A Two-Shock Model of the Impact of Crop Insurance on Input Use:

Analytic and Simulation Results

Y. Liu and R. Black *

Selected Paper prepared for presentation at the American Agricultural Economics Association Annual Meeting, Denver, Colorado, August 1-4, 2004

* Liu is a Ph.D. Candidate and Black is a Professor, Department of Agricultural Economics, Michigan State University. The authors would like to thank Scott Swinton for helpful and insightful comments.

A Two-Shock Model of the Impact of Crop Insurance on Input Use:

Analytic and Simulation Results

Abstract

By altering the probability distribution of farm income, crop insurance programs affect farmer's input use decisions. Ramaswami's (1993) one-shock (yield) model analyzed the effect of the crop insurance on single input use by allowing the randomness of yield while keeping price constant in revenue determination. The total effect of actuarially fair insurance on input use was decomposed into risk reduction effect and moral hazard effect; the directions of the two effects were examined. He showed that the total impact of actuarially fair crop insurance on input use was a) to reduce it if the input was risk decreasing and b) indeterminate if the input was risk increasing. However, the evidence from previous empirical work has been mixed. Horowitz and Lichtenberg (1993) suggested insured farmers raising corn use more fertilizers and pesticides while Smith and Goodwin (1996) obtained the opposite result for wheat. Smith and Goodwin also used more comprehensive econometric tests and had a higher quality data set. A common belief is that fertilizer is risk increasing and pesticide risk decreasing.

Ramaswami's model assumed crop price was constant and yield was the only source of randomness in farmer's revenue. In reality, market price is a random variable and often negatively correlated with the farmer's yield. For example, bad weather conditions tend to reduce yield across farms in a common region, which may cause diminished quantities supplied and higher crop price.

Our paper extends Ramaswami's one-shock model to a two-shock model, and generalizes the two propositions in that paper by introducing randomness to price as well as yield. With two random shocks, the total insurance effect on input use is indeterminate for both risk increasing and risk decreasing inputs, which is consistent with the mixed empirical evidence. Our study also provides a numerical method to decompose the total insurance effect into a risk reduction effect and a moral hazard effect using empirical data. The simulation based on 75 percent coverage level suggests the total insurance effect is economically small to the farmer for the current principal individual farm / parcel revenue insurance designs as are the risk reduction effect and moral hazard effect under mild risk aversion. And the moral hazard effect is less significant than the risk reduction effect. However, the moral hazard effect becomes larger if a higher coverage level is used.

Introduction

Crop insurance, including yield insurance and revenue insurance, is an essential risk management tool for the farmers in the United States. By altering the probability distribution of farm income, crop insurance programs also alter farmer's decisions on input use. Ramaswami (1993) developed a single input model for the supply response to crop insurance. He decomposes the total effect of actuarially fair insurance on input decision into risk reduction effect and moral hazard effect, and analyzes the directions of the two effects. His analysis suggests that the total impact of actuarially fair crop insurance on input use is a) to reduce it if the input is risk decreasing and b) indeterminate if the input is risk increasing. The evidence of previous empirical work has been mixed. The study conducted by Horowitz and Lichtenberg (1993) suggests insured farmers use more fertilizers and pesticides. While Smith and Goodwin (1996) obtain the opposite result. It is the widely held belief that fertilizer is risk-increasing and pesticide is risk-decreasing. A closer examination of the theoretical model should be useful.

Ramaswami's model assumes crop price is constant and yield is the only resource of farmer's revenue randomness. However, in the "real" world, price is random and sometimes negatively correlated with yield. For example, bad weather conditions tend to reduce yield in most farms in a common region, which may cause diminishing supply and higher crop price in local market. In this paper, Ramaswami's one shock model is reviewed followed by an examination of whether the results change after introducing a random price shock. This analysis is followed by a simulation exercise to compute risk reduction effect and moral hazard effect under crop insurance using empirical yield response to nitrogen and price data. The result of the insurance provider's maximumization decisions is assumed to be zero expected net profit; that is, competitive insurance markets (Rothschild and Stiglitz, 1976). Although viable competitive insurance markets for agriculture are not the norm (Chambers, 1989), this assumption can still be justified because most US crop insurance programs are subsidized by the government.

One-Shock Model

In Ramaswami's Single Input Model, a single input x enters the production function described by $q(x,\theta)$, $q_x > 0$. θ is a random production shock such that $q_\theta > 0$. An input is either risk increasing or risk decreasing. For a risk increasing (decreasing) input, the marginal product q_x is monotonic increasing (decreasing) in θ for all positive x. In an expected utility maximization framework, the two following propositions are derived:

Proposition R1: For all constant and decreasing risk averse utility functions and for an actuarially fair insurance contract, risk reduction effect tends to increase risk-increasing input use and decrease risk-decreasing input use.

Proposition R2: The moral hazard effect tends to reduce input use. So the total impact of actuarially fair crop insurance on input use is a) to reduce it if the input is risk decreasing and b) indeterminate if the input is risk increasing.

Two-Shock Model

The two-shock model maintains all the assumptions made in Ramaswami's one-shock model, except that crop price described by $p(\theta,\delta)$ is added explicitly into the model, where δ is a random price shock independent of θ, and $p_{\delta} > 0$, $p_{\theta} < 0$. Thus price and yield is negative correlated, and the dependence between them is only through θ. This is an appropriate assumption if farmers are small so that their individual input decisions do not affect the market price.

A farmer's optimal input decision is to solve the following expected utility maximization problem stated as

(1) $$\underset{\{x\}}{Max}\,\eta(x,I,P) = EU[\pi(x,\theta,\delta)] = EU[r(x,\theta,\delta) - wx + v(x,\theta,\delta) + W]$$

subject to $x \geq 0$

where,

I and P refers to indemnity and premium respectively,

$EU(.)$ refers to expected utility,

$\pi(.)$ refers to total wealth per acre,

$r(x,\theta,\delta)$ is farm's revenue per acre, which equals $p(\theta,\delta)q(x,\theta)$,

w is input cost per acre,

$v(x,\theta,\delta)$ is the payoff from insurance, which equals indemnity minus premium,

W is the farmer's initial wealth per acre.

In the case of no insurance, the first order condition (FOC) to the problem gives the optimal input level as follows,

(2) $$\eta_x(x,0,0) = E[U' \cdot (r_x - w)] = EU' \cdot E(r_x - w) + \mathrm{cov}(U', r_x) = 0$$

Dividing both sides by $EU' \cdot Er_x$,

(3) $$\frac{\eta_x(x,0,0)}{EU' \cdot Er_x} = \frac{Er_x - w}{Er_x} - \rho(x,0,0) \cdot \sigma_{MU}(x,0,0) \cdot \sigma_{MR}(x,0,0)$$

where, $\rho(x,I,P) = -\frac{\mathrm{cov}(U', r_x)}{\sqrt{\mathrm{var}(q_x)} \cdot \sqrt{\mathrm{var}(U')}}$, $\sigma_{MU} = \frac{\sqrt{\mathrm{var}(U')}}{EU'}$, $\sigma_{MR} = \frac{\sqrt{\mathrm{var}(r_x)}}{Er_x}$.

The first term on the right hand side of (3) is a mean effect; the second term is a risk effect. Marginal utility is monotonic decreasing in θ and δ for concave utility functions. Marginal revenue is monotonic increasing in δ, and it is monotonic increasing (decreasing) in θ if the input is risk-increasing (decreasing). Consequently, risk averse level of input use is smaller than the risk-neutral level of input use if the input is risk-increasing. The direction of risk-decreasing input use change depends on the coefficients. This result is slightly different from that in Ramaswami (1993). After adding a random price shock, risk averse level of input use gets smaller than that in Ramaswami case, no matter whether the input is risk-increasing or risk-decreasing.

After entering an insurance program $\{I,P\}$, the FOC to solve the utility maximizing problem can be correspondingly stated as

(4) $$\frac{\eta_x(x,I,P)}{EU'\cdot Er_x}=\frac{Er_x-w}{Er_x}-\rho(x,I,P)\cdot\sigma_{MU}(x,I,P)\cdot\sigma_{MR}(x,I,P)-\left[-\frac{E(U'\cdot v_x)}{EU'\cdot Er_x}\right]=0$$

Besides mean effect and risk effect, a moral hazard effect ($-\frac{E(U'\cdot v_x)}{EU'\cdot Er_x}$) appears in (4).

$v(x,\theta,\delta)=indemnity-premium$. v_x is negative, because premium is set constant for a specific policy, and indemnity is monotonic decreasing in *x*. Thus the moral hazard effect is always positive.

To compare the optimal input levels with and without insurance, define $x_i = x(I,P)$ (with insurance), $x_0 = x(0,0)$ (without insurance). From (3) and (4), we can derive

(5) $$\frac{\eta_x(x_i,0,0)}{EU'ER_x}=[\sigma_{MU}(x_i,I,P)\rho(x_i,I,P)-\sigma_{MU}(x_i,0,0)\rho(x_i,0,0)]\sigma_{MR}+[-\frac{EU'v_x}{EU'ER_x}]$$

Assume $\eta(x,0,0)$ is a concave function in *x*, which is true if $q_{xx}<0$. Then

(6) $$x_i \ge x_0 \Leftrightarrow \eta_x(x_i,0,0)\le 0, \qquad x_i < x_0 \Leftrightarrow \eta_x(x_i,0,0)>0$$

The first term of (5) is the risk reduction effect of insurance. The second term is the moral hazard effect. Ramaswami (1993) proves that under the assumption of non-increasing risk averse utility function, if the input is risk-increasing (risk-decreasing), the risk reduction effect is negative (positive). Including the randomness of price makes this result is a little bit different: if the input is risk-increasing, the risk reduction effect is negative; while if the input is risk-decreasing, the sign of risk reduction effect depends on the coefficients. Therefore, the risk reduction effect tends to increase risk-increasing input use, while has an indeterminate influence on risk-decreasing input use. Since the moral hazard effect is always positive, the total impact of actuarially fair crop insurance on input use is indeterminate.

After introducing the randomness of price, the two propositions brought up in Ramaswami (1993) now change into:

Proposition 1: For all constant and decreasing risk averse utility functions and for an actuarially fair insurance contract, risk reduction effect tends to increase risk-increasing input use, but has an indeterminate influence on risk-decreasing input use.

Proposition 2: The moral hazard effect tends to reduce input use. So the total impact of actuarially fair crop insurance on input use is indeterminate.

A Numerical Simulation

Based on the theoretical model, moral hazard effect and risk reduction effect are separated from the total insurance effect in the following way:

Assume

x^0: input choice with no insurance,

x^1: input choice with ideal actuarially fair insurance (no information asymmetry, i.e. insurer observes farmer’s input use),

x^*: input choice with real-world actuarially fair insurance (insurer doesn’t observe farmer’s input use),

then

$x^* - x^0 = \textit{total insurance effect}$;

$x^1 - x^0 = risk\ reduction\ effect$;

$x^* - x^1 = moral\ hazard\ effect$.

What is worthy to be noticed here is the insurance policy is actuarially fair in the ex post sense. That is, the insurer and the insured have reached a Nash equilibrium, and there is a moral hazard effect, but no moral hazard. In another words, the moral hazard effect here refers to the difference between the first-best result and the second-best result on input use.

We take nitrogen (N) fertilizer input and corn yield as an example. Fertilizer is typically considered a risk-increasing input (Ramaswami, 1993; Horowitz and Lichtenberg, 1993). Optimal N input levels under the two types of insurance, ideal and an approximation of existing individual trigger revenue contracts (ITRC) are obtained by 3000 Monte Carlo simulations. The coefficients used for simulations are based on research in the upper Midwest on the response of corn to nitrogen.

Assume there are numerous identical constant absolute risk-averse farmers in the market. They are assumed identical so that there is no adverse selection problem exists. Constant absolute utility function excludes the wealth effect on farmer's optimal input using.

The corn price is log-normally distributed and has negative correlation with yield with a correlation coefficient in the range of -.3 to -.6. Assume there are 15 production functions corresponding to 15 states of nature with probabilities and parameters shown in Table 1. Each function takes a quadratic-plateau functional form as follows:

(7) $q = a + bx - cx^2$ if $x < \bar{x}$; $q = a + b\bar{x} - c\bar{x}^2$ if $x \geq \bar{x}$

The use of quadratic-plateau functional form is justified by some previous empirical work (Cerrato and Blackmer 1990, Bullock and Bullock 1994). Corn price is assumed to be log-normally distributed with mean 2.50$/lb, standard deviation .50$/lb. The correlation coefficient between corn yield and price is assumed to be -.5. The N fertilizer cost $w = .21\$/lb$.

Table 1. The parameters of production functions under 15 states of nature

Group	a	b	c	$\bar{x}$	Prob (%)
1	15	0	0	0	0.7
2	22	0.46	0.0040	58	0.8
3	29	0.54	0.0044	62	1.2
4	34	0.66	0.0044	74	2.4
5	38	0.74	0.0037	99	3.5
6	42	0.82	0.0039	104	3.7
7	46	0.88	0.0037	118	4.2
8	50	0.93	0.0037	126	7.5
9	54	0.98	0.0037	133	12.7
10	58	1.03	0.0036	143	18.5
11	62	1.08	0.0036	149	19.7
12	66	1.13	0.0036	157	14.7
13	70	1.17	0.0036	164	8.0
14	74	1.21	0.0037	166	1.4
15	76	1.24	0.0036	173	1.0

Consider the following two actuarially fair revenue insurance policies.

1) A "real-world" actuarially sufficent insurance policy:

   1. Insurer knows the production conditions, such as long-term weather pattern and soil type in a specific area, but has no ex ante information on farmers' risk-averse type and their input use. The information set of insurer is

represented as $\{d\}$, where d refers to the states of nature, corresponding productions functions and probabilities.

2. Guarantee based on $E(q \mid d, x = risk - neutral\ optimal\ N\ level) = 130 lb / acre$.
3. Coverage rate: 0.75.
4. Premium: $E(indemnity \mid d, indemnity\ incurred\ in\ previous\ years)$. The insurance provider keeps adjusting the premium according to the indemnity he has paid during previous years until he finally be able to provide an actuarially fair policy.

2) An ideal actuarially fair insurance policy:

- The information set of the insurer is represented as $\{d, x\}$, where x refers to the farmer's actual input use.
- Guarantee based on $E(q \mid d, x = farmer's\ actual\ N\ input)$, where x refers to farmer's actual nitrogen use.
- Coverage rate: .75.
- Premium: $E(indemnity \mid d, x = farmer's\ actual\ N\ input)$. Insurer observes farmer's actual input use, and charges an actuarially fair premium rate according the actual input use.

Based on the above assumptions, 3000 Monte Carlo simulations are conducted. Farmer's choice set for nitrogen fertilizer use (lb/acre) is {0, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120, 130, 140, 150, 160, 170, 180}. It is set to be discrete for computational convenience. The simulation results are summarized in Table 2.

Table 2. Nitrogen fertilizer use response to single commodity revenue insurance, based on 3000 Monte Carlo simulations

Absolute risk averse coefficients*	Optimal *N* use (lb/ac)			Total insurance effect	Risk-reduction effect	Moral hazard effect
	no insurance (x^0)	ideal insurance (x^1)	real-world insurance (x^*)	(x^*-x^0)	(x^1-x^0)	(x^*-x^1)
0	130	130	130	0	0	0
.01	120	130	130	10	10	0
.02	100	130	120	20	30	-10
.03	70	120	110	40	50	-10

* The coefficients .02 to .03 are used in Kramer and Pope (1981), Holt and Brandt (1985) as the cases of strongly risk aversion (Raskin and Cochran, 1986).

The simulation result suggests

- Risk-reduction effect increases while moral hazard effect decreases nitrogen fertilizer use. That is consistent with Proposition 1 and 2.
- Total insurance effect, risk reduction effect and moral hazard effect tend to increase with the increase of risk aversion.
- Total insurance effect is positive because risk reduction effect overwhelms moral hazard effect under the simulation assumptions.

Summary and Conclusions

This study reviews the single input model for supply response to crop insurance provided by Ramaswami (1993), and examines the two propositions in that paper after introducing the randomness of price. With two random shocks (yield and price) the two propositions are slightly different from those in Ramaswami (1993). According the two propositions, total insurance effect on supply response is indeterminate. This is consistent with the mixed empirical results. This study also provides a numerical method to decompose the total insurance effect into a risk reduction effect and a moral hazard effect. The simulation result suggests the total insurance effect is economically insignificant, so are the risk reduction effect and moral hazard effect under mild risk aversion. Also the moral hazard effect is less significant than the risk reduction effect. However, this does not mean moral hazard is not a serious problem in insurance contract design. In this simulation, a coverage level of .75 is used. The moral hazard effect becomes larger if a higher coverage level used. Another assumption of the model is the insurance policy is actuarially fair. In the real world, it may take a long time for an insurance provider to obtain enough information to be able to provide an actuarially fair insurance. Sometimes he is never able to, because farmer's type may change over time. Actually moral hazard is so important that it is considered an important reason for missing private crop insurance (Chambers, 1989). This study excludes adverse selection by assuming all farmers are identical. That is a more rigid than realistic assumption. It is usually hard to distinguish the two types of asymmetric information in empirical work. It might be very interesting and rewarding to consider both adverse selection and moral hazard in future research.

References

Bullock, D.G. and D.S. Bullock."Quadratic and Quadratic-Plus-Plateau Models for Predicting Optimal Nitrogen Rate of Corn: A Comparison." *Agronomy Journal* 86, (1994) 191-195

Cerrato, M.E. and A.M. Blackmer. "Comparison of Models for Describing Corn Yield Response to Nitrogen Fertilizer." *Agronomy Journal* 82, (1990) 138-143

Chambers, R.G. "Insurability and Moral Hazard." *American Journal of Agricultural Economics* 71, (1989) 604-616

Holt, M.T. and J.A. Brandt "Combining Price Forecasting with Hedging of Hogs: An Evaluation Using Alternative Measures of Risk." *Journal of Futures Markets* 5: (1985). 297-309

Horowitz, J.K. and Erik Lichtenberg "Insurance, Moral Hazard, and Chemical Use in Agriculture." *American Journal of Agricultural Economics* 75, (1993)926-935

Kramer, R.A. and R.D. Pope. "Participation in Farm Commodity Programs: A Stochastic Dominance Analysis." *American Journal of Agricultural Economics* 63, (1981) 119-128

Ramaswami, B. “Supply Response to Agricultural Insurance: Risk Reduction and Moral Hazard Effects.” *American Journal of Agricultural Economics* 75, (1993) 914-925

Rothschild, M., and J. Stiglitz. “Equilibrium in Competitive Insurance Market: An Essay on the Economics of Imperfect Information.” *The Quarterly Journal of Economics* 90, (1976) 629-650

Raskin, R. and M.J. Cochrane “Interpretations and Transformations of Scale for the Pratt-Arrow Absolute Risk Aversion Coefficient: Implications for Generalized Stochastic Dominance.” *Western Journal of Agricultural Economics* 11, (1986) 204-210

Smith, V.H., and B.K. Goodwin “Crop Insurance, Moral Hazard and Agricultural Chemical Use.” *American Journal of Agricultural Economics* 78, (1996) 428-438.