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Economic and Environmental Impacts of Adoption of Genetically Modified Rice in California

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TABLE OF CONTENTS

TABLES

INTRODUCTION

Increasing chemical use, in conjunction with growing weed resistance and limited options for chemical weed control, has raised costs and depleted the bottom line for many rice producers in California. Many of the restrictions on farm chemical use can be traced to growing recognition of environmental externalities from chemicals used on the land and political pressure from environmental groups. For example, a recent district-court ruling banned the application of 38 pesticides along Northwest salmon streams, and estimates of the economic impact of the decision vary wildly (Welch).[1]

Environmental groups such as Greenpeace oppose the adoption and diffusion of genetically modified (GM) food crops such as GM[2] rice. This opposition is largely based on the uncertainty of potentially adverse health and environmental impacts of GM rice and the lack of labeling requirements for GM foods. This is a potentially ironic position for environmental groups to take, given the possible environmental advantages of GM crops over more conventional varieties that depend heavily on the use of multiple chemicals and applications that may prove more damaging than the corresponding GM regime. This issue is critical in California, where agriculture is intensive and a relatively heavy user of chemicals.

The economic impact on growers from chemical-use regulations depends critically on the number of substitution possibilities available for cost-effective weed control. The more options individual rice growers have to control weeds, the less severe will be the adverse impact of the regulations on grower profits. However, environmental activists, regulators, and the courts view a wide range of available chemicals that have varied environmental risks as undesirable.

In recent years, widespread adoption of GM crops such as herbicide-tolerant (HT) soybeans and canola and pest-resistant [e.g., *Bacillus thuringiensis* (Bt)] corn and cotton has provided growers with new production alternatives that reduce chemical usage. But the new technologies are not without controversy as some consumers (especially in Western Europe) have expressed resistance to purchasing foods made from transgenic materials. In California, environmental groups and organic-rice farmers are also opposed to any cultivation of GM rice in the state.

This report examines these issues in the context of California rice production. In particular, we estimate the potential economic impacts of one alternative weed-management strategy, namely, cultivation of HT transgenic rice. Potential grower benefits, measured by net returns over operating costs per acre of first-year adoption, are calculated using a partial-budgeting approach[3] based on a representative cost structure. Sensitivity analysis is then utilized to account for the heterogeneity in growing conditions across the state as well as uncertainty regarding yields, technology fees, and government assessments on transgenic seed. To augment these results, the partial-budgeting approach is applied to data from an independent three-year field trial designed to evaluate alternative herbicide regimes, including one transgenic rice cultivar. Potential environmental benefits of the technology are also discussed.

The report proceeds as follows: The next section reviews available information on transgenic rice (also known as GM) and describes the potential impacts of grower adoption in California, including market-acceptance issues. We then describe our methodology and present results for a typical California

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[1] Welch reports that a U.S. Department of Agriculture study estimates damages to fruit growers in Washington and Oregon at $100 million per year while a U.S. Environmental Protection Agency study estimates the total impact to be less than $5 million in Washington, Oregon, and California with most of that borne by California rice farmers. These studies assumed a ban on a greater number of chemicals than was actually enacted.

[2] We use the terms GM, herbicide-tolerant (HT), biotech, and transgenic rice in this report. Our empirical analysis is focused on HT rice but these results have implications for all GM crops in California and the biotech industry in general.

[3] The partial-budgeting approach is a static methodology that breaks returns per acre into revenue and cost components for each production alternative (see the section on cost-approach methodology for more details).

rice producer. Next, a range of estimated impacts based on alternative yield differentials and technology fees is presented, followed by a Monte Carlo analysis. The subsequent section provides an economic analysis corresponding to the three-year field study. Environmental regulations for rice production and potential environmental impacts of the new technology are then evaluated, and the final section discusses the limitations of our analysis and concludes.

TRANSGENIC RICE AS A POTENTIAL COST-MANAGEMENT TOOL

In 2003, California rice growers harvested 495,000 acres of rice, which yielded 39.6 million hundredweight (cwt), constituting about 16.5 percent of acreage and 20 percent of total rice production in the United States (Childs). The vast majority (96.2 percent) of California's rice is of the medium-grain variety while the southern U.S. states (Arkansas, Louisiana, Mississippi, and Texas) primarily produce long-grain varieties. Over the last several years, there has been no discernible trend in California acreage planted or in total volume of production.

World rice prices, on average, have been on a decreasing trend[4] and, simultaneously, California growers have faced increasing production costs, especially in the area of weed management [U.S. Department of Agriculture (USDA), Economic Research Service (ERS) 2002]. The top three weeds in California rice production are barnyardgrass, watergrass, and sprangletop while various other broadleaf plants, grasses, sedges, and cattails affect production [Gianessi et al.; California Rice Commission (CRC) 2003]. Interestingly, red rice, a weed of the same genus and species as domesticated rice, is not a major problem in California despite being the number one weed in Louisiana, Arkansas, and Missouri (Gianessi et al.). The combined effect of lower prices and higher production costs has put downward pressure on California rice grower returns and led to considerable research efforts to improve overall weed management through cultural, chemical, and other management means.

In California, both chemical (herbicide) and nonchemical (flooding, tillage, and management) techniques are used for weed control (CRC 2003). Recently, however, California rice production has experienced what has been called an "epidemic" of herbicide resistance, especially from watergrass, which has resulted in herbicide costs increasing to close to $200 per acre for some growers (Fischer 2002).[5] As such, technologies that allow for a small number of applications of chemicals where efficacy is not affected by the resistance problem, as would most likely be the case for HT rice, have the potential to significantly lower this component of rice production costs.

There are currently no commercialized GM rice varieties anywhere in the world. However, many transgenic varieties are in the "development pipeline," including HT, insect resistant (Bt), bacterial and fungal resistant, and nutrient-enhancing "Golden Rice," which produces beta-carotene, a substance that the body can convert to Vitamin A. A nontransgenic but genetically altered variety called Clearfield® IMI by BASF, a mutated HT variety, was released in the United States in 2002 (Williams, Strahan, and Webster). Approximately 200,000 acres of Clearfield® were planted across the Southeast in the 2003 growing season, accounting for about 8 percent of the seeded area in that region (*Delta Farm Press*).

Countries that are major rice producers and consumers, including China and Japan, are rapidly developing and testing GM rice varieties (Brookes and Barfoot). For instance, China has approved for environmental release three insect-resistant rice varieties and four disease-resistant varieties and is developing HT, salt-tolerant, and nitrogen-fixing cultivars (Huang and Wang; Huang, van Meijl, and van Tongeren). Many of these varieties have the potential to be of value to producers through reduced disease or pest-control costs and to the environment through reduced use of chemicals, thereby reducing runoff and water pollution. China will likely be one of the first countries in the world to commercialize GM rice.

In the United States, the two most widely visible, potentially commercially viable transgenic rice cultivars are Roundup Ready® rice by Monsanto and LibertyLink® by Bayer CropScience (previously

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[4] Average market prices for all rice types fell from $9.96 per cwt in 1996–97 to $4.22 per cwt in 2002–03. However, market prices have since risen to an average of $7.25 per cwt in 2003–04.

[5] National average chemical costs for rice production that includes herbicides were $49.44 per acre in 2001, as compared to $79.11 in California, according to USDA, ERS data in *Rice Production Costs and Returns, 2001–2002*. The $200 figure was provided by Hill and is supported with calculations provided in this report.

Aventis) (Gianessi et al.). Both are HT varieties—the former is resistant to Roundup® (glyphosate) and the latter to Liberty® (glufosinate ammonium), both nonselective herbicides able to control a broad spectrum of weeds (Gianessi et al.). Glyphosate is currently registered for rice in California but not widely utilized while glufosinate is not registered [California Department of Pesticide Regulation (DPR)]. As such, it is unlikely that local weeds have developed a natural resistance to these chemicals, unlike, for example, bensulfuron methyl (Agbios; Hill). In 1999, LibertyLink® rice cleared biosafety tests by USDA's Animal and Plant Health Inspection Service (APHIS) but is not commercially available at this time (Agbios).[6]

The primary direct effects of HT transgenic-rice adoption on the cost structure of California rice growers are reductions in herbicide material and application costs and the likely increased cost of transgenic seed. An HT cultivar differs from conventional seed in that a particular gene(s) has been inserted into the rice plant that renders the species relatively unharmed by a particular active chemical ingredient, thus allowing application of broad-spectrum herbicides directly to the entire planting area (Fernandez-Cornejo and McBride 2002; Gianessi et al.). This has the potential to simplify overall weed management strategies and to decrease both the number of active ingredients (AI) applied to a particular acreage and the number of applications of any one herbicide, thus decreasing weed-management costs. Reduced chemical use provides the major cost saving for growers. Similarly, herbicide application costs per acre depend on the specific chemical(s) involved and the means of application.[7] Typically, application by ground is 60 to 80 percent more expensive than aerial applications (Boyd; Williams et al. 2001). For this study, other pest-management practices and fertilizer applications are assumed not to change with adoption of HT rice.

The cost of transgenic rice seed will be greater than that of conventional seed because companies that sell transgenic varieties typically charge a premium (referred to here as a technology fee) to recoup their research investment costs.[8] Based on Roundup Ready® corn and soybeans (a single-gene technology currently on the market) as a reference point, the technology fee is approximately 30 to 60 percent of conventional seed costs per acre (Annou, Wailes, and Cramer; Gillam). Seed price premiums are in a similar range for Bt corn varieties (Benbrook). In addition to the technology fee, seed costs for transgenic rice will likely change as a result of the California Rice Certification Act (CRCA) of 2000 (California Assembly Bill AB 2622) signed by Governor Gray Davis in September 2000. With the full support of CRC,[9] the CRCA provides the framework for a voluntary certification program run by the industry, offering assurances of varietal purity, area of origin, and certification of non-GM rice (CRC 2002a).

A second, mandatory provision of the CRCA involves classification of rice varieties that have "characteristics of commercial impact," defined as "characteristics that may adversely affect the marketability of rice in the event of commingling with other rice and may include, but are not limited to, those characteristics that cannot be visually identified without the aid of specialized equipment or testing, those characteristics that create a significant economic impact in their removal from commingled rice, and those characteristics whose removal from commingled rice is infeasible" (AB 2622, p. 3). Under this legislation, any person selling seed deemed to have characteristics of commercial impact, which would include any

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[6] Bayer CropScience is currently projecting commercial release of the technology around 2007 (Mitten).

[7] An additional consideration may be the water level at time of application. For example, herbicides that require drained fields may involve higher costs associated with draining and reflooding of fields at certain stages of growth. These costs are not likely to be substantial under most circumstances and were assumed away here.

[8] At the retail level, the term "technology fee" typically refers to the "technology user agreement" associated with Monsanto's practice of charging a fee per acre to growers of Roundup Ready® crops that is 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 and/or the price of the associated herbicide. In this study, the technology fee can be regarded as the seed price premium.

[9] CRC, established by California law, is composed of producers and handlers of rice. Its express purpose is developing and managing a national and international promotional campaign for the California rice industry and engaging in educational activities and research regarding the industry and its products.

transgenic cultivars, must pay an assessment "not to exceed five dollars per hundredweight." This fee is currently assessed at \$0.33 per cwt with specific conditions for planting and handling divided into two tiers (AB 2622; CRC 2002b).[10] In addition, the first handler of rice having these characteristics will pay an assessment of \$0.10 per cwt (AB 2622). The \$0.33 seed assessment is approximately 2.4 percent of average seed costs while the \$0.10 fee represents 1.5 percent of average output price.[11] A portion of these assessments is likely to be passed to the grower, depending on the relative elasticities of supply and demand in the seed and milling markets.

In addition to generating cost savings, cultivation of HT rice will affect revenues as well. Net returns will be positively correlated with transgenic yield improvements. HT crops are not engineered to increase yields; rather, they are designed to prevent yield losses arising from pest or weed infestation. As such, potential yield gains depend on the degree of the pest and/or weed problem and the efficacy of the HT treatment relative to the alternatives. Many adopters of transgenic corn, cotton, canola, and soybeans have experienced positive yield effects on the order of 0 to 20 percent (Marra, Pardey, and Alston; Gianessi et al.; McBride and Brooks; Fernandez-Cornejo and McBride 2000). However, under more ideal conditions, a yield drag may occur if the cultivar exhibiting the genetic trait is not the highest-yielding variety or if the gene or gene-insertion process affects potential yields (Elmore et al.). Field tests of LibertyLink® in California have generally found a yield drag of between 5 and 10 percent relative to traditional medium-grain M-202 varieties (Fischer 2002; McKenzie). Similar results were found for HT soybeans at the time of their introduction (Elmore et al.; Benbrook). To the extent that a yield drag actually exists in the field, it is expected to quickly dissipate over time as a greater number of varieties with the HT trait become available.

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[10] Tier I rice currently includes A-201, A-301, Calmati 201, Akita Komachi, Calhikari 201, Calmochi 101, Calpearl, Hitomebore, Koshihikari, NFD 108, NFD 109, SP-2, Sasanishiki, Surpass, WRS-4431, Arborio, and Calriso. Tier II rice includes Black Japonica and Wehani (CRC 2002b).

[11] Based on an output price of \$6.50 per cwt.

MARKET ACCEPTANCE OF TRANSGENIC CROPS

Another effect of GM rice cultivation on California growers' returns is the potential development of price premia for conventional medium-grain rice varieties in world rice markets. Despite the predictions and evidence of producer financial benefits from transgenic crops, there is demand uncertainty in world grain markets, especially in the European Union (EU) and Japan (Foster, Berry, and Hogan). Although challenged by many of the major transgenic-crop-producing countries (the United States, Argentina, and Canada), the EU has prohibited imports of new GM crops.[12] Many other countries have varying GM-crop threshold labeling regulations, including China, Japan, the Republic of Korea, the Russian Federation, and Thailand (Carter and Gruere; Foster, Berry, and Hogan). These regulations have the potential to ensure that there is some demand for non-GM grain. Due to segregation requirements and the higher unit cost of production of non-GM crops, this introduces the potential for a price premium for non-GM rice. As a result, nonadopters may indirectly benefit from the introduction of transgenic rice.

There is good evidence that foreign regulations (especially in the EU) have affected export demand for transgenic crops, but there is mixed evidence of price premia for traditional non-GM grains. For example, after the United States started growing GM corn, EU (unprocessed) corn imports from the United States dropped from 2.1 million metric tons in 1995 to just under 22,000 metric tons by 2002 [USDA, Foreign Agricultural Service (FAS) 2003b]. Notably, however, the gap in U.S. corn sales to the EU was filled by Argentina, a transgenic producer that only grows varieties approved by the EU (Foster, Berry, and Hogan). On the other hand, imports of U.S. corn byproducts to the EU have dropped only slightly since 1995 (USDA, FAS 2003b). The U.S. GM soybean export share in Europe has suffered as well, declining by more than 50 percent since 1997 (Phillips and Corkindale). Price premia exist for non-U.S. corn in Japan and the Republic of Korea, traditional soybeans in Japan, and nontransgenic corn at elevators in the U.S., typically ranging from 3 to 8 percent (Foster, Berry, and Hogan). However, there is little evidence for price differentials between the GM and non-GM product in the canola market (Foster, Berry, and Hogan).

The global market for rice differs from the market for soybeans in that the majority of rice sold is for human consumption rather than for animal feed. As a result, the market-acceptance issue is likely to be a key determinant of the success of transgenic rice adoption in California (Brookes and Barfoot). As can be seen in Table 1, the export market for California rice accounts for approximately one-third to one-half of total annual production with Japan and Turkey as the major destinations. California Japonica rice imported by Japan is channeled through a quota system that was negotiated at the Uruguay Round in 1995. Most of California's rice exports are purchased by the Japanese government and used for food aid and for other industrial uses, including food and beverage processing (Dyck; Fukuda, Dyck, and Stout). Only a small portion of this imported high-quality rice is released into the domestic Japanese market (Dyck; Fukuda, Dyck, and Stout). Turkey is reportedly attempting to severely restrict imports of transgenic crops through health regulations, despite importing corn and soybeans from the United States (a transgenic producer), while Japan requires labeling of 44 crop products that contain more than 5 percent transgenic material as one of the top three ingredients (Foster, Berry, and Hogan; Carter and Gruere). Currently, several varieties of HT and viral-resistant rice have entered the Japanese regulatory system for testing but have not yet been approved for food or feed use (USDA, FAS 2003a).

As an illustration of potential market resistance, Monsanto suffered setbacks in Japan in December 2002 when local prefecture authorities withdrew from a collaborative study to develop a transgenic-rice cultivar after being presented with a petition from 580,000 Japanese citizens (*Rural UPdates!*). In 2002, China imposed additional restrictions on transgenic crops, including safety tests and import labeling (Kahn). However, this action may be nothing

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[12] The EU does allow three varieties of insect-resistant corn, one variety of herbicide-resistant corn, and all varieties of herbicide-resistant soybeans (Foster, Berry, and Hogan).

more than a trade barrier to reduce soybean imports from the United States. In addition, China is worried that introducing biotech food crops may jeopardize trade with the EU. Nevertheless, China is not taking a back seat in transgenic crop research, as it has a major ongoing research program on biotech rice and other crops and is predicted to be an early adopter (Brookes and Barfoot).

There is also some skepticism in the United States with regard to GM crops. Aventis was sued in 2000 over accidental contamination of taco shells by transgenic corn that was not approved for human consumption, resulting in an expensive food recall. The company subsequently decided to destroy its 2001 LibertyLink® rice crop (approximately 5 million pounds) rather than risk its potential export to hostile

Table 1. **Production and Export Demand for California Rice, 1999–2002**

	1999	2000	2001	2002
California Rice Production (1,000 cwt)				
Long Grain	340	639	1,001	448
Percent of U.S.	0.2%	0.5%	0.6%	0.3%
Medium Grain	32,850	40,400	35,939	41,085
Percent of U.S.	65.0%	67.9%	78.0%	78.7%
Short Grain	3,500	2,482	1,550	1,456
Percent of U.S.	96.6%	95.4%	96.3%	96.0%
Total	36,690	43,521	38,490	42,989
Percent of U.S.	17.8%	22.8%	18.1%	20.4%
California Rice Exports				
Total California Exports (1,000 cwt)	12,927	13,812	18,929	18,871
Percent of California Production	35.2%	31.7%	49.2%	43.9%
Percent of U.S. Rice Exports	14.5%	16.6%	20.0%	15.1%
Major Destinations (Percent of Total California Exports)				
Japan	74%	68%	59%	53%
Turkey[a]	10%	12%	11%	15%
Uzbekistan	NA	NA	6%	8%
EU-15 (European Union)	NA	NA	4%	NA
Taiwan	NA	NA	NA	13%
Korea	NA	NA	NA	6%
U.S. Rice Imports (1,000 cwt)				
Total Imports	10,105	10,850	13,191	14,830
U.S. Rice Domestic Disappearance (Percent of Total Use)				
Direct Food Use (Including Imports)	62.6%	62.1%	60.0%	60.2%
Processed Foods	22.2%	22.6%	24.5%	24.7%
Brewers' Use	15.2%	15.3%	15.6%	15.1%

[a] In August, 2003, the Turkish government ceased issuing import licenses for rice imports due to large domestic supplies.

NA = Not Available.

Notes: A subsequent policy enacted in April 2004 requires purchasers of domestic rice to obtain an import license.

Sources: USDA, ERS 2003a; University of California Agricultural Issues Center; USDA, FAS 2004.

nations (*Houston Chronicle*). Kellogg Company and Coors Brewing Company have publicly stated that they have no plans to use transgenic rice in their products due to fears of consumer rejection, and several consumer and environmental groups favor labeling of foods made from transgenic crops (*CropChoice News*). For most food and beverage products manufactured by these companies, however, rice accounts for a small input cost share, resulting in little financial incentive to support GM crop technology. In May 2004, Monsanto announced that it was pulling out of GM wheat research in North America, partly due to consumer resistance. This has important implications for commercialization of GM rice because both grains are predominantly food crops.

Many California rice farmers are concerned over the confusion regarding GM crops and do not want to jeopardize export market sales. This fear has been exacerbated by Measure D on the November 2004 ballot in a major rice-producing county (Butte) that would have prohibited farmers from growing GM crops.[13] A 2001 survey of California growers performed by the University of California Cooperative Extension (UCCE) showed that, of the respondents, 24 percent planned to use transgenic varieties, 37 percent would not, and the remainder were undecided (UCCE 2001a). Of those growers who answered "no," 78 percent responded that market concerns were a reason. Nevertheless, if profitability at the farm level increases, it is likely that a subset of California producers will adopt the technology (Fernandez-Cornejo and McBride 2002; Marra, Pardey, and Alston; Fernandez-Cornejo, Klotz-Ingram, and Jans). Presumably, those with the most significant weed problems and hence the highest costs would be the first to adopt.

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[13] The Butte County measure, along with similar measures in San Luis Obispo and Humboldt counties, were defeated. However, Marin, Mendocino, and Trinity counties currently ban growing GM crops.

COST-APPROACH METHODOLOGY AND DATA

Cost-Approach Methodology

This study uses a partial-budgeting approach to estimate changes in net returns over operating costs for the average rice producer in California's Sacramento Valley if the grower adopts transgenic HT rice. This approach has been used in a variety of *ex ante* studies for a number of transgenic crops (Annou, Wailes, and Cramer; Gianessi et al.; Fulton and Keyowski; Alston et al.). In addition to the basic analysis, we provide sensitivity analysis by varying yields, technology fees, and CRCA assessments using deterministic assumptions. We also use Monte Carlo methods to represent the stochastic nature of yields and output prices. We use returns over operating costs (not including overhead) as the measure of producer welfare.

We do not consider general-equilibrium market effects (potential price and quantity changes) that might occur with widespread technology adoption and domestic and foreign market acceptance. These effects could be estimated using marginal welfare models such as those in Lichtenberg, Parker, and Zilberman and in Sunding, assuming perfect substitutability between transgenic and conventional rice in the eyes of consumers and utilizing predictions of adoption rates both within and outside California. Such an analysis is outside of the scope of this study, though the potential of these market effects to change both consumer and producer welfare should be noted. Instead, our analysis focuses on the decomposition of the marginal cost effects of a representative transgenic rice adopter in the short run, thus allowing for detailed comparisons between producers with heterogeneous cost components.

To illustrate the partial-budgeting approach used here, let π_i represent expected per-acre returns over operating costs for the i^{th} technology [i = conventional (C) or HT] at the time of adoption. Specifically, let

$$(1)\quad \pi_i = (P_i - c)\,Y_i + GP - FC - SC_i - HC_i - IC_i - CRC_i,$$

where P_i is the farm-level price of type i rice; c is the yield-dependent cost of production per acre for both varieties; Y_i is the per-acre yield of the i^{th} rice; GP and FC are U.S. government payments and fixed costs per acre, respectively, and are not technology dependent; SC_i, HC_i, and IC_i are seed costs, herbicide material and application costs, and interest costs per acre for the i^{th} rice; and CRC_i is additional assessments per acre due to the CRCA. Subtracting returns from conventional rice cultivation from those from HT rice, we obtain

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

Equation (2) illustrates each of the aforementioned potential adoption impacts on the net returns of an HT grower. The $(P_{HT} - c)(Y_{HT} - Y_C)$ term on the right-hand side is the value from the yield effect, $-(P_C - P_{HT})Y_C$ is the effect of the price premium, and the remainder of the term is the cost effect of the technology.

To present the results, we first set the yield gain or loss, price premium, additional seed cost, and CRCA effects equal to zero as in Annou, Wailes, and Cramer so that only herbicide material and application costs and interest effects are captured. These results provide a base estimate of the economic rents associated merely with HT technology. Sensitivity analysis can then be conducted to predict the appropriation of these rents, as dictated by pricing and taxing schemes, or the aggregate levels of rents, in this case dictated by output price and yield structure. Heterogeneity of land, resources, and management ability can also be addressed in this manner.

We use two distinct methods to perform the sensitivity analysis. First, we relax the assumptions of zero yield and seed cost effects by deterministically varying the yields of the HT cultivar and the technology fee of the transgenic seed, assuming both zero and full pass-through of the additional CRCA assessments. This method provides a range of per-acre grower benefits in the presence of heterogeneity, as we suspect that eventual adopters tend to have greater weed pressure and thus would tend to experience significant yield gains from the technology. At the same time, other farmers may experience conditions closer to those in the field trials and thus experience no yield advantage or even a slight yield drag. Furthermore, it accounts for appropriation of the rents in the presence of seed price premia and the CRCA.

The second approach is to specify probability distributions for several of the variables in the equation and use a Monte-Carlo-simulation analysis to obtain an empirical distribution of the benefits of the new technology. Unlike the deterministic analysis, we make no attempt to describe appropriation of the rents between parties (through seed pricing policies and assessments) but rather describe the distribution of the total surplus generated from adoption. As such, we identify the yield of the HT rice cultivar (Y_{HT}), the price of the HT cultivar (P_{HT}), and the price premium of conventional rice over transgenic rice ($P_C - P_{HT}$) as stochastic variables, assume likely distributions based on trial data and past and current experience with transgenic crops, and take 10,000 draws from these distributions to estimate a confidence interval for the change in per-acre net returns from adoption in the presence of uncertainty.[14]

Cost Data

UCCE produces detailed cost and return studies for a wide variety of crops produced in California, including "Rice Only" and "Rice in Rotation." The studies are specific to the Sacramento Valley region where virtually all California rice is produced. Figures on herbicide applications are based on actual use data as reported by DPR and *UC Integrated Pest Management Guidelines* (Godfrey et al.). The most recent study completed for rice is by Williams et al. (2001) and is used as the basis for this study.[15]

As the potential adoption of transgenic rice is unlikely to significantly change farm overhead expenses on average, we focus on returns and operating costs per acre as reported in the sample-costs document. However, given weed-resistance evolution, changing regulations from DPR, and changes in the 2002 Farm Bill, the baseline (nontransgenic) cost scenario is adjusted here to account for changes in herbicide-use patterns, prices of herbicides and rice, and projected government payments. Using information from the 1999 pesticide use report compiled by DPR, the 2001 sample costs assume applications of bensulfuron and triclopyr, both broadleaf herbicides, on 25 and 30 percent of the acreage, respectively, and applications of the grass herbicides molinate and methyl parathion on 75 and 45 percent, respectively, of the acreage. These figures are updated using data from *Rice Pesticide Use and Surface Water Monitoring*, a 2002 report by DPR, as interpreted by the authors. We maintain the assumption of two applications of grass herbicides, although we increase the treated acreage to 80 and 60 percent with one application composed of 40 percent molinate and 40 percent thiobencarb and the other composed of propanil on 60 percent of the acreage. Broadleaf control was adjusted to one application of triclopyr on 45 percent of the total rice acreage. Material and application costs of the herbicides are updated as well using information provided by UCCE (DeMoura). Finally, all cash operations are assumed to be financed at a nominal interest rate of 10.51 percent in accordance with the UCCE sample-costs document (Williams et al. 2001). As such, any change in the cost structure directly affects interest on operating capital, though the magnitude tends to be small. Overall, these updates result in a per-acre cost increase of $17.69 (nominal dollars) over the 2001 cost study.

Estimated farm-level revenues are adjusted as well. To more accurately represent the current world rice market (despite the bullish outlook at the beginning of the 2003 growing season), we assume the market price per cwt at harvest is the average price from 1986 through 2002 of $6.50 with average yields at 80 cwt per planted acre. Government payments are divided into two components: direct payments and counter-cyclical income-support payments as described by USDA, ERS (2003b). In accordance with the 2002 Farm Bill, direct payments are calculated at 85 percent of average yields at $2.35 per cwt. Williams et al. (2001) estimate that growers of approximately 95 percent of planted acres have received this payment in the past, so the total direct payments are multiplied

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[14] An extension of this approach can be found in Bond, Carter, and Farzin.

[15] These costs are quite similar to corresponding cost data for California rice compiled by USDA, ERS as described in a report entitled *Rice Production Costs and Returns, 2001–2002* with the exception that UCCE costs include additional hauling, drying, and storage charges of approximately $145 per acre.

by 0.95. Countercyclical income-support payments are calculated using the ERS formula, which we can summarize as 85 percent of average yields at $1.65 per cwt. Incorporation of these changes results in a $28.01 increase in gross revenue per acre over the 2001 UCCE sample-costs study. The original and adjusted costs and returns per acre are reported in Table 2.

Given the public nature of experimental data on LibertyLink® rice grown in California and the full cooperation of Bayer CropScience through phone interviews and email correspondence, we use this transgenic variety as the basis for our analysis (Mitten). We assume a price for Liberty® (glufosinate) herbicide of $60 per gallon[16] and an application rate of 0.446 pounds of AI per acre [500 grams (g) AI per hectare (ha)] in accordance with the company's projected label recommendations (Mitten). To fully represent the fact that weed infestations will differ across plots, scenarios for transgenic cultivation are presented for both one and two applications of the herbicide on 100 percent of the acreage.

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[16] Promotional materials available for LibertyLink® corn and canola advertise a price of approximately $64 per gallon while a search of retail prices on the internet in September, 2003, uncovered prices as low as $55 per gallon.

Table 2. Costs and Returns of Producing Conventional and LibertyLink® Transgenic Rice in Dollars per Acre

	UCCE Returns 2001[c]	Adjusted UCCE Returns	Projected LibertyLink® Rice Returns	
			One Application	Two Applications
Gross Value of Production				
Primary Product, Rice	$640.00	$520.00	$520.00	$520.00
Farm Bill Provision	116.00	264.01	264.01	264.01
Total Gross Value of Production	**$756.00**	**$784.01**	**$784.01**	**$784.01**
Operating Costs				
Seed	$21.00	$21.00	$21.00	$21.00
Fertilizer	71.44	71.44	71.44	71.44
Insecticide and Fungicide	14.82	14.82	14.82	14.82
Herbicide[a]	68.70	83.69	16.03	32.05
Purchased Irrigation Water	59.13	59.13	59.13	59.13
Equipment Rent	14.67	14.67	14.67	14.67
Custom Operations[b]	66.12	68.13	63.70	75.70
Contract Operations	143.80	143.80	143.80	143.80
Labor	59.46	59.46	59.46	59.46
Fuel, Lube, and Electricity	50.39	50.39	50.39	50.39
Repairs	13.00	13.00	13.00	13.00
Interest on Operating Capital	15.04	15.73	12.91	13.90
Assessment	7.20	7.20	7.20	7.20
Total Operating Costs per Acre	**$604.78**	**$622.47**	**$547.56**	**$576.57**
Net Returns above Operating Costs per Acre	**$151.22**	**$161.54**	**$236.45**	**$207.44**
Net Returns above Operating Costs per Hundredweight	**$1.89**	**$2.02**	**$2.96**	**$2.59**
Supporting Information				
Price (dollars per cwt at harvest)	$8.00	$6.50	$6.50	$6.50
Yield (cwt per planted acre)	80	80	80	80
Farm Bill Provision Payments				
Direct Payments	$116.00	$151.81	$151.81	$151.81
Countercyclical Payments		$112.20	$112.20	$112.20
Effective Price per Hundredweight	$9.45	$9.80	$9.80	$9.80

Note: Adjusted UCCE returns incorporate price and chemical-use changes as estimated by the authors and detailed in the text. Projected LibertyLink® returns are estimated under assumptions of one and two applications of Liberty® herbicide on 100 percent of the acres.

[a] Includes chemical material costs only.

[b] Includes chemical application costs.

[c] Source: Williams et al. 2001.

RESULTS AND ANALYSIS

Deterministic Results

A comparison of the costs and returns per acre from producing LibertyLink® and conventional medium-grain rice varieties is provided in Table 2. Compared to the adjusted sample costs reported in the third column of Table 2, the herbicide costs for the new technology are 81 and 62 percent lower in the one- and two-application scenarios, respectively, while total custom-operations costs, including application rates, are 6 percent lower for the one-application scenario but 11 percent higher for the two-application scenario.

The latter result is a direct consequence of the cost differential between ground and air applications of herbicides; ground applications of glufosinate (and propanil products such as SuperWHAM!®) cost approximately $12 per acre while air applications range from $6 to $7.25 per acre (DeMoura). The savings in chemical costs, however, drive the overall cost savings associated with transgenic rice and are explained using the information provided in Table 3. While the price of glufosinate per pound of AI is greater than all of the chemicals under consideration with the exception of triclopyr, the application rate per pound of AI is only 6 to 13 percent of the average herbicide control system. This decreases the cost of herbicide materials per acre by almost 62 percent as shown in the last column Table 2.

When these results are combined, net returns over operating costs increase in the range of $45.89 to $74.90 per acre depending on the herbicide application rate, or $0.57 to $0.94 per cwt. Thus, this baseline scenario, which assumes *perfect* substitutability between medium-grain transgenic LibertyLink® rice and conventional varieties in terms of market acceptance (and, as a result, price) and yields, predicts considerable economic incentives for rice growers to adopt transgenic varieties with similar characteristics due to their increased profitability. It is important to recognize, however, that these results are based on average costs over the entire Sacramento Valley rice-growing region and utilize aggregate data to estimate the conventional herbicide weed-management regime. Individual growers, of course, will most likely differ in regime from these averages depending on the characteristics of the specific operation. Those growers

Table 3. **Per-Acre Chemical Use, Cost, and Gross and Active-Ingredient Application Rates**

	Share per Acre[a]	Gross Application Rate[b]	Active-Ingredient (AI) Application Rate[c]	Price per AI[d]	Price per Acre[e]
Ordram®/Molinate (Grasses)	0.40	30.00	4.50	$13.20	$59.40
Grandstand®/Triclopyr (Broadleaf)	0.45	0.44	0.20	$51.16	$9.98
SuperWHAM!®/Propanil (Grasses)	0.60	14.56	6.00	$8.87	$53.24
Bolero®/Thiobencarb (Grasses)	0.40	26.70	4.01	$14.67	$58.74
Liberty®/Glufosinate (Broad Spectrum)	1.00	2.45	0.45	$35.93	$16.03
Total Conventional Scenario[f]		31.62	7.09	$12.34	$83.69
Total Liberty® – One Application		2.45	0.45	$80.54	$16.03
Total Liberty® – Two Applications		4.90	0.89	$80.54	$32.05

[a] Assumed proportion of treatment area in adjusted UCCE and LibertyLink® scenarios.

[b] Pounds of herbicide per acre as assumed in UCCE (2001b) except for Bolero®, which is set at 26.7 pounds per acre per label.

[c] Pounds of AI per acre as calculated by authors based on label information.

[d] Price of herbicide in dollars per pound of AI applied.

[e] Total price of herbicide chemical per acre (does not include application costs).

[f] Conventional scenario includes applications of Ordram®, Grandstand®, SuperWHAM!®, and Bolero® at the share per acre indicated. Liberty® scenarios assume one and two applications of Liberty® herbicide on 100 percent of the acreage.

Sources: DPR and UCCE (2001b).

with "superior" land, as defined by lower aggregate weed-management costs, would benefit the least from adoption of transgenic rice while those with marginal land or serious weed-resistance problems tend to benefit more from the herbicide-management cost savings offered by the transgenic system and are hence most likely to adopt.

To further investigate these issues, the assumption of perfect chemical substitutability, which essentially drives the assumption of identical yields, can be relaxed. A severely infested plot with a large, resistant seed bank of watergrass or some other weed would likely experience yield increases with adoption of a transgenic control system. Such yield gains have been observed in practice for HT soybeans and HT canola in the range of 0 to 20 percent (Gianessi et al.; McBride and Brooks). However, yields are not necessarily guaranteed to increase for all plots. Under generally ideal conditions, a yield drag of between 5 and 10 percent for medium-grain cultivars of LibertyLink® rice relative to conventional varieties has been observed in California rice field trials. This is consistent with similar field trials of HT soybeans. Such losses would decrease revenues (and some costs, though to a lesser extent) and would thus reduce the increased profitability of adoption of this new technology. Yield drag should not be an issue with most growers given the advanced, widespread state of weed resistance to currently licensed chemicals for rice weed control in the Sacramento Valley. However, it is important to note that, in the short run, a few producers could actually experience a slight yield drag if the new technology was adopted; this is not expected to persist in the long run.[17]

A fall in demand for California rice due to consumer concerns, coupled with increased supply as a result of productivity gains, could cause rice prices to decline over time and decreasing net returns in the presence of yield changes. Similarly, a price premium for nontransgenic rice varieties could erode net-returns differences between traditional and HT cultivars but benefit conventional rice producers. Decreased yields or prices for transgenic rice, *ceteris paribus*, would reduce the gross rents from the technology.

Furthermore, the seller of the transgenic seed is likely to charge a premium of up to 60 percent of total per-acre seed costs, depending on the pricing structure of the technology. Roundup Ready® and Bt seed for commercially produced transgenic crops has historically been priced from 30 to 60 percent higher than nontransgenic varieties, and price premia for LibertyLink® corn seed range from 0 to 30 percent, although average chemical costs per acre are typically greater (Annou, Wailes, and Cramer; Gillam; Benbrook). Furthermore, growers will likely pay at least part of the burden of the fees assessed by the CRCA. Assuming that these effects are constant per cwt of output, they can all be represented as a unit increase in costs in terms of net returns. Increased unit costs of this form, *ceteris paribus*, would alter the *distribution* of the rents between stakeholders (growers, handlers, owners of the technology) but not dissipate gross rents.

As points of reference, base assumptions on price and yields are \$6.50 per cwt and 80 cwt per acre, so gross revenues from sales of rice output are assumed to be \$520. A price premium of \$0.25 per cwt for conventional rice as compared to transgenic rice (about 3.85 percent) with no associated change in yields would thus have the equivalent effect on net returns to the grower of a fee of about \$20 per acre. Note that changing output prices does not affect the cost structure of the average farm operation and, thus, there is a direct, linear relationship between net returns and price. To calculate the impact of these effects, simple subtraction of the product of the price change and yield from the baseline scenario is appropriate.

On the other hand, both a technology fee and the CRCA assessments directly enter the cost structure and, as such, affect interest costs as well. Tables 4 and 5 lay out these effects. A 30 to 60 percent technology fee, assuming a seeding rate of 1.5 cwt per acre and price of conventional seed of \$14 per cwt, is equivalent to \$6.30 to \$12.60 per acre. Total fees assessed as a result of the CRCA would currently be \$8.50 per acre at identical seeding rates and yields of 80 cwt per acre, although it is unlikely that 100 percent of these assessments would be passed to the grower. Table 4 assumes no pass-through to growers of the

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[17] Over time, these differences are expected to dissipate as the technology evolves and more cultivars are bred with the transgenic trait.

legislated fees while Table 5 assumes the maximum pass-through, thus bounding the estimates. Both conservatively assume two applications of glufosinate per growing season.

Without the CRCA legislation, adoption of LibertyLink® rice is profitable for a technology fee of $6.30 regardless of any realistic yield assumptions and profitable at a technology fee of $12.60 per acre so long as yield drag is no greater than 8.9 percent (see Table 4 for more information). With zero yield gains, net returns per acre in this range of seed price premium increase by between 21 and 25 percent over conventional rice returns with even greater benefits for those experiencing positive yield gains. If we assume a small price premium of, say, $0.25 per cwt, the technology is profitable for either yield losses of 7 percent with no technology fee or no yield change with an unrealistic $25.89 technology fee. This highlights the importance of yield and price assumptions on the calculation of net benefits. However, it is clear that, even with a small output price premium and a seed price premium at the upper end of the observed range, the most likely adopters (those experiencing yield gains as a result of increased weed suppression) will benefit from increased returns over costs.

Allocation of maximum CRCA assessments to the grower slightly changes the per-acre benefits but does not affect the qualitative conclusions (see Table 5). Net returns over the baseline scenario with a $6.30 technology fee are no longer positive with an 8.6 percent yield drag nor for a $12.60 technology fee and a 6.7 percent yield drag. However, identical yields still

Table 4. No CRCA Assessment – Sensitivity Analysis of Net Benefits from HT Adoption LibertyLink® Two-Application Scenario and Net Returns of HT Cultivation over Conventional Cultivation

Technology	Percent Change in Yield over Baseline Scenario (Yield Drag)				
Fee per Acre	−10%	−5%	0%	5%	10%
$0.00	8.92	27.41	45.89	64.38	82.87
$2.50	6.31	24.80	43.39	61.77	80.26
$5.00	3.70	22.19	40.89	59.16	77.65
$7.50	1.09	19.58	38.39	56.55	75.04
$10.00	−1.52	16.97	35.89	53.94	72.43
$12.50	−4.13	14.36	33.39	51.33	69.82
$15.00	−6.74	11.75	30.89	48.72	67.21

Note: Net returns of producing LibertyLink® rice with two herbicide applications less net returns of producing conventional rice according to assumptions in Table 2.

Table 5. Maximum CRCA Assessment – Sensitivity Analysis of Net Benefits from HT Adoption LibertyLink® Two-Application Scenario and Net Returns of HT Cultivation over Conventional Cultivation

Technology	Percent Change in Yield over Baseline Scenario (Yield Drag)				
Fee per Acre	−10%	−5%	0%	5%	10%
$0.00	1.26	19.36	37.45	55.54	73.63
$2.50	−1.35	16.75	34.84	52.93	71.02
$5.00	−3.95	14.14	32.23	50.32	68.41
$7.50	−6.56	11.53	29.62	47.71	65.80
$10.00	−9.17	8.92	27.01	45.10	63.19
$12.50	−11.78	6.31	24.40	42.49	60.58
$15.00	−14.39	3.70	21.79	39.88	57.97

Note: Net returns of producing LibertyLink® rice with two herbicide applications less net returns of producing conventional rice according to assumptions in Table 2.

result in net benefits of between $24.50 and $30.80 per acre, more than enough to cover a $0.25 price premium for conventional rice. To bound the per-acre benefits, we assume a lower bound of $0.25 per cwt price premium (a yield drag of 5 percent and a technology fee of $12.60 with maximum CRCA assessment) and an upper bound of no price premium (a yield gain of 5 percent and a technology fee of $6.30) with no CRCA pass-through. Under these assumptions, we conclude that the per-acre benefits of the transgenic HT technology are between −$7.22 and $58.10 for any given California rice grower with a midpoint estimate of $21.90. However, if we restrict attention to those producers most likely to adopt, as defined by at least zero difference in net returns, yield drag at the lower end of the range can be as high as 1.2 percent and they will still adopt.

Stochastic Sensitivity Analysis

The preceding deterministic sensitivity analysis accounts for heterogeneity in land, weed infestation, and management ability as well as for the distribution of the rents generated by the technology. However, the magnitude of these rents is determined primarily through assumptions regarding yield and the price of rice as well as base assumptions on the price of alternative herbicide systems. While these point estimates are based on the best information available, another approach is to parameterize the distributions of those variables, which can be perceived as stochastic, and use Monte Carlo simulations to estimate the distribution of the surplus benefits of the transgenic-rice technology.

We take the specification in the equation and estimate distributions for a transgenic yield premium, the transgenic-rice price, and a conventional-rice price premium. Yields for the HT cultivar are assumed to vary according to a symmetric triangular distribution centered around 80 cwt per acre with a minimum value of 72 cwt (−10 percent) and a maximum value of 88 cwt (+10 percent). This distribution allows for the possibility of yield gains and losses and, with symmetry, tends to be very conservative given the state of weed infestation and resistance across the state. Prices for California rice are essentially determined on the world market and thus are not influenced by the individual producer. Using historical data from USDA for 1986 through 2002, we assume a lognormal distribution for output price with a mean of $6.50 per cwt and a standard deviation of 1.67. Finally, the price premium for conventional rice is assumed to be distributed as a skewed triangular with a most-likely value of $0.25 (3.8 percent), a minimum value of zero, and a maximum value of $0.52 or about 8 percent. These values are consistent with experience with corn, soybeans, and canola cited previously (Foster, Berry, and Hogan).

To run the simulations, the technology fee and all CRCA assessments are set equal to zero and 10,000 draws from the distributions are made for each of four scenarios, depending on which parameters are assumed random. This gives an estimate of the gross surplus generated by the technology before pricing and assessment policies determine the distribution of those benefits. The first and second simulations assume no price premium with yields only and with both yields and price random; the third assumes that

Table 6. Monte Carlo Sensitivity Analysis at 95 Percent Confidence Interval, Per-Acre Benefits

Stochastic Element(s)	All Producers[a]			Yield Gainers[b]		
	2.5%	Median	97.5%	2.5%	Median	97.5%
Yield Only[c]	$17.21	$46.15	$74.59	$46.36	$56.90	$77.01
Yield + Price[c]	13.89	46.03	78.02	46.31	55.87	83.70
Yield + Premium[d]	−8.47	25.94	58.74	15.34	37.54	62.48
Yield + Price + Premium	−10.88	25.77	61.51	14.90	36.76	67.30

[a] "All Producers" defined as triangular transgenic yield distribution with premium +/− 10 percent.
[b] "Yield Gainers" defined as that portion of all producers with transgenic premium between 0 and 10 percent.
[c] Price premium set to zero.
[d] Output price set to mean of distribution, $6.50 per cwt.

yields and the price premium are stochastic with the output price fixed at $6.50 per cwt, and the fourth assumes that all three parameters are random. As per-acre benefits do not vary with output price alone, this scenario is excluded. In addition, each simulation is run for two groups—one that exhibits yields across the entire range of the distribution, labeled "all producers," and one in which attention is restricted to those growers who are expected to increase their yields with adoption of the transgenic crop. This group is labeled "yield gainers" and yields are distributed as a nonsymmetric triangular distribution with a most-likely and minimum value of 80 cwt per acre and a maximum value of 88 cwt (+10 percent). The yield gainers are most likely to adopt the new technology, and results from these simulations may more accurately represent the distribution of benefits among those who actually grow transgenic rice. Results from the Monte Carlo analyses are reported in Table 6.

Under these assumptions, gross benefits from the technology are generally positive except on the lower end of the distributions. Yield gainers, on average, see a return of between $9.84 and $11.60 per acre more than the overall average producer with a slightly smaller variance due to the smaller yield variance assumed for this group. For both groups, introduction of the price premium increases the variability of the benefits by more than the introduction of output price variability. The price premium also reduces the magnitude of the surplus gains by approximately $20 at the median.

Table 6 does not account for CRCA assessments or technology fees, generally bounded between $6.30 per acre (a 30 percent technology fee and no CRCA pass-through) and $21.10 per acre (a 60 percent technology fee and full CRCA pass-through). Although not exact, a "back of the envelope" calculation suggests that median farm-level benefits, after accounting for these fees, are expected to be positive; however, not all farmers will see increased returns. The same is true for yield gainers in that median benefits are greater than $21.10 for each scenario but the lower end of the distribution may experience negative returns from adoption. The majority in each group, however, will benefit.

More specifically, the exact probabilities of net returns greater than zero can be calculated. Assuming all three parameters are stochastic and bounding the fees according to the preceding assumptions, the probability that net returns are greater than zero for all producers is between 60.14 and 85.8 percent. For yield gainers, this range increases to between 89.4 and 100 percent, once again highlighting the importance of yield assumptions on net returns and hence on adoption.

Three-Year Trial

To further test the potential adoption impacts of the LibertyLink® transgenic rice variety, we apply the preceding methodology to the results of a three-year field study conducted by Fischer (2000, 2001, 2002). The study covered growing seasons between 1999 and 2001 and was funded by DPR. The exercise uses the weed-management regimes and corresponding yield measures of the Fischer study, together with the pricing assumptions previously maintained, to estimate net returns for a *hypothetical* farm using identical herbicide rotations.

To elaborate, Table 7 describes the rice-variety and herbicide-treatment regime used in each year of the Fischer study. The project was implemented on a rice field in Glenn County, California, on which watergrass was found to be resistant to molinate, thiobencarb, and fenoxaprop—three of the four chemicals registered in the state to control grass weeds at the time of the study (Fischer 2002). Four treatment regimes were analyzed: continuous molinate each year, an intensive combination of several chemicals each year, a rotate-mode-of-action regime in which chemicals with differing properties were rotated from year to year, and a continuous transgenic regime (LibertyLink®) resistant to glufosinate. Each regime was applied to four plots of 0.57 acres each, and indicator measures such as yields were averaged for each treatment group (Fischer 2002). It is important to note that the choice of treatment regime was not related to economic considerations but, rather, to evaluation of the efficacy of differing treatment regimes under resistance conditions (Fischer 2002).[18]

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[18] More specifically, the authors state that their objective was to "evaluate in a systems approach key management options for reducing herbicide selection pressure towards resistance" (Fischer 2002, p. 6).

Table 7. Seed Type and Treatment Regime of Fischer Field Trial

Regime	Rice Variety	Treatment
Trial Year: 1999		
Continuous Molinate	Conventional M-202	Ordram® (molinate), 4 lbs AI/acre
Intensive Combination	Conventional M-202	SuperWHAM!® (propanil), 4 lbs AI/acre
Rotate Mode of Action	LibertyLink® M-202	Liberty® (glufosinate), 0.36 lbs AI/acre + Ammonium Sulfate, 3 lbs AI/acre
Continuous Glufosinate	LibertyLink® M-202	Liberty® (glufosinate), 500 g AI/ha + Ammonium Sulfate, 3 lbs/acre
Trial Year: 2000		
Continuous Molinate	Conventional M-202	Ordram® 3 lbs AI/acre followed by Ordram®, 2 lbs AI/acre
Intensive Combination	Conventional M-202	Abolish® (thiobencarb), 4 lbs AI/acre + Regiment® (bispyribac), 15 g AI/acre followed by Clincher® (cyhalofop), 210 g AI/ha + SuperWHAM!® 6 lbs AI/acre
Rotate Mode of Action	Conventional M-202	SuperWHAM!® 4 lbs AI/acre followed by SuperWHAM!® 6 lbs AI/acre
Continuous Glufosinate	LibertyLink® M-202	Liberty®, 350 g AI/ha followed by Liberty®, 500 g AI/ha
Trial Year: 2001		
Continuous Molinate	Conventional M-202	Ordram®, 4 lbs AI/acre followed by MCPA[a], 1 pint/acre
Intensive Combination	Conventional M-202	Command® (clomazone) 0.6 lbs AI/acre followed by Regiment® (bispyribac-sodium), 12 g AI/ha
Rotate Mode of Action	Conventional M-202	Command®, 0.6 lbs AI/acre followed by MCPA[a], 1 pint/acre
Continuous Glufosinate	LibertyLink® M-202	Liberty®, 500 g AI/ha

[a] MCPA (aryloxyalkanoic acid) has a variety of trade names, including Agroxone®, Agritox®, Zelan®, Chiptox®, Frasan®, and Vacate®. The particular brand used in the Fischer (2002) study was not documented.

Source: Fischer 2002.

To estimate potential returns over operating costs, the yield and herbicide regime data are used in conjunction with the structure presented in Table 2 to estimate per-acre costs and revenues on a hypothetical farm unit. Herbicides, custom operations, contract operations, interest on operating capital, assessments, and yields vary according to the experimental data while the remainder of the cost components (including a subset of custom operations) are held constant at the levels presented in the first table. Again, to provide a basis for comparison, we set output prices for the transgenic variety equal to the conventional product and the CRCA assessments and technology fee equal to zero.

Table 8 reports the results of the exercise. The first year of the trial included eight plots planted with LibertyLink® M-202 seed (a popular medium-grain variety) treated once with varying levels of glufosinate mixed with ammonium sulfate and eight plots planted with conventional M-202 seed, four of which were treated once with molinate and the remainder of which were treated once with propanil. The continuous-molinate treatment served as a baseline for the entire experiment as the field had demonstrated watergrass resistance to this particular chemical (note the average yield for this treatment).

From an economic standpoint, the intensive-combination regime (propanil) was slightly superior to the two transgenic regimes with net returns per acre approximately 4 to 10 percent greater but less than the yield advantages of 8 to 13 percent. As operating costs for this treatment were higher than those for the transgenic rice, the difference in returns is explained primarily through yield advantages. It should be noted, however, that propanil drift is known to cause significant damage to fruit trees and cotton, and the chemical was banned in some areas at one point in the 1960s (Fischer 2001; Wilson). Both propanil and glufosinate achieved comparable control of the watergrass weed, prompting the authors to conclude that both are "options to control multiple-resistant watergrass. For these treatments to be effective in the long term, [watergrass] seed rain reinfestations still need to be much lower" (Fischer 2000). In other words, to control the weed in the future, multiple applications of each herbicide may be necessary, reducing the profitability of the transgenic system.

In response to this conclusion, the second trial year included two applications of varying chemicals for each herbicide regime with two treatments of propanil on conventional M-202 rice in the rotate-mode-of-action regime and two treatments of glufosinate on the LibertyLink® plots. Two issues with regard to this year warrant mentioning. First, the initial planting of LibertyLink® seed showed poor germination and was reseeded at 17 days after submergence (Fischer 2001). The additional reseeding costs are included in Table 8. Second, the researches mistakenly applied 350 g AI/ha of glufosinate in the first application rather than the recommended 500 g AI/ha. This presumably decreases both yields and costs, *ceteris paribus*, although watergrass control was still estimated at approximately 99.99 percent for this treatment regime (Fischer 2001).

The economic results show that the intensive-combination regime based on herbicide tank mixes is economically inferior with very small returns relative to the others due to relatively large herbicide material and application costs and little yield advantage. The propanil treatments again outperformed the transgenic regime in terms of yields and returns with advantages of 11 and 6 percent, respectively, despite significantly higher herbicide costs. However, seeding costs for the transgenic variety were twice as high (approximately $36 greater) due to the reseeding. The authors of the watergrass study attributed this poor germination to "the experimental nature of the LibertyLink® rice seed used in this experiment" (Fischer 2001). If the same yield results could be obtained without reseeding, the transgenic variety would dominate the alternative treatments with net returns of approximately $237.39, 11.8 percent higher than the next best alternative (the

Table 8. **Three-Year Returns, Costs, and Yields Associated with the Fischer Field Trial**

	Continuous Molinate	Intensive Combination	Rotate Mode of Action	Continuous Glufosinate
Trial Year 1999				
Net Returns per Acre (over Operating Costs)	$31.12	$258.70	$234.73	$249.71
Herbicide Material and Application Costs (per acre)	$60.30	$47.49	$24.98	$28.03
Yields (Hundredweight per Planted Acre)	42.86	89.21	78.94	82.87
Trial Year 2000				
Net Returns (over Operating Costs)	$201.16	$14.88	$212.76	$201.39[a]
Herbicide Materials and Application Costs (per acre)	$70.65	$163.31	$40.17	$28.03
Yields (Hundredweight)	67.60	81.71	77.69	77.69

[a] Additional reseeding due to poor germination resulted in increased costs of $36 for the continuous glufosinate (LibertyLink®) treatment. In the absence of this effect, net returns would be approximately $237.39.

Source: Fischer 2002.

rotation regime). Furthermore, the transgenic regime offered better control of watergrass than the rotational treatment (Fischer 2001).

The 2001 growing season offered the opportunity for the third and final year of the Fischer project. No propanil treatment regimes were included in this final year, and all but the transgenic regimes used multiple applications of chemical herbicides. Given the germination problems in the previous year, the seeding rate of LibertyLink® rice was increased from 1.5 to 2 pounds per acre and these increased costs are reflected in the results presented in Table 8.

Of the four treatment regimes compared in this year, the transgenic variety offered the highest returns—2 percent above the next best option (rotation). The intensive combination offered the highest yields but lowest economic performance due to the high cost of herbicide material and applications. It should be noted that, even with the higher seeding rate, the continuous glufosinate regime with LibertyLink® rice in this final year offered the highest returns of any of the years. Perhaps more significantly, when taken as a three-year program of management, the regime offered returns that were 72 percent, 68 percent, and 1 percent greater than the continuous-molinate, intensive-combination, and rotation-mode-of-action regimes. However, the undiscounted difference between the two best alternatives is $9.20 per acre, part of which would likely be as a technology fee.

The authors of the Fischer study concluded the following in their 2002 final report: “Overall, the use of glufosinate on transgenic LibertyLink® rice has demonstrated its potential as a viable strategy for the control of thiocarbamate-resistant watergrass.” The economic results presented here, based partially on those findings, suggest that a transgenic weed-management strategy can be, at the very least, competitive with alternative pest-control regimes such as herbicide-action rotation. Overall benefits of such a program, however, are subject to individual growing conditions, market acceptance, and the pricing strategy of the technology owners.

ENVIRONMENTAL IMPACTS

Most commercial rice production in the Sacramento Valley region is cultivated under flooded conditions and is heavily dependent on chemical herbicides and insecticides to control weeds and insect pests. Release of the standing water into the Sacramento Valley watershed is thus an important negative externality arising from rice farming and one that may be affected by introduction of transgenic varieties.[19] For example, in the early 1980s, a large number of fish were killed as a result of molinate poisoning in rice water drainage areas while small levels of thiobencarb were found to adversely affect the taste of drinking water (CRC 2003). These findings led to implementation of the Rice Pesticides Program by DPR in 1983 (Newhart). The program was originally designed to reduce molinate and thiobencarb (both herbicides) pollution of local waterways and expanded in the early 1990s to include performance goals for these and the insecticides methyl parathion and malathion and to address damage done by drift and dust from aerial application of herbicides (Newhart; CRC 2003). Other chemicals such as bentazon have been prohibited or at least restricted in geographic use as in the case of propanil (CRC 2003). Furthermore, the Central Valley office of the California Regional Water Quality Control Board passed an amended conditional waiver of waste discharge requirements for irrigated lands in 2003. This waiver tightens quality standards for water released from agricultural uses in the Central Valley as well as requires monitoring and reporting of water quality and implementation of management practices that improve the quality of discharged water. Coverage under the conditional waiver can take the form of a "coalition group" with a common interest, such as the rice industry, and CRC has indicated that a commodity-specific rice waiver is preferred (CRC 2003). Efforts to obtain this specific waiver are ongoing and have been received favorably by the board given the success of the rice pesticides program (Hill).

Many of the chemicals currently registered for use on rice in California require holding periods for floodwaters that range from four to fifty-eight days in length and vary by water-management system (Newhart). Ideally, these programs allow the chemicals to degrade in the water, resulting in ambient concentrations at least 90 to 99 percent less than the initial application (Newhart). While these programs are generally effective in holding ambient concentrations at monitoring stations at or below maximum allowable levels, with some exceptions, significant holding periods can affect water depth and salinity within farms and thus initial establishment of rice plants and yields (Scardaci et al.; Newhart). The program has been quite successful; peak molinate concentrations have been reduced by better than 90 percent in the Sacramento River and Colusa Basin Drain since the beginning of monitoring and thiobencarb concentrations have declined as well, although by a lesser percentage (CRC 2003). It should be noted that peak concentrations are an imperfect indicator as weather events and other sources of variability can significantly affect detectable levels of these chemicals.

The environmental and health effects of leaching and runoff of chemicals in U.S. agriculture are difficult to quantify, primarily due to measurement issues and uncertainty. Approaches to estimation of these external costs vary and include using abatement or clean-up costs directly; developing proxy variables for environmental damage, including pounds of AI applied or indices of chemical properties; and assuming a dollar value per unit of damage. Contingent valuation methods have also been used to estimate consumers' willingness-to-pay to avoid exposure through risk reduction (Brethour and Weersink; Swinton and Williams).

Although admittedly simplistic, one proxy for environmental damage is total pounds of chemicals applied. Based on 2002 acreage and use figures from DPR and the chemical labels, approximately 17.2 million pounds of herbicides were applied that year with 3.86 million pounds of active chemical ingredient. As shown in Table 3, total pounds of chemical herbicides applied per acre are expected to decrease by at least 84 percent with adoption of the HT system and total

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[19] Rice-straw burning, now limited in the Sacramento Valley through permits, contributes to air pollution in the region. However, these externalities are not likely to be affected by introduction of HT rice.

poundage of AI is predicted to decrease by at least 87 percent under the two-treatment scenario. Cultivation of HT rice could thus decrease total herbicide poundage by between 7.27 and 10.9 million pounds and AI poundage by between 1.69 and 2.53 million pounds, assuming 50 to 75 percent adoption. However, this simple measure ignores toxicity, mobility, and persistence of different chemicals in the soil and water that are likely to significantly affect external damage costs (Brethour and Weersink). Similarly, the mandatory water-holding periods currently in place are designed to dissipate the damage done by conventional chemicals.[20]

While this study makes no attempt to further quantify the reduced chemical damages from adoption of transgenic rice, several other projects have addressed the relationship between water quality and HT crops and are summarized in Gustafson. Computer-simulation models used by the U.S. Environmental Protection Agency (EPA) (Wauchope et al.) have predicted lower levels of chemical concentrations in runoff from transgenic corn systems than from conventional corn production. Furthermore, the herbicides used in the transgenic system have a "favorable chemical profile" in that EPA's water-quality standards allow for greater concentrations of these chemicals in water than the traditional herbicides used in conventional corn production (Gustafson, p. 1). Case studies cited in Gustafson for Bt cotton, HT corn, and HT soybeans confirm these results since concentrations of herbicides in watersheds were well below standards for a number of diverse geographic areas.

We conclude that, while most, if not all, pesticides applied in agricultural systems introduce some degree of risk and thus potential damage to the environment, the reduced application rates and chemical properties of glyphosate (Roundup Ready®) and glufosinate (Liberty®) have the potential to further reduce external damage costs from rice production. In addition, production benefits, specifically in terms of yields, may be enhanced if the holding period for floodwater is reduced for the transgenic system due to the lowered toxicity of the associated chemicals. This is in accordance with previous studies that concluded that cultivation of transgenic crops, in general, is consistent with increased environmental stewardship (Carpenter et al.). However, it should be noted that these conclusions are based on the assumption that weeds resistant to currently available chemical controls in California do not exhibit this property towards glyphosate and glufosinate. As with many chemical agents, repeated applications of the same AI on the same plot may result in self-selection of weed varieties resistant to that ingredient, thus potentially reducing the environmental benefits of transgenic-crop cultivation in the long run as producers increase applications or shift to alternative means of control.

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[20] To the extent that holding periods are currently required for conventional production technologies, they are reflected in the earlier analysis.

CONCLUSIONS

This study has used a static, partial-budgeting approach to estimate the potential net economic grower benefits associated with adoption of one cultivar of GM rice in California. Scenarios were developed based on average cost data and actual pesticide-use data, as well as on a three-year field study of herbicide-resistant weeds. Sensitivity analysis was conducted using both deterministic and stochastic methods to represent heterogeneity across growers and uncertainty regarding modeling assumptions. The results suggest that a production strategy including GM rice varieties could lead to significant economic benefits for many growers in at least the near term. Those most likely to benefit from adoption of transgenic rice are growers with relatively high herbicide material and application costs, likely as a result of weed resistance, and those who are restricted to certain chemical agents as a result of state or national regulations. Field-trial results suggested that a transgenic weed-management strategy over multiple years is competitive with a rotational strategy under certain assumptions and dominates a continuous-molinate and intensive-herbicide regime. These findings are generally consistent with *ex post* transgenic crop analyses for corn, soybeans, and cotton, most of which show positive or neutral economic benefits from adoption (Fernandez-Cornejo and McBride 2002; Marra, Pardy, and Alston; Fernandez-Cornejo, Klotz-Ingram, and Jans). In addition, water quality degradation is not likely to occur with transgenic rice adoption as chemical-application rates are expected to sharply decline and the toxicity of the associated chemicals is generally less than more traditional herbicides.

We must point out that this study has certain limitations. First, these results are based in large part on *ex ante* assumptions regarding outputs and inputs, especially the relatively lower cost of glufosinate herbicide per gallon relative to the alternatives. It is expected that Bayer CropScience will set the price of glufosinate in accordance with its portfolio of transgenic crops (primarily canola and corn at present), so the introduction of transgenic rice will not affect the price of this herbicide. However, this is far from certain. Additionally, this study does not account for the response of other chemical producers who may change their pricing strategy in response to the introduction of HT rice cultivars.

Second, this analysis is static or, in the case of the field trial, a sequence of static analyses. Thus, several important elements that have been purposely excluded may impact the conclusions. Among these is the lack of dynamic effects in the model, such as the potential of glufosinate resistance in rice fields through the natural selection process or the effects on watergrass or other weed seedbanks (Carpenter et al.). There has been little evidence of such resistance in the literature; nevertheless, it may become more of an issue if significant adoption occurs.

Third, we assume that GM rice will be accepted by the marketplace, that only a small share of the market will be willing to pay a non-GM price premium, and that the costs of segregating non-GM from GM rice will be modest. By the time GM rice is adopted in California, the political opposition to biotechnology will have likely declined in the state and elsewhere. More importantly, California may not be the first growing region in the world to adopt transgenic rice. If GM rice is first adopted in Asia, then adoption in California will have only a small impact on the market. Clearly, more research is required on the market response to GM rice.

Finally, general-equilibrium price and quantity effects that impact both consumer and producer welfare are not included in this analysis. In a highly differentiated market like the rice market in California, such effects are most likely at the aggregate market level and would impact the estimation of the total surplus lost from banning GM rice. However, we chose to focus our analysis at the agent level (our median representative producer) via the partial-budgeting approach and we reported sensitivity results assuming exogenous market conditions. Therefore, our model does not require forecasting of potential adoption rates or estimating systems of regional supply and demand (or their associated elasticities) for the conventional and biotech markets, thus considerably simplifying the analysis.

Notwithstanding these caveats, we believe that our overall conclusions are robust in that transgenic rice will most likely benefit the California rice industry. Further economic research will sharpen the estimates provided in this report. If, as this study suggests, cultivation of GM rice varieties offers significant economic advantages to growers, there is little doubt that the technology will be embraced by California rice growers.

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