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Review

Revisiting the synergy between no-till and roundup ready soybean technology

Edwin Clifford Mensah* and Ramin Cooper Maysami

Department of Economics, Finance and Decision Sciences, University of North Carolina, Pembroke, One University Drive, P. O. Box 1510 Pembroke, NC 28372, USA.

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The objective of this study has been to identify the factors that influence the concurrent adoption of no-till technology and roundup ready (RR) soybean technology. Using data from a survey of 610 soybean growers in the United States and a two-equation probit model, our results reveal that ignoring the simultaneous nature of the decision to use no-till and RR soybean technologies could lead to the mis-specification of the model and hence our ability to reveal and understand the factors that influence the concomitant adoption of these technologies will be obscured by the inconsistent estimates that will result.

Key words: Probit, soybean, concomitant, technology, adoption.

INTRODUCTION

The synergy between the use of roundup ready (RR) soybeans and no-till technology has greatly received the attention of researchers in recent years. As a soil conservation practice, no-till has been found to be both economically and environmentally beneficial. Some of the benefits of no-till farming include: increased residue, increased soil organic matter, reduced erosion potential, increased water holding capacity, improved soil tilt, reduced bulk density, increased earthworm populations, improved soil structure, elevated infiltration rates, and reduced field time. Proponents of no-till have reported higher yields and profits associated with farms where no-till is practiced even though a number of such farms initially reported lower profits (Sorrenson et al., 1997).

The initial lack of adequate information about the new innovation could possibly offer an explanation for this scenario since new technologies tend to require new management skills which farmers might acquire with time through "learning by doing." This, in addition to the farmer's initial investment in new equipment and seed input, may introduce some adjustment costs which may contribute to the lower initial profitability.

The farmer's decision to adopt no-till is further complicated when faced with the concurrent decision to adopt RR soybean, a new genetically modified crop that has been engineered to be resistant to glyphosate. Proponents of GMO's (genetically modified organisms) claim that the adoption of RR soybean varieties lowers adopters' costs by (a) allowing post emergence use of the inexpensive herbicide glyphosate, (b) saving on management costs because of its simple use, (c) reducing risk by widening the time window for post emergence spraying, and (d) the additional advantage of coupling RR soybean with no-till. Since its introduction, RR soybeans weed control system steadily gained market share, comprising about 60% of US plantings in the period 2000 - 2002. The question is: why do farmers adopt RR soybeans? Furthermore, does a farmer's adoption of RR soybeans result in the adoption of no-till as well?

The goals of this study are; first to verify whether the availability of RR soybeans encouraged farmers to adopt no-till practices for soybean production in 2002. Secondly, what factors influenced the concurrent adoption of no-till and RR soybeans. An overview of the development of the literature on technology adoption is also presented.

*Corresponding author. E-mail: edwin.mensah@uncp.edu. Tel: (910) 522-5713. Fax: 910.521.6750.

LITERATURE REVIEW

Researchers since Grilliches (1957) have employed economic decision models to derive theoretical results predicting the qualitative effect of factors (such as risk attitudes, farm size, liquidity constraints etc.) on the decision to adopt a new technology. However, most of the past studies of technology adoption have focused on either a single new technology (e.g. adoption of an improved seed variety or irrigation system as in Caswell and Zilberman, 1985) or on a set of technologies considered as a single unit (e.g. integrated pest management notably, Harper et al., 1990; McNamara, Wetzstein and Douce, 1991).

Byerlee and de Polanco (1986) argue in their paper that research and extension programs should take cognizance of the fact that farmers adopt improved techn0ological components in a stepwise manner. They use on- farm experimental survey data to provide evidence that farmers in a developing country such as Mexico adopted improved varieties, fertilizer and herbicide for barley in a stepwise process, in spite of the significant interaction between the components of the technological package. Hypothesizing that the time of initiation of adoption and the rate of adoption depend on profitability, riskiness, divisibility, complexity, availability and the interaction between components of an innovation, they argue that their results, like those of Rogers (1983), reveal that profitability and riskiness affect the adoption of each innovation most.

It has also been argued that farm size has an effect on the adoption of agricultural technologies (Feder 1980); Marra and Carlson (1987) provide evidence in support of this hypothesis. Marra and Carlson (1987) used farm-level data on the adoption of double-cropped wheat/ soybeans to empirically provide evidence to support the idea that the combined effects of decreasing absolute risk aversion and covariance of returns are likely to be limiting factors in the farm size- adoption relationship. Feder (1980), on the other hand, considered the effect of farm size on land allocation. The paper assumes risk aversion and utilizes a constant-returns-to-scale version of the stochastic production function $y=f(x)+g(x)$ to show that the share of land allocated for the cultivation of a modern crop as opposed to a traditional crop depends on the relationship between relative risk aversion and income. It was revealed that fertilizer use per acre (for the new crop) was independent of the degree of risk aversion, uncertainty and farm size when credit constraints are non-binding. In another study, Just and Zilberman (1983) extended the model in Feder (1980) to consider all inputs using the same production function. They argued that the intensity of use of modern inputs depends on whether it is risk reducing or risk increasing and on whether relative risk aversion is increasing or decreasing. They indicated that the correlation of output under alternative technologies played an important role in determining adoption rates. Feder (1982) presents a model that analyzes farm level decisions made regarding the choice of interrelated innovations. The innovations here were distinguished by their returns to scale and were assumed be adopted individually. The paper demonstrates that under conditions of uncertainty or binding credit constraints, the concept of complementarity of technologies might be misleading. It was emphasized that in examining the interrelationship between the different components of an innovation one cannot ignore endogenous constraints such as risk aversion and credit scarcity in order to establish that complementarity exists.

With regard to human capital, Wozniak (1984) developed a model of the decision to adopt interrelated technologies emphasizing the role of innovative ability as a measure of the economic incentive to be informed about innovations. The author hypothesizes that education; experience and the availability of information are measurable dimensions of innovative ability. By fitting univariate, conditional and joint logistic models it was shown that innovative ability contributes significantly to explaining the adoption of new technologies but does not explain its diffusion. It was also concluded from the results that the diffusion of previously available innovations depends on the introduction and adoption of interrelated current innovations. Kling et al. (2001) argue that "even when conservation practices can raise a farmer's expected profit, he might be reluctant to adopt either because he is risk averse and (or) because adoption involves sunk investment and real options are present. If so, the farmer adopts only if the additional profit of a conservation practice overcomes a premium." The paper contributes to the adoption literature in two ways. First, it avails a new modeling strategy that allows for full recovery of the structural coefficients and the direct computation of premiums needed for adoption of a farming practice and also calculates the amount of subsidy that is needed to achieve any given level of conservation tillage adoption. Economists have also used Bayesian models to explain aspects of technology adoption (O'mara, 1983; Jensen, 1982; Hiebert, 1974). However in explaining the sequential adoption of agricultural innovations, Dorfman (1996) and Leathers and Smale (1991) are of special interest as far as the adoption of multiple technologies is concerned. Leathers and Smale (1991) also presented a behavioral model for the sequential adoption of components of a technology as a consequence of learning by adopting farmers. They demonstrated that in order to learn more about the entire technological package, a risk neutral farmer who is unconstrained in his expenditures might adopt a component of an innovation instead of the whole package in spite of the profitability associated with the adoption of the whole package. Dorfman (1996) demonstrated how Gibbs sampling can be used to reduce the computational difficulty associated with applying the multinomial probit model to multivariate decision models. The author uses a multinomial probit model to model the adoption decisions of farmers facing multiple technologies, which he posits could be adopted in different combinations. Subsequently, he examines the farmer's adoption of improved irrigation and integrated pest management technologies as four possible relative choice decisions: adoption of neither, integrated pest management practice only, improved irrigation only, or both. The study proceeded with estimation in the Bayesian framework employing Gibbs sampling to estimate a multinomial probit model. The results of the research show that the adoption decisions are significantly influenced by off-farm labor supply. Wu and Babcock (1998) expanded the work on the adoption of single technologies to the simultaneous estimation of the choice of soil nitrogen testing, rotation and conservation tillage for corn farmers in the Central Nebraska Basins area. To estimate the joint adoption decisions of the conservation practices, they used a polychotomous-choice selectivity model to control for self-selection bias. They reported that the adoption of conservation tillage was significantly affected by the physical characteristics of the site and farmer education.

In their article, Marra et al. (2001) conducted a study on the various sources of information and the quality of information regarding the profitability of biotech cotton (Bt cotton) and how relevant such information is to farmers in the adoption process. They develop an adoption decision model that incorporates the role of information quality as well as the effect of the depreciation in current technology. The authors identified factors that determine the early adoption of Bt cotton technology and further found evidence supporting the fact that all three factors (the source, quality of information and depreciation of technology) are significant determinants of the adoption of Bt cotton. Khanna (2001) analyzed farmers' sequential decision to adopt two site-specific technologies (soil testing and variable rate technology) and the impact of their adoption on nitrogen productivity. The paper discusses the factors that motivate the adoption of the two technologies and their effect on the productivity of input. She found that in four Midwestern states, the location of the farm was important in the decision to adopt soil testing; however human capital, farm size and innovativeness of farmers had a significant impact on the adoption of variable rate technology. The author uses a double selectivity model was to correct for sample selection bias, and found significant gains in nitrogen productivity for farms whose soil qualities were above average when the two technologies were adopted.

Kalaitzandonakes and Suntornpithug (2003) observed that "previous adoption studies have considered the uptake of agro biotechnologies one at a time, that is, separately from the adoption of other related agronomic practices." The authors argue that this approach is likely to be narrow and might limit one's understanding of the factors that drive the adoption of such technologies and what their impacts might be. In their paper, it is argued that producers' behavior is characterized by multiple simultaneous and interdependent decisions on the adoption of three different cotton biotechnologies (Bollgard Cotton, RR Cotton and Stacked Bollgard/RR Cotton) with reduced tillage and irrigation technologies in US cotton production. The model used also allowed for partial adoption of one or more of these technologies as a way of optimizing their use through learning by doing. The adoption equations were estimated using Generalized Method of Moments (GMM), three stage least squares (3SLS) and full information maximum likelihood (FIML) procedures. These models produced similar results. It was concluded that reduced tillage practices encouraged the adoption of RR and Stacked Bollgard/RR Cotton. Their results confirmed the arguments made in a previous study by Marra et al. (2001) that depreciation and diminished effectiveness of conventional pest control practices is the most significant factor contributing to the rapid adoption and diffusion of Bollgard (BG) technologies.

The paper by Piggott and Marra (2008) is one of the few that incorporates non-pecuniary factors in the analysis of farm technology adoption. The utility maximization model developed considers the impact of non-pecuniary factors on the derived demand for a new biotech crop and shows that there is an increase in the derived demand for the new technology with demand becoming more inelastic to price increases as adopters find more value in the technology and become more accustomed to it.

In spite of the sizeable amount of work done on the adoption of agricultural technologies, the concurrent adoption of two or more technologies when non-pecuniary factors are present has not been fully exhausted--which is the motivation for the current study. Coupling the adoption of no-till technology with the adoption of the RR soybean varieties combines the adoption of two technological concepts where on one hand, a new mechanical technology that might modify the crop's interaction with the soil is used and, on the other, the utilization of a herbicide tolerant seed which is resistant to the broad- spectrum herbicide, RR with glyphosate. The question is asked; whether the availability of RR soybean varieties encourages farmers to adopt no-till farming technology for its cultivation and/or vice versa. It is our notion that the availability of RR soybeans is likely to affect the farmer's decision to adopt no-till and the adoption of no-till may also impact the decision to use RR soybean seeds. This suggests that the two decisions are endogenous to each other and may be made simultaneously.

Our analysis follows the model proposed by Fernandez-Cornejo and McBride (2002) however; unlike Fernandez-

Table 1. Farm acreage owned, or cultivated with roundup ready soybeans.

Farm acres in 2002	1153.56
Farm acres rented	619.53
Farm acres owned	534.03
Total crop acres in 2002	993.74
Total soybean acres in 2002	476.15
Percent soybean acres in 2002	48
Percent soybean acres used for roundup ready in 2002	72
Percentage of Southern growers who own 100% of land	19
Percentage of Southern growers who own 50% of land	11
Percentage of growers in Midwest who own 100% land	27
Percentage of growers in Midwest who own 50% land	4.5

Cornejo and McBride (2002) we will include some non-pecuniary factors that affect the simultaneous adoption of agricultural technologies. As discussed in Marra et al. (2004), the role of non-pecuniary factors (such as the value of operator and worker safety, environmental benefits and convenience characteristics of RR soybeans) in the adoption of RR technology and reduced tillage (including no- till) is key to explaining the concomitant nature of this adoption process. To model the simultaneous adoption decision, we construct a simultaneous two-equation econometric model, where the equations are binary given that the farmer may adopt the technology or not. We then test the hypothesis of simultaneity between the two decisions and also attempt to identify the factors that account for the simultaneous adoption of the technologies.

DATA

A survey data obtained from Doane Marketing Research, a firm that specializes in agricultural research, was used for this study. The survey covered farmers in the major soybean growing areas of the United States. In all, 610 respondents completed the survey; 525 in the Midwest and 85 respondents in the South. These were farmers who planted at least 250 acres of soybeans in the year 2002. Table 1 above, reports information on the acreage of land owned or leased and the percentage of acres used for Roundup Ready in the Midwest and the Southern soybean growers. It is shown in Table 1 that of the farms surveyed, the average farm size used for crops was about 993 acres and a mean of 1,154 acres in total farm land operated. Of the total land, approximately 46% is owned and about 48% of all crop acres are used for soybeans. Approximately 19% of Southern soybean growers owned 100% of the land used, about 11% of respondents in this region owned only 50% of land while others owned different proportions and were tenants on other plots they used. In the Midwest, 27% of farmers own their land and only 4.5% owned 50% of the land used for RR soybean. It is also indicated that about 72% of soybean acres was planted to RR soybean varieties but only 59% was reported in 2001. The survey revealed that about 60.5% of the respondents adopted RR soybean technology in 2002. Of this 57.9% cultivated only RR soybean and approximately 2% planted both RR soybean and non-RR varieties. The data was also analyzed for information regarding soybean growers in different regions. The distribution of farmers in the two regions is shown in Tables 2a and b.

Information collected indicated that soybean growers who responded were basically concentrated in the Southern states (that is, Alabama, Arkansas, Kentucky, Louisiana, Mississippi, North Carolina, South Carolina and Tennessee) and the Midwest states (including: Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, South Dakota, and Wisconsin). More responses were obtained from the Midwest region, with 525 respondents and only 85 farms from the southern region. In the South, the concentration of farms was higher in Arkansas (26 farms), followed by North Carolina, Kentucky and Mississippi each with 12 farms reported. Of those who planted 100% RR soybean, the results were quite comparable in both regions, 59% of respondents in the Southern states fully adopted RR soybean as opposed to approximately 60% in the Midwest. With respect to the farmer's intended acreage for 2003, it was realized that respondents in the Midwest plan to use at least 61% of land for Roundup Ready and southern soybean growers revealed an intended acreage of more than 59% percent of land. This shows that there was not a significant change in acreage comparing the roundup soybean acreage in 2002 to their intended acreages in 2003. While there was an increase of about 3.7% in acreage of land allocated for the planting of both RR soybean and non-RR varieties. The survey also showed that farmers intended to utilize about 73% of their soybean acreages for the cultivation of RR only in 2003.

Regarding the benefits of planting RR soybean, Table 3

Table 2a. The distribution of the number of farms surveyed in the South.

State	Alabama	Arkansas	Kentucky	Louisiana	Mississippi	North Carolina	South Carolina	Tennessee
No. of Farms	2	26	12	7	12	12	4	10

Table 2b. The Distribution of the number of farms surveyed in the Midwest.

State	Iowa	Illinois	Indiana	Kansas	Michigan	Minnesota	Missouri	Nebraska	Ohio	South Dakota	Wisconsin
No. of Farms (525)	95	93	50	27	19	62	42	44	41	39	13

Table 3. Percentage of farmers reporting some benefit from RR soybeans.

Type of benefit	Human safety	Environmental benefits	Convenience benefits	Equipment savings	Labor savings
Number of farms responding	458	449	437	528	429
% Reporting some benefits	57	62	56	49	60

Table 4. Farmer's reasons for not planting total acres of land with roundup ready soybean.

Reasons	Percentage of farmers (n-241) %
High cost of seed	19
Premium paid to grow traditional soybeans	12
Higher yields with traditional soybean	11
Too much market uncertainty	9
Lack of market acceptance	7
Preference for the use of saved seeds	5
Unsatisfactory technology fees	5
Other reasons	32

reveals that more than half of the number of RR soybean growers (about 57%) reported some human safety benefits, 62% reported environmental benefits, and 56% some convenience benefits from using RR soybean varieties. About 1% of the respondents placed a $20 value on the safety of RR soybean to humans and the environment. In the Midwest at least 1% of growers placed a value of $40 on the safety of RR soybean to the farm worker or operator. In spite of the reported benefits of planting RR soybeans, some farmers stated reasons why they did not grow 100% RR soybean. Table 4 presents a summary of the results. Of the responses from 241 farmers who responded to this question, 19% stated that, the high seed cost of RR soybean was a reason for not growing 100% RR soybean. About 12% of all farmers also argued that they are being paid a premium to plant the traditional varieties. Some also alluded to the fact that they were getting relatively higher yields from the traditional soybean varieties. These formed about 11% of the respondents. Finally, about 9% of the farmers revealed that market uncertainties and restrictions on the RR soybean variety diminished the per acre value of growing RR soybean. In fact, roughly 31% of farmers in the South argued that market uncertainties and seed restrictions can possibly decrease the per acre value of planting RR by at least $10. The same conclusion was made by 26% of the farmers in the Midwest states. About 32% of the respondents cited 'other' (an unidentified reason) as their justification for not planting 100% RR soybean.

With respect to the amount of time spent on crop production, responses from the survey suggest that while farmers who planted non- RR soybean varieties spent about 80% of their time on crop production, RR soybean adopters saved about 3% less of the time spent on crop production by non-adopters (that is, RR soybean adopters spent on average 77% of their time on crop

Table 5. Percentage of all soybean acres used for roundup ready soybean and the type of tillage technology.

Type of tillage system	Percent RR soybean acres (2001)	Percent RR soybean acres (2002)
Conventional Till	24	23.5
Reduced Till	34	35
No-till	41.6	41.4

Table 6. Percentage of all soybean acres used for non-RR soybean and the type of tillage technology.

Type of tillage system	Percent of Non-RR soybean acres (2001)	Percent of Non-RR soybean acres (2002)
Conventional Till	36.9	36.9
Reduced Till	34	30.9
No-till	29	32

production). In per acre dollar values, RR soybean adopters indicated that they saved about 19 min 0.15 s per acre (for a stated value of $5.6/acre of time savings); equipment savings was also valued at $4.3/acre. On the issue of the tillage practices used by farmers, researchers including Marra et al. (2004) agree that tillage trips decreases as the percentage of acres in no-till increases. Moreover, the value of time saved in tillage activities increases as farmers shift from traditional soybean to RR soybean varieties. Growers surveyed indicated that there are about 24% fewer tillage passes using RR soybean than when planting traditional soybeans. In a recent study Marra et al. (2004) calculated that the average number of tillage passes per season for non-RR soybeans was 1.73 per acre, while that for RR soybean was 1.39 per acre for the 2001/2002 seasons.

Information on the type of tillage practice used for Roundup and non-RR soybean is reported in Tables 5 and 6 respectively.

Generally, the survey revealed that in 2001 about 41% of soybean acres was used for RR soybean under no-till, which is quite comparable to 41.40% in 2002. On the other hand, the cultivation of RR soybean using reduced till and conventional till were about 34 and 24% in 2001, with 35 and 24% in 2002 respectively. On the acres used for non-RR soybean, growers reported using approximately 29% (in 2001) and 32% (in 2002) of soybean acres on no-till, while 34% (comparable to the Roundup Ready acreage under reduced till in 2001) was used on reduced till in 2001. However, the percentage of soybean acres used for non- RR soybean and reduced till was slightly lower in 2002 (30.9%), although the percentage of non-RR soybean acres under conventional till remained fairly constant at 36.90% during the 2001 and 2002 cropping seasons as seen in Tables 5 and 6. Of the respondents answering the question regarding the order in which the seed type and tillage practice were chosen, about 65% of full adopters indicated that they made the seed type decision first or simultaneously with the tillage type decision. The remaining 35% either chose the tillage practice first or simultaneously with the seed technology. Interestingly 66% of non-adopters also reported that they made the seed type decision before or at the same time as the tillage decision. Thus, there is no substantial difference between adopters and non-adopters in the 'tillage type-seed type' choice behavior (Marra et al., 2004).

Table 7 shows the summary of survey in responses to the question of the costs involved in growing RR soybeans and non-RR soybean with respect to the procurement of planting seeds, herbicide products and application costs as well as the harvesting costs for the respective seed technologies. Estimates of the costs reveal that on average, the difference between non-RR soybean cost and RR soybean cost is approximately -$9.02/acre which is expected since farmers pay relatively more for RR soybean seeds. However, there is not much difference in harvesting cost comparing the two technologies. Researchers have found some evidence that herbicide product costs are relatively lower on RR soybean acres than that of traditional soybeans. For example, Carpenter and Gianessi (2001) found lower weed control costs associated with RR soybeans compared to the traditional soybean varieties. The value of the estimated difference in herbicide product cost is approximately $8.68 per acre. Furthermore, the herbicide application cost is found to be about $1.40 per acre lower on RR soybean acres than on the traditional varieties. In Table 8, we present the demographic characteristics of the farmers in the survey. The average age of the respondents in the survey is 56 and the number of years of experience was about 33 years. The average number of years of experience is about 13 years. On average, growers spent about 90% of their time on farming activities as opposed to off-farm activities. However, 78% of their farming time was spent on crop production

Table 7. Average cost of farm activity / material cost by seed technology type.

Farm activity/ Material	Cost ($/acre) using	
	RR soybeans	Non-RR soybeans
Seed	24.12	14.98
Harvesting	19.26	18.99
Herbicide Material	15.36	23.94
Herbicide Application	6.01	7.02

Table 8. Demographic characteristics of survey respondents.

Variable description	Mean value of responses
Year born	1946
Years of formal education	13
Years of farming experience	33
Percentage of time spent in farming	90.13
Percentage of time on crops	78.5

activities.

VARIABLE DESCRIPTION

In the current study, the factors hypothesized to influence the adoption of RR soybeans include farm and farmer characteristics such as total acreage/farm size, land tenure, experience and farmer attitudes towards risk etc. Other variables shown in Table 9 include time savings and costs as technology Rogers (1993). In the current study, the variable FARMSIZE (the total crop acres used in 2002) is used to capture the effect of farm size on the adoption of RR soybeans. We propose that it would have a positive impact on the adoption of the technology. The acreage of land used for no-till technology (NT_RT_P02) is included in the study to allow us to verify whether the adoption of RR soybeans is influenced by the farmer’s allocation of land to no-till farming. It is expected that RR soybean acreage will be positively related to the no-till acreage. The variable RR_P01, the lagged variable of the dependent variable RR_P02 (percentage of total 2002 soybean acres used for RR soybean) is expected to have a positive impact on RR soybean adoption.

The survey also revealed that farmers either owned or leased the land used to cultivate soybeans. Different empirical results obtained by researchers have spawned an enormous amount of debate on the effect of land ownership on adoption of technologies (Feder et al., 1985). Some researchers, for example, Bultena and Hoiberg (1983) found no support for the proposition that land tenure has a significant effect on the adoption of conservation tillage. Fernandez-Cornejo and McBride (2002) have attributed these inconsistencies to the differences in the nature of the technologies. They argued that if an innovation requires investments that are tied to the land, tenants are less likely to adopt. This seems to imply that land tenure may not affect the adoption of RR per say. However it can be argued that because the planting of RR soybean is a short to medium term practice and does not require a long term fixed investment, it is likely that land owners will be willing to commit their land resource to the new technology. Moreover, the ease of switching from RR soybeans to conventional varieties will not hinder but allow land owners to exploit the advantages of adopting the new seed technology. It is therefore hypothesized that land ownership will encourage the adoption of RR soybean technology. The variable PCTOWNED has been assigned to capture the impact of land ownership on the adoption of the technology.

Farmers possessing greater human capital, technical skills and innovative ability are more likely to adopt new innovations. In this study, the availability of human capital is indicated by the number of years spent farming and the level of education. A higher level of education (EDUC) is therefore expected to increase a farmer’s ability to access, process and utilize information pertaining to the use of RR soybeans. It is hypothesized that the level of education is likely to induce the adoption of RR soybean in a positive way. The variable FARMYEARS used in this study represents the number of years a farmer has been operating a farm. Since experience can allow the operator to gain better management skills to handle new technology as opposed to a novice, it is hypothesized that the experience gained by farmers is likely to increase the probability of the adoption of the new technology. Furthermore, experienced farmers understand that early

Table 9. Variable descriptive statistics.

Variable	Variable description	N	Mean	Std. Dev.	Min	Max
tcostdif	Average total cost difference between Non-RR and RR soybean inputs ($/acre)	509	0.95	9.58	-52	53
rr_p01	% of total 2001 soybean acres used for RR soybeans	610	59.4	42.9	0	100
rr_p02	% total 2002 soybean acres used for RR soybeans	610	72.01	39.83	0	100
rr_p03	% of intended land for RR variety in 2003	596	74.1	38.54	0	100
nt_rt_p02	% of 2002 soybean acres used for not-till	610	81.11	35.59	0	100
nt_rt_p01	% total 2001 soybean acres used for not-till	469	75.57	41.25	0	100
farm_a02	Total 2002 farm acres of operation (acres)	610	1153.6	987.42	140	7000
pctowned	% of acres owned	610	50.94	34.39	0	100
vtime_rr	Value of RR soybean time savings ($/acre)	429	4.52	6.75	0	30
vequ_rr	Value of equipment savings under RR soybean ($/acre)	528	3.3	5.61	0	25
vhumenv	Value of human and environmental benefits for RR soybean ($/acre)	409	4.49	7.91	0	40
vtime_rt	Value of time savings using reduced till ($/acre)	610	10.01	8.61	0	40
vconv_rt	Value of convenience factors under reduced till ($/acre)	497	6.72	8.27	0	35
ylddif	Average yield difference between non-RR and RR soybean (bushels/acre)	610	1.1	2.36	-21	20
vuncseed	Value of market uncertainty on RR soybean ($)	501	6.02	7.72	0	35
time_pf	Percentage of work time spent in farming versus off-farm activities (%)	605	90.13	20.98	5	100
Educ	Last year of formal education completed (years)	610	13.43	2.12	8	18
Region	1if Midwest, 0 if south	610	0.8803	0.32	0	1
farm years	Number of years of operating farm (years)	608	33.32	11.88	4	78

adopters of a new technology tend to gain greater economic benefits than late adopters of the technology.

TCOSTDIF is a variable that represents the average total costs of adopting the technologies. It was computed by summing the average per acre cost of labor and equipment, herbicides products and application, harvesting and soybean seed costs for RR and non- RR and finding the difference between them. It is expected that an increase in the average cost of operation per acre will decrease the probability of adopting the new technology. The difference in yield between RR and non-RR soybeans is also represented by the variable YLDDIF and is expected to have a positive influence on the adoption of RR soybean technology. VTIME_RR designates the value of time-savings per acre. In the survey, farmers provided information on how much time they saved per acre in minutes with the RR soybean weed control system as opposed to the use of non-RR soybean weed control routine. Following this they were asked to indicate the value they place on the time saved per acre. It is our hypothesis that, the higher the value placed on time saved, the more likely farmers are to adopt the RR soybean technology, since it has been argued that there is considerable time savings cultivating RR soybeans instead of traditional ones. McNamara et al. (1991), among others, have provided ample evidence that a farmer's off-farm employment may constrain the adoption of management-intensive technologies because it tends to compete for farm managerial time. However, on the contrary, the adoption by households with off-farm employment may be encouraged if the technology is labor or time-saving. Therefore due to the managerial simplicity of the new technology, the percentage of time spent in farming activities compared to off-farm employment (TIME_PF) is hypothesized to be positively related to the odds of the technology being adopted.

The extent to which market uncertainties diminish the value of RR soybeans and its market price may also affect the adoption of the technology. In fact, the notion that technological innovation is perceived to be more risky than traditional practices may inhibit adoption (Feder et al., 1985). The variable VUNCSEED captures the impact of market uncertainty on the adoption of RR soybeans. It represents how much the value of market uncertainties diminishes the per acre value of growing RR soybeans. To estimate values for this variable, farmers were asked to place a dollar value on how much they perceive market uncertainty diminished the per acre value of growing RR soybean. It is hypothesized to influence the adoption of the technologies negatively. The added value per acre of human and environmental safety of RR (VHUMENV) is also hypothesized to be positively related to the adoption of the technology. Generally, the non-pecuniary factors used to explain the adoption of RR soybean technology are hypothesized to have a positive impact on the adoption of the technology. Table 9 presents a summary of the descriptive statistics of the explanatory variables included in this study.

MODEL

A probit model is used to investigate the adoption decision process. By extending a single-equation probit model to a two-equation probit model, a two-stage method is first used to estimate the following reduced-form probit equations:

$$Y_1^* = \rho_1' X_1 + \mu_1, \tag{1}$$

$$Y_2^* = \rho_2' X_2 + \mu_2. \tag{2}$$

Where; X_i is a vector of all the exogenous variables expected to impact the probability to adopt either of the two technologies (such as farm size, farm years, education, region, total cost difference, yield difference, value of time spent cultivating RR soybeans, value of market uncertainty, value of equipment savings etc) and i=1,2. Y_1 * is the dependent variable for the probability of adopting no-till and Y_2* represents the probability of adopting the RR soybean technology. ρ_1' and ρ_2' are the coefficients of the explanatory variables to be estimated.

After estimating equations (1) and (2) separately, the predicted values Y_1^{**} and Y_2^{**} are retrieved from the two equations respectively and then used to estimate the structural equations below:

$$Y_1^{**} = \eta_1' Y_2^{**} + {}_1' X_1 + \nu_1, \tag{3}$$

$$Y_2^{**} = \eta_2' Y_1^{**} + {}_2' X_2 + \nu_2, \tag{4}$$

Where the predicted values v_1 and v_2 are error terms, Y_1^{**} and Y_2^{**} are considered to be endogenous to each other interchangeably in this second stage of estimation and X_1 and X_2 are the explanatory variables expected to influence the decision to adopt no-till technology and RR soybean technology respectively. However this empirical procedure is difficult to estimate. Hence as explained in Fernandez-Cornenjo and McBride (2002), the simultaneous system described above is first estimated after which the two standard, single-equation probit models for the probability of the adoption of no-till and RR soybean technologies were estimated separately to test the simultaneous adoption decision. Each equation factors in the adoption of the other technology as one of the explanatory variables. The estimated parameters of the two models-the single equation and the simultaneous models) are then used to construct a Wu-Hausman test discussed below to test the simultaneity of the two decisions.

WU-HAUSMAN SPECIFICATION TEST

The Wu-Hausman specification test can be used to test a hypothesis in terms of the bias or inconsistency of an estimator Greene (2000, p. 384). Consider a linear regression model $y=X\beta + u$ where y is R x 1, is a K x 1 vector of parameters, X is an R x K matrix of observations and u is an R x 1 vector of disturbances with mean zero and a covariance matrix of $^2 I$. In this test if the elements of X are correlated with the error term, then the ordinary least square estimator $\hat{\beta} = (X'X)^{-1}X'y$ is inconsistent. In its specification the null hypothesis of no endogeneity is tested against the alternative that endogeneity is present and the test is conducted by comparing the asymptotically efficient estimator $\hat{\beta}$ to an estimator $\tilde{\beta}$ that is consistent under the alternative hypothesis. It is also assumed that $\hat{\beta}$ and $\tilde{\beta}$ are asymptotically jointly normal under the null hypothesis, H_0. Subsequently, if the difference between the two estimators is given by $\hat{q} = \tilde{\beta} - \hat{\beta}$ and there is no misspecification in the model, then the probability limit difference between the two estimators is zero else it is non zero. The Wu-Hausman test statistics is therefore given by:

$$m = \hat{q}'[\tilde{V} - \hat{V}]^{-1}\hat{q}$$

Where; $\tilde{V}$ and $\hat{V}$ are consistent estimates of the asymptotic covariance matrix of $\tilde{\beta}$ and $\hat{\beta}$ respectively. Hausman (1978) shows that under the null when no misspecification is present, the statistics: $m = \hat{q}'[\tilde{V} - \hat{V}]^{-1}\hat{q}$, is asymptotically distributed as chi- square with k degrees of freedom. Where k is the number of unknown parameters parameters in and $[\tilde{V} - \hat{V}]$ is nonsingular with a rank of k.

Table 10a. Nonlinear OLS parameter estimates results: No-till adoption.

Parameter	Estimate	Standard error	t value	Pr > |t|
rr_adopt_02	0.009939	0.00328	3.03	0.0026***
farm_a02	0.005734	0.00307	1.87	0.0626*
farmacsq	-0.00089	0.000649	-1.37	0.1731
pctowned	0.001931	0.000726	2.66	0.0083**
vtime_rt	0.004667	0.00286	1.63	0.1039
vconv_rt	0.00473	0.00285	1.66	0.0986*
venv_rt	0.000143	0.000102	1.41	0.1603
nt_rt_p01	0.000282	0.00232	0.12	0.9035
farmyears	0.000919	0.00187	0.49	0.6238
time_pf	0.000081	0.000047	1.72	0.0857*
educ	0.046338	0.00841	5.51	<.0001***
educ2	-0.00004	0.000019	-2.33	0.0206*
region	-0.44649	0.094	-4.75	<.0001***

R^2 =0.2082, Adjusted R^2 = 0.1745, ***1% significance level, **5% significance level, *10% significance level.

Using the Wu- Hausman test statistic, a test of the null hypothesis that, the standard probit model that ignores simultaneity or endogeneity is the correct specification against the alternative hypothesis that it is not can be conducted. The idea here is that if the decision to adopt no-till technology and RR soybean seed varieties is in fact simultaneous, then the estimates from the standard probit equations are inconsistent and the simultaneous model is the preferred model specification and thus will provide a better explanation of the factors that influence the adoption of the two technologies.

RESULTS AND DISCUSSION

Tables 10a - c present the results of the simultaneous adoption model. We find that farm size is positively related to the adoption of both no-till technology and RR soybean technology at the 10% level of significance. This implies that larger farms making this simultaneous decision are more likely to adopt the new technologies in spite of the initial investment cost in seeds, equipment and technology fees. It is also evident that the estimated coefficients of the value of the convenience factors had a direct and significant impact on the adoption of no-till. However, the value of time saved and the value of human safety and environmental benefits did not have a significant impact on the adoption of no-till nor RR soybean technology even though they all had the expected positive sign. This indicates that farmers are conscious and care about the environment and its possible deterioration as well as the safety of the health of their workers. When asked whether there were any human and environmental benefits of using the technologies about 71% of the adopters replied “Yes;” an equal percentage were willing to place a dollar value on the benefits. The value of market uncertainty also had the expected negative sign though not significant as well. This implies that farmers placed a negative value on additional market risk that may result from the use of RR soybeans possibly because of ethical issues surrounding the use and production of RR soybeans coupled with the fact that they cannot save up seeds from their stock (harvest) for replanting or sale.

The yield difference between RR technology and the non-RR soybean varieties was significant at the 1% level in the simultaneous adoption model unlike the single adoption model where it was not as significant. It is also seen that the yield difference has a positive impact on the adoption of the new seed technology. The greater the difference in yield between RR technology and the non-RR soybean varieties the more likely farmers were to adopt the new seed technology. It is however not surprising that it was not as significant in the single adoption model since very few respondents cooperated on revealing this difference. The results further show that the percentage of land owned by farmers enhanced the adoption of both RR soybeans and no-till technologies positively. Although this positive effect was apparent for the two technologies, whereas the impact of land ownership had a significant effect on the adoption of no-till it was not statistically significant with regard to its effect on the adoption of RR soybeans. In general, the number of years of farming experience had a positive but insignificant effect on the adoption of both technologies. This could probably be due to the fact that farmers being introduced to the dual components of this new farming technique were all novices at the time of questioning. On the other hand, the level of education was not only positively correlated with the adoption of the new techno-

Table 10b. Nonlinear OLS parameter estimates results: RR technology adoption.

Parameter	Estimate	Standard error	t Value	Pr > |t|
nt_rt_adopt02	0.010052	0.00196	5.12	<.0001***
tcostdif	-0.01044	0.00109	-9.62	<.0001***
rr_p01	0.523632	0.0402	13.02	<.0001***
farm_a02	0.030171	0.017	1.78	0.0769*
pctowned	0.000323	0.000468	0.69	0.4906
vtime_rr	0.002164	0.00227	0.95	0.3422
vhumenv	0.000118	0.000112	1.06	0.2913
ylddif	0.02024	0.00425	4.76	<.0001***
vuncseed	-0.00182	0.00205	-0.89	0.3759
farmyears	0.000753	0.00116	0.65	0.5166
time_pf	0.003135	0.000732	4.29	<.0001***
educ	0.010209	0.0053	1.93	0.0552*
region	0.054551	0.0642	0.85	0.3963

R^2 = 0.8353, adjusted R^2 = 0.8283, ***1% significance level, ** 5% significance level, *10% significance level.

Table 10c. Results of the test for simultaneous adoption.

	Simultaneous adoption test result	
	No-Till (T1)	**RR (T2)**
Chi-square values; df = 13	42.023747	89.336187

logies; its impact was significant at the 1% level for the adoption of no-till and the 10% level for the adoption of RR soybean technology. This is consistent with the findings of many studies which have concluded that the more educated the farmer is the greater the probability that he will adopt a new technology since he is able to understand the economic benefits of the technology better and earlier than the less educated who tend to be laggards. Thus the level of education is important in explaining the adoption of the two new technologies. The regional dummy included in the model was also statistically significant for the adoption of no-till but insignificant for RR soybean adoption. This is quite inconsistent with the results of the adoption of the technologies as single or individual technologies where the regional dummy was significant in the adoption of RR soybean technology not no-till.

Finally, in this simultaneous model, the time spent in off-farm activities is found to be positively correlated with the adoption of the two technologies. This is quite reasonable due to the compatibility of the timing of farming activities in the two technologies. It seems to suggest that adopting no-till and RR soybean technologies together creates a convenience for farmers regarding weed control and tillage activities thus allowing farmers the opportunity to engage in other off-farm activities. With reference to the simultaneity between the two decisions, after using the SAS program to estimate the coefficients of the parameters in the simultaneous model and the single standard probit models and retrieving the variance covariance estimates for the models, we then compared the results for the computation of the Wu-Hausman test statistic as discussed earlier. In the single equation probit models, the parameters generally did not have the expected signs and were not significant unlike the results of the simultaneous adoption model. The interaction between the adoption of no-till and RR soybean technologies were however found to be positive and significant in the simultaneous model. In other words, the adoption of no-till was a significant explanatory factor the adoption of RR soybeans and *vice-versa*. This result therefore supports the inference drawn from evaluating the two Wu-Hausman test statistics for the decision to adopt no-till and RR soybean technology.

After calculating the test statistic under the null hypothesis that the two standard probit models instead of the simultaneous model is the correct model specification, a chi-square statistic (^{2}, df=13) of 42.02 for the no-till model, and 89.3 for the adoption of RR soybeans model is computed. Therefore we can reject the null hypothesis that the two standard probit models instead of the simultaneous model is the correct model specification in favor of the alternative hypothesis that the simultaneous model is the most preferable model and hence we conclude that we cannot ignore the simultaneity between the two decisions. This inference is partially shared by

Fernandez-Cornejo, and McBride (2002) except that they found that accounting for simultaneity is necessary for the adoption of no-till but not for the decision to adopt RR soybean technology. Subsequently as anticipated by Fernandez-Cornejo, and McBride (2002), it seems that RR soybeans was gaining some acceptance through the extensive commercialization by agronomists and Monsanto and the convenience of using no-till with this seed technology is also enhancing the simultaneous adoption of the two technologies.

In conclusion, these results reveal that farmers who adopted no-till were more likely to adopt the use of RR soybean technology as well and conversely the decision to adopt RR significantly influenced the probability of adopting no-till. Evidently, since cultivation without tillage (no-till) could make the land prone to weed infestation, farmers using no-till technology found the need to adopt RR soybean technology as a means to control weeds. Apparently, the characteristics of no-till farming offered some convenience with RR soybeans for farmers compared to the other conventional tillage practices. For example, No-till allows for less tillage time and fewer passes on a given plot and thus saved farmers some time and money. It could also be that the aggressive commercialization of RR soybeans has encouraged the use of no-till technology.

Another inference from this data analysis suggests that ignoring the simultaneous nature of the decision to use no-till and RR soybean technology could lead to the mis-specification of the model and hence our ability to understand the factors that influence the concomitant adoption of these technologies could be obscured by the inconsistent estimates.

CONCLUSION

The aim of this study was to explore and explain the factors that influence simultaneous adoption of no-till and RR soybean technologies. We analyze a 2002 survey data of soybean farmers in the United States. To address the question-whether the farmer's decision to adopt no-till was dependent on the availability of RR soybean technology, a simultaneous equation model was used to explain the concurrent adoption of the two technologies. We find evidence that the introduction of RR soybeans had a significantly positive impact on the adoption of no-till technology. The survey also reveals that farmers placed a significant value on the better weed control system and other non-pecuniary benefits such as human and environmental benefits associated with the use of RR soybean. However, there is a significant negative impact of market uncertainty on the adoption of RR soybean technology. This is not surprising given the unsettled ethical issues on the safety of the human consumption of GM crops. Should the consumer resistance against GM crops continue to increase, the impact of the value of market uncertainty will be stronger since it could even cause the price of RR soybeans to decrease well below that of conventional soybeans and thus eliminate the incentive to adopt RR soybean. The level of education and farm size were found to play a positive role in explaining the adoption of both no-till and RR soybeans. Our results also show that experienced influenced adoption positively.

The cost difference and the yield difference between RR soybean and conventional varieties had the expected signs, with the former having a negative impact on adoption and the later, a positive impact. These factors were found to be statistically significant. This seems to suggest that the transitioning from the old to the new technology was dependent on, and is constrained by the maximum yield and cost minimization that could be achieved. Since a significant percentage of the total cost of adoption (in this study) stems from the cost of herbicide and pest control, it can be argued that the significant impact of the cost difference supports the fact that the relative effectiveness of agro-biotechnologies against that of conventional herbicide and pest control practices is one of the key drivers of adoption. This also confirms arguments made in previous studies for exam-ple, Marra et al. (2001) who found that the depreciation and diminished effectiveness of conventional pest control practices is the most significant factor contributing to the rapid adoption and diffusion of bollgard (BG) technologies.

Finally, using a system of simultaneous equations and comparing the results to that of the two separate single probit estimated equations, it is realized that we cannot neglect the simultaneity existing between the decision to adopt no-till and RR soybeans. In fact the results support the fact that the decision to adopt no-till is influenced by the decision to adopt RR soybeans and *vice versa*. Thus, the use of herbicide tolerant crops encourages more farmers to adopt no-till.

LIMITATIONS AND FUTURE DIRECTION

While the current study contributes some valuable insights on the role of non-pecuniary factors in explaining the simultaneous adoption of agricultural technologies, there are some limitations. A major drawback of this study is that due to data unavailability, the authors of this study were constrained to use information from a 2002 survey. We surmise that although it is possible that conditions regarding the acceptance of RR soybean have improved, it is equally probable that farmers have not realized the promised profits to incentivize them enough to adopt the technology at the 2002 rates or higher today. This nonetheless, offers an opportunity for defining the future direction of this study. We will seek to apply the model to a much more current data to see if RR soybeans are still been adopted concurrently with no-till. Several questions could also be answered like; Do the benefits of adoption outweigh market uncertainty; has consumer resistance intensified or enervated? Has RR soybeans gain some acceptance through the extensive commercialization? How has that affected the price of RR soybean and ultimately, the dual adoption of the technologies? Is simultaneity in this adoption process still an issue today or farmers are back to using the traditional planting methods? The current study can by no means address these pertinent questions however; it exposes avenues for further research into the current trends of the adoption process.

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