The Role of Farm Size and Resource Constraints in the Choice between Risky Technologies

Michele C. Marra and Gerald A. Carlson

This paper investigates the relationship between farm size and technology adoption by applying a model recently developed by Just and Zilberman to the choices of a sample of southeastern soybean farmers. The adoption of double cropping soybeans with wheat is evaluated with an expanded model which includes availability of specialized equipment and human capital. It is found that the empirical farm size-technology adoption relationship is consistent with risk aversion and a high covariance of returns between the old and new technologies. Accounting for human and physical capital differences across farms improves the power of the hypothesis tests.

Key words: double cropping, farm size, risk, technology adoption.

Public and private research has generated many new technologies for agricultural production over time. As these technologies have been introduced, economists have studied their diffusion and their effect on aggregate production (Griliches) as well as the relationship between producer characteristics and the adoption process (Rahm and Huffman). The purpose of this paper is to investigate one of the more recent models of technology adoption proposed by Just and Zilberman (1983, 1984). One theoretical result of their model is that there may be a limit to the proportion of a farmer’s cropland which he devotes to a new, profitable technology. In particular, smaller farms may not adopt the new technology at all and larger farms may devote less area to the new technology as farm size increases. Understanding the farm size-technology adoption relationship is important for two reasons. First, there is the question of equity of the public research that generates new technologies if, for example, the research tends to benefit only a certain size farm. Second, it is important for policy makers to be able to project the effects of technological advances on the survival of smaller or family size farms.

The Just and Zilberman model is an extension of the original Baron-Sandmo approach to producer behavior under uncertainty. Their approach provides a theoretical basis for study of the role played by firm size, risk attitudes and the joint distribution of returns, credit constraints, and fixed costs of adoption in the choice between two risky technologies.

The emphasis of this paper is to provide an empirical test of some of the theoretical results derived by Just and Zilberman by using two cross-sectional surveys of individual farms. We test the hypotheses on risk attitudes, credit constraints, and fixed costs of adoption stemming from their derivation by examining the technology adoption-farm size relationship. In addition, 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 measures for available human and physical capital to take account of differences in expected profitability across individuals there-

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by to improve specification of the relationship between farm size and technology adoption. The plan of the paper is as follows. In the first section we briefly describe the relatively new technology of double cropping wheat and soybeans. The next section contains a short summary of the theory proposed by Just and Zilberman with particular emphasis on the implied mathematical form of the relationship between farm size and optimal allocation of land between old and new, risky technologies.

The third section describes the data, presents specific hypotheses that link the theory with size-adoption curves, and reports regression results from a simple and a more complete model. Conclusions and implications follow.

**Double Cropping Systems**

Double cropping soybeans and small grain (primarily wheat) constitutes a relatively new, but rather extensively used, production technology in the southeastern United States. A double-cropped system involves planting a small grain crop in the fall and planting late-season soybeans as soon as possible after the small grain harvest, which is in late spring or early summer. Over the last fifteen years in the Southeast, the soybean acreage devoted to double cropping has increased to about 30% of all soybeans and has also moved north into the southern Corn Belt and the Middle Atlantic states (Marra and Carlson).

Double-cropped soybeans are usually planted thirty to fifty days later than full-season soybeans and usually have lower yields and more yield variability. However, a shorter period between wheat harvest and double-dropped soybean planting in general will result in higher and less variable double-cropped soybean yields. The crucial timing of wheat harvest and soybean planting provides incentive for use of conservation tillage practices which require specialized equipment but take less time to accomplish than conventional planting. Also, double cropping requires more management input than is required for full-season soybean production. Although double-cropped soybean yield variability may be higher, double cropping may still provide income-stabilizing potential through diversified product price risk and some reduced total yield variability from staggered planting time and more diversified exposure to drought and pest threats.1 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 variability and increasing expected profits of this cropping system.

**A Theory of Acreage Allocation and the Farm Size–Technology Adoption Relationship**

The Just and Zilberman (1983, 1984) objective function for the farm firm can be written as

$$\max EU[P_1L + \pi_0L_0 + \pi_1L_1 - rK]$$

s.t. $L_0 + L_1 \leq L$,

where $EU$ is the expected utility of end-of-period wealth, $U' > 0$, $U'' < 0$; $P_1L$ is the value of total land to be allocated; $\pi_0L_0$ is the return from production for the portion of the land, $L_0$, allocated to the old technology; $\pi_1L_1$ is the return from production for the portion of the land, $L_1$, allocated to the new technology; and $rK$ is the annualized, fixed costs of adoption.2 Assuming full land utilization ($L_0 + L_1 = L$), an internal solution ($0 < L_1 < L$), and exogenous product and input prices, they derive an approximation of the first-order condition by a first-order Taylor-series expansion of the marginal utility of wealth ($U'$) around mean, end-of-period wealth. This yields the first-order condition with respect to allocation of land to the new technology, $L_1$, in terms of expected returns $[E(\pi_1)$ and $E(\pi_0)]$ and variances ($\text{var}$) and covariances ($\text{cov}$):

$$1/U'(\delta U/\delta L_1) = E(\pi_1) - E(\pi_0) - \Phi(L_1(\text{var}(\pi_0)) + \nu^2\text{var}(\pi_1) - 2\nu\text{cov}(\pi_0, \pi_1)) + L(\nu\text{cov}(\pi_0, \pi_1) - \text{var}(\pi_0)) = 0,$$

where $U'$ is marginal utility, $\Phi$ is the Pratt-Arrow measure of absolute risk aversion ($-U''/U'$), and $\nu$ is a parameter indicating the contribution of the new technology to the overall

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1 Whether double cropping results in more or less variable net returns is an empirical question. Because the Just and Zilberman model can be applied in either case, it is not important to answer the question for our purposes.

2 Fixed costs of adoption are input expenditures involved in changing from one technology to another which are independent of the size of the land area. They would include learning, testing, and adapting the technology to the particular resources of the firm. (See Welch for a discussion.)
riskiness of production \( (\nu = \delta \text{var}(\pi_0 + \pi_1)/\delta L) \). Simplifying and solving (2) for the optimal level of land to allocate to the new technology \( (L_1^*) \) gives:

\[
(3) \quad L_1^* = [E(\pi_0) - E(\pi_1) + \Phi L(\text{var}(\pi_0) - \nu \text{var}(\pi_1))/\Phi(\text{var}(\pi_0) + \nu^2 \text{var}(\pi_1) - 2\nu \text{cov}(\pi_0, \pi_1))].
\]

From (3) it is possible to derive the farm size-intensity of technology adoption relationship under various assumptions about the covariance of returns between the old and new technologies \( \text{cov}(\pi_0, \pi_1) \) and risk aversion.\(^3\) The additional assumptions needed for this derivation are that (a) wealth is adequately measured by expected net income at the end of the current period plus the value of land holdings \( (P, L) \), and (b) that total variability and risk aversion are closely related to the variance of the current period’s net returns. Arrow argues convincingly that a decision maker will likely exhibit increasing relative and decreasing absolute risk aversion. We will, therefore, confine our analysis to these assumptions in what follows, although Just and Zilberman derive the implied farm size-adoption curves for other cases, as well.

The appropriate family of possible farm size-adoption curves, with no fixed costs of adoption and no credit constraints are reproduced from Just and Zilberman in figure 1. The upper curve, OB_B,R, corresponds to the assumption that the covariance of returns between the old and new technologies is low or negative. Thus, at small farm sizes, farmers allocate all their land to the new technology; that is, 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. The next curve in figure 1 is OB_B,R, 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 \( (B_s < B_4) \), 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 particular size \( (B_6) \) is reached, and then it declines. When the covariance of returns between the old and new technologies 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_B,. 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 realism of significant fixed costs and credit constraints is represented in figure 2. The rationale behind the basic relationships is the same as above, but now the curves may be truncated to reflect situations where fixed costs make it uneconomic for small farms to adopt at all or where credit constraints make it impossible to fully adopt. With fixed costs of adoption as represented by OB_B, there is no acreage devoted to the new technology at farm sizes \( (L) \) less than \( B_5 \). As fixed costs increase, this minimum adoption size increases, and it is possible to have no adoption take place \( (OB_B) \). Alternatively (or in combination), a credit constraint which is assumed to be proportional to land area can be represented by line AC, and it could intersect the horizontal axis at any size depending upon the constraint of the land collateral needed for borrowing. The effect of this type of credit limit is to eliminate any adoption choices represented by points above and to the left of the line AC.

**Empirical Evidence on the Farm Size–Double Cropping Relationship**

**The Data and Questions to be Investigated**

The 1978 and 1982 Soybean Cost of Production Surveys [U.S. Department of Agriculture (USDA)] contain information for individual farmers on their farm size and their acreage devoted to double-cropped soybeans. The individual farm observations are a random sample of farms from the southeastern states including Alabama, Arkansas, Georgia, Louisiana, Mississippi, North Carolina, South Carolina, Tennessee, and Virginia. Three measures of farm size (variable \( L \) in the specifications that follow) are available in the surveys: total soybean acreage, total crop-land acreage, and total operated acreage. Since

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\(^3\) This is accomplished by making specific assumptions and taking limits as total acreage \( (L) \) expands. For a complete development of the mathematics, we refer the reader to their original article, Just and Zilberman 1983.
the Just and Zilberman interior solutions require that all acreage is devoted to either the old or the new technology, total soybean acreage per farm is the measure of size chosen here. However, by considering multiproduct jointness, models could be specified to include other product choices and their influence on the amount of acreage devoted to the new technology, although the complexity would increase exponentially since each pair-wise covariance would have to be considered. The total soybean acreage planted per farm in the

Source: Just and Zilberman 1983, 1984

**Figure 1.** The relationship between farm size and adoption intensity with no fixed costs and no credit constraints

**Figure 2.** The relationship between farm size and adoption intensity with fixed costs and credit constraints

**Figure 3.** The relationships between farm size and adoption intensity, 1978 and 1982, for two model specifications
1978 and 1982 surveys has a median of 330 and 348 and ranges from 0 to 14,800 and 0 to 4900, respectively.

Three questions relating to the size-adoption relationship can be investigated with these data. First, is there some size above which the total area per farm devoted to double cropping decreases? This corresponds to the high covariance, decreasing absolute risk aversion case which is represented by the downturn portions of the farm size-adoption curves in figures 1 and 2. Second, where adoption occurs, do farmers fail to fully adopt at small farm sizes? This corresponds to the notion of a moderately limiting credit constraint as represented by the truncation of the curve by line AC in figure 2. Third, do the data indicate that very small farms are not adopting at all? This corresponds to the notion of high fixed adoption costs or a more severely limiting credit constraint. Both would result in a curve with a horizontal intercept at some positive farm size such as $B_2$ in figure 2.

The Simple Model and Hypotheses to Be Tested

As the simplest representation of the possible farm size-adooption curve as shown in figures 1 and 2, we regressed total double-cropped acres on linear and quadratic farm-size variables:

$$L_1 = B_0 + B_1L + B_2L^2 + e.$$  \hspace{1cm} (4)

where $L_1$ is thousands of double-cropped soybean acres per farm, and $L$ is thousands of planted soybean acres per farm.\(^5\)

A test of the first question posed above corresponds to $H_c: B_2 = 0$ versus $H_a: B_2 < 0$. If the null is rejected, the results support the notion of an upper limit on the acreage per farm allocated to the new technology as farm size increases. Recall that this upper limit is predicted by the theory in the plausible case of a high covariance between full-season soybean and double-cropped wheat and soybean returns coupled with decreasing absolute risk aversion. This test is relatively weak, however, because there may be other constraints which cause larger farmers to choose a smaller proportion of double-cropped acreage. In particular, differences in expected profitability from the new technology across producers based on differences in management skill and certain physical capital may be important. The model developed in the next section contains proxies for these additional factors as explanatory variables so that a more powerful test can be performed.

A test of the second question corresponds to $H_c: B_1 = 1$ versus $H_a: B_1 < 1$. If the null is rejected, then there is some supporting evidence of a binding credit constant. But there are other reasons possible, as well, for less than complete adoption ($L_1^* = L$) at smaller farm sizes. For example, smaller farms may tend to try a new technology on a small proportion of acreage to learn about it while avoiding significant potential losses from inexperience (Welch).

A test of the third question corresponds to $H_c: B_0 = 0$ versus $H_a: B_0 < 0$. If the null is rejected in this test, then the results support the existence of high fixed adoption costs or a severely limiting credit constraint. The two reasons cannot be distinguished without data to locate either the credit constraint or fixed adoption costs, so the test is for the existence of one or both.

The OLS regression results for each of the survey years are given in table 1. The model explains very little of the total variation in double-cropped acreage in 1978; however, the parameter estimates are all significant at the 1% level.\(^6\) The largest farm sampled in 1978 was an outlier (greater than three standard deviations from the mean), so the model was reestimated omitting that farm. The results are qualitatively similar to those reported in table 1 with the largest farm included. The linear term ($B_1$) is quite small, indicating little increase in double-cropped acres with increases in farm size. The regression results also indicate that double-cropped acres per farm reach a maximum of about 150 acres at approximately 6,200 total soybean acres and then decline. Note that the maximum double-cropped acreage only occurs for farms far larger than

\[^4\] It is possible to have full adoption on small farms and some fixed adoption costs if fixed costs are small relative to the expected gain in profit.

\[^5\] The quadratic functional form is used as a simple, concave function of the farm size-adoption relationship which Just and Zilberman derive from (3).

\[^6\] A low $R^2$ value and relatively high t statistics are common in cross-sectional studies involving many individual economic units. The explanation is that, although the included explanatory variables are the relevant ones, their influence on the dependent variable is weak relative to the random disturbance (Kmenta).
the median size of 330 acres. Also, the total soybean acreage devoted to the new technology in the Southeast in 1978 was slightly less than 15%. However, the general shape of the farm size-adoption relationship is concave, which is consistent with the most plausible risk aversion assumption (decreasing absolute risk aversion) in the Just and Zilberman model.

By 1982, more than 30% of soybean acreage was being double cropped in the Southeast. The regression for 1982 has much more explanatory power ($R^2 = .37$) and the curvature of the relationship is much greater than in 1978 (see fig. 3). The intercept term ($B_0$) is not statistically less than zero, which is consistent with the hypothesis of no fixed adoption costs. The linear term ($B_1$) is statistically less than one at the .99 level, indicating less than full adoption. This may be caused by credit constraints, risk factors, or scarce capital available to accomplish timely planting on all of the acreage. The quadratic term ($B_2$) is statistically less than zero indicating that, on average, farmers larger than about 430 acres of soybeans reduce acreage double cropped as farm size increases. If we assume credit constraints are less binding for large landholders (although we have no specific data substantiating this for this set of farmers), the proportional decrease in double-cropped acres at large farm sizes probably reflects responses to the overall riskiness of the new technology and conforms to the Just and Zilberman case of high covariance and decreasing absolute risk aversion. Again, there are other explanations for each of the findings, and, clearly, this simple model suffers from missing variables to which we now turn.

The Model with Proxies for Other Resource Constraints

In examining differences in adoption of a risky, new enterprise, Just and Zilberman (1984) explicitly mention between-farmer differences in risk aversion, available credit, and fixed adoption costs. In their model each of these characteristics is directly linked to the amount of cropland allocated to the old and new technologies. This gives rise to the possible regions of adoption by farm size as illustrated in figure 2. 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 (3), $E(\pi_i) - E(\pi_o)$ represents the gain in expected returns from adoption of the new technology on a particular farm. These expected profits will be a function of expected output and input prices, which are assumed to be relatively constant across individuals at a point in time, and of the individual's ability to coordinate the new technology with other inputs that may be stochastic, such as weather, pests, and machine breakdown. 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 ceteris paribus. 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 (3) is also frequently affected by the endowment of physical capital equipment of the decision maker. In dynamic production models the demand for equipment, chemicals, and labor can change dramatically over the production cycle (Antle). Double cropping is an intensification of crop production which involves increasing the use of the land and climatic resources per year. This can more than proportionally increase the demand for labor and equipment in particular time periods. Current amounts and types of equipment may constrain adoption choices. Farmers may not move quickly 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 noninstantaneous adjustment may not be closely related to the availability of credit as modeled by Just and Zilberman. In the double-cropping adoption case considered here, type of equipment (i.e., equipment more easily adaptable to conservation tillage practices) may be more important than the amount of existing 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) and dynamic production functions (Antle and Hatchett) for classes of "typical" farms are two different approaches used to find 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." Although we acknowledge their importance, these land characteristics are not measured in the USDA Cost of Production Survey, so they cannot be included in our specification.

Availability of appropriate management skill, 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, the covariance of returns between enterprises \( \text{cov}(\pi_0, \pi_1) \). 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 generally will increase average yields and decrease yield variance.

To account for cross-sectional differences in management ability, we developed a management index from the 1982 survey data\(^7\). There are four classes of survey responses that may contain information related to management ability: crop yield, use of technical services, futures market participation, and the use of narrow row spacing to provide quicker canopy cover to control weeds. Table 2 contains the scoring for each of the four factors used in construction of the index for each producer.

<table>
<thead>
<tr>
<th>Independent Variables</th>
<th>1978</th>
<th>1982</th>
<th>Hypothesis Tested</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>.02475*</td>
<td>.00998</td>
<td>( H_0: = 0; H_1: &lt; 0 )</td>
</tr>
<tr>
<td></td>
<td>(.00720)</td>
<td>(.01614)</td>
<td></td>
</tr>
<tr>
<td>Acres ((L))</td>
<td>.02531*</td>
<td>.35952*</td>
<td>( H_0: = 1; H_1: &lt; 1 )</td>
</tr>
<tr>
<td></td>
<td>(.00905)</td>
<td>(.03363)</td>
<td></td>
</tr>
<tr>
<td>Acres(^2) ((L^2))</td>
<td>-.00218*</td>
<td>-.04151*</td>
<td>( H_0: = 0; H_1: &lt; 0 )</td>
</tr>
<tr>
<td></td>
<td>(.00086)</td>
<td>(.01000)</td>
<td></td>
</tr>
</tbody>
</table>

Note: Asterisk indicates statistically significant at the .99 level.

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 is only a proxy for a multifaceted, unobservable variable. The dilemma of the use of proxy variables is that, although inclusion of a proxy variable will lead to more asymptotically consistent estimates than those from a model which omits the variable altogether, inclusion of the proxy can lead to parameter estimates with higher variance compared to the model without the proxy (Judge et al.). Thus, if a particular parameter estimate is found not to be statistically different from zero, it may either be solely because of the use of the proxy or it may be because the variable has little explanatory power. Since the parameter estimates of interest are all found to be statistically significant in models that include the proxy, use of the proxy is preferable both on theoretical and econometric grounds.

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 a function not only of management skill but of available capital equipment as well. 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.

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. If any equipment was report-

\(^7\) Not all of the management and equipment information was available in the 1978 survey, so the model accounting for human and physical capital differences was tested with the 1982 data only.
Table 2. Factor Scoring for the Management Index

<table>
<thead>
<tr>
<th>Observed Activity</th>
<th>Amount Added to Index Score (S)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Yield (adjusted for irrigation)</td>
<td>One point per bushel yield</td>
</tr>
<tr>
<td>2. Technical services (including soil tests,</td>
<td>Ten points if any reported</td>
</tr>
<tr>
<td>lab tests, tissue analysis, or insect or</td>
<td></td>
</tr>
<tr>
<td>disease scouting)</td>
<td></td>
</tr>
<tr>
<td>3. Futures market participation</td>
<td>Ten points if reported</td>
</tr>
<tr>
<td>4. Narrow row spacing</td>
<td>Fifty points minus row spacing in inches</td>
</tr>
</tbody>
</table>

Index \( M = \sum_{i=1}^{4} S_i \)

ded to be used in the field operations that would have disturbed more than 30% of the soil surface, then we assumed the respondent did not use conservation tillage practices. The specific design of the equipment, the way in which it was used, and soil and weather conditions are all important factors but are not known. The known factors are used to determine an indicator tillage variable, \( T \).

After including the above factors, the farm size-technology adoption regression equation becomes

\[
L_i = b_0 + b_1L + b_2L^2 + b_3M + b_4T + \epsilon,
\]

where \( M \) is the individual's index of management ability described in table 2, and \( T \) is a dummy variable which equals 0 if the farmer did not use conservation tillage practices and 1 if he did, and the other variables are as described previously.

The results of estimation of the parameters of \( (5) \) are presented in table 3. The parameter estimates associated with management ability and conservation tillage practices \((M)\) and \( T \) are statistically significant, indicating that these factors are associated with the allocation of land to a new technology. The coefficient on the quadratic term \((b_2)\) is still negative and statistically significant, which is consistent with the likelihood of high covariance of returns between the old and new technologies and decreasing absolute risk aversion for the average farmer. Simple correlation tests showed no systematic relationship between the size variable and either the management index \((M)\) or the physical capital proxy \((T)\). These tests and a finding of nonsignificant linear interaction terms between fixed resource constraints and enterprise size in regressions like \((5)\) indicate that such interactions are not contributing to the observed downturn of the curves. Given a higher level of total explanatory power \( (R^2) \) and no significant interaction between either the management index or the equipment proxy and farm size, the test of \( b_2 < 0 \) should be a more powerful test of the role of the joint distribution of returns and risk attitudes in the relationship between farm size and technology adoption than the test performed with the simple model.

The linear term \((b_1)\) is statistically less than one (at the .99 level), indicating partial adoption over the middle range of sizes. This is consistent with the credit constraint, but it is also consistent with other hypotheses as described earlier. After accounting for human and physical capital differences, the intercept term \((b_0)\) is negative and statistically significant (implying a positive horizontal intercept); which shows that for this sample of farmers, the very small farmers tend not to adopt the new technology. This supports the notion of relatively large fixed costs of adoption, although the inability to distinguish this explanation from a binding credit constraint remains. Recall that

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Table 3. 1982 Regression Results for Farm Size-Double Cropping Relationship Accounting for Human and Physical Capital

<table>
<thead>
<tr>
<th>Independent Variable</th>
<th>Parameter Estimate (Standard Error)</th>
<th>Hypothesis Tested</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>-.11441* (.03770)</td>
<td>( H_0: = 0; H_1: &lt; 0 )</td>
</tr>
<tr>
<td>Acres ((L))</td>
<td>.35458* (.03339)</td>
<td>( H_0: = 1; H_1: &lt; 1 )</td>
</tr>
<tr>
<td>Acres(^2) ((L^2))</td>
<td>-.04055* (.00986)</td>
<td>( H_0: = 0; H_1: &lt; 0 )</td>
</tr>
<tr>
<td>Management Index ((M))</td>
<td>.00167* (.00072)</td>
<td>( H_0: = 0; H_1: \neq 0 )</td>
</tr>
<tr>
<td>Conservation Tillage Dummy ((T))</td>
<td>.08955* (.01984)</td>
<td>( H_0: = 0; H_1: \neq 0 )</td>
</tr>
</tbody>
</table>

Note: Asterisk indicates statistically significant at the .99 level.
the exclusion of the management and conservation tillage variables in the simple model shown in table 1 implied no fixed cost of adoption.

The magnitude of the coefficients on the linear and quadratic terms \((b, \text{ and } b_2)\) for 1982 are similar between the simple model (table 1) and the model accounting for human and physical capital differences (table 3). Even after accounting for possible differences in expected profitability and possible interactions between size and fixed endowments of capital, there is a significant decrease in double-cropped acreage at relatively large farm sizes. Figure 3 shows the farm size-adoption curves estimated from both surveys and from both models for 1982. Accounting for differences in management and available physical capital results in an almost vertical downward shift of the 1982 curve.

**Conclusions and Implications**

The Just and Zilberman model provides some theoretical insight into the questions of production and technology adoption under risk and the relationship between farm size and technology adoption. This work represents a first step toward empirical implementation of the Just and Zilberman approach. Although the data used lack some information necessary for direct estimation of the Just and Zilberman model, the empirical tests of the features of the farm size-adoption relationship are encouraging. The empirical evidence does not reject the hypothesis that differences in farmers’ attitudes toward risk coupled with the covariance of enterprise returns play a role in cross-sectional differences in intensity of adoption. Although the evidence supports the theory, possible alternate explanations result in relatively low power statistical tests for most of the hypotheses tested. Statistical inferences are improved by including proxies for additional resource constraints in a second model specification. The most powerful test in this work supports the interesting theoretical result that the combined effects of risk attitudes and the covariance of returns are likely to be limiting factors in the size-adoption relationship, although the separate influence of each cannot be determined. More tests of the model with improved measurements on credit constraints, fixed adoption costs and/or measurements of risk aversion, and the covariance of returns seems warranted.

The negative quadratic term in all models implies that there may be a limit to the amount of double cropping per farm undertaken in the Southeast under current conditions. As farms grow, the double-cropped acreage may not increase proportionally because of price and yield risk factors and farmers’ risk attitudes. The total level of double cropping in the region will depend upon loan rates for wheat and other factors affecting the relative mean and variability of profits (Marra and Carlson).

The results above are all conditioned on the maintained hypothesis that the true relationship can be approximated adequately by a continuous quadratic function. Other, more flexible specifications may be possible. For example, Just and Zilberman 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.”

Much additional work is suggested by this research. One shortcoming of the model is the assumption that farm size is predetermined. Since Welch has argued that technology itself 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 in a given year. A model to explain simultaneously enterprise size, conservation tillage, and double cropping probably would 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 which has not yet been fully addressed is how changes in farm program specifications of loan rates and acreage reduction qualifications for wheat program payments will affect adoption of double crop-

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*It may be 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 a subject for future work.*
ping and other new production technologies in the agricultural sector. Incorporation of policy variables, which can influence the distribution of prices and, perhaps, yields, into the land allocation decision may prove both interesting and fruitful.

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References


