MODELS OF TECHNOLOGY ADOPTION UNDER RISK: SOME PRELIMINARY RESULTS

Michele C. Marra and Gerald A. Carlson[1]

Introduction

Recently there have been some extensions to the original work of Baron (1970) and Sandmo (1971) that have shown promise both theoretically and empirically for understanding production behavior under risk. Holthausen (1979) introduced hedging opportunities to the theoretical model and showed that a risk-averse producer would adjust production based on changes in the futures price. Grant (1984) built on Holthausen's work by introducing quantity uncertainty and showed that if both output and price were uncertain, optimal scale of production and the optimal forward position depend upon empirical estimates of risk aversion and the joint distribution of price and quantity. Marra and Carlson (1984) and Just and Zilberman (1983, 1984) extended the original theoretical model to include choice between two outputs, both with uncertain returns. This extension allows consideration of problems dealing with technology adoption under risk as well as production. The Marra-Carlson (MC) model and the Just-Zilberman (JZ) model, while employing different methods of derivation and slightly different underlying assumptions, yield similar results on optimal allocation of a fixed resource between two alternative outputs.

The MC and JZ models were derived for different purposes and have had different applications thus far. The parameters of the MC optimal land allocation equation have been estimated to gain some knowledge of

[1]The authors are Assistant Professor, University of Maine at Orono and Professor, North Carolina State University. Part of this work was accomplished under Research Agreement No. 58-319V-4-00232, NRED/ERS/USDA.

the factors affecting double cropping as a new technology in the southeastern U.S. JZ have taken a more theoretical direction and have provided some insight into the role of risk aversion, fixed costs, credit constraints, and farm size on technology adoption.

The purposes of this paper are threefold. First, we describe the double crop technology and report on the results of the MC model as applied to state level, time series data. The emphasis is on choice through time with multiple sources of risk with multiple outputs. Second, we apply some of the theoretical results of JZ to a 1982 cross-sectional survey of individual farms to test their hypotheses on fixed costs of adoption, risk aversion and credit limitations. Finally, we point to the importance of timing of agricultural inputs as a possible source of constraints to the adoption of certain new technologies such as double cropping. We introduce additional resource constraints to explain the relationship between farm size and technology adoption with the same survey data.

Double Cropping Systems

Double cropping soybeans and small grain (primarily wheat) constitutes a relatively new production practice in the Southeast. A double-cropped system involves planting small grain in the fall and planting late-season soybeans as soon as possible after the small grain harvest in late spring or early summer. The soybean acreage devoted to double cropping has increased over the last fifteen years in the Southeast but has neither advanced steadily nor proceeded at the same rate in all states (see Figure 1).

Double-cropped soybeans are usually planted thirty to fifty days later than full-season soybeans and generally have lower yields and more yield variability. The sooner the double-cropped soybeans are planted after wheat harvest, the higher and less variable is expected soybean yield. The crucial timing of wheat harvest and soybean planting provides incentive for use of conservation tillage which takes less time to accomplish than conventional planting. Double cropping requires more management input along with more labor and equipment resources than is generally required for full-season soybean production. Extra income from the wheat crop may, however, more than offset the decreased income from the late-planted soybean crop. Double cropping may also provide income-stabilizing potential through diversified price risk and reduced technical risk from a diversified exposure to drought and pest threats. In the last few years introduction of higher-yielding wheat and late-planted soybean varieties, development of more effective post emergent herbicides, and improvements in minimum tillage equipment and practices have probably contributed to reducing yield risk and increasing expected profits of this cropping system.

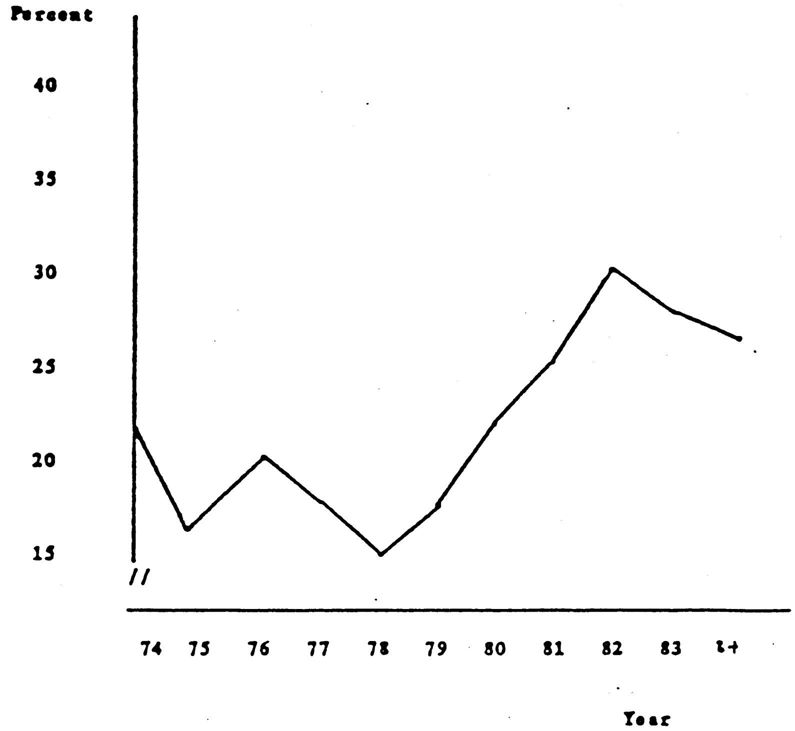

Figure 1. Average Proportion of Soybean Acreage Double Cropped in the Southeast Over Time.

Average of Alabama, Arkansas, Georgia, Kentucky, North Carolina, South Carolina, Tennessee, and Virginia. Source: USDA, unpublished data.

Double Cropping over Time

Theory

To try to understand the factors affecting double cropping patterns over time, we have developed a model that is an extension of the work of Baron, Sandmo, Holthausen, and Grant. We assume an individual producer is an expected utility maximizer and can allocate his soybean acreage between full-season soybeans and wheat-soybeans to maximize end-of-period profit from his soybean acreage.

An individual's utility of profit is defined as:

(1) $U(\pi) = U[(\alpha P_B X + rP_W WX + P_B(1-X) - C(X))L]$,

where $U(\pi)$ = utility of profit from the soybean acreage,

α = the percentage of double-cropped soybean yield relative to full-season soybean yield, $0 < \alpha \leq 1$,

P_B = the uncertain return of soybeans per acre,

X = the fraction of total soybean acreage double cropped,

r = 1 + the opportunity interest rate on operating capital,

P_W = the uncertain return of wheat per acre,

$C(X)$ = the total cost of production per acre for the soybean acreage including both the single- and double-cropped acreage, and

L = the total acreage planned to be either single or double cropped.

Equation (1) is a function of two random variables, P_B and P_W.[2] The producer maximizes the expected utility of profit, $EU(\pi)$, with respect to the proportion of total soybean acreage double cropped, X. The first-order condition for a maximum, FOC, can be written (with ' denoting derivatives) as:

(2) $FOC = \delta EU(\pi)/\delta X = E\{U'(\pi)[(\alpha P_B + rP_W - P_B - C'(X))L]\} = 0.$

Taking the expectations operator, E, through (2) and combining terms gives:

$$(3) \quad EU'(\pi)\{[(\alpha-1)E(P_B) + rE(P_W) - C'(X)]L\}$$
$$+ (\alpha-1)L\mathrm{cov}(U'(\pi),P_B) + rL\mathrm{cov}(U'(\pi),P_W) = 0.$$

---

[2]We consider the distribution of total revenue from each crop rather than distributions of prices and outputs separately. We do, however, take the price-output covariances into consideration empirically.

Dividing through by L and applying Stein's Theorem to $\mathrm{cov}(U'(\pi),P_bB)$ and $\mathrm{cov}(U'(\pi),P_wW)$ gives:[3]

$$\text{(4)}\quad EU'(\pi)(\alpha-1)E(P_bB) + EU'(\pi)rE(P_wW) - EU'(\pi)C'(X)$$
$$+ (\alpha-1)EU''(\pi)\{(\alpha X-X-1)L\mathrm{var}(P_bB) + rXL\mathrm{cov}(P_bB,P_wW)\}$$
$$+ rEU''(\pi)\{(\alpha X-X-1)L\mathrm{cov}(P_bB,P_wW) + rXL\mathrm{var}(P_wW)\} = 0.$$

Solving (4) for X and rearranging it in terms of the unknowns, $EU'(\pi)$ and $EU''(\pi)$, gives:

$$\text{(5)}\quad X^* = [EU'(\pi)X_1 + EU''(\pi)X_2]/\ [EU'(\pi)X_3 + EU''(\pi)X_4]$$

where: X^* = the optimal proportion of soybean acreage double cropped,

$X_1 = (1-\alpha)E(P_bB) - rE(P_wW)$,

$X_2 = (1-\alpha)L\mathrm{var}(P_bB) - Lr\mathrm{cov}(P_bB,P_wW)$,

$X_3 = -C'(X)$, and

$X_4 = (\alpha-1)^2L\mathrm{var}(P_bB) + r^2L\mathrm{var}(P_wW) + [2(\alpha-1)]rL\mathrm{cov}(P_bB,P_wW)$.

The resulting econometric model is:

$$\text{(6)}\quad Y = a_0 + (B_1X_1 + B_2X_2)/(B_3X_3 + B_4X_4) + e.$$

We added an intercept term to the theoretical derivation to take into account locational differences and to expedite global minimization in the nonlinear regression program (SAS NLIN). We also assume the error term, e, has an expected value of zero and takes into account factors known to decisionmakers but not observable by the authors. Note that, because of aggregation to the state level, the coefficients B1 through B4 cannot

---

[3]See Grant and Marra and Carlson for additional references and a more complete description of Stein's method for decomposing the covariance term for broad classes of probability distributions.

be interpreted as being the expected values of the derivatives of the utility function since they also contain aggregation function parameters.*

Evidence

Elasticities for 1982 from estimation of the parameters of (7) using state-level data from 1966 to 1982 are presented in Table 1. Note that the elasticities with respect to the first two moments of wheat return are much larger in absolute magnitude than their soybean revenue counterparts. For the most part, the elasticities have expected signs. The exceptions are the elasticity with respect to additional cost [C'(X)] for Georgia and the variance of wheat revenue [V(TR)Wheat] for Kentucky and Tennessee.

To illustrate how this model fares in terms of explaining the inter-state and inter-year variation in the proportion of soybean acreage double cropped, we present graphically the actual and predicted proportions for Alabama, North Carolina, and Tennessee for 1970 through 1984 in Figures 2 through 4. At least for this particular application, the model seems to track the wide swings in the proportion across years fairly well. Again, the major factor seems to be the change in the distribution of wheat revenue with changes in additional cost also counting as an important factor.

---

*We present only a brief discussion of our model here. See Marra (1984) for more complete discussions of the model derivation, econometric assumptions, data description, and further empirical results.

Table 1. Elasticities from the MC model for 1982[a]

State	Int. rate(?)[b]	E(TR)Soybeans(-)	E(TR)Wheat(+)
AL	0.0511	-0.1687	1.0502
AR	-0.0011	-0.1174	1.2347
GA	0.1456	-0.0390	0.3818
KY	0.0940	-0.0183	0.6335
NC	-0.0994	-0.0453	1.2726
SC	0.0832	-0.0393	1.0146
TN	0.6590	-0.2357	1.3820
VA	0.0751	-0.0139	0.2078

V(TR)Soybeans(0)	V(TR)Wheat(0)	Cov(TR)(0)	C'(X)(-)
-0.000040	-0.008900	0.0158	-0.8241
-0.008400	-0.000100	-0.0455	-1.4947
-0.016300	-0.087800	-0.2251	1.1709
0.000007	0.000015	0.0007	-0.6652
0.006300	-0.023900	-0.0230	-0.6167
-0.000900	0.016800	0.0860	-1.1498
0.001300	-0.001400	0.0066	-0.1096

[a]1982 is the last in-sample year and the one for which we had the most complete data.

[b]Expected signs under risk neutrality are in parentheses.

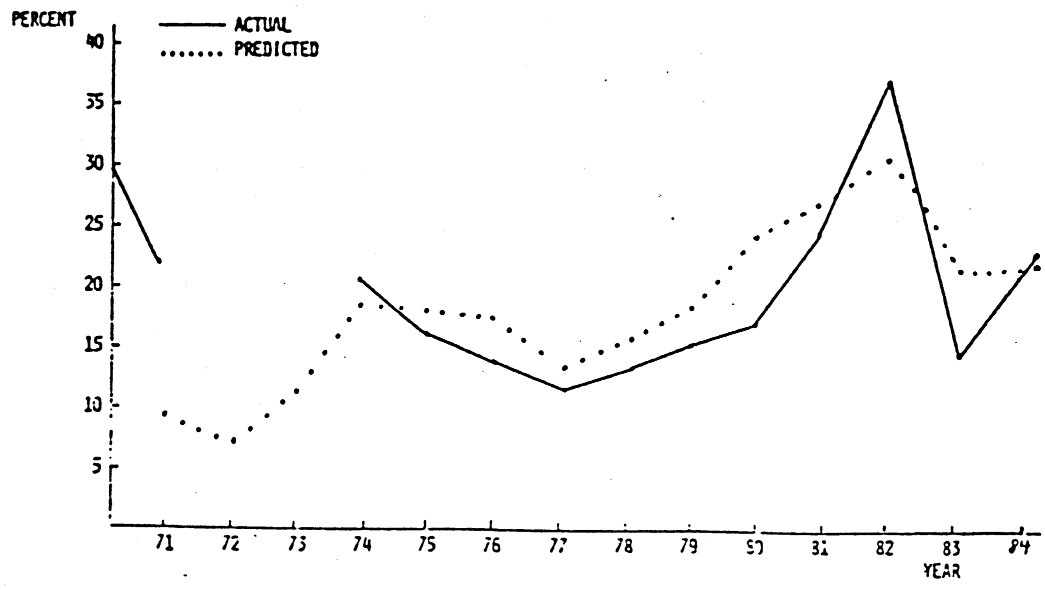

Figure 2. Actual and Predicted Proportion Double Cropped for Alabama over Time.

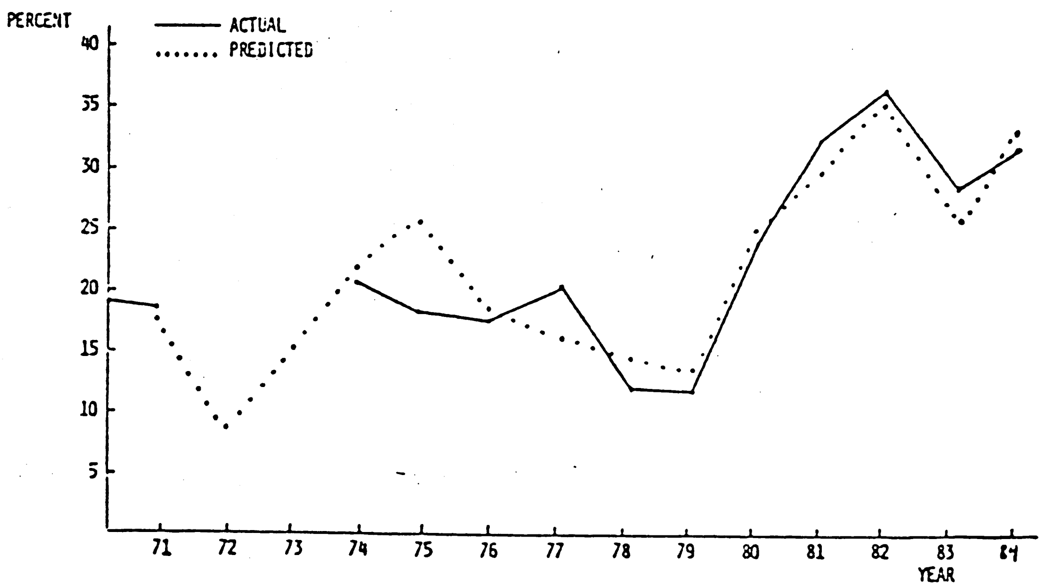

Figure 3. Actual and Predicted Proportion Double Cropped for North Carolina over Time.

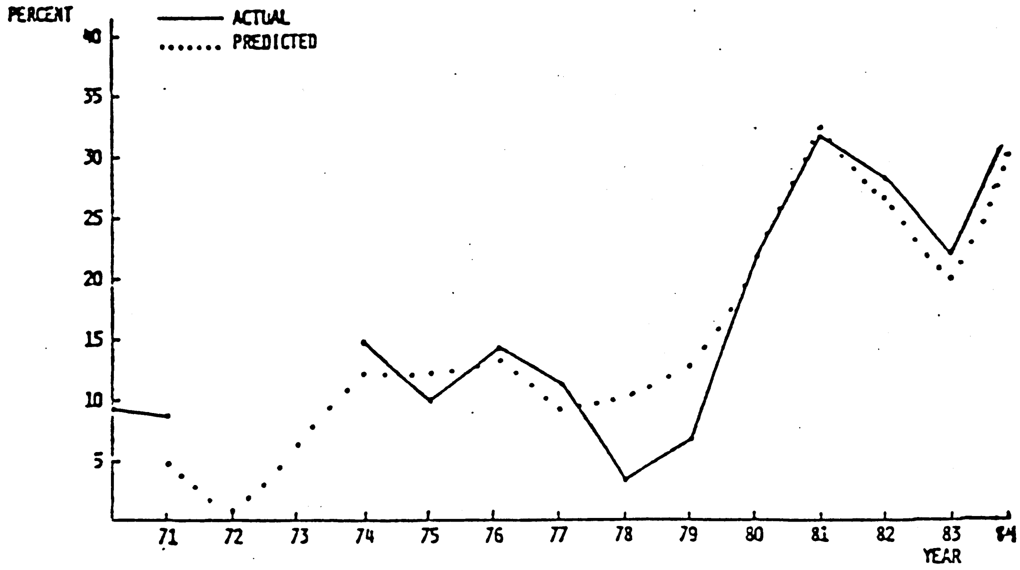

Figure 4. Actual and Predicted Proportion Double Cropped for Tennessee over Time.

The Farm Size-Double Cropping Relationship

Theory

Just and Zilberman (1983, 1984) have developed a similar model of production under uncertainty and, while their model contains extensions of the basic theory in slightly different directions than the one derived above, they are able to provide interesting theoretical insight into the relationship between farm size and the adoption of a new technology. The purpose of the following sections is to compare their theoretical results to some empirical evidence on double cropping and farm size from the 1982 USDA Cost of Production survey. In this way, we hope to provide some increase in the understanding of the distribution of this new technology across firms beyond the results obtained from our specification above.

The JZ objective function is the following:

$$(7)\quad \text{MAX } EU(\pi) = EU[PL + \pi_o L_o + \pi_1 L_1 - rK]$$

$$\text{s.t. } L_o + L_1 = \leq L$$

where PL = the value of total land at the end of the period, (wealth),

$\pi_o L_o$ = the return from production of the portion of the land, L_o, allocated to the old technology,

$\pi_1 L_1$ = the return from production of the portion of the land, L_1, allocated to the new technology, and

rK = the annualized fixed costs of adoption.

Assuming full land utilization ($L_o + L_1 = L$) and an internal solution ($0 < L_1 < L$), they derive an approximation of the first order condition by expanding U' around expected end-of-period wealth, W, using a first order Taylor-series expansion. This yields the first order condition with respect to L_1 as:

$$(8)\quad 1/\bar{U}' (\delta U/\delta L_1) = E(\pi_1) - E(\pi_o) - \xi[L_1(var(\pi_o) + v^2 var(\pi_1) - 2v cov(\pi_o,\pi_1) + L(v cov(\pi_o,\pi_1) - var\ (\pi_o)] = 0$$

where $\bar{U}'$ = U' evaluated at mean wealth,

ξ = the Pratt-Arrow measure of absolute risk aversion evaluated at mean wealth ($-\bar{U}''/\bar{U}'$), and

v = a parameter indicating the contribution of the new technology to the overall riskiness of the production ($\delta v/\delta L_1 = \delta var(\pi_o + \pi_1)/\delta L_1$).

Simplifying and solving (8) for L_1 gives:

$$(9)\quad L_1^* = [E(\pi_1) - E(\pi_o) + \Phi L(var(\pi_o) - v var(\pi_1))]/$$
$$\Phi(var(\pi_o) + v^2 var\ (\pi_1) - 2v cov(\pi_o, \pi_1).$$

Note the similarities between equations (9) and (6).

From (9) JZ derive the expansion path of technology adoption with increases in farm size under various assumptions about the covariance of returns and absolute and relative risk aversion.[5] Underlying assumptions of this derivation are that mean wealth is adequately measured by the value of land holdings (PL) and expected income and that risk aversion (Φ) varies systematically with end of period mean wealth. It will suffice for our purposes to present only the graphic results under the most plausible assumption of increasing relative and decreasing absolute risk aversion. That this is the most likely case is convincingly argued in Arrow (1971).

From JZ the appropriate set of possible expansion paths assuming no fixed costs of adoption and no credit constraints are reproduced in Figure 5. The outer envelope, $OB_5B_4R_3$, corresponds to the assumption that the covariance of returns between the old and new technologies is low or negative. Thus, at small farm sizes, all farmers allocate all their land to the new technology, and the acreage devoted to the new technology increases at a constant rate as farm size increases. After some size, B_4, farmers spread risks by diversifying between the two technologies.

---

[5]For a complete development of the mathematics, we refer the reader to their original article (Just and Zilberman, 1983).

The next curve in Figure 5 is $OB_5B_8R_4$ which represents the case where the covariance of returns between the two technologies is high and absolute risk aversion is slightly decreasing, but nearly constant. In this case, small farmers will adopt fully, but at a smaller size limit ($B_5 < B_4$) farmers will begin to allocate some of their land to the old technology. The amount of land allocated to the new technology will increase, however, until a critical size (B_8) is reached, and then it declines.

Where the covariance is high and the decrease in absolute risk aversion is sufficiently large, there will be a size limit on adoption of the new technology. This is shown by OB_6B_7. In other words, in this case, there exists a relatively small farm size (at B_7) above which there is no acreage devoted to the new technology because the disutility of the increased risk outweighs the utility of additional expected profit.

The additional possibilities of significant fixed costs and credit constraints are represented in Figure 6. The rationale behind the basic paths are the same as above, but now the curves may be truncated to take into account the areas where fixed costs make it uneconomic for small farms to adopt at all or where credit constraints make it impossible to fully adopt. The fixed cost constraint is represented by OB_9 where there is no acreage devoted to the new technology at farm sizes less than B_9. As fixed costs increase, this minimum adoption size increases until, at some point, no adoption takes place ($OB_{10}B_{12}B_{13}$). The credit constraint is represented by line AC and can, of course, intersect the horizontal axis at any size depending upon the severity of the constraint. Its effect is to eliminate any acreage represented by points above and to the left of the line AC.

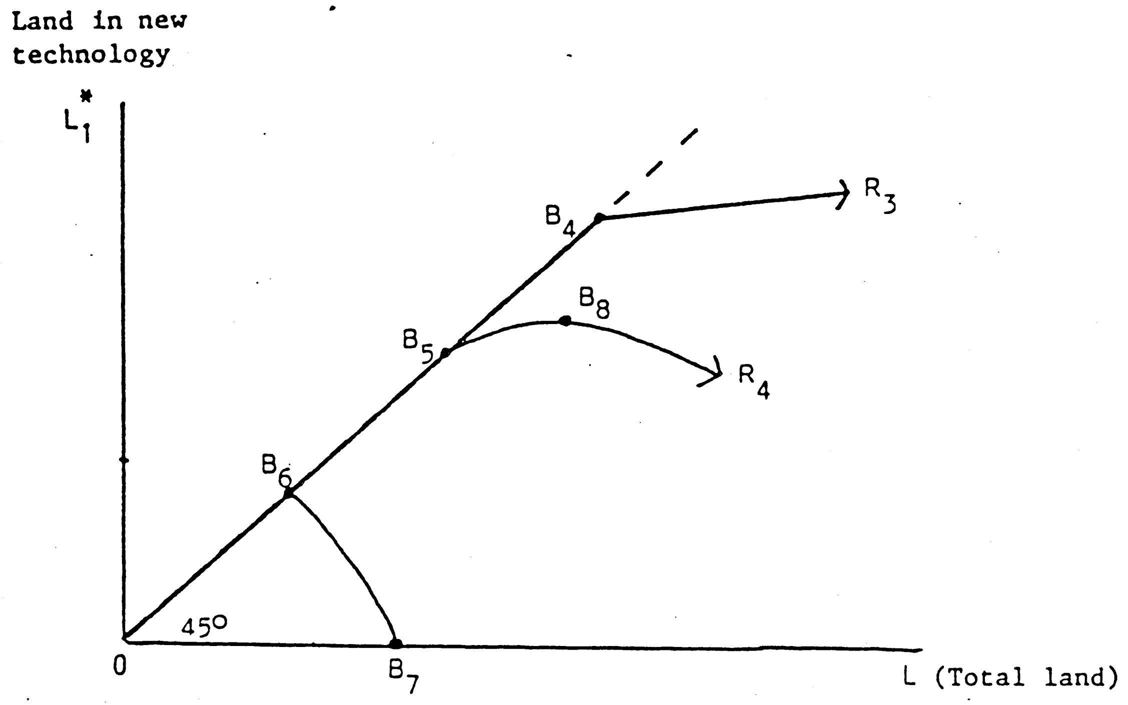

Figure 5. The Relationship Between Adoption Intensity and Farm Size Assuming No Fixed Costs and No Credit Constraints.*

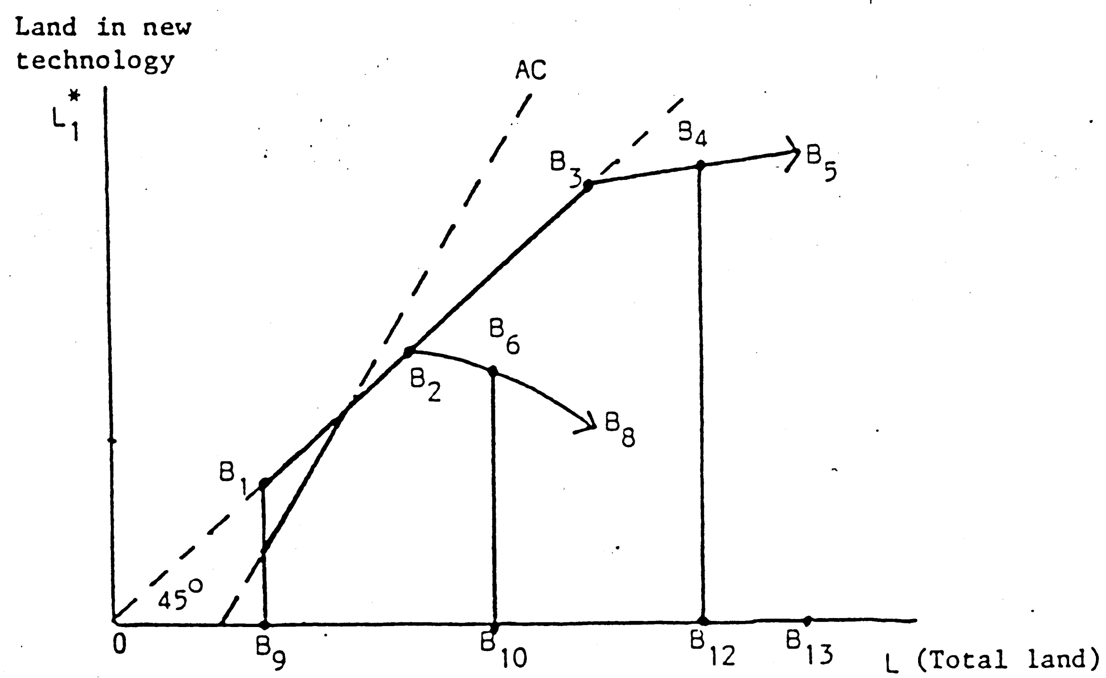

Figure 6. The Relationship Between Adoption Intensity and Farm Size with Fixed Costs and Credit Constraints.*

* Source: Just and Zilberman (1983, 1984).

Evidence

The 1982 Soybean Cost of Production Survey (USDA) contains information for individual respondents on their farm size and their acreage devoted to double cropped soybeans. Three measures of farm size are available in the survey; total soybean acreage, total cropland acreage, and total operated acreage. Since the JZ model includes acreage devoted to an old and a new technology, total soybean acreage is the measure of size most consistent with model. All of the soybean land must be devoted to either full season or double cropped soybeans to conform to theoretical model.

We now present the evidence from this survey on the relationship between acres devoted to the new technology and farm size and compare this evidence to the theoretical paths postulated by JZ and illustrated in Figures 5 and 6. Three questions can be investigated with this data. First, do the data indicate that small farms are not adopting at all? This corresponds to the notion of high fixed costs of adoption. Second, where adoption occurs, do farmers fail to fully adopt at small farm sizes? This corresponds to the notion of a credit constraint. Third, is there some size above which the acreage per farm devoted to double cropping falls? This corresponds to the high covariance, decreasing absolute risk aversion case.

As the simplest representation of the empirical expansion path ($\delta L_1^*/\delta L$) we regressed double cropped acres on linear and quadratic size variables with an intercept term. The resulting econometric model is:

$$(10) \quad DC = B_0 + B_1 Acres + B_2 Acres^2 + e$$

Where DC = the number of soybean acres double cropped/1000, and

Acres = the total number of soybean acres planted/1000.

The 502 individual farm observations are from the southeastern states including Alabama, Arkansas, Georgia, Louisiana, Mississippi, North Carolina, South Carolina, Tennessee, and Virginia. The regression results appear in Table 2.

Table 2. Regression Results from the Simplest Model of the Farm Size-Double Cropping Relationship

Independent Variables	Parameter Estimate	Standard Error
Intercept	0.00998	0.01614
Acres	0.35952	0.03363
Acres squared	-0.04151	0.01000

R^2 = 0.36797, N = 502.

The intercept term is not significantly different from zero. This is consistent with the hypothesis of no fixed adoption costs. However, this result is not distinguishable from the common practice of trying a new technology on some acreage to learn how the new technology applies to given land, management and other factor endowments (Welch, 1978). The linear term is less than one, indicating less than full adoption. This may be due to credit constraints, risk factors, or scarce capital available to accomplish timely planting on all of the acreage. The quadratic term is negative and statistically significant indicating that farmers larger than about 430 acres of soybeans reduce the acreage double cropped. Since we generally assume credit constraints are less binding for large landholders (although lately this is subject to some debate), the proportional decrease in double cropped acres at large farm sizes is probably reflective of responses to the overall riskiness of the new technology and conforms to the JZ case of high covariance and decreasing absolute risk aversion.

Other Resource Constraints

In examining differences in adoption of a risky, new enterprise, JZ (1984) explicitly mention between-farmer differences in risk aversion (δ), available credit ($K = aL$), and fixed adoption costs (rK per acre of new enterprise). In their model each of these characteristics is directly linked to the amount of cropland allocated to the old and new technology. This gives rise to the possible regions of adoption by farm size as illustrated in Figure 6. However, there are also likely to be other human and farm resources which are not closely linked with farm size that affect the relative expected returns and variances of the two enterprises. These will be related to fixed endowments of land, management and, perhaps, equipment.

In equation (9), $E(\pi_1) - E(\pi_0)$ represents the gain in expected returns from adoption of the new technology on a particular farm. These enterprise profits also depend upon coordination of the new technology with other inputs that may be stochastic such as weather, pests, and labor disruptions. Coordination involves finding proper input proportions and optimal timing of the use of inputs. Differences in management ability or specific human capital across farmers would, therefore, lead to differences in adoption rates <u>ceteris paribus</u>. In moving to an estimation model we want to account for managerial differences as well as farm size.

The expected gain from technology adoption shown in equation (9) is also frequently affected by the capital equipment endowment of the decision maker. In a dynamic production model (Antle, 1983) the demand for equipment, chemicals and labor can change dramatically over the production cycle. New technologies such as intensification of crop production involves increasing the use of the land and climatic resources per cycle. This can more than proportionally increase the demand for labor and equipment in particular periods. Current amounts and types of equipment may constrain adoption choices. Farmers may not quickly move to new optimal machinery complements because the stochastic nature of production does not immediately reveal the range of weather events and probabilities specific to the new technology. This reason for non-instantaneous adjustment may not be closely related to the quantity of capital held (rK) as modeled by JZ. In the double cropping adoption case considered here, type of equipment may be more important than amount of equipment. Economic models which account for within-year changes in the values of crop equipment are scarce. Multi-period linear programming studies (Danok, McCarl, and White, 1980) and dynamic production functions (Antle and Hatchett, 1984) of classes of "typical" farms are two different approaches to finding such shadow prices for equipment.

Land characteristics are also farm-specific resources which affect adoption incentives. Land qualities suitable for adoption of a new technology may not be linked to farm size and are not usually included in "fixed costs of adoption". In the case of double cropping, soil types suited to minimum tillage which also hold moisture for late-planted soybeans should encourage more adoption. Land located in areas with a longer growing season should also be more valuable.

Availability of high levels of management, correct types of equipment, and suitable soil all aid in the proper timing of the use of variable inputs such as chemicals and labor. The timing of the use of these inputs can also affect the variance of returns and, perhaps, cov(π_0, π_1). For example, in the case of double cropping, the shorter the interval between wheat harvest and late soybean planting, the higher and less variable the double cropped soybean return is likely to be. The ability to plant late season soybeans in a timely manner will increase average yields and decrease yield variance.

We assume that the additional management, equipment and land constraints enter the farmer's maximization problem (7) in a linear additive form. This may or may not change the shapes of the farm-size expansion paths shown in Figure 6 depending upon which constraints are binding. The estimation model will be a simple additive expansion of the quadratic expression shown in equation (10).

To account for cross-sectional differences in management ability we developed the following management index from the survey data. There are four classes of survey responses that may contain information on management ability; crop yield, narrow row spacing, use of technical services and futures market participation. Yield in bushels per acre is reported for single cropped and double cropped soybeans for both irrigated and non-irrigated acres. We adjusted for the effects or irrigation by taking 70% of the irrigated yield since, on average, the non-irrigated yields are 70% of the irrigated yields for the whole set of respondents. We then used a simple average of the yields in each category for which there was positive acreage and used this figure as the base of the index. Generally, this number ranges from 8 to 45 bushels per acre in this sample. We then added ten points to the index if any of the following technical services were used by the producer; soil tests, lab tests, tissue analysis, or insect or disease scouting. We also added ten points to the index if the producer participated in the futures market by either buying or selling a futures contract at any time during the production year (at planting, at harvest, or during the storage period). We completed the index by adding 50 minus the average row spacing in inches for the soybean crop. Thus, the index is higher for those who planted in narrow rows and lower for those who planted in wider rows. Narrow row spacing is considered to be an effective management practice to provide quicker canopy cover to control weeds and to discourage attacks of some insect species.

The range of the total index for this sample is from 19 to 89, which is a scale appropriate to the magnitude of the rest of the data used in the regression analysis. The mean management index for this sample is 47.4 with a standard deviation of 14.0. As with most indices of this type, this index is only a proxy and, as such, the following results should be viewed with some caution. We did, however, believe it important to take account of this factor and proceeded using the best available information.

The capacity to shorten the time interval between wheat harvest and soybean planting can mean the difference between profit and loss in a double cropped system. This capacity is not only a function of management skill, but of available capital equipment. To approximate this ability we used information on field operations from the survey responses. In particular, we attempted to proxy the use of conservation tillage practices for each respondent from the equipment use reported in their soybean field operations. We had no information on their wheat harvest equipment.

Conservation tillage provides less soil disturbance than conventional tillage which promotes future soil productivity and conserves soil moisture. It also takes less time to accomplish by eliminating some trips over the field for disking and plowing, thus shortening the crucial time interval between wheat harvest and soybean planting in a double cropped system.

Since there is no universally accepted definition of conservation tillage at present, we relied upon the definition most widely accepted among agricultural engineers. If not more than 30% of the soil surface is disturbed then we assumed some type of conservation tillage was practiced by the producer. After consulting with agricultural engineers and extension personnel, we attempted to deduce the type of tillage practice used from the list of equipment reported in the respondent's field operations. Appendix A contains all of the equipment from the machinery list supplied to the respondents that has the capacity to disturb more than 30% of the soil surface. If any of this equipment was reported in the field operations, then we assumed the respondent did not use conservation tillage practices. Again, caution should be observed in interpreting the result because of the arbitrary nature of the decision criteria. The specific design of the equipment, the way in which it was used, and soil and weather conditions are all important factors and are not known.[6]

This survey did not include measurements of soil quality so no land variable is included in the estimation model.

After accounting for the above factors, the regression equation is:

$$(11)\quad DC = b_0 + b_1Acres + b_2Acres^2 + b_3M + b_4T + \epsilon$$

where M = the individual's index of management ability described earlier,

T = a dummy variable which equals 0 if the respondent did not use conservation tillage practices and 1 if he did,

and the other variables as described previously.

The results of estimation of the parameters of (11) are presented in Table 3.

[6]Another criterion that has been used by Rahm and Huffman (1984) is whether or not the producer used a moldboard plow on any of his acreage. Since we had additional information on equipment, we could refine the criterion somewhat, although our regression results are similar under either criterion.

Table 3. Regression Results for the Relationship Between Double Cropped Acres and Farm Size Including Human and Physical Capital Differences

Independent Variable	Parameter Estimate	Standard Error
Intercept	-0.11441	0.03770
Acres	0.35458	0.03339
Acres Squared	-0.04055	0.00986
Management	0.00167	0.00072
Conservation Tillage	0.08955	0.01984

R^2 = 0.39773, N = 502.

The parameter estimates associated with management ability and conservation tillage practices are significant indicating that these factors do affect the choice of double cropped acreage. After accounting for human and physical capital differences, the intercept term is negative and statistically significant which provides some evidence that very small farmers tend not to adopt the new technology. This is consistent with the notion of significant fixed costs of adoption described earlier. The linear term is less than one indicating partial adoption over the middle range of sizes. This is consistent with the credit constraint but may also be consistent with other hypotheses as described earlier. The quadratic term is negative and statistically significant which is consistent with the likely case of high covariance of returns between the old and new technology and decreasing absolute risk aversion on average. The coefficients on the linear and quadratic terms (b_1 and b_2) are similar between the simple JZ model and the more complex one (11). This seems to indicate that the fixed resource constraints are not closely associated with farm size. The negative quadratic term in both models also implies that there may be a limit to the amount of double cropping undertaken in the Southeast under current conditions. As farms grow, the double cropped acreage may not increase proportionally due to price and yield risk factors. This speculation is conditioned upon the present price support policies remaining in place in the future; a scenario which may be unlikely given the current national debate over the cost of farm programs.

The above results are all conditioned on the maintained hypothesis that the true relationship can be adequately approximated by a continuous quadratic function. Other, more flexible specifications may be possible. For example, JZ propose fitting spline functions to estimate the relationship between adoption and size. In the case of this problem, however, the join points would have to be estimated along with the parameters since there is no way to tell how small is "a small farm" and how large is "a large farm".[7]

---

[7]It is possible to use an iterative procedure similar to a nonlinear regression algorithm and minimize the error sum of squares by trying different combinations of join points. A procedure of this type, while elegant, changes the confidence intervals of the hypothesis tests and may provide some misleading results. Determination of the exact distributions of such parameter estimates is beyond the scope of the present work.

Conclusions

Both models discussed in this paper provide some additional insight into the question of production and technology adoption under risk. The empirical tests of both are encouraging. The MC model has shown that southeastern farmers are responding to temporal changes in the riskiness of the new technology of double cropping as well as changes in expected returns. The JZ model has shown that differences in farmers' attitudes toward risk and other farm features related to farm size play a role in cross sectional differences in adoption patterns. Much additional work is suggested by this research. One shortcoming of both models is the assumption that the chosen total soybean acreage is predetermined. Since Welch (1978) has shown that technology may not be scale neutral, this assumption may be too restrictive. The model given here also assumes that conservation tillage equipment purchases are not affected by the level of double cropping. A model to simultaneously explain enterprise size, conservation tillage and double cropping would probably improve the explanation of adoption of double cropping across producers. Also, more complete modeling of the trade-offs involved in the optimal timing of inputs should prove to be very helpful in understanding behavior under risk. To date, little work has been done in this very interesting area. Another important and timely question the has not yet been fully addressed is how changes in farm programs will affect adoption of double cropping and other new production technologies in the agricultural sector. Incorporation of policy variables into the adoption decision may prove both interesting and fruitful.

References

Antle, John M. "Incorporating Risk in Production Analysis." _American Journal of Agricultural Economics_ 65(1983):1099-1106.

Antle, John M. and Stephen Hatchett. Issues in Formulating and Estimating Dynamic Production Models. Paper presented at 6th Conference of the Society of Economic Dynamics and Control, 1984, mimeo, University of California at Davis.

Baron, D.P. "Price Uncertainty, Utility, and Industry Equilibrium in Pure Competition." _International Economic Review_ 3(1970): 989-995.

Danok, Abdulla B., Bruce A. McCarl, and T. Kelley White. "Machinery Selection Modeling: Incorporation of Weather Variability." _American Journal of Agricultural Economics_ 62(1980): 700-708.

Grant, Dwight M. "Theory of the Firm with Joint Price and Quantity Uncertainty and Forward Markets." _American Journal of Agricultural Economics_, Forthcoming.

Holthausen, Duncan M. "Hedging and the Competitive Firm under Price Uncertainty." _American Economic Review_ 69(1979): 989-995.

Just, Richard E. and David Zilberman. "Stochastic Structure, Farm Size, and Technology Adoption in Developing Countries." _Oxford Economic Papers_ 35(1983):307-328.

Just, Richard E. and David Zilberman. "The Role of Micro-Risk Behavior in Aggregate Relationships." pp. 40-73 in _Risk analysis for Agricultural Production Firms: Concepts, Information Requirements and Policy Issues_ Dept. of Agricultural Economics, University of Illinois, Chanpagne-Urbana, Illinois, July, 1984.

Marra, Michele C. _An Examination of Double Cropping Patterns in the Southeast: An Application of the Expected Utility Maximization Approach_, University Microfilms, Ann Arbor, Michigan, 1984.

______________ and Gerald A. Carlson. "Examining Double Cropping with Utility Theory." Paper presented at the AAEA meetings, Cornell University, Ithica, N.Y., August, 1983.

Rahm, Michael R. and Wallace E. Huffman. "The Adoption of Reduced Tillage: The Role of Human Capital and Other Variables." _American Journal of Agricultural Economics_ 66(1984): 405-413.

Sandmo, Agnar. "On the Theory of the Competitive Firm Under Price Uncertainty." _American Economic Review_ 61(1971): 65-73.

Welch, Finis. "The Role of Investments in Human Capital in Agriculture." pp. 259-281 in _Distortions of Agricultural Incentives_ (T.W. Schultz, ed.) Indiana University Press, 1978.

Appendix A. List of Machinery that Generally Disturbs More than Thirty Percent of Soil Surface

1. Regular Moldboard Plow
2. Two-Way Moldboard Plow
3. Disk Plow
4. Plowing Tandem Disk
5. Light Duty Offset Disk
6. Heavy Duty Offset Disk
7. One-Way Disk Tiller
8. Landall, Do-all (disk, shovels, reel, and spikes)