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Market Impacts of Adopting Herbicide-Resistant Rice in the Southern United States

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Herbicide-resistant (HR) rice varieties offer U.S. rice producers a powerful tool for control of red rice infestations. However, improved weed control can shorten crop rotations and boost yields, resulting in expanded rice production and lower domestic market prices. Declining market returns diminish the benefits of HR rice adoption and substantially reduce net returns for nonadopters. More competitive prices increase U.S. rice exports, causing a slight decline in world rice prices. The dependence of the rice marketing loan program on world prices prevents loan deficiency payments from adequately offsetting producers' market revenue losses. U.S. consumers gain from lower rice prices.

Key Words: biotechnology, crop rotation, herbicide resistant, red rice, rice, simulation models, technology adaptation

JEL Classifications: Q11, Q16, Q18, O33, C53

Since the successful commercialization of Roundup-Ready soybeans in 1996, herbicide-resistant (HR) technology has been applied to cotton, corn, canola, and, more recently, to rice. The benefits of HR seed varieties for producers include reduced herbicide applications, superior weed control, and reduced contamination of harvested grain by weed seeds. In addition, HR production systems are often simpler to implement than conventional weed control programs and are compatible with conservation tillage practices (Carpenter and Gianessi). The use of HR technology can have positive external benefits by reducing herbicide runoff into surface and groundwater, facilitating the use of reduced tillage systems, and creating more flexibility in crop rotations (Marra, Carlson, and Hubbell).

Previous analyses of the producer benefits of HR rice adoption suggested that HR rice technology represents a cost and risk-reducing strategy for rice producers in the southern United States. Using a partial budgeting framework, Annou, Wailes, and Cramer found that HR rice adoption may increase producer net returns by $12–$40/acre, depending on the soil type and the technology fee. The benefits to producers were derived from a combination of lower weed control costs and a quality improvement from reducing the red rice contamination of harvested rice. Red rice is a common weed problem in rice fields in the southern United States that can significantly reduce rice yields and quality. Producers typically minimize the risk of red rice infestation through a combination of herbicide applications, crop rotations, and use of certified seed. HR rice is a potentially powerful tool for moderating production risk that can be used in

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combination with or as a substitute for conventional red rice control programs.

The introduction of HR rice into producers' production risk management strategies may have important ramifications for annual rice cultivated area. For example, rice producers in Texas often plant rice on a field only one year out of three, to control red rice. The adoption of herbicide-resistant rice varieties, such as BASF's Clearfield IMI rice or Aventis' Liberty Link rice, has the potential to shorten this rotation to two crops of rice in three years (Annou and Wailes; Annou, Thomsen, and Wailes). Implementing this rotation change would have doubled annual rice area in Texas and increased annual U.S. rice production by >7% from 1998 to 2000. Thus, more frequent rice plantings and lower production costs due to HR rice adoption may increase rice production in the United States, putting further downward pressure on already weak domestic and international prices.

The objective of the present study was to analyze the market effects of adopting HR rice in the southern United States on U.S. rice production, prices, trade, and producer returns. Given the recent development of HR rice, few studies of the economic impacts of HR rice adoption have been published, and the existing research has abstracted from the effects of adoption on rice markets. The primary contribution of our study is to analyze HR rice adoption in the broader context of the U.S. rice market and to provide estimates of producer and consumer benefits and government costs. Analogous to other studies that have measured the *ex ante* impacts of technology adoption (Griffith, Vere, and Bootle; Lemieux and Wohlgenant; Norton and Davis), the present study draws on prior research to generate assumptions regarding factors that affect market supply after adoption, such as potential changes in variable costs, yields, and crop rotation patterns. These assumptions are incorporated into the Arkansas Global Rice Model (AGRM), which is used to simulate introduction of HR rice at a number of adoption rates. We measure the impacts of adoption for U.S. producers and consumers in deviation from the 2000 baseline projections (Wailes et al.).

The next section describes the nature of rice production in the United States, highlighting the producer incentives for adoption of HR varieties and the likely consequences for costs, yields, and crop rotation. This discussion is followed by a brief description of the AGRM and the scenario outcomes for rice production, prices, and trade. The last section draws implications from the scenarios for producer income, consumer benefits, and government costs in the United States.

Rice Production in the United States

Annual U.S. rice plantings have averaged 3.2 million acres in recent years, ~85% of which were in the southern states of Arkansas, Louisiana, Mississippi, Missouri, and Texas. California accounts for the remaining rice area. From 1992 to 1996, U.S. rice acreage decreased from 3.176 to 2.824 million acres, with much of the decline occurring in Texas. Rice acreage increased to 3.531 million acres in 1999 before declining to 3.317 million acres in 2001. Increased plantings in Arkansas and Missouri accounted for the bulk of the expansion in the latter half of the 1990s. These substantial swings in rice acreage have been driven largely by variability in crop prices, increased planting flexibility under the Federal Agricultural Improvement and Reform Act, and growing environmental concerns. The variability of rice acreage can also be attributed, in part, to crop rotations that shift area among soybeans, cotton, wheat, or forage crops.

Southern rice growers typically alternate between rice and other crops to maintain soil fertility and to control pests. Red rice (*Oryza sativa*) is the most challenging weed problem for U.S. rice producers. Both common red rice ecotypes, strawhull and blackhull, produce seeds that can easily shatter and germinate or remain dormant for several years. About 25% of the rice area in the southern United States is considered heavily infested with red rice (Cartwright). Red rice infests, to some degree, 30%–40% of the rice area in Arkansas, 50% in Mississippi, 40%–50% in Texas, and nearly all of the rice area in Louisiana (Deshaies). Although red rice was a concern in California in the 1930s, the use of certified seed virtually eliminated red rice from California fields more than three decades ago (Smith and Seaman).

The presence of red rice increases producer costs and reduces returns in several respects. First, red rice competes with commercial rice for nutrients and space, reducing rice yields. Smith estimated the yield losses due to weed invasions to have reached 34% in Texas, 12% in Missouri, and 17% in Arkansas, Louisiana, and Mississippi. Second, red rice seeds contaminate the harvested rice and diminish its market value by lowering its grade. A survey of weed distribution in Arkansas found red rice on 38% of rice acreage, and red rice alone caused price discounts for 20% of harvested rice (Baldwin). Third, red rice tends to lodge easily, which increases harvesting costs (Wheeler). Finally, red rice infestations lower producers' revenues over time by forcing them to keep land fallow or plant less valuable crops—such as soybeans, sorghum, and forages—to reduce the risk of red rice infestations in future rice crops.

Red rice is genetically compatible with domestic rice; as a consequence, herbicides that are routinely used to control red rice are also harmful to the commercial rice crop. Currently, red rice management depends on farm management practices that break the cycle of seed accumulation with preplant herbicides, certified rice seeds, flooding, and crop rotation (Noldin et al.). Soybeans are commonly planted in rotation with rice, with producers planting rice every second or third year. Rice farmers in the southern United States seldom plant continuous rice. The Agricultural Extension Service frequently recommends a 3-year rotation cycle for keeping red rice density at a manageable level (Baldwin), although shorter rotation is possible on fields with moderate red rice infestations.

Herbicide-resistant rice is a cost-saving and risk-reducing tool that farmers could use to control red rice infestations. Recognizing the potential benefits for rice farmers, a number of seed and biotechnology companies have undertaken the development of rice varieties that are resistant to herbicides that are effective against red rice. These HR rice varieties include BASF's Clearfield IMI rice, which is used in conjunction with Imidazolinone herbicide, and Aventis' Liberty Link rice, which is resistant to glufosinate ammonium herbicide. Monsanto was also developing a Roundup Ready rice variety, but the project was recently discontinued.

The Clearfield IMI variety was produced by radioactive bombardment of conventional rice, a breeding technology that has been used to successfully produce short stature rice varieties. IMI rice, although herbicide tolerant, is not strictly considered a genetically modified (GM) crop, because gene transfer techniques were not used in the development process. Liberty Link rice is a GM variety. It was developed by inserting the bar gene encoding phosphinothricin acetyl transferase directly into Bengal rice and other varieties to neutralize the ammonia synthetase in normal plants. Both technologies provide a potentially lower cost means of lessening the negative impacts of red rice infestations on producer returns.

As noted above, the adoption of HR rice is expected to alter the present practice of crop-rice rotation to combat red rice, intensifying rice cultivation by reducing the average rotation cycle to 2 years (Annou, Thomsen, and Wailes). Widespread adoption of HR rice could increase the average area under rice cultivation in the southern United States and may result in a growth in the rice supply. If this occurs, rice prices would decline, given that the demand for rice is relatively inelastic.

Model Description and HR Rice Adoption Scenarios

To study the market impacts of HR rice adoption in the United States, several scenarios were analyzed with the AGRM.[1] The AGRM is a multicountry econometric model that provides projections for 23 major rice-producing or rice-trading countries. The model disaggre-

[1] The following discussion provides a brief description of the AGRM model, but readers interested in a more detailed description, including elasticity values, should consult Hansen et al.

gates the United States into separate model components for the major rice-producing states: Arkansas, California, Louisiana, Mississippi, Missouri, and Texas. The model also differentiates between long-grain and medium- or short-grain varieties. Given macroeconomic projections and prices for other crops, modelers with the University of Arkansas Rice Modeling Group use the AGRM to generate annual projections for global rice production, consumption, trade, and prices extending out 10 years into the future. The AGRM projections from January 2001 are the baseline for our analysis.

The supply side of the U.S. component of the AGRM is modeled at the state level. Rice producers are assumed to be profit maximizers operating in a competitive market. Rice production is modeled as the product of rice area harvested and yield per acre. Rice areas harvested for long- and medium-grain rice in each state are a function of producers' real expected net returns. Yields are driven by research expenditures and a technology trend, both of which are exogenous to the model. National production of long- and medium-grain rice is the sum of production in the individual states.

The demand for rice consists of several components, including food demand, seed use, brewer demand, and stocks. Food use is a function of the real retail rice price, real income, lagged consumption, and a time trend. Seed use depends primarily on sown area, and brewer demand depends on the real rice price and real income. Stock demand is residual.

U.S. rice trade for long- and medium-grain rice is determined by import and export equations. Exports depend on the world price (the Thai free-onboard shipping point price), the U.S. Department of Agriculture announced world price, and the available exportable surplus. Imports are driven primarily by the Thai price. U.S. net exports of both long- and medium-grain rice enter the model's global market-clearing equation, which determines the world price level that is consistent with equilibrium in international rice markets.

The adoption of HR rice in the United States is anticipated to have an impact on production costs, rice yields, and crop rotations. Annou, Thomsen, and Wailes estimated that the direct cost savings attributed to the adoption of HR rice would vary from $11.67 to $20.98 per acre, depending on soil type and tillage practices. These savings do not account for additional seed costs resulting from a technology fee. The cost reduction amounts to a 4%–7% decline in direct costs. In addition, producers could receive a $19.89 per acre quality premium for reducing the percentage of red rice in harvested rice. This premium constitutes a 4.7% increase in gross revenues for adopters of HR rice. Annou, Thomsen, and Wailes used a linear programming model with both economic and agronomic content to analyze the impacts of HR rice on optimal rotation strategies for red rice control. Although optimal planting strategies changed with different technology fees charged for HR rice, producers generally found it optimal to adopt a 2-year rice and soybean rotation, increasing rice planting from 1 in 3 to 1 in 2 years. In addition, the average rice yield increased by 1% over the baseline when HR rice was planted. The yield gains were largely attributed to the reduction in competition from red rice for water and nutrients during the growing season. On fields with serious red rice infestations, yields may increase as much as 20% with HR rice. The results generated by Annou, Thomsen, and Wailes are experimental and depend heavily on the agronomic and economic parameters used in the model, which are most indicative of rice production conditions in Arkansas. Nevertheless, they do point out that it is optimal for some producers to alter their crop rotations when HR rice is available.

On the basis of the results of these studies, we adjust the appropriate equations in the AGRM components for long-, medium-, and short-grain rice in the southern United States to account for HR rice adoption. Although the California component of the model responds to the changes in the southern states, we do not assume that California producers adopt HR rice. Red rice is not a problem for California rice growers, and the types of HR rice under development are not typically grown in California. In the regions where adoption occurs, the costs and net returns are assumed to

Table 1. U.S. Rice Sector Average Percentage Change from Baseline: 10%, 30%, and 50% Adoption Rates

Technology Fee:		$15			$25	
Adoption Rate:	10%	30%	50%	10%	30%	50%
	Percent Change					
Yield (rough basis)	0.02	0.06	0.09	0.02	0.06	0.08
Total harvested area	0.88	2.63	4.37	0.83	2.48	4.12
Supply (rough basis)	1.33	3.97	6.58	1.25	3.73	6.18
Production	0.90	2.69	4.46	0.85	2.54	4.21
Beginning stocks	5.89	17.58	29.16	5.50	16.42	27.23
Imports	0.15	0.46	0.76	0.14	0.43	0.71
Domestic use (rough basis)	0.16	0.49	0.81	0.16	0.47	0.77
Food	0.18	0.53	0.88	0.17	0.51	0.84
Seed	0.58	1.70	2.77	0.52	1.50	2.43
Brewing	0.02	0.06	0.09	0.02	0.05	0.09
Residual	0.00	0.00	0.00	0.00	0.00	0.00
Exports	1.81	5.41	8.96	1.71	5.11	8.48
Total use	0.79	2.36	3.91	0.75	2.23	3.70
Ending stocks	6.78	20.24	33.57	6.33	18.90	31.35
Prices						
Season average farm price	−2.37	−7.08	−11.75	−2.26	−6.75	−11.21
Adjusted world price	−0.33	−0.98	−1.63	−0.31	−0.93	−1.54
Thai 5% broken price	−0.25	−0.73	−1.21	−0.23	−0.69	−1.14

reflect a 5% reduction in variable costs and a 5% quality premium on the price of rice grown. Rice area harvested is increased exogenously to account for the additional area planted to rice as a consequence of a change from a 3- to a 2-year rice rotation. Data regarding actual average rotation periods in the U.S. is not collected or reported. As a consequence, we assume that 50% of the rice area in the southern states is currently using a 3-year rotation, so the rotation change is only applied to half of the area cultivated to HR rice. The assumption that only 50% of adopters would increase rice plantings following HR rice adoption is based on the estimate that roughly half of the rice area infested with red rice is heavily infested. Producers raising rice on this land are more likely to use crop rotations of two or more years between rice crops. Moderate red rice infestations can be managed effectively with rice plantings every other year, and HR rice may not have significant impacts on rotations for these farmers. Finally, yield equations are augmented to include an assumed a 1% increase in yields on area sown to HR rice.

Adoption rates and technology fees charged by seed companies are treated exogenously. Scenarios assume HR rice adoption on 10%, 20%, 30%, 40%, and 50% of the baseline rice acreage. For each adoption rate, one scenario was run under the assumption that the technology fee charged by the seed company was $15 per acre and a second scenario with a technology fee of $25 per acre. In total, the model was simulated 10 times. Table 1 reports the impacts of HR rice adoption on 10%, 30%, and 50% of the baseline rice area. Impacts are measured by computing the deviation from the baseline on an annual basis. Because adoption rates are held constant over the projection period, the bulk of the adjustments occur in the first 3 years of the simulation period. The values reported in Table 1 are the average annual percentage change over the 9-year simulation period and reflect the long-run impacts.

Results

The adoption of HR rice increases U.S. rice production by up to 4.46% and lowers domestic farm prices up to 11.75%. Average rice yields increase by <0.1% over the baseline because the 1% increase in yields due to HR rice adoption is applied to only a portion of the total rice area. As a consequence, the bulk of the increase in production stems from the expansion of rice area following rotational changes. Rice area entering production due to the shortening of the rotation period accounted for a 2.1%, 6.3%, and 10.4% increase in area in the southern states for 10%, 30%, and 50% HR rice adoption, respectively. Actual area increases are less than half of the exogenous change from shortened rotation. Area harvested for nonadopters declines as net returns decline, offsetting ~58% of the additional area harvested as a result of shorter rotations.

Rising rice production puts downward pressure on U.S. farm prices, particularly long-grain rice prices. The decline in average farm prices is largely absorbed in the milling and marketing margins, resulting in average retail price declines of 0.64% to 3.32%. Consumers increase rice purchases by <1%. Lower U.S. farm prices increase the competitiveness of U.S. rice on world markets, and U.S. rice exports rise 1.5–7.7 million hundredweight over the baseline level (1.7% to 9%), accounting for >80% of the annual growth in output. The additional rice on international markets prompts world prices to decline by <1% in most scenarios. The AGRM model assumes that producers will not anticipate the market impacts of HR rice adoption in the first year after release; as a consequence, U.S. stocks increase substantially in the first year of the simulation. By the third year of the simulation, rice ending stock levels stabilize, with stocks averaging 1.5–7.8 million hundredweight above baseline levels.

Impacts on Producer Returns

Given the changes in market prices and the assumed costs and yields, the change in producer net revenues per acre for both HR rice adopters and nonadopters were calculated. Table 2 displays the average change for the 10%, 30%, and 50% adoption scenarios. By assumption, the cost per acre does not change for nonadopters, but market revenues fall as average prices decrease. With adoption of HR rice on 10% of acreage in the southern United States, average net returns for nonadopters decline \$11.76–\$12.27 per acre, roughly a 10% decrease. As adoption increases to 50%, net returns decline \$58.01–\$60.54 per acre, constituting a >90% reduction in market net returns and a 50% reduction in net returns including marketing loan gains. Marketing loan gains and loan deficiency payments (LDPs) increase slightly in response to world price declines, but the increase in government payments offsets only 6% of the drop in market returns because LDPs are based on the announced world price rather than a domestic market price.

HR rice adopters fare somewhat better, achieving an \$8.74–\$18.20 per acre increase in net returns with 10% adoption. However, as adoption rates increase, the impacts on market prices offset the productivity gains achieved by HR rice adopters. Analysis of herbicide-resistant soybean adoption suggests that adoption is positively related to market prices (Fernandez-Cornejo, Klotz-Ingram, and Jans). As a consequence, actual HR rice adoption rates will likely be sensitive to market price impacts. The scenario results indicate that net returns for adopters would be slightly above the baseline at a 20% adoption rate and a \$15 technology fee, but increasing the technology fee to \$25 would make adoption unprofitable.

Historically, most rice varieties reach a maximum adoption rate of ~30% within a few years after introduction. Cultivation of a particular variety tends to decline fairly rapidly as new varieties with improved characteristics are commercialized (Slaton). If profitable, herbicide-resistant rice has the potential to reach adoption rates of much greater than 30% because it represents a class of rice varieties rather than a single variety. Profitability, however, may not be the dominating factor influencing adoption of HR rice. Recent empirical studies

Table 2. Average Change in Producer Net Returns: 10%, 30%, and 50% Adoption Rates

	Adopter			Non Adopter		
Adoption Rate:	10%	30%	50%	10%	30%	50%
$15 Technology Fee			$/Acre			
Revenues						
Market revenue	−8.71	−34.82	−60.61	−13.06	−38.92	−64.45
Quality premium	21.98	20.68	19.39	0.00	0.00	0.00
LDP/loan gains	0.79	2.36	3.91	0.79	2.36	3.91
Costs						
Variable costs	−19.14	−19.14	−19.14	0.00	0.00	0.00
Technology fee	15.00	15.00	15.00	0.00	0.00	0.00
Net returns	**18.20**	**−7.64**	**−33.17**	**−12.27**	**−36.56**	**−60.54**
$25 Technology Fee						
Revenues						
Market revenue	−8.15	−33.15	−57.84	−12.50	−37.27	−61.70
Quality premium	22.01	20.76	19.53	0.00	0.00	0.00
LDP/loan gains	0.74	2.23	3.69	0.74	2.23	3.69
Costs						
Variable costs	−19.14	−19.14	−19.14	0.00	0.00	0.00
Technology fee	25.00	25.00	25.00	0.00	0.00	0.00
Net returns	**8.74**	**−16.02**	**−40.48**	**−11.76**	**−35.04**	**−58.01**

of adoption of other GM crops have not found a statistically significant difference in net returns to GM adopters and nonadopters (Fernandez-Cornejo, Klotz-Ingram, and Jans; McBride and Books; McBride and El-Osta). The decline in production risk, ease of use, compatibility with conservation tillage practices, environmental benefits, and ability to increase long-run revenues by more frequent rice plantings may substantially influence the ultimate level of HR rice adoption.

Impacts on Consumers and Government Costs

Table 3 displays the change in U.S. consumer surplus and government costs for the 10%, 30%, and 50% adoption scenarios. With 10% adoption of HR rice, the reduction in retail rice prices generates an average annual increase in consumer surplus of $54–$57 million. Consumer gains reach as much as $276 million annually when the adoption rate is 50%. Over

Table 3. Change in U.S. Consumer Surplus and Government Costs

Technology Fee:	$15			$25		
Adoption Rate:	10%	30%	50%	10%	30%	50%
			Million Dollars			
Consumer Surplus						
Average annual change	57.4	166.9	275.7	54.8	159.1	262.8
Cumulative change	516.6	1,501.7	2,481.6	493.2	1,431.7	2,365.2
Government Cost						
Average annual change	4.2	12.8	21.5	4.0	12.1	20.3
Cumulative change	38.0	115.0	193.1	35.9	108.6	182.3

the 9-year simulation period, the total benefits from price reductions in response to HR rice adoption range between $493 million and $2.48 billion. In the present study we have assumed that consumers are indifferent between HR rice and other rice varieties, so the consumer benefits in Table 3 do not take into consideration any negative valuation consumers may attach to HR rice created through genetic engineering. Consumers may be reluctant to purchase HR rice if they perceive (correctly or incorrectly) that it is genetically modified, and the rice demand curve may shift down in addition to the movement along the curve to the lower supply price. As a consequence, the results from our study represent an upper bound on consumer gains.

The slight decline in world prices prompted by higher U.S. rice exports generates a $4–$21 million annual increase in LDP outlays, leading to as much as a $193 million rise in total government payments to rice producers over 9 years. The fact that the marketing loan program uses an adjusted world price rather than a posted county price to determine payments keeps government costs well below the change in producer market returns. Were government payments based on domestic price fluctuations, marketing loan payments would offset the bulk of market losses under appropriate market conditions. In essence, the government would be indirectly subsidizing the adoption of herbicide-resistant varieties. As noted above, this is not the case for the marketing loan program in the rice industry, but government countercyclical and marketing loan programs in other crop sectors have the potential to play an important role in the adoption of productivity-enhancing technologies, particularly in a low commodity price environment.

Conclusions

HR varieties of rice have tremendous potential for increased control of red rice in the southern United States. According to previous studies, the combination of reduced production costs and improved quality of harvested rice can yield substantial benefits to producers that adopt HR rice varieties. However, when adoption of HR rice leads to more frequent rice plantings and yield increases, the losses due to market price impacts can more than outweigh the gains from adoption. Simulation results in the present study indicate that HR rice adoption is not profitable when adoption rates are >20% in the United States, unless the technology fee for HR rice seed is <$15 per acre or cost reductions and quality improvements exceed our assumed values. In addition, the reliance of government rice support programs on world prices prevents substantial indirect subsidization of HR rice adoption through the marketing loan program.

The impacts on producer returns from the present study do not include the impacts of HR rice adoption on input prices. If the widespread adoption of HR rice dramatically increases the use of imidasolinone and glufosinate, the costs of these herbicides could increase, lowering net returns for HR rice adopters. On the contrary, use of other herbicides may decline, lowering their prices. This decline in input costs for nonadopters would dampen the negative impacts on net returns from introduction of HR rice. Similarly, changes in rotation patterns that increase the frequency of rice plantings may have an impact on land rental values. More frequent rice crops may increase the value of rice land and increase costs to producers that rent rice area.

The consumer benefits from our study should be viewed as optimistic estimates, because they do not account for any potential differentiation of HR rice in the market place. If domestic or international consumers develop a negative association with HR rice that is produced through genetic engineering, gains in consumer surplus due to lower prices will be moderated as consumers that are averse to GM foods decrease purchases of U.S. rice. Likewise, if producers are required to segregate HR rice from other varieties, the potential negative impacts on market returns and increase in marketing costs will detract from the gains generated by the herbicide-resistant attributes.

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