Effects of Federal Risk Management Programs on Optimal Acreage Allocation and Nitrogen Use in a Texas Cotton-Sorghum System

Sangtaek Seo, Paul D. Mitchell, and David J. Leatham

Authors are, respectively, graduate student, assistant professor, and professor
Department of Agricultural Economics, Texas A&M University, College Station,
TX 77843-2124, e-mail p-mitchell@tamu.edu.

Selected Paper prepared for presentation at the American Agricultural Economic Association

Annual Meeting, Denver, Colorado, August 1-4, 2004

Acknowledgments: The authors would like to acknowledge the GAMS programming assistance of Bruce A. McCarl and Dhazn Gillig.

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Abstract

We analyze the effects of crop insurance and the Marketing Loan Program on optimal nitrogen use and acreage allocation for a case cotton-sorghum farm in Texas. A mathematical programming model is used to simulate the optimal nitrogen fertilizer rate, crop acreage allocation, coverage level, and price election factor, along with participation in the crop insurance (APH and CRC) and the Marketing Loan Program for both crops. Results show that current insurance programs increase the optimal fertilizer rate 1-3% and increase the optimal cotton acreage 16-129%. The Marketing Loan Program slightly changes optimal fertilizer rates and increases optimal cotton acreage an additional 1-9%.

Key words: crop insurance, extensive margin, intensive margin, loan deficiency payments, revenue insurance

Introduction

Federal risk management programs such as federal crop insurance and the Marketing Loan Program (MLP) have effects beyond directly improving farmer welfare. The income and risk changes that result from farmer participation in these and similar programs affect crop acreage allocation (the extensive margin) and the use of inputs on each crop (the intensive margin). The extensive and intensive margin effects are important, since these effects can counteract or enhance the goals of other programs. These effects can induce farmers to increase or decrease acreage of more erosive or chemically intensive crops, or to use more or less chemicals on land already allocated to specific crops. For example, Goodwin and Smith find that about half of the reductions in soil erosion due to the Conservation Reserve Program (CRP) were offset by increases in erosion from farmer responses to income support programs. Similarly, Babcock and Hennessy and Smith and Goodwin find that farmers purchasing crop insurance have incentives to reduce use of fertilizer and other chemicals. However, Horowitz and Lichtenberg find that crop insurance increases the use of agricultural chemicals.

The extensive and intensive margin effects of federal risk management programs continue to be a pertinent issue as the availability and subsidization of federal risk management programs has increased in recent years. The Agricultural Risk Protection Act (ARPA) of 2000 has resulted in increased premium subsidies and an expansion in the types of policies available, the crops covered, and the geographic availability. Total acres covered by crop insurance increased from 182 million in 1998 to 216 million in 2002, with total liability increasing from $28 billion to $37 billion (USDA-RMA 2002a). Among the most popular insurance programs are Actual Production History (APH) yield insurance and Crop Revenue Coverage (CRC) revenue insurance, with liabilities in 2002 of $15 billion and $8 billion respectively (USDA-

RMA 2002a). The Farm Security and Rural Investment Act of 2002 continued the Marketing Loan Program (MLP), which provides loan deficiency payments as a form of price insurance that protects farmers from low prices, much as APH protects from low yields. Loan deficiency payments equaled $6 billion for the 2000 crop year (USDA-FSA 2002a).

Many studies have analyzed the effects of crop insurance and other federal programs to quantify their intensive and/or extensive margin effects and interactions among different programs. These studies have been econometric (Goodwin and Smith; Horowitz and Lichtenberg; Smith and Goodwin; Wu), simulation-based (Babcock and Hennessy; Chavas and Holt), or mathematical programming based (Kaylen, Loehman, and Preckel; Turvey). Most studies examine the intensive margin or the extensive margin effects of crop insurance in isolation. An exception is Wu, who found that in Nebraska, crop insurance increased acreage for chemically intensive crops at the extensive margin and decreased chemical use on crops at the intensive margin, with an overall increase in chemical use. Also, Smith and Goodwin and Goodwin and Smith show the importance of accounting for the endogeneity of farmer behavior when examining the intensive or extensive margins and farmer participation in risk management programs.

Among those using a mathematical programming approach, Kaylen, Loehman, and Preckel examined the effect of crop insurance on production decisions. However, their analysis did not endogenize the choice of insurance coverage level and the price election factor. Turvey developed a mathematical programming model for a Canadian example to examine optimal acreage allocations and farmer welfare with different policies and parameters, but did not endogenize input use.

We develop a mathematical programming model of a representative Texas farmer to determine how federal risk management programs affect optimal farm level acreage allocation to cotton and sorghum (extensive margin) and the optimal use of nitrogen fertilizer on each crop (intensive margin). We endogenize input use and land allocation decisions, as well as the farmer's participation in federal risk management programs for each crop, specifically APH yield insurance, CRC revenue insurance, and the MLP. In addition, we endogenize the farmer's choice of coverage level and the price election factor for APH and CRC. We combine the mathematical programming and simulation-based approaches by using direct expected utility maximizing non-linear programming (Lambert and McCarl). What follows first is a brief review of crop insurance programs and the MLP. Next, we specify the model objective function and constraints, and then explain the data and estimation of model parameters. Finally, we present and discuss our empirical results relative to previously published results.

Federal Risk Management Programs

A farmer with APH insurance coverage receives an indemnity if the harvested yield is less than the yield guarantee. Farmers choose a yield coverage level ranging from 50% to 75% (up to 85% in some counties) by 5% increments of the approved APH yield and a price election factor ranging from 55% to 100% by 1% increments of the officially announced expected market price. A farmer with CRC insurance receives an indemnity if the guaranteed revenue exceeds calculated revenue. The price for calculating revenue is derived from the daily settlement price of futures contracts for a given period for an appropriate month for the crop. Again, the farmer must choose a coverage level (50% to 85% by 5% increments) and either a 95% or 100% price election. Farmers receive a smaller indemnity with CRC than with APH when the realized market price used to calculate the APH indemnity exceeds the CRC base price or harvest price used to calculate CRC indemnities. Farmers participating in the MLP receive a loan deficiency payment (LDP) when the marketing loan rate exceeds the posted county price or the world market price depending on the crop. A LDP can be utilized when the eligible crop is still owned by the farmer at the time of harvest.

The specified model includes all eight possible combinations of APH crop insurance, CRC revenue insurance, and the MLP. In each case, the participation in insurance programs and/or the MLP is chosen separately for each crop among the available alternatives, so that the insurance policy type, the coverage level, and price election factor can differ for each crop. The eight combinations (and their abbreviations) are: no program, Marketing Loan Program only, APH crop insurance only, APH crop insurance with the Marketing Loan Program (APH+MLP), CRC revenue insurance only, CRC revenue insurance with the Marketing Loan Program (CRC+MLP), both APH crop insurance and CRC revenue insurance available (APH+CRC), and both APH crop insurance and CRC revenue insurance available with the Marketing Loan Program (APH+CRC+MLP).

Conceptual Framework

The modeled representative farmer earns income by allocating total acreage A and a purchased input x to crops j = 1 to J. The farmer can also purchase crop or revenue insurance and choose to participate in the Marketing Loan Program. Thus, the farmer also chooses the price election factor (PEF_{ij}) and coverage level (CVG_{ij}) for each insurance policy i = 1 to I and crop j. The farmer can purchase only one type of insurance for each crop and if a crop is insured, all planted acres of that crop are insured, all with the same price election and coverage level. However, the farmer can purchase different types of insurance for different crops. These restrictions are in accordance with current federal crop insurance programs.

Per acre income with crop insurance program i and crop j for the most general case when all risk management programs are available is:

$$\pi_j = p_j y_j(x_j) - c_j - rx_j + \lambda_j LDP_j + \sum_i \left(I_{ij}(PEF_{ij}, CVG_{ij}) - M_{ij}(PEF_{ij}, CVG_{ij}) \right), \qquad (1)$$

where p_j is the random crop price, y_j is the random crop yield as a function of the input level x_j, c_j is the non-random variable cost, and r is the price of the input x. LDP_j is the random loan deficiency payment and λ_j is an indicator variable for participation in the marketing loan program ($\lambda_j = 1$ if the farmer chooses to participate, 0 otherwise). I_{ij} is the random insurance indemnity and M_{ij} is the non-random insurance premium for policy i, which both depend on the chosen price election factor (PEF_{ij}) and coverage level (CVG_{ij}). Because only one type of insurance can be purchased for any crop j, at most $PEF_{ij} > 0$ and $CVG_{ij} > 0$ for only one policy i for each crop j. Income per crop is $A_j\pi_j$, where A_j is acreage planted to crop j, and total crop income π is the sum of income over all crops: $\pi = \sum_j A_j \pi_j$.

The representative farmer maximizes the expected utility of income, choosing the acreage allocation A_j, input use x_j, and participation in the MLP λ_j for all j, the price election factor PEF_{ij} and coverage level CVG_{ij} for all i and j, and insurance program i:

$$\max_{A_j, x_j, i, PEF_{ij}, CVG_{ij}, \lambda_j} \int u(\pi) dF(p_1, p_2, ..., p_J, y_1, y_2, ..., y_J), \qquad (2)$$

where $u(\cdot)$ is the farmer's utility function ($u' > 0$, $u'' < 0$) and $F(\cdot)$ is the joint distribution function of prices and yields. Constraints include an acreage allocation constraint ($A \geq \sum_j A_j$), as well as technical constraints on the insurance programs (e.g., one policy per crop, and a PEF and a CVG from available levels). Solving this optimization program gives the optimal acreage allocation and input use for each crop (A_j and x_j for all j), as well as the optimal participation in risk management programs (PEF_{ij}, CVG_{ij} for all i and j, and λ_j for all j).

The intensive margin effect of each risk management program for a crop is the difference in the optimal use of the input x_j when the program is available versus when it is not. Similarly, the extensive margin effect is the change in optimal acreage A_j when the program is available versus when it is not. Determining the intensive and extensive margin effects of these federal risk management programs requires finding the solutions to problem (2) for the eight possible combinations of program availability. However, once the details of each program are accurately specified, analytical solutions generally become intractable. As a result, we use numerical methods to solve problem (2) for a representative farmer and sensitivity analysis to generalize from this specific case.

Empirical Model

For empirical analysis, we develop data and a model for a case farm in San Patricio County, Texas, near Corpus Christi. Texas accounted for 41% and 33% of total U.S. planted acres of cotton and sorghum respectively in 2002 and San Patricio County accounted for 2.2% and 2.9% of total cotton and sorghum acres planted in Texas in 2002 (USDA-NASS). Followings are the model specifications and data used for the empirical analysis.

Utility and Profit

The analysis uses direct expected utility maximizing non-linear programming (DEMP) in combination with a simulation approach (Lambert and McCarl). DEMP uses mathematical programming to find the crop acreage, input use, and risk management program parameters that maximize expected utility as a function of randomly drawn prices and yields. We use DEMP to maximize expected utility directly, as opposed to using quadrature (Kaylen, Loehman, and

Preckel), Monte Carlo integration combined with a grid search (Hurley, Mitchell and Rice), or a small set of observations as an empirical distribution (Turvey; Lambert and McCarl).

The empirical analysis here uses a negative-exponential (constant absolute risk aversion) utility function. As a result, wealth effects (including those from premiums) do not affect production decisions, and so all other income is ignored. With negative-exponential utility, the DEMP objective function for problem (2) is

(3) $$\sum_k [1 - \exp(-R\pi_k)],$$

where k indexes each state (Monte Carlo random draw), R is the coefficient of absolute risk aversion, and $\pi_k = \sum_j A_j \pi_{jk}$ is profit in state k. Income from crop j in state k is

(4) $$\pi_{jk} = p_{jk} y_{jk}(x_j) - c_j - rx_j + \lambda_j LDP_{jk} + \sum_i \left(I_{ijk}(PEF_{ij}, CVG_{ij}) - M_{ij}(PEF_{ij}, CVG_{ij}) \right),$$

which is the same as equation (1) except that each random variable has an index k. Values for R were chosen so the farmer's risk premium was a reasonable percentage of the income standard deviation (Babcock, Choi and Feinerman), which also satisfies the upper bound suggested by McCarl and Bessler.

The APH and CRC insurance indemnities for any state k and crop j are

(5a) $$I_{APH,jk} = PEF_{APH,j} P_j^e \max\{CVG_{APH,j} \bar{y}_j - y_{jk}, 0\},$$

(5b) $$I_{CRC,jk} = \max\{PEF_{CRC,j} \max\{p_j^b, p_j^h\} CVG_{CRC,j} \bar{y}_j - p_{jk} y_{jk}, 0\},$$

where $\bar{y}_j$ is the average yield used by both APH and CRC, p_j^e is the expected price used to calculate the APH indemnity, and p_j^b and p_j^h are the futures price before planting (base price) and the futures price before harvest (harvest price) used to calculate CRC indemnities. Available APH and CRC coverage levels in San Patricio County range 50% to 85% for cotton and 50% to 75% for sorghum, both by 5% increments. The available APH price election factor ranges from

55% to 100% by 1% increments, but with CRC the price election factor is either 95% or 100% (USDA-RMA 2002c).

The non-random insurance premium for each crop depends on the chosen coverage level and the price election factor. The analysis uses the actual (subsidized) premium the representative farmer would pay (USDA-RMA 2002c). The expected net indemnity is the expected difference between the indemnity and the premium. Since the premium is nonrandom, the expected net indemnity is the expected indemnity minus the actual premium. Because the integration required to calculate the expected indemnity is analytically intractable for the model, Monte Carlo integration is used to numerically estimate the expected indemnity (Greene, pp. 181-183). Thus, the expected indemnity is the average indemnity for each policy over all states k: $\sum_k I_{ijk}(PEF_{ij}, CVG_{ij})$.

The per acre loan deficiency payment (*LDP*) for any crop *j* in state *k* is

$$LDP_{jk} = \max\{MLR_j - p_{jk}, 0\} y_{jk}, \tag{6}$$

where MLR_j is the marketing loan rate set for crop *j*. The marketing loan rate guarantees a minimum price and so this program serves as price insurance without a premium. The marketing loan rate for this region in 2002 was $0.52/lb for cotton and $2.17/bu for sorghum (USDA-FSA 2002b).

Prices, Yields, and Correlations

The four-year county average yield and the four-year state average price from 1997 to 2000 are used for the mean price and yield for each crop (USDA-NASS). Mean yields are 677.0 lbs/ac for cotton and 70.0 bu/ac for sorghum. Because field level yield variability is greater than the variability of county average yield, the empirical analysis uses a yield standard deviation of

256.3 lbs/ac for cotton and 19.96 bu/ac for sorghum, which are 1.5 times greater than for the county data. These levels were chosen to be comparable to results from crop insurance studies (Coble, Heifner, and Zuniga).

For cotton, the mean price is $0.51/lb, with a standard deviation of $0.08/lb. For sorghum, the mean price is $1.98/bu, with a standard deviation of $0.41/bu. APH price guarantees in 2002 were $0.50/lb for cotton and $1.85/bu for sorghum. Base prices (futures price before planting) in 2002 for CRC were $0.42/lb for cotton and $2.18/bu for sorghum (USDA-RMA 2002b). The base price was used for the CRC harvest price for both crops, since it is a commonly used estimate of the harvest price at planting time. The price of nitrogen ($0.20/lb), nitrogen application rates of 75 lbs/ac for cotton and 60 lbs/ac for sorghum, and the variable costs of production ($316.40/ac for cotton and $116.70/ac for sorghum) are from crop budgets (Texas Cooperative Extension).

USDA-NASS county average yields and state price data from 1982-2000 were used to estimate the price-yield variance-covariance matrix. The respective correlation coefficients between own price and yield are –0.45 for cotton and –0.54 for sorghum. However, since county data normally have higher correlation between price and yield than farm level data, we reduced the correlations by one-third and used an own price and yield correlation coefficient of –0.30 for cotton and –0.36 for sorghum, which are comparable to values reported by Coble, Heifner and Zuniga. The correlation coefficient between cotton and sorghum prices is 0.43 and between cotton and sorghum yields is 0.56. Lastly, the correlation coefficient between cotton yield and sorghum price is -0.30 and between sorghum yield and cotton price is -0.26.

Cotton has a larger yield coefficient of variation, 37.9% versus 28.5% for sorghum, and sorghum has a larger price coefficient of variation, 20.9% versus 16.4% for cotton. These coefficients of variation for price and yield are comparable to those reported by Coble, Zuniga, and Heifner using crop insurance data. They report cotton yield coefficients of variation that range 32–61% and 22–25% for the cotton price. Following crop budgets, cotton seed proportionally increases cotton revenue by 12% (Texas Cooperative Extension). When no risk management programs are used, cotton has the larger mean and standard deviation for income, \$60.00/ac and \$142.90/ac respectively, versus \$29.30/ac and \$40.60 respectively for sorghum, and so is generally considered riskier than sorghum.

Crop Production Function

Random crop yield follows a beta distribution with mean and variance that depend on applied nitrogen fertilizer. The beta distribution is commonly used for crop insurance analyses (Goodwin and Ker review several examples). The beta density function for yield y is

$$b(y) = \frac{(y-A)^{\nu-1}(B-y)^{\gamma-1}\Gamma(\nu+\gamma)}{(B-A)^{\nu+\gamma+1}\Gamma(\nu)\Gamma(\gamma)}, \quad (7)$$

where A is the minimum, B is the maximum, ν and γ are shape parameters, and $\Gamma(\cdot)$ is the gamma function (Evans, Hastings, and Peacock).

As developed by Nelson and Preckel, the conditional beta density for crop yields specifies the parameters ν and γ as functions of inputs such as fertilizer, and either estimates or imposes values for the minimum and maximum. Nelson and Preckel use Cobb-Douglas functions for the parameters ν and γ, but for the analysis here, the method described by Mitchell, Gray, and Steffey is used for the conditional beta density. First the mean and variance of crop yield as functions of the fertilizer rate are specified, and then the implied functions for the parameters ν and γ are derived.

For a crop yield following a beta density, the mean and variance are

(8) $$\mu_y = (B-A)\nu/(\nu+\gamma)$$

(9) $$\sigma_y^2 = (B-A)^2\nu\gamma/[(\nu+\gamma)^2(\nu+\gamma+1)].$$

Solving these equations for ν and γ gives:

(10) $$\nu = \frac{(\mu_y - A)^2(B-\mu_y) - \sigma_y^2(\mu_y - A)}{\sigma_y^2(B-A)},$$

(11) $$\gamma = \frac{(\mu_y - A)(B-\mu_y)^2 - \sigma_y^2(B-\mu_y)}{\sigma_y^2(B-A)}.$$

Using a conditional beta density for crop yield requires specifying or estimating the mean μ_y and the variance σ_y^2 as functions of the nitrogen fertilizer rate, and then substituting these functions into equations (10) and (11) to obtain equations for ν and γ.

With this conditional distribution for yield, the farmer directly chooses the mean and the variance of the yield distribution when choosing the nitrogen fertilizer rate. With the Nelson and Preckel conditional yield distribution, the farmer's choice of the nitrogen fertilizer rate also determines the mean and variance of the yield distribution, but the choice is indirect through the approximating functions used for the parameters ν and γ.

For the analysis here, the functions for the dependence of the mean and variance of cotton yield on the nitrogen application rate were estimated using unpublished data from experiments conducted in 1999, 2001, and 2002 in Wharton County, Texas, near San Patricio County (McFarland). Nitrogen fertilizer rates were experimentally varied from 0 to 150 lbs/acre and cotton lint yields measured for each plot for a total of 48 observations. Polynomial terms in the fertilizer rate were added successively for both the mean and variance until coefficient estimates were insignificant. The final result was a quadratic equation for both the yield mean and the variance, with all estimated coefficients significant at the 1% level.

The estimated coefficients were calibrated so that the optimal risk neutral nitrogen application rate matched that reported in crop budgets (Texas Cooperative Extension) and the associated mean and variance of yield matched the observed county data. For the mean, this calibration primarily required changing the intercept term, and then slightly changing the quadratic term to increase the curvature. For the variance, only the intercept term was changed. The final equations for the mean (μ_c) and variance (σ_c^2) of cotton yield as a function of the nitrogen rate (x_c) are

(12) $$\mu_c = 63.5 + 16.25x_c - 0.108x_c^2,$$

(13) $$\sigma_c^2 = 12{,}500 + 453.6x_c + 2.800x_c^2.$$

Since experimental data were not available for sorghum, published estimates from Preckel, Loehman, and Kaylen for sorghum were calibrated in a similar manner so that again the optimal risk neutral nitrogen application rate matched that reported in crop budgets and the mean and variance of yield matched observed county data. The final equations for the mean (μ_g) and variance (σ_g^2) of sorghum yield as a function of the nitrogen rate (x_g) are

(14) $$\mu_g = 16.5 + 1.68x_g - 0.013x_g^2,$$

(15) $$\sigma_g^2 = 40.0 - 5.40x_g + 0.400x_g^2 - 0.004x_g^3.$$

Model Implementation

The model was solved using the nonlinear program (NLP) solver or the simple branch and bound (SBB) solver in GAMS (General Algebraic Modeling System). The optimal fertilizer rate was determined as an integer variable by specifying fertilizer rates in 0.1 lb/ac increments centered at the county mean for each crop. Output was examined to ensure that the fertilizer rate on the boundary was never optimal.

To draw yields from the beta distribution with the mean and variance implied by the fertilizer rate, GAMS was linked to Excel using the GDXXRW program distributed with GAMS. GAMS sends the required means and variances to Excel, then Excel generates appropriately correlated yields and prices using the method of Richardson and Condra. This method begins with appropriately correlated uniform random variables, the inverse beta cumulative distribution function in Excel is used to obtain yields with a beta distribution and transformed normal random variables are used to obtain prices with a lognormal distribution. Experimentation indicated that 5,000 random draws were needed for model results to stabilize.

Empirical Results and Discussion

Tables 1 and 2 report the optimal fertilizer use, acreage allocation, and insurance coverage level when the current subsidized insurance is available. Table 1 reports results without the MLP and table 2 reports results with the MLP to indicate the effect of the MLP. Results for the price election factor *PEF* are not reported since the optimum in all cases was the maximum available (100%).

Table 1 shows that APH and CRC crop insurance both generally have a small positive effect on the optimal nitrogen fertilizer rate for both cotton and sorghum. Depending on the crop and the farmer's level of risk aversion, the optimal rate increases about 1-2 lbs/ac, or 1-3%. Crop insurance has a large effect on the optimal acreage allocation. When APH is available, optimal cotton acreage more than doubles, accompanied by an appropriate decrease in sorghum acres. When only CRC is available, the acreage effect is qualitatively the same, but much smaller—optimal cotton acreage increases 16-23% depending on the level of risk aversion. When both APH and CRC are available, the optimal purchase is APH for cotton and CRC for sorghum, with a 70% coverage level for cotton APH and a 70% or 75% coverage level of CRC sorghum, depending on the farmer's risk aversion. When only CRC is available, it is optimal to purchase cotton CRC, but the optimal coverage level is relatively smaller than for APH.

Comparing tables 1 and 2 indicates the effect of the Marketing Loan Program on optimal nitrogen fertilizer rates and acreage allocations. The MLP decreases optimal nitrogen rates for cotton and increases optimal nitrogen rates for sorghum, but the effect is quite small, generally less than a 1% change. The MLP increases cotton acres 1-9% depending on the program and farmer risk aversion, with an accompanying decrease in sorghum acres. The only exception is the difference between the no program and MLP only cases, for which cotton acres decrease about 10%. This case is different because for the no program case, it is optimal to plant only a total of 1575 acres for both crops, less than the 1700 available. Once the MLP is available, it becomes optimal to plant 1700 acres, with a net decrease in cotton acres. Lastly, the MLP has no effect on insurance participation, except that the optimal coverage level for sorghum when only APH is available increases from 70% to 75%.

The results in tables 1 and 2 also show that as farmer risk aversion increases, the optimal nitrogen rate decreases for all alternatives regardless of the crop because nitrogen is used as a risk increasing input in this study. In addition, optimal cotton acreage decreases and optimal sorghum acreage increases, because cotton is the riskier crop. For the range of risk aversion levels explored, the optimal insurance coverage level did not change for cotton, but increased for sorghum. To understand this result, table 3 reports the expected net indemnity (expected indemnity minus the premium) for each case.

Table 3 indicates that for cotton APH, the 70% coverage level has the largest expected net indemnity by a substantial amount and so is optimal over a wide range of risk aversion levels. For sorghum APH, the expected net indemnity is always negative and fairly similar in value for many coverage levels. Though the 60% coverage level has the highest expected net indemnity, the 70% coverage level is optimal over the range of risk aversion levels explored because the added risk benefit it provides exceeds the small decrease in the expected net indemnity. For CRC for both crops, the optimal coverage level is higher than the coverage with the largest expected net indemnity because again the added risk benefit exceeds the slight decrease in the net indemnity.

The results in table 3 also explain the optimal choice of APH for cotton and CRC for sorghum when both insurance programs are available. For cotton, APH has a positive expected net indemnity up to the 75% coverage level, while expected net indemnities are negative for CRC, indicating why APH is preferred to CRC. Sorghum has negative expected net indemnities for all coverage levels for both programs, but expected net indemnities are largest for CRC, indicating why CRC is preferred to APH. These results are consistent with the actual farmer behavior in San Patricio County. In 2002, 98.6% of farmers in the county buying crop insurance for cotton bought APH and 62.3% of those buying crop insurance for sorghum bought CRC (USDA-RMA 2002d).

The magnitude and direction of intensive and extensive margin effects vary according to the crops and regions, largely depending on the effects of inputs such as fertilizer and specific crops on the variability of income. In our study, the small positive effect of crop insurance on the intensive margin occurs for both crops and both APH and CRC. This result is generally consistent with the econometric analysis of Horowitz and Lichtenberg, who report that crop insurance increases fertilizer use for corn in the Midwest. However, Smith and Goodwin in their econometric study of wheat farmers in Kansas find that crop insurance decreases fertilizer use, as do Babcock and Hennessy in their simulation-based analysis of corn in Iowa.

The difference between our findings and those of Babcock and Hennessy is largely due to the effect of nitrogen fertilizer on the variance of crop yield. In the range of the fertilizer rates that Babcock and Hennessy report, nitrogen is a variance decreasing input for corn, while for the rates in tables 1 and 2, nitrogen is a variance increasing input for cotton and sorghum in our study. Regardless of the yield distribution, when crop insurance is available, farmers find it optimal to bear more risk and so choose fertilizer rates accordingly. For the Babcock and Hennessy conditional yield distribution, this implies a reduction in the fertilizer rate. For our conditional yield distributions, this implies an increase in the fertilizer rate. However, focusing only on the variance effect of fertilizer on crop yields is a simplification of our analysis, since the farmer also simultaneously chooses the crop acreage allocation and insurance coverage levels.

Our simulation-based results are generally consistent with the results of Wu's econometric analysis of Nebraska corn-soybean farmers, since he finds that crop insurance increases fertilizer use and acreage of the riskier crop (corn). Similarly, Chavas and Holt find that price supports (comparable to the Marketing Loan Program) create moderate acreage increases in the supported crop (corn) and that cross-commodity risk reductions are important to consider, much as we find. Turvey's method of analysis is similar to our method, but only focuses on acreage effects. However, he finds that the Canadian crop insurance program increases optimal acreage devoted to riskier crops, just as we find for the U.S. insurance program.

Table 4 reports farmer certainty equivalents when implementing the optimal choices reported in tables 1 and 2. From the farmer's perspective, having all three federal risk management programs available is preferred—APH+CRC+MLP has the highest certainty equivalent regardless of the risk aversion level. Relative to the no program case, these programs increase the farmer's certainty equivalent 170-240% depending on the level of risk aversion.

About 2/3 of this increase is due to MLP and about 1/3 is due to crop insurance. Also, the optimal farmer response for all scenarios examined is to change fertilizer use and crop acreage to increase the standard deviation of income (along with the mean). These responses indicate that these risk management programs encourage farmers to bear more risk.

Fixing the nitrogen fertilizer rate and endogenizing the acreage allocation, or fixing the acreage allocation and only endogenizing the nitrogen fertilizer rate, the bias that results from analyzing the intensive and extensive margin effects in isolation from one another, as opposed to simultaneously, can be determined. Results are not reported, but the bias is rather small for this empirical example. In general, the magnitude of both the intensive and extensive margin effects is larger when analyzed in isolation, as opposed to simultaneously. This result is not surprising, since the farmer uses two instruments (both nitrogen fertilizer and crop acreage) to respond to changes in risk for the simultaneous case, but only one when the effects are examined in isolation. However, the magnitude of the resulting bias is not substantial for this empirical example—the optimal nitrogen fertilizer rate is 1-2 lbs/ac different and the crop acreage allocation is generally less than 5% different.

Conclusion

To examine the effects of federal risk management programs on optimal nitrogen fertilizer use and land allocation to crops, we developed a mathematical programming model of a representative cotton-sorghum farm in San Patricio County, Texas. The model endogenizes nitrogen fertilizer rates and land allocation, as well as the insurance coverage levels, price election factors, and participation in insurance programs and the Marketing Loan Program (MLP). We use direct expected utility maximizing non-linear programming in combination with a simulation approach. We assume a conditional beta distribution for crop yields, a lognormal distribution for crop prices, and impose historical correlations on yields and prices.

Results show that with current crop insurance programs, the optimal nitrogen fertilizer rate slightly increases (1-3%) and the optimal cotton acreage substantially increases (16-129%). The MLP only slightly changes optimal nitrogen fertilizer rates for both cotton and sorghum (less than a 1% change), but increases optimal cotton acreage an additional 1-9%. These results depend crucially on the variance increasing effect of nitrogen fertilizer and of cotton in our model. Other intensive and extensive margin responses would be optimal for other specifications for the stochastic revenue functions.

Optimal participation in the available federal risk management programs includes using the MLP for both cotton and sorghum and purchasing APH insurance for cotton and CRC for sorghum. Optimal coverage levels are 70% for cotton APH and 70% or 75% corn sorghum CRC. The optimal price election factor is always the maximum available (100%). The farmer's expected net indemnity from these insurance programs largely explains the optimal insurance participation choices and coverage levels. Together, all three federal risk management programs increase farmer certainty equivalents 170-240%, of which about 1/3 is from crop insurance and 2/3 from the MLP.

In general, the modeled farm responds optimally to these federal risk management programs by changing input use and crop acreage allocations to bear more risk. These intensive and extensive margin effects of these and other federal programs have associated environmental effects that are being increasingly scrutinized since they can enhance or counteract the goals of other programs (Goodwin and Smith; Skees). Assuming the environmental effects of crop insurance and the MLP are positively related to nitrogen fertilizer use, both types of risk management programs imply negative environmental effects. Crop insurance increases optimal nitrogen use through both the intensive and extensive margin effects. The MLP increases optimal nitrogen use through the extensive margin effect, which dominates the slight decrease in optimal nitrogen use it creates for cotton. The extensive margin effect of both types of programs is the dominant effect in our empirical analysis and of sufficient magnitude that it should probably be included in any comprehensive analysis of the environmental effects of federal policies.

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Table 1. Optimal farmer choices without the Marketing Loan Program (MLP).

	Moderately Risk Averse[a]		Highly Risk Averse[a]	
	Cotton	Sorghum	Cotton	Sorghum
Government Program	-------- Optimal Nitrogen Fertilizer Rate (lbs/ac) --------			
No Program	70.7	57.8	70.4	56.8
APH only	72.4	58.8	72.1	58.1
CRC only	72.1	58.6	72.0	57.7
APH and CRC[b]	72.5	58.6	72.3	57.7
Government Program	------------- Optimal Acreage Allocation (ac) -------------			
No Program	561	1,139	295	1,281
APH only	1,164	536	678	1,023
CRC only	652	1,049	362	1,338
APH and CRC[b]	1,134	566	651	1,049
Government Program	--------- Optimal Insurance Coverage Level (%) ---------			
No Program	--	--	--	--
APH only	70	70	70	70
CRC only	60	70	60	75
APH and CRC[b]	70	70	70	75

[a] Coefficients of absolute risk aversion are 4.0×10^{-6} and 7.0×10^{-6} for moderately and highly risk averse, respectively.
[b] Optimal choice when both insurance programs are available is APH for cotton and CRC for sorghum.

Table 2. Optimal farmer choices with the Marketing Loan Program (MLP).

	Moderately Risk Averse[a]		Highly Risk Averse[a]	
	Cotton	Sorghum	Cotton	Sorghum
Government Program	------- Optimal Nitrogen Fertilizer Rate (lbs/ac) -------			
MLP only	70.5	58.2	70.0	56.7
APH and MLP	71.8	59.2	71.3	58.3
CRC and MLP	71.8	59.1	71.9	58.3
APH+CRC+MLP[b]	71.8	59.1	71.5	58.2
Government Program	---------- Optimal Acreage Allocation (ac) ----------			
MLP only	569	1,131	265	1,435
APH and MLP	1,255	445	697	1,003
CRC and MLP	673	1,027	367	1,333
APH+CRC+MLP[b]	1,230	470	678	1,022
Government Program	------ Optimal Insurance Coverage Level (%) ------			
MLP only	--	--	--	--
APH and MLP	70	70	70	75
CRC and MLP	60	70	70	75
APH+CRC+MLP[b]	70	70	70	75

[a] Coefficients of absolute risk aversion are 4.0×10^{-6} and 7.0×10^{-6} for moderately and highly risk averse, respectively.
[b] Optimal choice when both insurance programs are available is APH for cotton and CRC for sorghum.

Table 3. Expected Net Indemnity ($/ac) for each insurance program.[a]

	Coverage Level						
Crop-Program	55	60	65	70	75	80	85
Cotton APH	3.04	4.47	4.91	5.77	4.22	-0.90	-11.85
Sorghum APH	-0.76	-0.61	-0.83	-0.91	-1.82	--	--
Cotton CRC	-1.77	-1.77	-3.19	-4.45	-8.67	-16.98	-31.58
Sorghum CRC	-1.02	-0.74	-0.91	-0.77	-1.71	--	--

[a] Using a nitrogen application rate of 70 lbs/ac for cotton and 60 lbs/ac for sorghum.

Table 4. Certainty equivalent and mean and standard deviation of profit ($1,000's) with optimal farmer choices.

	Moderately Risk Averse[a]			Highly Risk Averse[a]		
Govt. Program	Certainty Equivalent	Mean Profit	St. Dev. Profit	Certainty Equivalent	Mean Profit	St. Dev. Profit
No Program	32.7	54.7	104.9	20.6	41.4	77.3
APH only	48.4	85.4	144.1	32.5	62.2	98.2
CRC only	36.4	56.5	102.9	26.8	43.6	72.8
APH and CRC[b]	48.9	84.1	140.4	34.2	60.2	92.2
MLP only	68.1	95.6	115.5	52.6	80.6	87.4
APH+MLP	88.0	135.6	162.0	67.8	103.8	106.9
CRC+MLP	72.8	98.8	115.2	60.4	81.8	80.3
APH+CRC+MLP[b]	88.4	134.3	158.9	69.2	102.8	103.1

[a] Coefficients of absolute risk aversion are 4.0×10^{-6} and 7.0×10^{-6} for moderately and highly risk averse, respectively.
[b] Optimal choice when both insurance programs are available is APH for cotton and CRC for sorghum.