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A Dynamic Decision Model of Technology Adoption under Uncertainty: Case of Herbicide-Resistant Rice

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Herbicide-resistant (HR) rice technology is a potential tool for control of red rice in commercial rice production. Using an *ex ante* mathematical programming framework, this research presents an empirical analysis of HR rice technology adoption under uncertainty. The analysis accounts for stochastic germination of red rice and sheath blight to model a profit maximization problem of crop rotation among HR rice, regular rice, and soybeans. The results demonstrate that risk attitudes and technology efficiency determine adoption rates and optimal rotation patterns.

Key Words: biotechnology, herbicide resistance, mathematical programming, profit maximization, rice, risk, rotation, technology adoption

JEL Classifications: Q16, Q18, O33, C61

Herbicide-resistant (HR) rice technologies are being developed to provide alternatives to the current program of red rice control (*Oryza sativa*). Once available, the new technology will have an impact on the ways that cropping decisions are made because of better weed management efficiency. Presently, adequate red rice control requires cumbersome management operations (Noldin et al.). While pressure is mounting for more environmentally acceptable production practices, farmers are looking for ways to reduce the quantity of chemicals required to control red rice. If HR rice technology provides a potential solution, its adoption may also alter the current crop rotation pattern.

Adoption research has traditionally focused on studying the characteristics of adopters using probabilistic models to estimate adoption (Feder, Just, and Zilberman; Kislev and Shchori-Bachrach; Zepeda). Mathematical programming has received attention as a risk modeling method (Dillon; Norton and Davis), and applications in an *ex ante* framework with uncertainty have been frequent in the literature (Boisvert and McCarl; Hazell; Yassour, Zilberman, and Rausser). Also, the trend of contemporary farm management research puts a special interest on the role of risk as a limiting factor of technology adoption (El-Nazer and McCarl; Hazell). In agriculture, where personal experience and risk perception are important decision factors, the producer risk attitude is a major determinant of timing and pace of technology adoption (Alston, Norton, and Pardey; Dillon).

The underlying idea of this research relies

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on the assumption that with appropriate technology, farmers can change the way that weeds affect farm productivity (Cousens; Kropff; Kwon, Smith, and Talbert; van Groenendael). The objective of this paper is to conduct an *ex ante* analysis of HR rice technology adoption in a cropping environment with uncertainty regarding red rice emergence and control. The research hinges on the hypothesis that the cropping decision is a dichotomous choice between an existing technology and an innovation for which benefits are uncertain.

Under stochastic conditions, red rice germination is not well known, and this uncertainty and other biotic problems make rice production risky. The benefits of choosing HR rice would materialize if red rice emergence is high and disease damage is low. While HR rice technologies would increase output in a rotation program, other risks will persist or even increase. For example, sheath blight is a serious constraint to continuous rice production in the southern United States. In the longer run, risk of transfer of the HR gene to red rice could undermine the sustainability of HR rice technology altogether.

The remaining portions of this paper are organized as follows. The next section presents the nature of the red rice and sheath blight problem followed with a description of the model. This is a profit maximization approach to analyze technology adoption within the rice production system of the southern United States. Rotation patterns are examined based on risk tolerance profiles, technology fees, and efficiency. The last section provides a discussion and a summary of the key findings.

Pest Control Problem

Red rice is a challenging weed to most rice producers throughout the southern United States. This wild rice type causes considerable yield loss and price docking for poor quality. Because of genetic compatibility with cultivated rice, herbicides are not efficient at killing red rice without harming the cultivated rice crop. Presently, farmers control red rice with integrated weed management programs, including an herbicide application before planting, use of certified seeds, flooding, and crop rotation (Noldin et al.; Smith). Yet red rice plants often survive weed treatments in cultivated rice to perpetuate a cycle of red rice seed production, dispersion, and germination in subsequent years.

Sheath blight is caused by the fungus *Rhizoctonia solani AG1-1A,* also called *Thanatephorus cucumeri*, which infects plant residues from previous years. The damage occurs during the rice reproductive stage because the disease curtails the stage of grain formation and causes uneven maturation. The result is a grain of poor quality that easily breaks during milling. In Arkansas alone, sheath blight was found present in 50%–66% of rice fields, causing 5%–15% yield reductions in 2001 (Cartwright and Lee). Factors that exacerbate sheath blight damage include planting of susceptible rice varieties, high rates of nitrogen fertilizer, and short crop rotation cycles.

HR Rice Technology

A number of biotechnology companies are expected to release new rice varieties resistant to herbicides that are effective against red rice. These include Clearfield® rice, Liberty Link® rice, and *Roundup Ready*® rice. BASF developed Clearfield® IMI® rice from a mutation to tolerate *Imidazolinone* herbicide (www.agproducts.basf.com). IMI rice is not strictly considered a genetically modified crop because it did not involve gene transfer. IMI rice accounted for about 8% of southern rice acreage in 2003, which suggests acceptance of the technology among some producers (Delta Farm Press). Another variety is the transgenic Liberty Link® rice from Aventis, which resists herbicides containing glufosinate ammonium. It is a single-gene technology that consists of insertion of the bar encoding *Phosphinothricin acetyl transferase* (PAT) into the Bengal rice variety and other varieties to neutralize ammonia synthetase in normal plants.

A third technology is Monsanto's *Roundup Ready*® rice, which is developed based on gene technology to resist glyphosate herbicides (BU Growers, Ltd). If profitable, rice producers are likely to adopt the technology that helps them control red rice and better manage yield variability. HR rice technology has the potential of providing farmers with a greater predictability of yields and hence less problematic planning operations.

This article presents a mathematical programming model of farm technology adoption with a portfolio of three feasible crops: (1) regular rice, (2) HR rice, and (3) soybeans. The model makes a distinction between returns if each crop is separately considered and returns if crops are correlated on a long time frame. Results are interpreted to identify the rotation plans that maximize long-term farm profitability.

Model

The structure of this model draws on El Nazer and McCarl's timeless rotation framework. A quadratic programming model with risk consideration is used to maximize the aggregate gross margin of a farm enterprise producing HR rice, regular rice, or soybeans in rotation. The solution to the problem represents a long-run cropping strategy subject to a land constraint and crop rotation constraints and incorporates the producer's risk preference. The model can be stated as follows:

(1) Maximize

$$\sum_{i=1}^{N}\sum_{j=1}^{N}\sum_{k=1}^{N} G_{ijk}X_{ijk} - \theta\sigma_g^2$$

Subject to:

$$\sum_{i=1}^{N}\sum_{j=1}^{N}\sum_{k=1}^{N} X_{ijk} \leq 1;$$

$$\sum_{i=1}^{N} X_{ijk} - \sum_{r=1}^{N} X_{jkr} \leq 0$$

$$\text{for all} \begin{cases} j = 1, 2, \ldots, \\ k = 1, 2, \ldots, \end{cases} \qquad X_{ijk} \geq 0,$$

where θ = risk aversion coefficient, σ_g^2 = variance of gross margins, G_{ijk} = gross margin per acre for crop i following crops j and k, and X_{ijk} = acreage of crop i following crops j and k. The objective function maximizes risk-adjusted gross margins of all feasible crop rotations. The first constraint limits planted acreage to not exceed the available total land. The second set of constraints imposes rotational linkages among all possible crop combinations planted in preceding years. Specifically, these constraints ensure that the sum of acreage planted to all crops following crops j and k does not exceed the sum of the acreage previously planted to crops j and k. As noted by El Nazer and McCarl, solving the model does not require an assumption of a finite production horizon, and the results are considered to replicate the optimal rotation plans.

Data

A data set consisting of 100 observations was simulated for use in the programming model. Specifically, the data set consists of 27 gross margin series that fully characterize all possible 3-year rotation sequences of the three crops under consideration. Gross margins were estimated as a function of rice–red rice competition and the rotational relations among crops on yields, production costs, and prices. The necessary background information and assumptions used to simulate the gross margin data are described as follows.

Rice Yield

Rice yield and its variability are determined by the dynamics of red rice and the ability to control it. Red rice density is modeled as a function of seed bank, emergence rate, and the kill rates associated with the crops in rotation. Red rice seed production (Y_{rt}) is modeled as an inverse function of red rice and cultivated rice competition (Pantone and Baker). It is assumed that 70% of the seed production shatters to replenish the seed bank in the soil. Germination of red rice seeds is assumed to be a random variable that follows a truncated normal distribution with mean 0.4, standard deviation of 0.2, and a minimum of 0.001.

It is further assumed that farmers eliminate 75% of red rice in regular rice with preemergent herbicides and other practices. HR herbicides sold with HR technology are assumed to provide a higher baseline kill rate of 95%. Although HR rice technology can potentially achieve superior weed control, such high rates require more active ingredients that can cause injury to cultivated rice. The dynamics of red rice control is mathematically formalized as follows:

(2) $D_{wt} = B_t[G_t(1 - K_j)]$

(3) $Y_{wt} = [(a_{wo} + a_{ww}D_{wt} + a_{wi}D_i)^{-1}]D_{wt}$

(4) $B_t = B_{t-1} + S_w Y_{wt-1}$

(5) $B_0 = B_0$ (Given),

where B_t = red rice seed bank in number of seeds per square meter, D_{wt} = red rice density in number of plants per square meter, D_i = seeding rate for regular rice or HR rice, S_w = red rice shattering rate, G_t = red rice germination rate, K_j = herbicide kill rate under crop j, Y_{wt} = yield of red rice per square meter, a_{wo} = maximum yield of one single plant, a_{ww} = competition coefficient among red rice plants, and a_{wi} = coefficient of competition between red rice and crop i (i = regular rice and HR rice). Modeling the dynamics of red rice is useful to estimate the yields of cultivated rice. This is done using an inverse competition function between red and cultivated rice varieties given weed control efficiency. The functions are as follows:

(6) $Y_{it} = (a_{i0} + a_{ii}D_i + a_{iw}D_{wt})^{-1}D_i$,

where Y_{it} are yields of regular and HR rice, D_i are seeding rates of regular and HR rice, D_{wt} is the density of red rice, a_{i0} is an intercept constant, a_{ii} is the competition coefficient within rice variety, and a_{iw} is the coefficient of intercompetition of variety i with red rice.

Also important is the efficiency of using soybeans to control red rice. Red rice does not affect soybean yields, but switching out of rice to other crops such as soybeans breaks the cycle of red rice production and, thus, makes rice more profitable in the following year(s). It is assumed that red rice is 99% controllable in soybeans.

In order to simulate the average rice yield under the current crop rotation practice in Arkansas, parameter values and an initial red rice seed bank were chosen. In addition, a 10% yield loss was incorporated in all rotation plans in which rice follows rice to account for damage due to sheath blight (Cartwright and Lee). Soybean production was estimated assuming that yields of irrigated soybeans follow a normal distribution with a mean of 45 bushels per acre and a standard deviation of 10.

Production Costs

Production costs for regular rice and soybeans were obtained from the University of Arkansas Cooperative Extension Service. Detailed crop budgets are published on a per acre basis and for a single-year cropping plan. Expense items in the rice budget were adjusted to reflect a 3-year cropping horizon (Annou, Thomsen, and Wailes). For rice crops following soybeans, production costs were estimated at $257 per acre for regular rice and $262 per acre for HR rice. A cost of $8.40 per acre was added to either variety to account for higher fertilizer and fungicide rates if rice follows rice in the rotation. If HR rice is chosen, production costs are raised by a baseline technology fee of $10 per acre. Soybean production costs were set at $130 per acre.

Price

For the purpose of simplicity, consumer acceptance was assumed equal for both HR and regular rice. However, a docking fee was added as a penalty for red rice contamination. The resulting market prices are assumed to reflect product quality as measured by the percent of red rice in commercial rice. The prime product is the U.S. standard number 2 with less than 2.5% of red rice contamination and selling for $6.50 per hundredweight. Two intermediate quality standards were priced $5.90 and $5.50 per hundredweight, respectively. The lowest-quality rice contains 15% of red rice and sells for $4.50 per hundredweight. Soybeans are sold at the loan rate of $5.40 per bushel.

Risk Premium

Gross margin depends on the efficacy of managing pests and red rice being uncertain; thus, gross margin takes the character of a random variable. The producer's expectation is to realize at least a maximized lower-level confidence limit of gross margin. Thus, risk attitude can play an important role in the diffusion of

Table 1. Model Parameters

Parameter	Description	Value
Red ice		
B_0	Initial red rice seed bank	25 per m^2
B_t	Red rice seed bank	Estimated
D_{wt}	Density of red rice per square meter	Estimated
G_t	Germination rate ~ truncated normal with minimum of 0.001	Random ~n(0.4, 0.2)
K_R	Proportion of red rice killed in regular rice regime	75%
K_H	Proportion of red rice killed in HR rice	95%
K_S	Proportion of red rice killed in soybean	99%
S_w	Shatter rate of red rice seeds	70%
Y_{wt}	Red rice yield	Estimated
Regular and HR rice		
Y_{it}	Yield of cultivated rice	Estimated
D_t	Seeding rate of cultivated rice	100 per m^2
a_{wo}	Intercept in the red rice yield function	0.00745
a_{ww}	Coefficient of competition among red rice plants	0.00154
a_{wr}	Coefficient of competition—red rice, regular or HR rice	0.00049
$a_{r0} = a_{h0}$	Intercepts in regular or HR rice yield functions	0.001109
$a_{rw} = a_{wh}$	Coefficient of competition between cultivated and red rice	0.000448
$a_{cc} = a_{hh}$	Coefficient of competition among regular or HR rice plants	0.000112
Soybeans	Yield for irrigated soybeans	45 bushels
Production costs	Production cost for regular rice	\$257 per acre
	Production cost for HR rice	\$262 per acre
	Production cost for soybeans	\$130 per acre
	Extra fungicide cost for rice follow rice	\$8.40 per acre
	Technology fee	\$10 per acre
Prices	Price of rice U.S. standard #2	\$6.50 per cwt
	Price of rice with less than 2.5% of red rice	\$5.90 per cwt
	Price of rice with 2.5% to less than 4% of red rice	\$5.50 per cwt
	Price of rice with 4% to less than 6% of red rice	\$5.50 per cwt
	Price of rice with 6% to less than 15% of red rice	\$4.50 per cwt
	Soybean price	\$5.40 per bushel
Discount rate	Discount rate	5%
Risk coefficients (θ)	0.00; 0.000025; 0.00005; 0.000075; 0.0001; 0.00015; 0.0002; 0.0003; 0.0005; 0.001 θ = 0.00015 is reported as moderate risk aversion; θ = 0.0003 is reported as high risk aversion.	

HR rice technology. In order to capture the impact of risk on adoption, the model is solved for 10 different levels of the risk aversion parameter (Collender and Zilberman). However, only rotations at the neutral, moderate, and high levels of risk aversion are reported in the final results.

Gross Margins

The values of the parameters used to estimate rice yields and otherwise compute gross margins for the different rotations are presented in Table 1. The actual historic 10-year (1991–2000) average yield for rice was estimated at 6,085 lbs. per acre with a standard deviation of 491.7 and a coefficient of variation (CV) of 0.0807. This number was used to calibrate the typical rotation plan of rice–soybeans–soybeans, although the aggregate county-level data do not fully reflect the extent of yield variability at the farm level. The simulation model estimated the yield of the typical rotation plan at 6,119 lbs. per acre. All together, 27 rotation plans were estimated, consisting of 18 plans to produce rice in the current year and nine plans having soybeans in the current year.

Table 2 reports summary statistics for rotations with rice in the current year and suggests that specialization into HR rice is feasible but in most cases appears less profitable than rice–soybean rotations. Low yields and docking fees for poor quality explain the negative gross margins observed for many specialized rice only rotations.

As noted earlier, attempts were made in the simulations to capture the impact of red rice dynamics on the variability of gross margins. Table 2 shows that cropping plans that include HR rice technology better stabilize yields because of the higher efficacy of red rice control of the technology.

After simulating the gross margin data sets, the mathematical programming model was solved using the General Algebraic Modeling System. The iterative process allows convergence of the decision variables to identify the optimal rotation sequences, including land allocations that maximize gross margins. Cropping plans in the sequences compare to the current rotation practice to indicate whether and when HR rice technology enters the optimal solution.

Results and Discussion

Adoption under Risk Neutrality

Under risk neutrality, the optimal crop rotation represents a slight modification to the current 1 year in rice and 2 years in soybeans rotation practice used on most farms in the southern United States. As shown in Table 3, under the baseline scenario of a 95% red rice kill rate in HR rice, this rotation practice continues to be optimal; however, regular rice is displaced by HR rice (Table 3). The practices hss, shs, and ssh included in the optimal solution indicate that 33% of the land is allocated to HR rice and 67% to soybeans in a given year. By adopting HR rice in rotation with soybeans, the farmer expects to realize a gross margin of $176 per acre with a CV of 0.147. The switch from regular to HR rice represents a gain of $34 per acre over rotations involving regular rice (1 year) following soybeans (2 years).

The alternative, low-efficiency scenario reported in Table 3 tests the adoption impact of the relative low efficiency of HR rice as a tool of red rice control. The scenario consists of reducing HR kill rate from 95% in the baseline to 80%, thus awarding HR rice technology with just a 5% advantage over regular rice. Even with such a low weed control, HR rice was found attractive, but rotation cycles are longer. In that case, the optimal solution involves HR rice adoption in rotation either with soybeans or with soybeans and regular rice. The patterns hss (20%), shs (20%), rsh (20%), srs (20%) and ssr (20%) combine into in a 5-year three-crop rotation practice hssrs. HR rice is planted in the current year on 20% of the land in the cycle following 2 years of soybeans; 60% of the land is planted to soybeans in the current year, while regular rice is planted on the remaining 20% of the land following 1 year of soybeans preceded by HR rice. The scenario generates an expected gross margin of $137 per acre with a CV of 0.195. This outcome suggests that HR rice is likely to displace regular rice if the technology has an unequivocally superior weed management power. However, cross-pollination may cause red rice to become resistant to herbicides, and the ensuing loss in the efficiency of weed control can discourage potential adopters. A real or alleged decline in the HR rice technological advantage may result in reduced expected benefits of adoption and thus limit the impact of HR rice introduction on cropping patterns.

Adoption under Risk Aversion

The producer's response to risk was examined, and the results are reported in Table 4. The response to a moderate risk aversion is the replacement of regular rice with HR rice and the adoption of a longer rotation cycle, hhshss (column 1). This 6-year two-crop rotation is a mixed production practice with two main components. The principal component in the practice, hss, stands for planting 1 year of HR rice for 2 years of soybeans on 79% of the

Table 2. Gross Margins under Alternative Rotations[a]

Regular Rice in Current Year									
Cropping plans	rrr	rrh	rrs	rhr	rhh	rhs	rsr	rsh	rss
Yield (lbs./acre)	1,207	1,268	2,237	1,214	2,509	3,706	2,474	6,237	6,119
Mean GM (U.S.$)	−179	−206	−141	−210	−120	−33	−206	145	137
STDEV	29	75	138	88	120	112	153	83	78

[a] rsh means regular rice was preceded by soybeans and HR rice, rss means regular rice was preceded by soybeans in the 2 previous years, and so on.

HR Rice in Current Year									
Cropping plans	hrr	hrh	hrs	hhr	hhh	hhs	hsr	hsh	hss
Mean yield (lbs.)/acre	1,731	2,842	4,713	2,914	4,819	6,692	5,287	7,747	8,793
Mean GM (U.S.$)	−191	−111	24	−106	35	161	63	230	299
STDEV	138	89	110	117	93	66	127	67	40

[a] hss means HR rice was preceded by soybeans in the 2 previous years, hsh means HR rice was preceded by soybeans and HR rice, and so on.

land. The second component, hhs, is a reversal of the first because it involves 2 years of HR rice for 1 year of soybeans on the remaining 21% of the land. Both segments combine to allocate 40% of the land to HR rice in every year in the cycle. This practice generates an expected gross margin of $174 per acre and a CV of 0.12.

For the high-risk-averse farmer, optimal adoption includes largely planting HR rice in rotation with soybeans (column 2). This practice is mixed with two core elements. In the first element, hhs, HR rice is intensely adopted on 26.8% of the land in a 3-year two-crop rotation practice with 2 years of HR rice for 1 year of soybeans. The second part, hss, is also a 3-year two-crop cycle on 73% of the land where HR rice is adopted once in the cycle. Annually, HR rice acreage accounts for about 42% of the land, while 58% of the land is allocated to soybeans. The risk-averse farmer is expected to earn $173.5 per acre in gross margin for a CV of 0.116. Overall, the results suggest that risk aversion encourages HR rice adoption, but the technology is only second to rotation out of rice to break red rice accumu-

Table 3. Optimal Adoption under Risk Neutrality ($\theta = 0$)[a]

	Baseline Scenario[b] Kill Rate = 95%[d]			Low-Efficiency Scenario[c] Kill Rate = 80%		
Current Crop	Rotation	Land Percent	Optimal Adoption	Rotation	Land Percent	Optimal Adoption
HR rice	hss[e]	33.3		hss	20	
			hss . . .			hssrsh . . .
Regular rice		00.0		rsh	20	
Soybeans	shs	33.3		shs	20	
	ssh	33.3		srs	20	
				ssr	20	
	Gross margin = $176 per acre			Gross margin = $137 per acre		
	Coefficient of variation = 0.147			Coefficient of variation = 0.195		

[a] θ is the coefficient of risk aversion.
[b] Baseline scenario assumes that red rice is controlled at 75% in regular rice and 95% in HR rice.
[c] Low-efficiency scenario assumes that red rice is controlled at 75% in regular rice and 80% in HR rice.
[d] Kill rates reflect the level of control of red rice in regular rice or HR rice.
[e] hss means HR rice is preceded by soybeans in the 2 previous years, hsh means HR rice preceded by soybeans and HR rice, rsh means regular rice preceded by soybeans and HR rice, and so on.

Table 4. Optimal Rotation under Risk Aversion

	Baseline Scenario[a] HR Kill Rate = 95%[c]				Low-Efficiency Scenario[b] HR Kill Rate = 80%			
	Moderate Risk Aversion[d] θ = 0.00015		High Risk Aversion θ = 0.0003		Moderate Risk Aversion θ = 0.00015		High Risk Aversion θ = 0.0003	
	Column 1		Column 2		Column 3		Column 4	
Crop as Current Crop	Rotation	Land Percent	Rotation	Land Percent	Rotation	Land Percent	Rotation	Land Percent
HR rice		40.2		42.3		21.0		19.0
	hhs[e]	8.6	hhs	10.7				
	hsh	3.4	hsh	5.4	hss	21.0	hss	19.0
	hss	28.2	hss	26.2				
Regular rice		0		0		16.4		17.3
					rsh	12.0	rsh	9.2
					rss	4.4	rss	8.2
Soybeans		59.8		57.7		62.7		63.7
	shh	8.6	shh	10.7				
	shs	23.0	shs	20.8	shs	21.0	shs	19.0
	ssh	28.2	ssh	26.2	ssh	9.1	ssh	9.9
					srs	16.3	srs	17.4
					ssr	16.3	ssr	17.4
Gross margin	$174.0		$173.5		$135.2		$134.0	
Coefficient of variation	0.120		0.116		0.169		0.160	

[a] Baseline scenario assumes that red rice is controlled at 75% in regular rice and 95% in HR rice.
[b] Low-efficiency scenario assumes that red rice is controlled at 75% in regular rice and 80% in HR rice.
[c] Kill rates reflect the level of control of red rice in regular rice or RH rice.
[d] θ is the coefficient of risk aversion.
[e] hhs means HR rice follows a preceding year of HR rice and a year of soybeans before that, hss means HR rice is preceded by soybeans in the 2 previous years, hsh means HR rice is preceded by soybeans and HR rice, rsh means regular rice is preceded by soybeans and HR rice, and so on.

lation cycle. HR rice comes in the solution as one more crop in a diversified production practice.

Columns 3 and 4 of Table 4 show adoption rates under the lower-efficiency scenario—80% red rice kill rate with HR technology. The results show that the moderate-risk-averse farmer adopts HR rice, yet the practice consists of three main adoption schemes (column 3). The first scheme, hss, substitutes HR rice for regular rice in the current rotation practice. This practice (hss, shs, ssh) involves 51% of the land. The second scheme consists of planting both HR and regular rice in rotation with soybeans, rsh, on 12% of the land. Third, the farmer pursues the current rotation practice (rss) on the remaining 37% of the land. The combined schemes result in a gross margin of $135 per acre with a CV of 0.169.

Under high risk aversion, adoption of a less efficient HR technology is yet optimal, but the solution produces a less convenient cropping arrangement (column 4). HR rice is adopted in tandem with soybeans (hss, shs, ssh) on only 48% of the land. On about 9% of the land, the solution is a 3-year crop rotation, including both rice varieties and soybeans. The remaining 43% of the planted land does not involve HR rice at all. Gross margin amounts to $134 per acre with a CV of 0.16.

Sensitivity of Adoption to Technology Cost

Imperfect competition in the biotechnology industry appears to induce strategic rent extrac-

Table 5. Sensitivity of Adoption to Technology Fee

	Zero Technology Fee				$30 Technology Fee			
	Risk Neutral $\theta = 0$[a]		Risk Averse $\theta = 0.0003$		Risk Neutral $\theta = 0$		Risk Averse $\theta = 0.0003$	
	Column 1		Column 2		Column 3		Column 4	
Crop in Current Year	Rotation	Land Percent	Rotation	Land Percent	Rotation	Land Percent	Rotation	Land Percent
HR rice		50.0		43.2		33.3		39.5
	hsh[b]	50.0	hhs	11.9	hss	33.3	hhs	9.4
			hsh	5.8			hsh	2.6
			hss	25.5			hss	27.6
Regular rice		0		0		0		1.4
							rsh	1.4
Soybeans		50.0		56.8		66.7		59.1
	shs	50.0	shh	11.9			shh	9.4
			shs	19.4	shs	33.3	shs	20.8
			ssh	25.5	ssh	33.3	ssh	26.2
							srs	1.4
							ssr	1.4
Gross margin	$182.5		$181.6		$175.4		$170.5	
coefficient of variation	0.24		0.1219		0.1601		0.1317	

[a] θ is the coefficient of risk aversion.
[b] hsh means HR rice follows soybeans, following HR rice; shs means soybeans follow HR rice, following soybeans; and so on.

tion (Falck-Zepeda, Traxler, and Nelson). Typically, the company owning the technology enjoys a monopoly situation because of patent protection. Hence, the companies are inclined to price their technology high to rapidly recoup their costs and eventually adjust the fee down as proprietary rights are used up or become unenforceable. If the technology is affordable, farmers pay a contractual fee for the right to adopt. In a profit-maximizing framework, adoption is expected to expand as the contractual fee decreases. If the technology is provided free, farmers are likely to plant HR rice on all available land unless factors other than cost limit adoption.

Two levels of technology fee were simulated to estimate the upper bound of technology adoption and the size of the technology's potential of rent creation. The first level test is a zero technology fee. As expected, a free technology results in larger adoption, induces higher rice intensity, but does not lead to rice specialization (Table 5). With free access to HR rice, farmers do not specialize but increase the rotation ratio of HR rice to soybeans to a maximum of 1:1, meaning it is optimal to produce HR rice every other year. The ratio is 0.76:1 when risk aversion is considered. At this point, the scenario's gross margin is also a measure of total rent to be shared between the company and the producer. Gross margin was estimated at $182.5 per acre for the risk-neutral adopter and $181.6 per acre for the risk-averse adopter. The impact of risk attitude is more visible in the measure of gross margin variability. The risk-averse farmer reduces the variability of gross margin to 0.12 from 0.24 for the risk-neutral adopter.

Pricing of the technology is important to its acceptance. The less risk averse the farmer is, the lower the technology fee he or she is willing to pay and the lower the possibility of rent extraction. In order to test the impact of an expensive HR rice technology, the model assumed a $30 technology fee in the baseline scenario. The results show that in the case of HR rice, cost is less important to adoption than weed control efficiency (Table 5, column 3).

It turns out that even the higher-priced technology is attractive to farmers seeking optimal weed management. For instance, the decision to adopt or not appears less sensitive to the consideration of cost than the assurance that the technology provides an efficient tool of weed control.

Risk-neutral farmers appear indifferent whether access to technology requires paying $30 per acre or the baseline $10 per acre if other attributes stay the same. Adoption is optimal and includes a ratio of 1:2 between HR rice and soybeans. Risk aversion changes the dynamics of adoption and crop planning (Table 5, column 4). The risk-averse farmer applies the technology as a means of diversification because he or she chooses to add the risk-reducing crop to the farm portfolio. Overall, HR rice is adopted on 96% of the land. It is the dominant crop on 21.4% of the land (hhs, hsh, shh) and second to soybeans on 74.6% of the land (hss). The risk-averse farmer may find regular rice admissible either with HR rice (rsh) or solely with soybeans (srs, ssr) on about 4% of the land. Gross margin is estimated at $171 with a CV value of 0.13.

On the whole, the cost scenarios suggest that red rice control efficiency and risk considerations are more important than the price of the technology in determining the size and timing of adoption. The overall results imply that the diffusion of HR rice technology follows a pattern of adoption/rotation leading sometimes to moderate rice intensification but never to continuous rice production.

Summary and Conclusions

The overall goal of this research is to investigate the impact of HR rice technology on rice–soybean rotation in a production environment where risk consideration is important. Specific objectives were to analyze the effects of risk preference, technology efficiency, and cost of HR rice technology adoption. The empirical application focused on optimally planting HR rice technology, regular rice, and soybeans to maximize a farm gross margin in the southern United States.

A nonlinear mathematical programming model was applied to a mean-variance framework to estimate the factors and the size of adoption. Farm-level data for a silt loam rice farm in eastern Arkansas were used to analyze the problem under uncertainty. HR rice was assumed a privately owned technology that is commercially available. In order to realize the objectives of the study, assumptions were made that red rice dynamics is the principal random factor of rice yield variability. Thus, adoption was modeled to depend on the cost and the power of HR rice technology to control red rice. In addition, where continuous rice is deemed profitable, pest control may pose a problem, as sheath blight is more associated with intensive rice production.

The results suggest that the optimal technology adoption does not include continuous rice production. Rather, profit maximization is better achieved within a framework of adoption/rotation of the technology. Under baseline conditions, the technology replaced regular rice in the current crop rotation cycle. However, even if the technology were to be made available at no cost, rotations out of rice would still occur. Lastly, an expensive fee does not deter adoption to manage production risk. Risk aversion appears to support the diffusion of the technology, suggesting that risk-averse farmers are likely to be early adopters.

Interpretation of the study results must take into account some limitations. This study is based on secondary data on weed–rice competition, originally estimated from a different rice variety. It assumed that herbicide kill rates and sheath blight damage are known with certainty. In practice, many stochastic conditions, such as weather, influence the efficacy of managing such pests. The study did not account for potential yield drags as shown by some genetically modified crops like corn and soybeans. In addition, the model did not consider the effects of market risk due to public attitudes toward genetic engineering of food. A further study with actual experimental data could benefit from a framework of market segregation, as marketing of genetically modified rice is likely to involve the emergence of specialized identity preservation channels. Likewise, the study did not address the potential relation between farm size and adoption of HR rice to identify how capital drives innovation. Whether farm size and other farm characteristics, including soil types and water availability, influence adoption patterns would be especially interesting for future study.

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