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Producer Surplus Distributions in GM Crops: The Ignored Impacts of Roundup Ready® Wheat

Scott R. Huso and William W. Wilson

Release of a genetically modified (GM) crop variety would lower prices of competing pesticides used on conventional varieties. This causes an increase in surplus for those farmers who adopt the GM variety, as well as for those who plant the conventional variety. A Cournot model was developed to determine the equilibrium quantities of conventional pesticides. A market with conventional wheat was compared to a market with both conventional and GM wheat varieties to identify price decreases of the conventional pesticide as a result of the GM trait introduction.

Key words: genetically modified crops, Roundup Ready®, wheat

Introduction

A major debate has ensued in North American agriculture during the past few years about the potential value of Monsanto's Roundup Ready® (RR) wheat. Monsanto had the trait under review by regulatory agencies in both the United States and Canada and was pursuing plans for commercialization (Wilson, Janzen, and Dahl, 2003). A number of studies quantified the prospective welfare distribution (e.g., Furtan, Gray, and Holzman, 2005; Carter, Berwald, and Loyns, 2004b, 2005) for this trait. Other studies estimated the real option value of RR wheat (Furtan, Gray, and Holzman, 2003; Carter, Berwald, and Loyns, 2004a).

Each of the above studies, as well as the public dialogue, ignored the trait's prospective impacts on equilibrium in the input market. Indeed, a major benefit of the introduction of a GM trait occurs if the trait provides direct competition to, and pricing pressures on, conventional technologies. In this case, not only do adopters benefit, but nonadopters benefit due to these reduced prices. The demand for this GM trait depends on weed pressures, grower idiosyncrasies, and prices. Welfare analysis without attending to these effects would result in an understatement of the benefits.

Weeds compete with wheat for moisture, nutrients, and sunlight. Conventional herbicides are used to kill or stunt weeds and allow the wheat plant to compete and survive, but are limited to specific weeds which may require herbicide mixtures. Combinations of hard-to-kill weeds may force farmers to target certain weeds and allow others to remain. These factors, combined with the possibility of multiple applications of chemicals, affect farmers' demand for the RR technology in wheat.

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Roundup herbicide provides superior control of a broad spectrum of weeds, thus reducing the need for several herbicides and widening the farmer's application window. However, despite these attributes, Monsanto realigned its research portfolio and decided to defer commercialization of RR wheat. Reasons given for the deferment include the decline in spring wheat acreage in the United States, a lack of widespread need for superior weed control in the wheat market, and the success of other traits in Monsanto's research portfolio (Monsanto, 2004, p. 287).

The case of RR soybeans provides insight to the possible price impacts involved with RR wheat. Adoption of RR soybeans has been rapid since 1996, reaching a level of 87% of total U.S. soybean acres in 2005. Reasons for farmers' aggressive adoption range from higher yield, to improved weed control without crop injury, to reduced management time spent to supervise production (Gianessi and Carpenter, 2000; Fernandez-Cornejo and Hendricks, 2003). As noted by Carpenter and Gianessi (2003), from 1995 to 2000, the percentage of U.S. soybean acres treated for each herbicide class, except glyphosate, declined. Imazethapyr use decreased by 32%, trifluralin by 16%, and chlorimuron by 6%. In contrast, the authors found that the use of glyphosate increased from 20% of acres in 1995 to 62% of acres in 2000.

In an earlier study, Gianessi and Carpenter (2000) documented that the price of chlorimuron and imazethapyr declined by 40%–50% in 1997 and 1998, and the price of glyphosate declined by 22% in 1998. Gianessi and Carpenter concluded: "The result of lower priced Roundup Ready treatments in comparison with competitive herbicides and the lowering of the price for key herbicides including glyphosate meant that soybean growers spent significantly less on herbicides in 1998 than in 1995" (p. 62). Indeed, this price reduction may have also limited adoption of RR soybeans and the economic benefits associated with the RR technology.

Not all farmers benefit equally from the release of GM traits, resulting in a "significant heterogeneity of farmers' economic gains linked to the adoption of GM seed" (Lemarie and Marette, 2003, p. 287). Differing plant protection problems and greater profits from using conventional chemical pesticides are two of the major factors limiting the expected adoption and diffusion of GM crops. While adoption rates for commercialized GM crops are observable, this is not the case for a trait that has not been released. Previous studies on RR and other GM wheat varieties used varying approaches regarding adoption rates and technology fees, though these were not their foci.

For example, Johnson, Lin, and Vocke (2005) assumed technology fees at $6/acre and adoption rates at 50%. Carter, Berwald, and Loyns (2004a, b, 2005) assumed 75% adoption rates for GM wheat. Furtan (2005) used a differentiated product trade model and endogenized technology fees and adoption rates. Depending on the scenario, these were in the $6/acre area and adoption rates were 75% to 83%. Wilson et al. (2005) endogenized adoption decisions in a spatial equilibrium welfare model. Results suggested adoption varied internationally and geographically within each country, largely dependent on yields, effectiveness of the trait, and relative location versus non-GM markets.

The purpose of this study is to analyze prospective changes in prices of competing technologies of GM wheat varieties (particularly RR wheat), if and when the trait is introduced, and how this price change affects farmers and agbiotechnology firms. The model incorporates prices of substitutes in adoption choices for a new technology. Stochastic simulation is used to incorporate random variables in the model, representing uncertain outcomes associated with an unreleased product. Random values associated with the release of GM wheat include yield, quality, input costs, and market acceptance. Simulation results reflect the prospective range of outcomes for technology fees and adoption rates.

Price Impacts of GM Adoption on Competing Inputs

This section develops a model to analyze the impacts GM trait introduction has on input prices, adoption rates, and welfare distribution. It builds on the model of Lemarie and Marette (2003), which is based on the 1978 vertical differentiation model of Mussa and Rosen. Adoption of GM seeds affects both output prices and prices of competing inputs. Lapan and Moschini (2000) analyze how an innovator's pricing is affected when the adoption of the innovation may change the price of some other input used by final producers. If input prices were endogenous, the monopolist innovator would price the new input such that both new and old inputs would be used, leading to "pure production inefficiency." Lapan and Moschini use land as the competing input, but Lemarie and Marette argue that the price of land may not be the best explanation for the endogeneity of diffusion because its adjustment may be slower compared to other input prices. Incomplete adoption results from the heterogeneity of farmers and the competition with conventional seed and chemical inputs.

Seeds that are genetically modified to express the RR trait allow farmers to apply the non-selective herbicide (glyphosate) through much of the crop's growth cycle. Consequently, conventional post-emergent herbicides can be substituted with the non-selective herbicide. The RR seed is a complement to the non-selective herbicide, and the bundle [RR seed + non-selective herbicide] is a substitute to the conventional bundle [conventional seed + post-emergent herbicide] (Lemarie and Marette, 2003).

In a market with only a few sellers, pricing and production strategies of any one firm affect industry price and production levels. In the Cournot model, the strategic choice of each firm is quantity and is used in markets where firms make production decisions in advance and are committed to selling all of their output. Because prices adjust more quickly than quantities, each firm sets a price that lets it sell all it produces. Each firm assumes that if a firm lowers its price, it cannot expect to steal customers from its rivals.

Alternative technology choices are indexed by i, where $i = 0$ refers to the conventional plant protection solution and $i = 1$ refers to the plant protection solution based on the use of RR. Technology choice i is supplied by n_i firm(s) which compete(s) on quantity. The marginal production cost of this technology is c_i and the price is p_i (both c_i and p_i are expressed in $/lb.). The conventional and RR inputs are both produced with a constant unit cost ($c_0 = c_1$). This assumption aids in explicitly modeling innovations that take the form of vertically differentiated inputs (e.g., a more productive seed variety). Excluding costs of research and development, production costs of the conventional and RR inputs are assumed to be the same (Lapan and Moschini, 2000).

The farmer pays both the price of the non-selective herbicide (p_1) and a technology fee (or price premium) for the GM seed (p_L). The conventional herbicide price for the non-adopter is p_0. The technology fee is determined by the agbiotechnology firm, which is assumed to have a monopoly with respect to the RR trait at least over the patent period.

The technical efficiency (or production efficiency) for technology choice i is x_i, with $x_1 > x_0$. The farmer's choice between the different plant protection solutions is made on a per acre basis. Farmers are assumed heterogeneous and each has a willingness to pay (WTP) equal to θx_i for technology choice i, where θ represents individual pesticide demand or the intensity of production problems for each farmer, and θ is assumed uniformly distributed between 0 and 1. A farmer with highly intensive weed pressures corresponds to a θ close to 1, while those with less weed pressure correspond to a θ close to 0. Use of technology choice i (at the required per acre dosage of each technology choice, a_i) provides an indirect utility of u_i. The indirect utilities are written as:

$$\text{(1)} \qquad \begin{cases} u_0 = \theta x_0 - a_0 p_0, \\ u_1 = \theta x_1 - a_1 p_1 - p_L. \end{cases}$$

The farmer selects the technology with the highest indirect utility (i.e., adopt RR if $u_1 > u_0$). If the indirect utility for all choices is negative for a given θ, then no product is purchased. The total number of farmers by acreage is denoted by N. In period 1, the biotechnology firm determines the license price; and in period 2, pesticide manufacturers determine quantities they produce (Cournot competition). In period 3, farmers determine various quantities of these inputs to purchase.

Conventional herbicides (i.e., technology choice 0) are used if RR is not chosen or available. A farmer who is indifferent between buying technology choice 0 and buying nothing is identified by the preference parameter $\hat{\theta}$. All farmers with $\theta > \hat{\theta}$ purchase technology choice 0. As θ is uniformly distributed between 0 and 1, the total demand for conventional herbicides is:[1]

$$\text{(2)} \qquad Q_0 = Na_0(1 - \hat{\theta}).$$

Designating $p_0(Q_0)$ as the inverse demand function, the profit for seller k is then:

$$\text{(3)} \qquad \pi_{0k} = \left(p_0(Q_0) - c_0\right)q_{0k}.$$

To determine the profit-maximizing quantity for seller k, the following first-order condition must be met:

$$\text{(4)} \qquad \frac{\partial \pi_{0k}}{\partial q_{0k}} = \frac{x_0}{Na_0^2}\left[Na_0 - 2q_{0k} - \sum_{j=1}^{n_0-1} q_{0j}\right] - c_0 = 0,$$

with all other $n_0 - 1$ sellers being $j = 1, 2, 3, \ldots, n_0 - 1$. Solving for q_{0k} yields:

$$\text{(5)} \qquad q_{0k} = \tfrac{1}{2}\left\{\left[Na_0 - \frac{Na_0^2 c_0}{x_0}\right] - \sum_{j=1}^{n_0-1} q_{0j}\right\}.$$

Under a symmetric Cournot-Nash equilibrium, all sellers of the conventional technology have the same production quantity of technology choice 0, $q_{0k} = q_{0j}$ for any j. Substituting q_{0k} for q_{0j} and solving for q_{0k} leads to the equilibrium quantity for each seller:

[1] Market equilibrium conditions were derived using Mathematica and are available from the authors on request (also see Huso and Wilson, 2005).

(6) $$q_0^* = \frac{Na_0(x_0 - a_0c_0)}{x_0(n_0 + 1)}.$$

Total production equals individual firm production times the number of firms:

(7) $$Q_0^* = q_0^* n_0.$$

Substituting Q_0^* into the inverse demand function and solving for the equilibrium price, p_0^*, gives:

(8) $$p_0^* = \frac{x_0 + a_0c_0n_0}{a_0(n_0 + 1)}.$$

Using q_0^* and p_0^*, solving for the optimal profit yields:

(9) $$\pi_0^* = \frac{N}{x_0}\left[\frac{x_0 - a_0c_0}{n_0 + 1}\right]^2.$$

The farmers' surplus, s_0^*, in the one-product case is represented by:

(10) $$s_0^* = N\left[\left\{\frac{x_0}{2} - \frac{x_0 + n_0a_0c_0}{n_0 + 1}\right\} - \left\{\frac{\hat{\theta}^{*2}x_0}{2} - \frac{\hat{\theta}^*(x_0 + n_0a_0c_0)}{n_0 + 1}\right\}\right],$$

and is comprised of three main elements. N is the total number of acres for wheat production. The first bracketed term is the indirect utility of a farmer with $\theta = 1$, or the highest need for technology choice 0. The second bracketed term is the indirect utility of a farmer with $\theta = \hat{\theta}$, or the lowest level of adoption for technology choice 0. The difference between the two terms is the surplus per acre for farmers who adopt technology choice 0. Multiplying by N gives total farmer surplus. Sector welfare is defined as:

(11) $$W = n_0\pi_0^* + s_0^*.$$

With two competing plant protection solutions including RR, the price for selecting the RR plus non-selective herbicide combination is $p_L + p_1$. A farmer who is indifferent (i.e., receives the same utility) between technology choices 0 and 1 is denoted by $\tilde{\theta}$. Technology choice 1 is used by a farmer with $\theta > \tilde{\theta}$, while technology choice 0 is used by the farmer with θ such that $\hat{\theta} < \theta < \tilde{\theta}$. Since θ is $U[0, 1]$, the demand functions for technology choices 0 and 1 are:

(12) $$Q_0 = Na_0(\tilde{\theta} - \hat{\theta})$$

and

(13) $$Q_1 = Na_1(1 - \tilde{\theta}).$$

The difference between $\tilde{\theta}$ and $\hat{\theta}$ is the difference in demand per acre for technology choice 0. Multiplying by the amount applied per acre (a_0) and the total number of acres (N) gives total demand for technology choice 0. Equation (13) represents these farmers with the greatest need for technology choice 1. Multiplying by a_1 and N gives the total demand for technology choice 1.

Simultaneously solving the two technology choice demand functions for p_0 and p_1, the inverse demand functions are:

$$(14)\qquad p_0(Q_0, Q_1, p_L) = \frac{x_0}{a_0}\left(1 - \frac{Q_0}{Na_0} - \frac{Q_1}{Na_1}\right)$$

and

$$(15)\qquad p_1(Q_0, Q_1, p_L) = \frac{x_1}{a_1}\left(1 - \frac{Q_0}{Na_0} * \frac{x_0}{x_1} - \frac{Q_1}{Na_1}\right) - p_L.$$

Equation (14) shows that the price for technology choice 0 (p_0) is a function of demand for technology choice 0 (Q_0), demand for technology choice 1 (Q_1), and the license price for technology choice 1 (p_L) (because both Q_0 and Q_1 are functions of p_L). The inverse demand function for technology choice 1 [equation (15)] shows that the price for technology choice 1 (p_1) is also a function of Q_0, Q_1, and p_L. Since p_1 represents only the price for the complementary herbicide, p_L must be subtracted to determine the price of the herbicide only.

Substituting the inverse demand functions in the profit functions and maximizing profit for the n_0 and n_1 sellers under a symmetric Cournot-Nash equilibrium leads to the following first-order conditions:

$$(16)\qquad \frac{\partial \pi_{0k}}{\partial q_{0k}} = \frac{x_0}{a_0}\left(1 - \frac{(n_0 + 1)q_0}{Na_0} - \frac{n_1 q_1}{Na_1}\right) - c_0 = 0$$

and

$$(17)\qquad \frac{\partial \pi_{1k}}{\partial q_{1k}} = \frac{x_1}{a_1}\left(1 - \frac{n_0 q_0}{Na_0} * \frac{x_0}{x_1} - \frac{(n_1 + 1)q_1}{Na_1}\right) - p_L - c_1 = 0.$$

The first-order conditions are solved to obtain equilibrium quantities for sellers of each technology choice. These quantities can then be used to determine the equilibrium prices:

$$(18)\qquad p_0^*(p_L) = \frac{a_0 c_0 x_1 n_0 (n_1 + 1) + x_0\big(x_1 + (a_1 c_1 + a_1 p_L - a_0 c_0 n_0) n_1\big)}{a_0\big(-x_0 n_0 n_1 + x_1 (n_0 + 1)(n_1 + 1)\big)}$$

and

$$(19)\qquad p_1^*(p_L) = \frac{\begin{pmatrix} x_1(x_1 + a_0 c_0 n_0 - x_0 n_0 + x_1 n_0) \\ - a_1\big(p_L x_1 (n_0 + 1) - c_1 (x_1 - x_0 n_0 + x_1 n_0) n_1\big) \end{pmatrix}}{a_1\big(-x_0 n_0 n_1 + x_1 (n_0 + 1)(n_1 + 1)\big)}.$$

Equation (18) is the equilibrium price of technology choice 0, and equation (19) is the equilibrium price of the complementary pesticide needed in technology choice 1. If two companies supply technology choice 1 ($n_1 = 2$), one firm is the agbiotechnology firm providing the RR trait while selling the complementary non-selective herbicide, and the other sells only a competitive complementary herbicide. The firm selling only the complementary pesticide does not gain profit from the RR trait itself, but only from the sale of the complementary pesticide.

The price of technology choice 0 before and after the introduction of the new technology can be discerned by comparing equations (8) and (18). Differences are the efficiency of technology choice 1 (x_1), the number of firms producing technology choice 1 (n_1), and the license price for technology choice 1 (p_L). Large differences in technical efficiency between the two technology choices ($x_1 > x_0$), an increase in the number of firms producing technology choice 1, and an increasing license price are reasons that p_0^* will decrease as the market moves from one technology to two technology choices.

Equilibrium prices and quantities determine firm profits:

$$\pi_0^*(p_L) = \frac{N\left(a_0 c_0 x_1 (n_1 + 1) - x_0\left(x_1 + a_1(c_1 + p_L)n_1\right)\right)^2}{x_0\left(x_0 n_0 n_1 - x_1(n_0 + 1)(n_1 + 1)\right)^2} \tag{20}$$

and

$$\pi_1^*(p_L) = \frac{N x_1\left(x_1 + a_0 c_0 n_0 - x_0 n_0 + x_1 n_0 - a_1(c_1 + p_L)(n_0 + 1)\right)^2}{\left(x_0 n_0 n_1 - x_1(n_0 + 1)(n_1 + 1)\right)^2}. \tag{21}$$

Equilibrium quantities, prices, and profits are a function of the license price, p_L, which is determined by the agbiotechnology firm. The agbiotechnology firm gains profit from both the sale of the complementary herbicide to its RR trait and from the license price received from the sale of RR, p_L. Therefore, the profit function for the agbiotechnology firm is calculated as $\pi_B = n_1 q_1^*(p_L)p_L + \pi_1^*(p_L)$. Profit maximization for the agbiotechnology firm with respect to p_L gives the equilibrium license price p_L^* in equation (22), which depends on the number of firms providing technology choice 0 (n_0), the number of firms providing technology choice 1 (n_1), and the level of technical efficiency of each technology choice (x_0 and x_1):

$$p_L^* = \frac{\begin{pmatrix} \left(x_1 + a_0 c_0 n_0 - x_0 n_0 + x_1 n_0 - a_1 c_1(n_0 + 1)\right) \\ * \left(-x_0 n_0 n_1^2 + x_1(n_0 + 1)(-2 + n_1 + n_1^2)\right) \end{pmatrix}}{2a_1(n_0 + 1)\left(-x_0 n_0 n_1^2 + x_1(n_0 + 1)(-1 + n_1 + n_1^2)\right)}. \tag{22}$$

If n_0 increases, competition increases and p_L^* decreases. If n_1 increases, the price of the complementary herbicide decreases, resulting in an increase in p_L^*. If the difference in technical efficiency between the two technology choices decreases, p_L^* will decrease because of the increased competitiveness between the two technology choices.

The surpluses for farmers purchasing technology choices 0 and 1 are defined as follows:

$$s_0^* = N\int_{\hat{\theta}^*}^{\tilde{\theta}^*} u_0 \, d\theta \tag{23}$$

and

$$s_1^* = N\int_{\tilde{\theta}^*}^{1} u_1 \, d\theta. \tag{24}$$

Sector welfare is $W = n_0\pi_0^* + (n_1 - 1)\pi_1^* + \pi_B^* + s_0^* + s_1^*$. Because two technology choices are available, sector welfare is now represented by including the firms producing technology choice 1, as well as those farmers who adopt technology choice 1.

Empirical Model Description and Data

The model is applied to hard red spring (HRS) wheat in North Dakota. The potential release of RR was used to evaluate the prospective impacts on prices of competing conventional herbicides. Players are conventional herbicide-producing firms, the agbiotechnology firm, incumbent firms producing the herbicide that complements the RR trait, and farmers who decide which technology to adopt. The agbiotechnology firm establishes the technology fee (p_L), then all sellers of conventional herbicides and/or RR wheat and complementary herbicide bundles determine quantities (Cournot competition), and finally, farmers determine the quantities of each technology choice to purchase (i.e., adoption). The model begins with only conventional wheat to identify an equilibrium for comparison between input prices to a market with both conventional and RR wheat. Analysis is then done on the market with conventional and RR wheat.

Data are used to represent HRS production in North Dakota. Variables included in the model along with their respective sources (in parentheses) are described as follows:

N = Number of acres annually planted to HRS in the United States (USDA/National Agricultural Statistics Service);

n_0 = Number of firms producing conventional herbicides labeled for use on HRS in North Dakota (Zollinger, 2004);

n_1 = Number of firms producing the complementary herbicide to RR (one of the firms is the agbiotechnology firm) (Zollinger, 2004);

c_0 = Marginal production cost of the conventional herbicide;

c_1 = Marginal production cost of the RR-complementary herbicide solution;

x_0 = Technical or production efficiency of the conventional wheat variety (USDA/National Agricultural Statistics Service);

x_1 = Technical or production efficiency of the RR wheat variety (Blackshaw and Harker, 2002);

a_0 = Required per acre dosage of the conventional herbicide (assuming no multiple tank mixes are necessary) (Zollinger, 2004);

a_1 = Required per acre dosage of the complementary herbicide; and

θ = Idiosyncratic pesticide need for each farmer.

Distributions for yield variables were obtained by using *Bestfit*, a distribution estimation procedure. Table 1 summarizes the base case assumptions. Total HRS acres, marginal cost of production, required per acre dosage, and the number of firms selling conventional or complementary herbicides plus GM technology were assigned values. In the base case, $c_0 = c_1 = 0$. A large portion of the total cost associated with a GM trait is fixed due to extensive research and development over many years, and data do not exist on the value of the marginal cost of production and distribution of a GM seed trait. Following Lemarie and Marette (2003), the base case assumes this value at nil. However, we recognize the marginal cost of production is not nil, and sensitivities are conducted to illustrate the marginal cost of production.

The analytic model is a set of mathematical relationships that determine the value of inputs. Simulations were conducted using *@Risk* to account for randomness in some variables (Palisade Corporation, 2000). Probability distribution functions representing uncertainty are used to define risk. Ten thousand iterations were performed until distributions were adequately filled and simulated results were plausible.

Table 1. Base Case Assumptions

Variable/Parameter	Unit/Value	Logic
N	15.212 million acres	U.S. average HRS annual planting acreage
n_0	1 or 2	Representing monopoly and competition among conventional pesticide firms
n_1	2	Conventional herbicide firm and agbiotechnology firm
$c_0 = c_1$	0	Assumption for simplicity
x_0 (yield used as efficiency)	Mean = 35.81 bu./acre Std. Dev. = 4.14 bu./acre	Reflective of N. Dak. CRD-3 HRS yield over period 1990–2003
x_1 (RR yield efficiency)	11%–14% benefit over conventional yield	Blackshaw and Harker (2002) and Monsanto (2004) field trials across various geographic regions
$a_0 = a_1$	1	Assumption for simplicity
θ	$U[0, 1]$	Farmers with low WTP for GM = 0; farmers with high WTP for GM = 1

Base Case Results

Results are first shown for equilibrium in the conventional technology and then with the introduction of the GM trait. In a market with conventional products only, herbicide-producing firms decide quantity which determines prices. Two simulations were conducted, the first with one competitor and the second with two. Farmers who are indifferent between purchasing the conventional herbicide and buying nothing are indicated by $\hat{\theta}$; therefore, the demand for the conventional herbicide is determined by those farmers whose need is greater than $\hat{\theta}$. Demand (or adoption) for the conventional technology is 1 − 0.5 of total HRS acres (table 2). In simulation 2, competition decreases the price of the conventional herbicide (p_0) from $17.90 to $11.94. The price decrease results in more farmers purchasing the conventional herbicide, as indicated by $\hat{\theta}$ dropping to 0.33. Individual firm profit (π_0) in simulation 1 is $136 million, and under simulation 2 is $61 million (because simulation 2 includes two firms, total firms' profit is $122 million). Farmer surplus (s_0) is $68 and $121 million under simulations 1 and 2, respectively. Sector welfare (W) of $204 million in simulation 1 increases to $242 million under simulation 2.

The prospective release of RR requires a complementary non-selective herbicide (e.g., glyphosate). One agbiotechnology firm provides the RR trait and also sells a complementary herbicide. When $n_1 = 2$, one firm is the agbiotechnology firm and the other sells a competing complementary glyphosate. Simulations 3 and 4 illustrate key changes (table 2).

Introduction of RR wheat would cause a 34% decrease in p_0 from $17.90/lb. to $11.73/lb. in simulation 3. The agbiotechnology firm sets an equilibrium technology fee (p_L) of $7.72/acre in simulation 3, and 34% of the farmers adopt the RR-complementary herbicide bundle. Those farmers who adopt the conventional plant protection technology (such that $\hat{\theta} < \theta < \tilde{\theta}$) represent 33% of the total. There is a shift in firm payoffs and farmer surplus post-introduction of the GM trait. From simulations 1 to 3, the conventional

Table 2. Price Impact Model Results, Conventional and RR

Simulation	Structure	p_0	p_1	p_L	Conventional Adopt	RR Adopt	π_0	π_1	π_B	s_0	s_1	W
		<— ($/acre) —>					<———— ($ millions) ————>					
#1	$n_0 = 1;\ n_1 = 0$	17.90	—	—	50%	—	136	—	—	68	—	204
#2	$n_0 = 2;\ n_1 = 0$	11.94	—	—	67%	—	61	—	—	121	—	242
#3	$n_0 = 1;\ n_1 = 2$	11.73	6.95	7.72	33%	34%	58	18	59	29	98	263
#4	$n_0 = 2;\ n_1 = 2$	8.24	6.24	5.09	36%	30%	29	15	39	57	107	276

Note: Values shown are the means of the distributions from the simulation results.

herbicide firm payoff decreases from $136 million to $58 million, while the payoff to a glyphosate-producing firm is $18 million, and the payoff to the RR agbiotech firm is $59 million post-introduction of RR. Surplus for conventional farmers decreases from $68 million to $29 million from simulation 1 to simulation 3, while the surplus to the farmers who adopted RR is $98 million under simulation 3. Due to the introduction of RR, sector welfare increases by 29% from simulation 1 to simulation 3, from $204 million to $263 million.

The cumulative distributions of prices and license fees are graphed in figure 1. The prospective range in prices for the conventional herbicide, as well as the technology fee, is shown. Results illustrate the impact of uncertainty on the range of potential prices for these traits.

Comparing simulations 2 and 4 (when $n_0 = 2$), the agbiotechnology firm set p_L at $5.09/acre. The price of the conventional herbicide, p_0, decreases by 31% in this case, from $11.94/lb. to $8.24/lb. (table 2). Farmers benefit from competition and product diversity. Farmer surplus increases from simulation 2 to simulation 4, but it is mostly shifted from conventional farmers to those farmers who adopt RR. Conventional farmer surplus decreases from $121 million to $57 million, while surplus to those farmers who adopt RR is $107 million post-introduction of RR. The payoff to the conventional herbicide-producing firm decreases from $61 million to $29 million, while the glyphosate-producing firm has a payoff of $15 million and the agbiotech firm has a payoff of $39 million in simulation 4. Finally, sector welfare increases by 14%, from $242 million to $276 million.

Variations of Surplus

The release of a GM trait, combined with price decreases of conventional technologies, results in adoption of the new technology by some farmers, while others continue using the conventional technology. Variations in surplus (Lemarie and Marette, 2003) were used to compare farmer surplus as the market shifts from conventional wheat to conventional and RR wheat. Farmers with the highest WTP for the RR trait (i.e., farmers with the highest θ) adopt the RR technology. Some farmers continue adopting the conventional protection. Some farmers who did not adopt protection when only conventional protection was available may purchase the conventional herbicide in the new market because of their low need or willingness to pay.

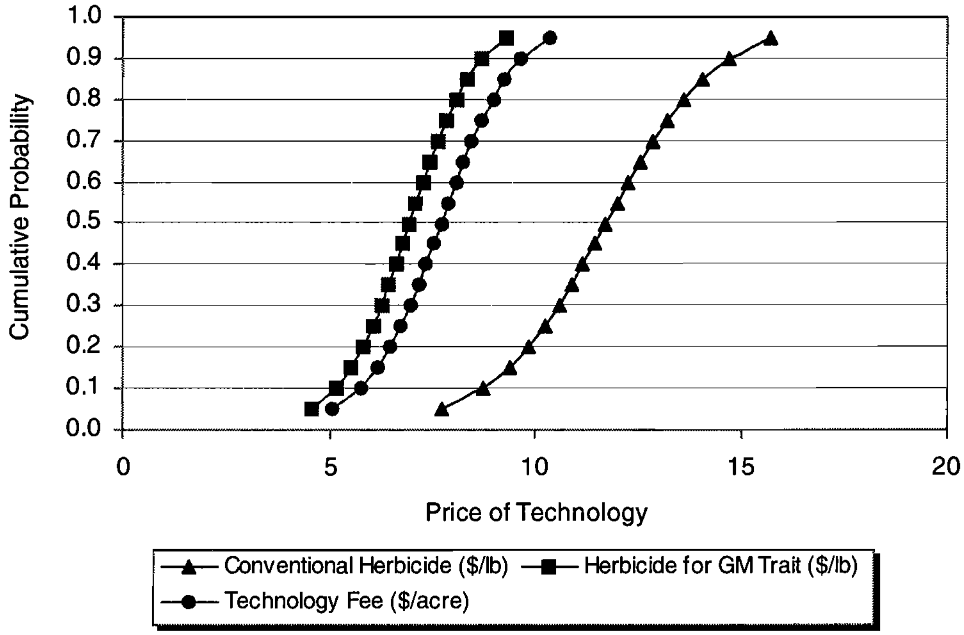

Figure 1. Cumulative distribution of prices in simulation 3

Table 3. Variations of Surplus ($ millions)

Initial Simulation	Final Simulation	$\Delta S_{\phi\to 0}$	$\Delta S_{0\to 0}$	$\Delta S_{0\to 1}$	ΔS	$n_0 * \Delta\pi_0$	$\Delta\pi_1 + \Delta\pi_B$	ΔW
#1	#3	8	15	36	60	-78	77	59
#2	#4	3	20	21	44	-63	53	34

The variations in surplus show the changes in surplus for one group of farmers as the market moves from conventional to conventional plus RR (table 3). Moving from simulation 1 to simulation 3, $\Delta S_{\phi\to 0}$ is the change in surplus of those farmers who purchase no plant protection in simulation 1, then purchase technology choice 0 (conventional herbicide) in simulation 3. In simulation 1, 50% of farmers adopt no protection solution and 50% adopt the conventional protection solution. In simulation 3, 34% of farmers with the highest θ adopt RR, 33% adopt the conventional herbicide, and 33% adopt no protection solution. This indicates that 17% of farmers moved from purchasing no protection in simulation 1, to purchasing the conventional protection in simulation 3 (50% - 33%). Introducing RR, the surplus for the 17% of total farmers who switched from nothing to conventional herbicide increased by $8.1 million.

The surplus to farmers who purchased conventional herbicides in both simulations 1 and 3 ($\Delta S_{0\to 0}$) increases by $15 million (table 3). Conventional adoption was 50% and 33% in simulations 1 and 3, respectively, and adoption of RR was 34% in simulation 3 (table 2). Thus, farmers with the highest WTP for the new technology become adopters in simulation 3. This leaves 16% of farmers purchasing conventional herbicide in both simulations. Therefore, the increase in surplus to those 16% of farmers is a direct result of the price decrease of the conventional herbicide.

The surplus to farmers who purchase the conventional herbicide in simulation 1 and then adopt the RR in simulation 3 ($\Delta S_{0\to1}$) increases by \$36 million (table 3). Adoption of the conventional herbicide in simulation 1 was 50% and adoption of RR was 34% in simulation 3 (table 2). Those 34% of total farmers with the highest WTP for RR are the ones who moved from conventional to RR. So, the change in farmer surplus for those 34% of total farmers was an increase of \$36 million. As observed from table 3, total farmer surplus increased by \$60 million from simulation 1 to simulation 3. Because of the price decrease of the conventional herbicide, the total change in payoff for the conventional herbicide-producing firms ($n_0 * \Delta\pi_0$) was a decrease of \$78 million from simulations 1 to 3. The total change in payoffs for the glyphosate-producing firm and the RR agbiotech firm ($\Delta\pi_1 + \Delta\pi_B$) increased by \$77 million. Thus, sector welfare increased by \$59 million from simulation 1 to simulation 3.

The variation of surplus solidifies the notion that adopters of a new trait are not the only group to gain surplus. In fact, from simulation 2 to simulation 4, the increase in surplus for farmers who purchase conventional protection in both simulations and the increase in surplus for the farmers who move from conventional to RR technology are similar. From simulations 2 to 4, $\Delta S_{0\to0}$ = \$20 million and $\Delta S_{0\to1}$ = \$21 million (table 3). These findings suggest that farmers who continue to use conventional protection post-introduction of an RR wheat variety benefit almost equally compared to those who adopt the new RR variety.

Sensitivities

Number of RR Agbiotech Firms

In the base case, one firm produced the RR technology and the complementary non-selective glyphosate herbicide, while another firm produced competitive generic glyphosate herbicide. An increase in n_1 in the conventional plus RR scenario represents an increase in competition in the production of the glyphosate herbicide.

Monsanto recently experienced these effects in soybeans. It held patents on both the Roundup herbicide and RR trait technology. As the patent on the Roundup herbicide expired, agrochemical firms entered the glyphosate herbicide market to compete with Roundup. For this reason, Monsanto decreased the price of its Roundup herbicide (Burchett, 2004), but captured more rents by increasing the technology fee on its RR soybean varieties because farmers' WTP for the RR trait + glyphosate bundle did not change. This scenario is represented below in the case of RR.

As the number of glyphosate-producing firms increases from two to nine, the price of glyphosate herbicide decreases from \$6.24/lb. to \$1.80/lb., and the price of conventional herbicides decreases from \$8.24/lb. to \$7.13/lb. Because of the decrease in the price of the glyphosate, the agbiotechnology firm increases the license price from \$5.08/acre to \$8.00/acre to capture the remaining WTP of producers for the RR + glyphosate herbicide bundle (figure 2). As competition in glyphosate production increases from two to nine firms, adoption of the RR technology increases from 31% to 40%, and conventional protection adoption decreases from 46% to 40%. The surplus to the farmers purchasing the conventional technology decreases while the surplus to those purchasing the RR technology increases as competition increases. The increased competition results in lower payoffs for both glyphosate- and conventional herbicide-producing firms, while the agbiotech firm that produces the RR technology gains profit from the increase in the license price.

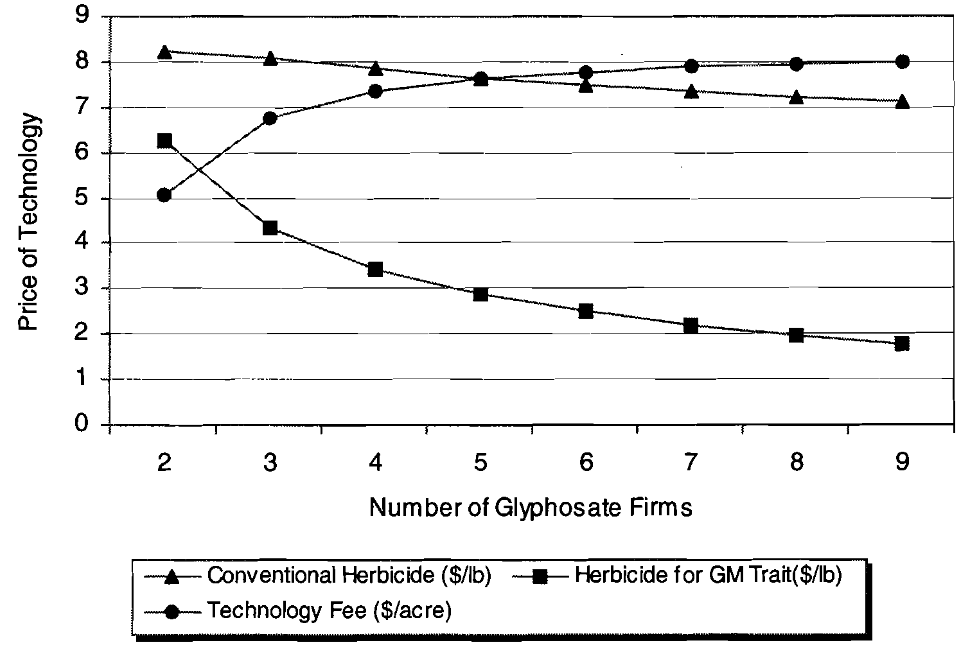

Figure 2. Impact of glyphosate-producing firms on technology prices

Marginal Production Cost of Glyphosate Herbicide

The assumption of no marginal production cost of the glyphosate herbicide was used because the value is unknown. Obviously this is not the case, so sensitivities were conducted to illustrate how the results change in response to changes in costs. As the marginal production cost of glyphosate increases from $1 to $7, the price for glyphosate also increases, from $6.86/lb. to $10.58/lb. (figure 3). This increase in the price of glyphosate causes the technology fee of the RR trait to decrease from $4.77/acre to $2.92/acre because of the increasing cost of the bundle (RR trait + glyphosate). As the price of glyphosate increases, so does the price of the conventional herbicide. As a direct result of the increase in the price of the RR bundle and an indirect result of the increase of marginal production costs, adoption of RR decreases from 29% to 17%, and adoption of conventional technology increases from 47% to 55%. Coinciding with this result, surplus to farmers purchasing the conventional technology increases while surplus to farmers purchasing the RR technology decreases with an increase in marginal production cost. Also, payoffs to firms involved in the production of the RR bundle decrease while profits to conventional herbicide-producing firms increase.

Summary

Release of a GM variety impacts prices of competing pesticides used on the conventional varieties, making the conventional variety less costly than prior to introduction of the GM variety. This causes an increase in surplus for those farmers who adopt the GM

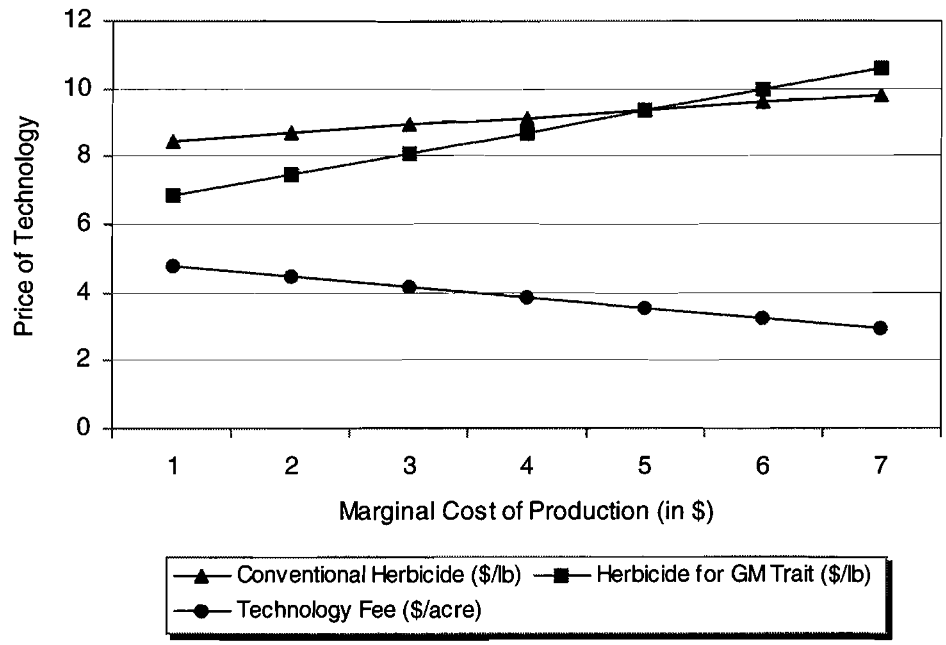

Figure 3. Impact of marginal cost of glyphosate production on technology prices

variety, as well as those who plant the conventional variety, clearly posing strategic questions for agbiotechnology and conventional pesticide firms in their estimates of adoption rates, prices, and profits.

A Cournot model was developed to identify the equilibrium quantities of conventional pesticide and agbiotechnology firms. The agbiotechnology firm established a profit-maximizing technology fee ($/acre) for its GM trait. The market with conventional wheat only was compared to the market with both conventional and GM wheat varieties to determine the equilibrium price changes as a result of the GM trait introduction. Changes in farmer surplus, technology firm payoffs, and sector welfare were also analyzed.

An important contribution of this study is its development of a model to predict price changes of current technologies due to the introduction of a new competing technology. The price impact model is applied to a contemporary problem in GM trait development of HRS wheat. Other prospective GM traits in wheat are under development and will face similar price impact issues. The model used here can also be applied to different GM traits and crops, as well as other problems involving a new technology and its effects on the pricing of an incumbent technology.

The results indicate the release of an RR wheat variety would decrease the price for conventional herbicides. This allows farmers with a low WTP for the GM variety to realize cost savings in the production of conventional HRS wheat. The surplus to those farmers using a conventional variety post-introduction of RR HRS wheat increased by $13 to $20 million. Assuming market equilibrium quantities of the conventional and RR wheat technologies, adoption rates were 47% for conventional varieties, 30% for RR wheat adoption, and 23% for no product adoption. These adoption rates differ from those assumed in previous studies on RR, which were typically in the area of 75%, and the equilibrium technology fees were slightly less than those assumed in other studies—though these are highly dependent on many factors, as illustrated.

Several implications from these results are summarized below:

- First, adoption of a new GM wheat variety may not be as high as expected or as assumed in other studies, due to likely concurrent price decreases of conventional pesticides. The price decrease leads to a lower cost of using conventional varieties and technologies. Some of the farmers who would have adopted the GM variety, if there were no price decrease, do not adopt because of the lower cost of using conventional technology. This price decrease must be included in the determination of potential adoption rates by agbiotechnology firms in their pricing decisions.

- Second, the release of a GM wheat variety results in an increase in surplus for all types of wheat farmers (GM adopters, conventional pesticide adopters, and no technology adopters). GM adopters benefit because of the release of the GM variety. Conventional pesticide adopters benefit due to the price decreases of the conventional pesticides. Farmers who do not adopt any technology prior to the release of GM wheat may adopt the conventional pesticide because of the lower cost.

- Third, the release of a GM wheat variety would result in slightly lower payoffs for conventional pesticide-producing firms but higher payoffs for agbiotechnology firms. Overall, surplus to farmers and conventional and agbiotechnology firms increases due to the release of a GM wheat variety.

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