AgBioForum, 6(4): 146-154. ©2003 AgBioForum.

Medium Grains, High Stakes: Economics of Genetically Modified Rice in California

Craig A. Bond, Colin A. Carter, and Y. Hossein Farzin
Department of Agricultural Economics, University of California, Davis

This paper gives estimates of the potential profitability of herbicide-tolerant (HT) rice cultivation in the Sacramento Valley region of California. We estimate first-year returns for the average producer and use both deterministic and stochastic methods to perform sensitivity analysis to account for heterogeneity and uncertainty with respect to potential adoption. Results show that adoption of the HT rice technology will likely be profitable for a majority of rice producers in California, even in the presence of nontransgenic price premia and technology fees.

Key words: California, genetically modified, GM food crop, herbicide tolerant (HT), Monte Carlo, rice.

In May 2004, Monsanto Company decided to shelve its research program on genetically modified (GM) spring wheat in North America (Reuters, 2004). There were a variety of reasons cited by the company for this decision, but grower perception of market resistance was clearly a factor. Wheat is viewed as more of a food grain than either corn or soybeans, which have successfully shifted to transgenic varieties. As such, the issues surrounding the release of GM wheat are similar to those facing similar technologies in rice. Now that transgenic wheat is on the back burner in North America, attention may turn to GM rice due to its status as the primary staple for over half of the world's population (United States Department of Agriculture Economic Research Service [USDA ERS], 2004).

This paper combines an ex ante partial budgeting approach, based on sample rice production costs with Monte Carlo analysis, to estimate the potential farm-level profitability of herbicide-tolerant (HT) rice cultivation in the Sacramento Valley region of California. In addition to estimating first-year deterministic profitability gains for the typical producer, we utilize both deterministic and stochastic sensitivity approaches to account for uncertainty in yield and market-level effects of adoption.

Biotechnology and Rice Production in California

Rice production in California is concentrated in the Sacramento Valley, with medium-grain varieties dominant. Although traditional breeding and other research has resulted in increased yields by up to 46% since 1975 (USDA ERS, 2003b), producers have recently seen a dramatic increase in the resistance of weeds (especially watergrass) to conventional chemicals, which has increased herbicide costs to nearly $200/acre (Fischer, 2002; J. Hill, UC Davis, personal communication, April 18, 2003). Driven by environmental concerns, the California Department of Pesticide Regulation restricts alternative chemical options, contributing to rising costs and thus lowering the profitability of rice farming.

Herbicide-tolerant varieties are expected to be the first transgenic rice cultivars introduced on a large scale (Gianessi, Silvers, Sankula, & Carpenter, 2002; Williams, Strahan, & Webster, 2002). These varieties are engineered to exhibit resistance to a particular broad-spectrum chemical agent (herbicide), allowing for broadcast applications that eliminate weeds while leaving the crop relatively undamaged. This technology has several potential advantages for the individual grower, including increased yields (due to fewer weeds) and decreased chemical costs. There are also potential environmental gains from reductions in the use of active chemical agents applied to the rice fields, although the environmental effects are a subject of considerable debate (Bond, Carter, & Farzin, in press).

However, any potential farm profitability gains can be eroded due to a number of factors, such as technology pricing policies, market response (as manifested in conventional rice price premia), yield drag, and additional regulatory assessments (Fernandez-Cornejo & McBride, 2002; Foster, Berry, & Hogan, 2003; Gianessi et al., 2002; Marra, Pardey, & Alston, 2002; McBride & Brooks, 2000). An example of the latter is the California Rice Certification Act of 2000 (CRCA), which permits the California Rice Commission (CRC) to collect fees from sellers of transgenic seed and millers and/or dryers of rice "having characteristics of commercial impact" (CRCA, 2000, p. 3).

The extent of adoption of HT rice in California will be determined, in large part, by the differential in expected profitability between the new and conventional technologies. Any change in profits will vary across growers and will be driven by weed management cost savings, yield differences, and price differentials between HT and conventional rice, including segregation costs. Market acceptance issues will play a major role in the segmentation of the market into HT and conventional rice sales. Tolerance levels for adventitious presence of transgenic rice will be an important determinant of segregation costs. In the case of corn and soybeans, price premia exist for non-GM varieties; these premia range from 3 to 8% (Foster et al., 2003). Many of these variables affecting expected profitability are uncertain before commercial introduction, thus requiring the use of sensitivity analysis to predict farm-level benefits.

Methodology[1]

The partial budgeting approach has been used in a variety of ex ante studies on transgenic crops (Alston, Hyde, Marra, & Mitchell, 2003; Annou, Wailes, & Cramer, 2000; Fulton & Keyowski, 1999; Gianessi et al., 2002). Although it is based on (a) representative producer(s) and data for the conventional technology, and thus requires a number of assumptions, the approach is defensible in the absence of farm-level data for a technology that has yet to be introduced commercially.

To illustrate the approach, we adapt the equations in Alston et al. (2003) to the case of herbicide-tolerant rice. Let π_{ij} represent per-acre returns over operating costs for the j^{th} grower if the i^{th} technology is selected (i = conventional [C] or herbicide tolerant [HT]), such that

$$\pi_{ij} = (P_i - c_j)Y_{ij} + GP_j - FC_j - SC_{ij} - HC_{ij} - IC_{ij} - CRC_{ij}. \qquad (1)$$

P_i is the farm-level price per hundredweight of type i rice, which we will assume is of the medium-grain variety (90–93% of California rice production) with the price exogenous to individual growers (USDA ERS, 2002). Costs invariant to technology but dependent on yields per acre Y_{ij} are denoted by c_j, and include operations such as hauling, drying, and storage, and CRC assessments. GP_j are government payments per acre, including direct payments and countercyclical payments as defined by the 2002 Farm Bill (USDA ERS, 2003a). FC_j denotes costs per acre not dependent on yields, and includes rent on capital equipment, insecticide and fungicide materials and application, fertilizer application and material costs, laser leveling, water, burning permits, labor, fuel, and miscellaneous capital uptake and repair expenditures. Neither GP_j nor FC_j are assumed to change with adoption of the HT rice.

The final four terms in Equation 1 are not yield dependent either, but will most likely vary across technologies. SC_{ij} are seed costs per acre for the i^{th} technology—most likely higher for the transgenic variety, due to the technology fee. For other transgenic crops, this fee has been levied either as a direct charge (such as the technology fee charged by Monsanto) or incorporated directly into the retail price of the seed (as is practiced by Bayer CropScience). HC_{ij} are herbicide application and material costs per acre for the i^{th} technology, which at current prices will be significantly lower for the transgenic variety, and CRC_{ij} are additional assessments per acre due to the CRCA discussed above. Finally, IC_{ij} are interest costs per acre for the i^{th} rice, which vary by technology because we assume that operations are financed.

Subtracting conventional from HT rice returns, and dropping the j subscript for notational convenience, we obtain a measure of per-acre benefits of transgenic rice adoption at the farm level for an individual grower:

$$(\pi_{HT} - \pi_C) = (P_{HT} - c)(Y_{HT} - Y_C) - (P_C - P_{HT})Y_C - (SC_{HT} - SC_C) - (HC_{HT} - HC_C) - (IC_{HT} - IC_C) - CRC_{HT}. \qquad (2)$$

Equation 2 captures each of the aforementioned potential adoption impacts on the net returns per acre. The first term on the right side is the yield effect, the second is the effect of the price premium, and the remainder of the terms are the cost effects of the technology.

We estimate the short-run farm-level benefits for three representative California cost structures in order to account for heterogeneity of land, resources, and management ability (j = low, median, or high cost). To obtain a base estimate of the economic rents associated with the HT technology, assuming perfect substitutability in production and consumption between conventional and transgenic rice, we first set the yield, price premium, seed cost, and CRCA effects equal to zero, as in Annou et al. (2000). As such, the gross rents from adoption of the technology are attributable to differ-

---

[1] *For a more complete description of the partial budgeting methodology and data, see Bond et al. (in press).*

ences in herbicide material and application costs and interest costs alone, such that Equation 2 becomes:

$$(\pi_{HT} - \pi_{C}) = (HC_{C} - HC_{HT}) - (IC_{HT} - IC_{C}). \qquad (3)$$

Note that the chemical and interest costs included in Equation 3 are known with a high degree of certainty relative to the other effects in Equation 2, assuming that the price of the herbicide does not change.[2] However, both the magnitude and distribution of these rents will be affected by the output price, yields, seed price, and assessments associated with the HT technology. Because no transgenic rice variety has yet been commercially introduced, the first three of these effects are relatively uncertain. For example, yields can be viewed as a random variable that depend on weather, weed infestation, and other factors that are unknown until well after planting decisions are made. Similarly, output prices are determined on the world market and can be viewed as an exogenous random variable. Finally, any potential price premium for conventional rice over the new biotech crop will be realized in the market and will depend on the relative demand and supply of the two rice types. In the absence of the ability to forecast any of these effects with an adequate degree of certainty at the (uncertain) time of introduction, other methods such as sensitivity analysis must be used.

One form of sensitivity analysis is deterministic in nature, in which we relax the assumptions of zero yield and seed cost effects by varying the yields and the technology fee, assuming full pass-through of the additional CRCA assessments. This combines assumptions for a particular growing situation across both time and space. A similar analysis could be done by varying output price and/or the conventional rice price premium, although we do not do so here due to space constraints.

The second method of sensitivity analysis specifies probability distributions for several of the variables in Equation 2 and uses Monte Carlo simulation to obtain an empirical distribution of the likely benefits of the new technology. Unlike the deterministic analysis, with the Monte Carlo simulation we do not focus on the appropriation of the economic rents among parties (through seed pricing policies and assessments) but rather the distribution of the total surplus generated from adoption. As such, we identify yield of the HT rice cultivar (Y_{HT}), price of the HT cultivar (P_{HT}), and the price premium of conventional rice over transgenic rice ($P_C - P_{HT}$) as stochastic variables. We assume likely distributions of these variables based on field trial data and past and current experience with transgenic crops. We take 10,000 draws from these distributions in order to estimate a confidence interval for the change in per-acre net returns from adoption in the presence of uncertainty.

Data

The basic data source for this study is the University of California Cooperative Extension (UCCE) cost and return report.[3] Given growing weed resistance problems in California, changing environmental regulations, and changes in the 2002 Farm Bill, the baseline (nontransgenic) median cost UCCE scenario was adjusted. Herbicide use was updated using data from the "Rice Pesticide Use and Surface Water Monitoring, 2002" report by the California Department of Pesticide Regulation (DPR, 2002), as interpreted by the authors. Herbicide and application costs were updated using information provided by UCCE (R. DeMoura, UC Davis, personal communication, May 29, 2003). These changes resulted in a per-acre cost increase of $17.69 over the 2001 UCCE cost study. The adjusted cost and return data are reported in Table 1 as the median cost scenario.

Estimated farm-level revenues were adjusted as well. We assume the market price per hundredweight (cwt) at harvest is the average price from 1986 through 2002 of $6.50, with average yields maintained at 80 cwt per planted acre. Government payments were updated in accordance with the 2002 Farm Bill as described by USDA (USDA ERS, 2003a) and were divided into two components: direct payments and countercyclical income support payments. Incorporation of these changes resulted in a $28.01 increase in median gross revenues per acre over the 2001 UCCE sample costs study.

To represent heterogeneity of land, resources, and management ability across California, low-cost and high-cost production scenarios were derived from the

---

[2] *Commercially available transgenic crops, such as corn and canola, often use identical chemicals for weed control; thus, it is unlikely that the introduction of HT rice will dramatically affect the price of herbicides.*

[3] *For more information about the components of the assumed costs for rice production in California, the reader is referred to the sample costs produced by University of California Cooperative Extension (UCCE, 2001), available at http://www.agecon.ucdavis.edu/outreach/crop/cost.htm.*

Table 1. California conventional rice costs and returns by cost group ($/acre).

	Low-cost scenario	Median-cost scenario	High-cost scenario
Gross value of production:			
Primary product: rice	$527.54	$520.00	$467.25
Farm Bill provision	267.84	264.01	237.23
Total, gross value of production	**795.37**	**784.01**	**704.47**
Operating costs:			
Seed	18.27	21.00	22.53
Fertilizer and soil conditioners	54.90	71.44	104.13
Chemicals	62.67	98.51	123.98
Custom operations[a]	186.04	226.60	255.51
Fuel, lube, and electricity	38.39	50.39	68.73
Repairs	9.69	13.00	15.88
Purchased irrigation water	19.14	59.13	104.06
Interest on operating capital[a]	9.18	15.76	22.80
Hired labor	32.09	59.46	81.40
Assessments[a]	7.30	7.20	6.47
Total, operating costs ($/acre)	**437.67**	**622.50**	**805.49**
Total, operating costs ($/cwt)	**5.39**	**7.78**	**11.21**
Net returns above operating costs ($/acre)	**357.70**	**161.51**	**-101.01**
Net returns above operating costs ($/cwt)	**4.41**	**2.02**	**-1.41**
Yields (cwt/acre)	81.16	80.00	71.88

Note. Original data for median-cost scenario obtained from UCCE, 2001, and adjusted with information from California DPR (2002) and UCCE. Low-cost and high-cost scenarios developed using national-level data compiled by Livezey and Foreman (2004).

[a] *Interest costs, assessments, and a subset of custom operations estimated by authors after weighting of other cost components.*

adjusted median budget (column three in Table 1). Estimates of the distribution of costs across California rice growers are not readily available, so we instead utilized information reported in "Characteristics and Production Costs of U.S. Rice Farms" (Livezey & Foreman, 2004). Specifically, each cost component and yield for the low-cost and high-cost national groups in Livezey and Foreman was divided by the corresponding median-cost component to obtain ratios of each of the cost components. With a few exceptions, these weights were subsequently multiplied by each of the components of the adjusted median cost scenario (described above) to obtain representative costs and returns for low-cost and high-cost farms in California. The exceptions are yield-dependent CRCA assessments and interest costs, which were estimated directly, and yield-dependent contract operations (a subset of custom operations) associated with hauling, drying, and storage of harvested rice. Revenues, costs, and returns for each cost group are reported in Table 1.

Given the public nature of experimental data on Liberty Link rice grown in California and the cooperation of Bayer CropScience through phone interviews and e-mail correspondence, we use this transgenic variety as the basis for our analysis. We assume a price for Liberty (glufosinate) herbicide of $60/gallon[4] and an application rate of 0.446 lbs of active ingredient (ai) per acre (500 g/ha), in accordance with the company's projected label recommendations (D. Mitten, Bayer CropScience, personal communication, May 29, 2003).

Deterministic Results

It is assumed that 85% of the chemical costs from the conventional rice regime will be replaced by the costs associated with the new HT technology for each cost group. Conventional herbicide application costs (in the custom operations category) are $0.20 per dollar of herbicide, on average, whereas the Liberty application costs are assumed to be $12/acre. Estimates of the net benefits of HT rice adoption, as defined by Equation 3, are presented in Table 2 for each cost group, assuming one and two applications of the broad-spectrum herbicide (glufosinate) to allow for heterogeneity in efficacy across fields. As expected, per-acre benefits from adoption (assuming perfect market substitutability between rice varieties) are positive and increasing with operating costs per cwt, ranging from $9.83 for the low-cost grower at two herbicide applications to $105.33 for the high-cost grower.

Although these calculations are instructive, we recognize the potential for differential farm-level returns from adoption. Both the magnitude and appropriation of the economic rents are affected by the ex ante assump-

---

[4] *Promotional materials available for Liberty Link corn and canola advertise a price of approximately $64/gallon, although a search of retail prices on the Internet in September 2003 uncovered prices as low as $55/gallon.*

Table 2. Net benefits of HT rice: deterministic estimates ($/acre).

	Low cost	Median cost	High cost
Single herbicide application:			
Chemicals	-$37.21	-$67.66	-$89.30
Custom operations	-0.3	-7.33	-12.33
Interest on operating capital	-1.36	-2.73	-3.7
Net benefits for transgenic ($/acre)	**38.88**	**77.73**	**105.33**
Net benefits for transgenic ($/cwt)	**0.48**	**0.97**	**1.47**
Two herbicide applications:			
Chemicals	-$21.19	-$51.64	-$73.27
Custom operations	11.7	4.67	-0.33
Interest on operating capital	-0.35	-1.71	-2.68
Net benefits for transgenic ($/acre)	**9.83**	**48.68**	**76.28**
Net benefits for transgenic ($/cwt)	**0.12**	**0.61**	**1.06**

Note. Does not include CRCA assessments or technology fee(s).

tions regarding yields, prices, and assessments. Of course, the extent of adoption of the technology is expected to be highly correlated with its improved profitability, necessitating sensitivity analysis of these basic results (Fernandez-Cornejo, Klotz-Ingram, & Jans, 2002; Fernandez-Cornejo & McBride, 2002; Marra et al., 2002).

Additional scale effects from transgenic rice adoption are determined primarily by the yield differential between conventional and transgenic rice varieties. Herbicide-tolerant varieties are engineered not to increase yields but rather to resist broad-spectrum herbicides, such that weed control efficiency is enhanced with just one chemical. Accordingly, adoption of the new technology may enhance yields by reducing weed pressure. A severely infested field with a large seed bank of watergrass or some other resistant weed (consistent with general California growing conditions) would likely generate yield increases with adoption of HT rice. Such yield gains have been observed in practice for HT soybeans and HT canola in the range of 0–20% (Gianessi et al., 2002; McBride & Brooks, 2000). However, under generally ideal conditions, a yield drag of 5–10% has been observed in field trials for HT rice (Fischer, 2002; McKenzie, CA Rice Experiment Station, personal communication, May 12, 2003). This is consistent with field trials of HT soybeans at the time of their introduction (Elmore et al., 2002). Possible explanations for any yield drag are the differences in yields between the transgenic cultivar and more productive conventional hybrids that have not received the new trait, or some unknown characteristics of the technology.

Yields may also vary over time. Rice in California is generally grown in a single-crop rotation on an annual basis with planting in spring and harvesting in fall. Given the annual nature of the production process, a comparison of conventional yields in year t and transgenic yields in year $t + 1$ (or more generally, $t + s$) on the same plot embodies both the technology dimension and the time dimension due to potentially disparate growing conditions in each year. Furthermore, consecutive years of the same herbicide regime—be it transgenic or otherwise—tends to self-select resistant forms of weeds over time, thus increasing weed pressures. In this study, the dynamic dimension of yield changes are not addressed; rather, the counterfactual used is the average year, defined by conventional rice yields as in Table 1.

The primary determinant of the distribution of the benefits between the grower and the owners or sellers of the technology (in this case, Bayer CropScience) is the technology fee.[5] For most transgenic crops introduced to date, this fee is approximately 30–60% of seed costs, but Liberty Link corn seed tends to sell at a relatively small premium at the low end of this range (Annou et al., 2000; Benbrook, 2001; Gillam, 2003). In addition, growers will likely pay part of the fees assessed by the CRCA and administered by the California Rice Commission (CRC), depending on the elasticities of supply and demand in the seed and milling/drying markets. At current rates, these assessments are $0.33/cwt for transgenic seed and $0.10/cwt for "first handlers"—likely millers or dyers (CRCA, 2000, p. 3). Thus, the gross rents will be distributed between growers, the technology owner, and the CRC.

Calculation of net benefits using deterministic sensitivity analysis of the variables discussed above is presented in Table 3. To be conservative, we assume a maximum pass-through of the CRCA assessment and two applications of glufosinate per acre per year.

---

[5] *At the retail level, the term "technology fee" typically refers to the technology user agreement associated with Monsanto's practice of charging a per-acre fee to growers of Roundup Ready crops, directly payable to the company. Other firms, including Bayer CropScience, do not directly charge growers but rather pass on the seed price premium through the seed dealer. In this study, no distinction is made between these alternative pricing practices.*

Table 3. Deterministic sensitivity analysis of net benefits ($/acre).

Technology fee ($/acre)	Change in yield over baseline scenario				
	-10%	-5%	0%	5%	10%
Low-cost scenario:					
$0.00	-$17.37	$1.35	$20.07	$20.07	$38.79
6.30	-42.44	-23.72	-5.00	13.72	32.43
12.60	-48.80	-30.08	-11.36	7.36	26.08
Median-cost scenario:					
$0.00	$4.06	$22.16	$40.25	$58.35	$76.44
6.30	-2.29	15.80	33.90	51.99	70.08
12.60	-8.65	9.45	27.54	45.63	63.73
High-cost scenario:					
$0.00	$35.46	$52.04	$68.62	$85.20	$101.78
6.30	29.11	45.68	62.26	78.84	95.42
12.60	22.75	39.33	55.91	72.49	89.07

Note. Includes maximum CRCA assessment borne by producer.

Although the representative high-cost producer realizes positive net benefits from transgenic rice adoption for the range of assumed technology fees and yield effects (at least in the range reported here), this result does not hold for the low- and median-cost producer. Adoption of Liberty Link rice for the low-cost grower is profitable for a 30% technology fee of $6.30 so long as yields increase by at least 1.3%, and is profitable with a 60% technology fee of $12.60 per acre so long as yields increase by at least 3%. For the median-cost grower, the critical yield effects are -9.4% and -7.6%, respectively, for the medium and high technology fees. With zero yield gains, net returns per acre for this range of technology fees increase by between $27.54 and $33.90 (17–21%) over conventional rice returns for the median cost producer, but drop to -$5.00 and -$11.36 (a loss of 1–3%) for the low-cost grower. Not surprisingly, the high-cost producer will generally benefit the most, with estimated gains of $55.91 to $62.26 per acre, which correspond to a 38–45% increase in net returns.

Stochastic Results

The deterministic sensitivity analysis above accounts for heterogeneity in land, weed infestation, and management ability, as well as the distribution of the rents generated through the technology fee. This methodology is especially appropriate in the presence of specific a priori information about, say, a particular farm unit, allowing for specific assumptions to be pieced together. Another approach is to parameterize the distributions of those stochastic variables (from the standpoint of the farmer) and use Monte Carlo simulation to estimate the distribution of the surplus benefits of the transgenic rice technology.

One advantage of this approach is the ability to represent uncertainty in markets and technology. The assumptions are on the distributions of the random components, which can be based on information from other transgenic crops. Other advantages include the ability to estimate the potential distribution of the net benefits of adoption for purposes such as risk analysis for the individual grower as well as the impact of each of the random components on the variance of this distribution.

As such, we take the specification in Equation 2 and assume distributions for the uncertain elements: the yield premium, the output price, and a conventional rice price premium. Yields for the HT cultivar on any given type j plot in any year are assumed to be randomly distributed as symmetric triangular centered around mean yields for each of the three producer types, with a minimum value of -10% and maximum value of +10%. To check the robustness of these results, an alternative specification assumes that yields for the transgenic crop are normally distributed with mean yields and variances such that 95% of the density is within ±10%. Each draw from a distribution thus represents a particular state of the world (measured by yields) as a result of any type j producer adopting the new technology and following the production processes implied by the j^{th} cost function. No allowances were made for in-season deviations from this production process as a result of the grower observing information over the course of the season.

Using 1986–2002 data from USDA, we assume a lognormal distribution for output price with a mean of $6.50/cwt and standard deviation of 1.67. Producers are assumed to face identical output prices for each draw. Finally, we assume two different distributions for the price premium for conventional rice, akin to the assumptions made for yields. One is a skewed triangular distribution, with most likely value $0.25 (3.8%), minimum value of zero, and maximum value of $0.52, or about 8%. The second is lognormal, with mean of $0.25 and variance such that $Pr(\text{premium} < 0.52) = .95$. These values are consistent with the experience of corn and soybeans cited above (Foster et al., 2003) and are assumed independent of the output price.

To run the simulations, we assume two applications of glufosinate, set the technology fee and all CRCA assessments equal to zero, and then take ten thousand draws from the distributions for each type of producer for four scenarios. Two of the scenarios assume no price premium with only yields and price random; one sce-

Table 4. Monte Carlo sensitivity analysis, 95% confidence interval, per-acre benefits ($/acre).

	Triangular yields/premium[a]			Lognormal yields/premium[b]		
Stochastic element(s)	**2.50%**	**Median**	**97.50%**	**2.50%**	**Median**	**97.50%**
Low-cost scenario:						
Yield only[c]	-$19.84	$10.05	$39.39	-$28.92	$9.58	$47.54
Yield + price[c]	-22.09	9.87	43.50	-31.32	9.69	51.13
Yield + premium[d]	-45.39	-11.00	22.23	-59.55	-8.96	33.04
Yield + price + premium	-47.69	-11.01	25.07	-63.34	-9.19	36.08
Median-cost scenario:						
Yield only[c]	$20.14	$48.60	$77.40	$11.54	$48.63	$86.42
Yield + price[c]	16.26	48.54	81.46	9.56	48.63	90.65
Yield + premium[d]	-5.51	27.81	61.24	-20.89	30.08	71.20
Yield + price + premium	-8.77	27.99	64.65	-24.25	30.21	74.01
High-cost scenario:						
Yield only[c]	$50.05	$76.32	$102.94	$43.05	$76.40	$110.16
Yield + price[c]	46.67	76.16	105.31	38.38	75.97	112.61
Yield + premium[d]	27.93	58.00	88.11	13.48	59.42	95.77
Yield + price + premium	25.04	57.63	90.17	10.69	59.25	98.27

Note. Technology fee and CRCA fees are set equal to zero.

[a] *Yield distribution assumed symmetric triangular, with min/max at ±10%. Conventional rice price premium assumed skewed triangular with minimum 0 and maximum $0.52.*

[b] *Yield distribution assumed normal with variance s.t. 95% of density within ±10%. Conventional rice price premium assumed lognomal with 95% of density less than $0.52.*

[c] *Price premium set to zero.*

[d] *Output price set to mean of distribution, $6.50/cwt.*

nario assumes that yields and the price premium are stochastic with output price fixed at $6.50/cwt; the fourth scenario assumes that all three parameters are random. Following the draws for the random parameters, partial budgets (as described in Table 1) were calculated, including updated revenues and contract operations, interest, and assessment costs, and the net returns were recorded to generate the empirical distributions of the gross surplus generated by the technology (i.e., before the technology and the CRC assessments). The results can be interpreted as the ex ante distribution of likely outcomes from first-year adoption of the technology for each of the three type *j* representative producers, accounting for the uncertainty in the production technology itself (in terms of yields) and market conditions (in terms of output prices and the conventional price premium). Results from the Monte Carlo analysis are reported in Table 4.

The results are in general accordance with the deterministic analysis, as should be expected; however, several patterns emerge. First, a conventional rice price premium of the magnitude observed for other transgenic crops reduces the median net benefits of adoption by between $17 and $21 per acre, depending on the grower. As such, median net benefits for the low-cost producer turn negative, while percentage reductions in net benefits for the median and high cost producers are approximately 38–43% and 22–24%, respectively. In addition, assuming a stochastic price premium substantially increases the variance of the net benefit distributions relative to scenarios where only the yield is stochastic. Variations in the output price, however, only slightly decrease expected median benefits and slightly increase the variance. In essence, these results highlight growers' concerns regarding international (and to a lesser extent, domestic) market acceptance of transgenic rice. From the point of view of the producer, the uncertainty in the market not only decreases the likely net benefits of the technology, but also increases the risks associated with adoption.

Assuming all of the three potentially stochastic cost elements are random, one can calculate the probability that the gross rents from the technology are non-negative for the j^{th} type of producer. For those growers with high costs, the probability is greater than 99%; the probability drops to 89–94% for the median-cost scenario and to just 26–32% for the low-cost producer. However, Table 4 does not account for CRCA assessments or technology fees, generally bounded between $6.30/acre (a 30% technology fee and no CRCA pass-through) and $21.10/acre (a 60% technology fee and full CRCA pass-through). Assuming maximum fees, the probability that adoption by high-cost producers is profitable decreases to 98%, with corresponding probabilities of 69–79% for the median-cost grower and only 4–7% for the low-cost producer.

Although we make no attempt to forecast the potential adoption rates of HT rice in California, the results presented above suggest that in the absence of considerable risk aversion, high-cost, profit-maximizing producers will most likely adopt the new technology. Given our assumptions regarding the distribution of the yield and market effects, and assuming the most conservative assessment scenarios, we predict the short-run, farm-level benefits of the technology for high-cost growers to be between $0 and $87 per acre—most likely in the range of $37 to $47. Low-cost producers, however, are likely to experience losses with adoption, bounded on the low end by $84 per acre with a median loss of $30 to $32 per acre. Those growers who tend to have approximately average costs can expect small positive benefits ranging from $7 to $17 per acre on average, but uncertain technology and market effects could result in a loss as great as $36 per acre or a gain as great as $60 per acre.

Conclusions

This study estimated the potential farm-level impacts of herbicide-tolerant (HT) transgenic rice adoption in the state of California. Heterogeneity across rice growers was incorporated using three representative cost structures, estimated for California using weights derived from national data. In addition to the deterministic partial budgeting approach often used to estimate the benefits of adoption of transgenic crops, both deterministic and stochastic sensitivity analysis was used to account for the uncertainty of the technology and the market. Limitations of our study include the dependence of our results on ex ante assumptions and the lack of inclusion of any dynamic or industry-level general equilibrium effects.

The results highlight the differentials in potential profitability due to grower heterogeneity (represented by cost differences) and uncertain yield and market effects. The Monte Carlo analysis performed in this paper provides an estimate of the distribution of potential benefits across potential states of the world and can be used as one measure of the risk of new technology adoption.

In general, we can state that high-cost producers are most likely to benefit significantly from HT rice introduction in the short run and thus to adopt the new technology. Low-cost producers are unlikely to see significant profitability gains, and those in between will likely experience small positive benefits. True adoption decisions will depend on cost structure and the degree of risk aversion, likely resulting in adoption patterns consistent with herbicide-tolerant soybeans and canola.

References

Alston, J., Hyde, J., Marra, M.C., & Mitchell, P.D. (2003). An ex ante analysis of the benefits from the adoption of corn rootworm resistant transgenic corn technology. *AgBioForum*, *5*(3), 71-84. Available on the World Wide Web: http://www.agbioforum.org.

Annou, M., Wailes, E., & Cramer, G. (2000). *Economic analysis of adopting Liberty Link rice* (RCS-2000, Rice Situation and Outlook, 55-61). Washington, DC: United States Department of Agriculture Economic Research Service.

Benbrook, C.M. (2001). *Troubled times amid commercial success for Roundup Ready soybeans* (AgBioTech InfoNet technical paper 4). Sandpoint, Idaho; Northwest Science and Environmental Policy Center.

Bond, C., Carter, C., & Farzin, Y.H. (in press). *Economic and environmental impacts of herbicide-tolerant transgenic rice adoption in California.* Davis, CA: Giannini Foundation, University of California.

California Department of Pesticide Regulation. (2002). *Rice pesticide use and surface water monitoring 2002* (EH02-09). Sacramento, CA: Report to the California Regional Water Quality Control Board.

California Rice Certification Act of 2000. (2000). California State Assembly Bill No. 2622.

Elmore, R.W., Roeth, F.W., Shapiro, C.A., Nelson, L.A., Martin, A., Knezevic, S.Z., & Klein, R.N. (2002). Yield suppressions of glyphosate-resistant (Roundup Ready) soybeans (NF02-539). Lincoln, NE: Nebraska Cooperative Extension. Available on the World Wide Web: http://www.ianr.unl.edu/pubs/fieldcrops/nf539.htm.

Fernandez-Cornejo, J., Klotz-Ingram, C., & Jans, S. (2002). Farm-level effects of adopting herbicide-tolerant soybeans in the U.S.A. *Journal of Agricultural and Applied Economics, 34*(1), 158-172.

Fernandez-Cornejo, J. & McBride, W. (2002). *Adoption of bioengineered crops* (agricultural economic report 810). Washington, DC: United States Department of Agriculture Economic Research Service.

Fischer, A. (2002). *Managing watergrass (Echinochloa spp.) resistance to rice herbicides in an aquatic environment:*

Research and demonstration in producer-affected fields (DPR Contract No 00-0216S). Sacramento, CA: California Department of Pesticide Regulation.

Foster, M., Berry, P., & Hogan, J. (2003). *Market access issues for GM products: Implications for Australia* (ABARE eReport 03.13). Canberra, Australia: Australian Bureau of Agricultural and Resource Economics.

Fulton, M. & Keyowski, L. (1999). The producer benefits of herbicide-resistant canola. *AgBioForum*, *2*(2), 85-93. Available on the World Wide Web: http://www.agbioforum.org.

Gianessi, L., Silvers, C., Sankula, S., & Carpenter, J. (2002). *Plant biotechnology: Current and potenital impact for improving pest management in U.S. agriculture: Case study 27, herbicide tolerant rice*. Washington, DC: National Center for Food and Agricultural Policy. Available on the World Wide Web: http://www.ncfap.org.

Gillam, C. (2003, August 8). Monsanto seed price hikes spark anger. *The Boston Globe*.

Livezey, J. & Foreman, L. (2004). *Characteristics and production costs of U.S. rice farms* (statistical bulletin number 974-7). Washington DC: United States Department of Agriculture Economic Research Service.

Marra, M., Pardey, P., & Alston, J. (2002). The payoffs to transgenic field crops: An assessment of the evidence. *AgBioForum*, *5*(2), 43-50. Available on the World Wide Web: http://www.agbioforum.org.

McBride, W.D. & Brooks, N. (2000). Survey evidence on producer use and costs of genetically modified seed. *Agribusiness*, *16*(1), 6-20.

Reuters. (2004, May 11). Monsanto suspends GM wheat program.

University of California Cooperative Extension. (2001). *Sample costs to produce rice, Sacramento Valley, 2001*. Davis, CA. Available on the World Wide Web: http://www.agecon.ucdavis.edu/outreach/crop/cost.htm.

United States Department of Agriculture Economic Research Service. (2002). *2002 rice yearbook* (89001). Washington, DC: USDA ERS. Available on the World Wide Web: http://www.ers.usda.gov/data/sdp/view.asp?f=crops/89001/2002/.

United States Department of Agriculture Economic Research Service. (2003a). *The 2002 farm bill: Provisions and economic implications.* Washington, DC: USDA ERS. Available on the World Wide Web: http://www.ers.usda.gov/features/farmbill/.

United States Department of Agriculture Economic Research Service. (2003b). *Rice production costs and returns, 1975-1999*. Washington, DC: USDA ERS. Available on the World Wide Web: http://www.ers.usda.gov/briefing/farmincome/costsandreturns.htm.

United States Department of Agriculture Economic Research Service. (2004). *Briefing room: Rice.* Washington, DC: USDA ERS. Available on the World Wide Web: http://www.ers.usda.gov/briefing/ rice/background.htm.

Williams, B.J., Strahan, R., & Webster, E.P. (2002). Weed management systems for Clearfield rice. *Louisiana Agriculture*, *45*(3), 16-17. Available on the World Wide Web: http://www.lsuagcenter.com/Communications/LouisianaAgriculture/agmag/45_3_articles/weedmanage.asp.

Acknowledgement

This research was funded by the Giannini Foundation of Agricultural Economics. C. Carter and Y.H. Farzin are members of the Giannini Foundation. We thank the editor and two reviewers for helpful comments.