standard deviation of $150/ac, farmer reservation utility $U_r = \$60{,}000$, share $\delta = 0.5$, crop insurance coverage level of 75%, and premium subsidy of 55% so that the farmer pays 45% of the actuarially fair premium.

[b] Risk aversion coefficient α_a multiplied by 1,000,000.

[c] Farmer's certainty equivalent equals the reservation utility of $U_r = \$60{,}000$.