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Development of GM wheat has not progressed as quickly as other crops. Contributing factors include a combination of complex genetics, market size relative to other crops, exports are of greater relative importance, and import country regulations. In addition, competition among exporting countries would be affected by the need for dramatic changes in the marketing systems to comply with identity preservation needs (Wilson et al., 2003). Several forms of GM wheat are currently being developed. At the forefront in North America are Roundup Ready (RRW) by Monsanto (which has since been deferred), fusarium resistant (FRW) by Syngenta, and drought tolerance. These are input traits because the producer directly realizes the benefits. Introduction of GM traits would likely have the impact of reducing prices of competing conventional technologies.

Wheat competes with weeds for moisture, nutrients, and sunlight. Conventional chemicals 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 use of herbicide mixtures. Combinations of hard-to-kill weeds may limit the farmer 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 Roundup Ready technology in wheat. 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. Monsanto, however, realigned its research portfolio and decided to defer commercialization of Roundup Ready wheat (RRW). Reasons 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).

Another input trait is fusarium resistance in wheat. Fusarium head blight (FHB) is a fungus disease that can occur on all small grain crops, but is most commonly seen in North Dakota on spring wheat, durum, and barley (McMullen and Stack, 1999). Some conventional varieties are labeled "moderately resistant" to FHB, such as Alsen from North Dakota State University (Ranson and Sorenson, 2003). Although Alsen is a conventional variety, it does not prevent FHB infestation. Currently, most farmers use a fungicide (e.g., Folicur®-Bayer) to reduce the susceptibility of the plant to the disease. This fungicide is typically applied at the onset of flowering. However, the window of application is small and for this reason fungicides are not 100% effective. Besides yield reduction, FHB causes reduction in quality resulting in price discounts and quality concerns shared by elevators, food processors, as well as consumers. Fusarium resistant technology would eliminate risks related to fungicide application and quality concerns related to this disease.

Although adoption of GM grains has increased significantly over the past seven years, not all farmers benefit equally resulting in a "significant heterogeneity of farmers' economic gains linked to the adoption of GM seed" (Lemarie and Marette, 2003). Differing plant protection problems and greater profits from using conventional chemical pesticides are two reasons

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that the ceiling of expected adoption and diffusion of GM seeds will be less than 100%. The release of RR soybean in 1996 resulted in a 40% price decrease of two major herbicides, Chlorimuron and Imazethapyr (Gianessi and Carpenter, 2000). This price reduction may have also limited the level of adoption of RR soybeans and the economic benefits associated with the RR technology (Lemarie and Marette, 2003).

Decisions on farmer adoption depend on prospective benefits and costs associated with growing the GM crop variety versus conventional technology. If prices of competing technologies for the GM variety decline, farmers who would otherwise consider planting the GM variety may continue using conventional technologies because of the lower input cost. Such a price decline would also affect the pricing of the new GM technology.

The objective of this study is to analyze prospective changes in prices of competing technologies of GM wheat varieties (particularly FRW and RRW), if and when the trait is introduced, combined with the determination of conditions under which a farmer would adopt a particular GM wheat trait. The model incorporates prices of substitutes in the adoption of a new technology. Stochastic simulation is used to implement random variables into the models representing the uncertain outcomes associated with an unreleased product. Simulation results reflect the prospective range of outcomes without the availability of historical data.

Background

GM Traits in the Pipeline

Commercially available GM crops have traits that are input-oriented and these provide direct benefits to farmers in the form of yield increases, cost savings, or ease of production. In corn, permits were granted for the testing of biotech crops with input-oriented traits that are yield increasing, drought and cold tolerant, fusarium resistant, and herbicide tolerant. Testing of biotech corn with output-oriented traits include seed color altered, starch metabolism altered, protein altered, and lysine level increased. In soybean, new traits include yield increasing, fungal resistant, herbicide tolerant, insect resistant, protein altered, oil profile altered, and fatty acid level altered. In cotton, traits being tested include fiber quality altered, fungal resistant, and herbicide resistant (USDA APHIS, n.d.).

Although no GM wheat varieties are currently available, research and development of GM traits is moving forward. Private firms and public institutions are working to develop different GM traits in wheat. Monsanto and Syngenta are leading the way in GM wheat trait development with herbicide tolerant wheat (RRW-Monsanto) and GM fusarium resistant wheat (FRW-Syngenta) (Wilson et al., 2003). In addition, a number of public institutions are working on drought tolerance.

Commercialization of RRW has been deferred. This was due to "portfolio review and dialogue with wheat industry leaders," and that Monsanto has realized that opportunities associated with RRW are "less attractive relative to Monsanto's other commercial priorities" (Monsanto, 2004, para. 2). Monsanto chose to wait until other GM wheat varieties are introduced before continuing commercialization, which is estimated to happen in the next four to eight years (Pratt, 2004). GM FRW is also expected to near commercialization in the latter part of this decade. Syngenta's anticipated launch of GM FRW was aggressively set for 2007 (Syngenta, 2004). Another, more conservative estimate from Syngenta indicates that GM FRW may be ready for the market in seven years (Pates, 2004). Besides RRW and GM FRW, other GM wheat traits are being developed. Traits that are currently being field tested include those with altered agronomic properties such as drought tolerance, cold tolerance, and yield increases. Other traits include fungal resistance (being tested by ARS, Syngenta, and University of Minnesota), herbicide tolerance (ARS and Monsanto), virus resistance (University of Idaho), and a marker gene (Montana State University). GM traits that constitute product quality alterations include

digestibility improvement (Applied Phytologics and Ventria Bioscience), starch metabolism altered (Biogemma), improved bread making characteristics (Montana State), and several others (USDA APHIS, n.d.).

Impacts of GM Crops on Conventional Pesticides

The global market for conventional agrochemical products was valued at $2.8 billion in 2000. The most significant component of the market was herbicides (51%), followed by insecticides (26%) and fungicides (20%). The largest regional market for agrochemicals was North America (31%), followed by East Asia (24%), Western Europe (20%), and Latin America (18%) (McDougall and Phillips, 2003). The herbicide sector grew at an average rate of 2.5% per year over the period of 1980 to 1999, but the value fell by 4.8% during 1999, mainly because of the increase in adoption of herbicide tolerant crops (McDougall and Phillips, 2003). The largest herbicide class, in terms of value, is amino acids. Within amino acids, glyphosate is by far the most significant chemical, with 2000 sales totaling over $3.12 billion. From 1995 to 2000, the sales of most classes of herbicides decreased from 0.3% to 11.6%. Some classes increased in sales at a small value. The amino acid class has seen a sales increase of 14% from 1995 to 2000. This increase in sales is mainly due to the rapid expansion of the overall non-selective herbicide market. Two factors contributing to this market are the increase in adoption of conservation tillage practices and the increase in acreage of crops that have been genetically modified to be tolerant to key members of the amino acid group (McDougall and Phillips, 2003). The impact of the adoption of GM crops on the use of conventional pesticides has been examined for each commercialized GM crop (Carpenter and Gianessi, 2003).

The effect of these GM varieties on pesticide use was examined by Carpenter and Gianessi (2003). Between 1995 and 2000, the percentage of total corn acres treated for four insecticides targeted at the European corn borer (ECB) decreased marginally. However, use of a newly introduced insecticide, in 1996, increased by 2% over the same time period. Carpenter and Gianessi suggest several possible explanations for the decrease in use of insecticides for ECB. One possible explanation is the introduction of Bt corn varieties and the resulting reduced need for insecticides targeted at the ECB. Another possible reason for the slight decrease in insecticide use from 1995 to 2000 is the relatively light ECB infestations during certain years in the interval. Other reasons include the introduction of new insecticides and a decline in insecticide treatments targeted at pests other than the ECB (Carpenter and Gianessi, 2003).

Cotton is a major pesticide market in the US. The long growing season, higher pest pressure, and high value of the crop require intensive pest management. Cotton growers spend approximately $320 million for herbicides and apply approximately 30 million pounds of active ingredient each year. Use of insecticides on cotton acres in six major cotton producing states decreased by approximately 3.1 million pounds of active ingredient from 1995 to 2000, a decline of 16%. This decline is believed to be directly linked to the introduction of Bt cotton varieties, but it must also be noted that other factors, such as differences in pest pressure from year to year, may also have caused some decline in insecticide use (Carpenter and Gianessi, 2003).

The case of RR soybeans provides insight to the possible price impacts involved with RR wheat. Adoption of the herbicide tolerant soybeans caused price decreases in conventional herbicides for soybeans since the commercial release of GM soybeans in 1996. However, this is not indicative of all herbicide tolerant varieties. It must be noted that herbicide tolerant corn had minimal effect on the overall pesticide market because of its limited adoption.

Adoption of RR soybeans has been rapid since 1996, reaching a level of 81% of total U.S. soybean acres in 2003. 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). From 1995 to 2000, the percentage of U.S. soybean acres treated for each herbicide class, besides glyphosate, declined (Carpenter and Gianessi, 2003). In some cases, the decline was significant. Imazethapyr use decreased by 32%, trifluralin use decreased by 16%, and chlorimuron use decreased by 6%. The use of glyphosate increased from 20% of acres in 1995 to 62% of acres in 2000 (Carpenter and Gianessi, 2003). Using the 1999 Illinois Agricultural Pest Management Handbook from the University of Illinois, Gianessi and Carpenter (2000) found that the per pound cost of chlorimuron and imazethapyr declined by 40% to 50% in 1997 and 1998 and the price of glyphosate declined by 22% in 1998. Gianessi and Carpenter (2000) then determined: "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). In North Dakota, a similar pattern of herbicide price decrease was noted for key herbicides used on conventional soybeans (Pursuit® and Poast®) as well Roundup® herbicide.

Empirical Model Description

An input equilibrium model was developed and applied to hard red spring wheat (HRS) in North Dakota. The prospective release of fusarium resistant wheat (FRW) and Roundup Ready wheat (RRW) are scenarios used to evaluate the impacts on prices of competing conventional herbicides and fungicides after the release of these GM wheat traits. Players are conventional pesticide producing firms, the agbiotechnology firm, incumbent firms producing the pesticide that complements the GM trait, and farmers who decide which technologies to adopt. The agbiotechnology firm determines the license price (p_L), then all sellers of conventional chemicals and/or GM-chemical bundles determine quantities (Cournot competition), and finally, farmers determine the quantities of the two technology choices to purchase (i.e., adoption).

The model begins with only conventional wheat to determine an equilibrium for comparison between input prices to a market with both conventional and GM wheat. The second scenario includes the release of GM FRW along with availability of the conventional variety. This GM wheat trait would not require a complementary pesticide, so there are no sellers of complementary pesticides to this product. Farmers choose between purchasing a conventional wheat variety and applying a fungicide treatment or a GM FRW variety. The agbiotechnology firm providing the GM FRW trait has a monopoly with respect to that trait and receives profits only from the license price for the GM FRW trait. The third scenario is the market with conventional wheat and RRW. RRW requires the application of a glyphosate herbicide. The agbiotechnology firm providing the RR trait has a monopoly on that trait and also sells the complementary herbicide. This firm receives profits from both the license price of the seed, and the sale of the complementary herbicide. Other firms that sell the complementary herbicide do not receive profits from the GM trait, but only from the sale of the herbicide. Total HRS acres, marginal cost of production, required per acre dosage, and the number of firms selling conventional or complementary pesticides plus GM technology were assigned values rather than simulated. In the base case, it was assumed that the marginal cost of production of both GM and conventional varieties is zero. 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. The base case assumes this value to be nil. However, marginal cost of production is not nil and sensitivities are conducted to illustrate the impact of increasing marginal cost of production.

Because of the assumption of no tank mixed pesticides, the use of one or two technology providing firms in the model simplifies the impacts of increased competition in the respective industry and also adds consistency to the analysis. Sensitivities were conducted on the number of firms to more critically detail the impacts of

increased competition. Conventional grass and broadleaf control herbicides that are labeled for use in North Dakota are produced by eleven different firms. Nine firms produce a glyphosate herbicide that is labeled for use in North Dakota (i.e., on burndown, HT soybeans, HT corn, pre-harvest for wheat, etc.). Four firms produce fungicides that are labeled for the suppression of FHB in HRS in North Dakota (McMullen and Bradley, 2004). For simplicity in the base case, one producing firm denotes a monopoly with respect to that product, and two producing firm indicates competition among firms. Sensitivities were conducted to evaluate the effects of more competitors on prices, adoption, profits, and welfare.

The analytic model is a set of mathematical relationships that determine the value of outputs. 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

Base Case Results

The base case provides results for comparison under different possible conditions or changes in parameters. The three scenarios are described individually followed by a comparison.

Market with only conventional products. In the market with conventional products only, pesticide producing firms decide quantity which ultimately determines prices. Scenario 1 is illustrated for both the conventional market with one (simulation 1) and two competitors (simulation 2) in the conventional pesticide industry. Thus, demand (or, adoption) for the conventional technology is 50% (1 - 0.5) of total HRS acres (Table 1). In simulation 2, competition decreases the price of the conventional technology, p_0, from \$17.91 to \$11.94. The price decrease results in more farmers purchasing the conventional pesticide. Thus, demand is 67% (1 - 0.33), of total HRS acres. Individual firm profit, π_0, in simulation 1 is \$136 million and in simulation 2 is \$61 million (simulation 2 includes two firms so total firm profits is \$122 million). Farmer surplus, s_0, is \$68 million in simulation 1 and \$121 in simulation 2. Sector welfare, *W*, of \$204 million in simulation 1 increased to \$242 million in simulation 2.

The production efficiency of GM FRW is analogous to the yield loss prevention quality of the new GM variety. In CRD 3 (northeastern North Dakota), the average HRS yield loss due to FHB over the period 1993-2000 is 18.3%, and we assume the genetically modified FR wheat would provide 100% prevention of the potential losses due to FHB. Simulations 3 and 4 correspond to

Table 1. Price Impact Model Results – Conventional and GM FRW

Sim.	Structure	P_0	P_L	Conv. Adopt	FRW Adopt	π_0	π_B	s_0	s_1	W
		--- \$ per acre ---				---------- \$ million ----------				
#1	$n_0 = 1$ $n_1 = 0$	17.91		50%		136		68		204
#2	$n_0 = 2$ $n_1 = 0$	11.94		67%		61		121		242
#3	$n_0 = 1$ $n_1 = 1$	11.46	15.06	32%	36%	56	83	28	104	271
#4	$n_0 = 2$ $n_1 = 1$	8.44	12.35	47%	30%	30	57	61	103	281

market equilibrium with conventional wheat (being provided by one or two firms) and GM FRW (being provided by a single firm owning the trait patent). The total price of the GM plant protection solution is p_L ($/acre). In the market with two products, the conventional protection solution was adopted by 32% of the farmers, and 32% of the farmers purchased no plant protection. In simulation 4, the adoption of FRW was 30%, conventional technology adoption was 47%, and 23% of the farmers purchased no plant protection.

The agbiotechnology firm sets a license price, p_L, for FRW of $15.06/acre. The availability of FRW results in a price decrease of 36% for the conventional fungicide, p_0, from $17.91 to $11.46. Also, introduction of GM FRW transfers a majority of firm payoffs from the conventional to the agbiotechnology firm. From simulation 1 to 3, payoffs for the conventional firm decrease from $136 million to $56 million (a decrease of 59%) while the payoff to the agbiotech firm was $83 million in simulation 3. Much of farmer surplus shifted to those farmers who adopt the GM FRW. From simulation 1 to 3, conventional farmer surplus decreases from $68 million to $28 million, while the introduction of GM FRW resulted in a farmer surplus of $104 million to those farmers who adopted the GM FRW technology in simulation 3. Farmer surplus increases because of more product choices. Sector welfare increased by 32.8% from simulations 1 to3.

Comparing simulations 2 and 4 (when $n_0 = 2$), the agbiotechnology firm sets a p_L of $12.35/acre and the price of the conventional fungicide decreases by 30%, from $11.94 to $8.44. This lower price allows farmers with a low willingness-to-pay to purchase the conventional fungicide. For this reason, comparing simulations 3 and 4, adoption of FRW decreased while adoption of the conventional fungicide increased. Introduction of the GM FRW results in a shift of the firm payoffs and farmer surpluses. From simulation 2 to 4, payoffs to the conventional firm decreased from $61 million to $30 million, while the agbiotech firm gained a payoff of $57 million after introduction of the GM FRW. Surplus for conventional farmers decreased from $121 million to $61 million from simulation 2 to 4, while the surplus to those farmers that adopted the GM FRW technology was $103 million in simulation 4.

Market with conventional and GM Roundup Ready® wheat. The prospective release of Roundup Ready wheat (RRW) is met by the need for a complementary non-selective herbicide (i.e., glyphosate). In this scenario, one agbiotechnology firm provides the Roundup Ready 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. Production efficiency for RRW is assumed to be the potential yield benefit of RRW over conventional wheat based on various field trials, an 11-14% increase over conventional varieties. Simulations 1 and 2 are shown along with simulations 5 and 6 to illustrate key changes (Table 2).

Table 2 Price Impact Model Results – Conventional and RRW

Sim.	p_0	p_1	p_L	Conv Adopt	RRW Adopt	π_0	π_1	π_B	s_0	s_1	W
	------$ acre-------					---------- $ million ----------					
#1	17.90			50%		136			68		204
#2	11.94			67%		61			121		242
#5	11.73	6.95	7.72	33%	34%	58	18	59	29	98	263
#6	8.24	6.24	5.09	36%	31%	29	15	39	57	107	276

Introduction of RRW causes a 34% decrease in p_0 from simulation 1 to 5, from \$17.90/lb to \$11.73/lb. The agbiotechnology firm sets an equilibrium license price, p_L, of \$7.72/acre in simulation 5. From this, 34% of the farmers adopt the RRW-complementary herbicide bundle. Those farmers who adopt the conventional plant protection technology are 33% of the total. Finally, 33% of the farmers adopt no plant protection solution. There is a shift in firm payoffs and farmer surplus post introduction of the GM trait. From simulation 1 to 5, the conventional herbicide firm payoff decreased from \$136 million to \$58 million, while the payoff to a glyphosate producing firm was \$18 million and the payoff to the RRW agbiotech firm was \$59 million post introduction of RRW. Surplus for conventional farmers decreased from \$68 million to \$29 million from simulation 1 to 5, while the surplus to the farmers that adopted RRW was \$98 million in simulation 5. Due to the introduction of RRW, sector welfare increased by 29% from simulation 1 to simulation 5, from \$204 million to \$263 million.

Comparing simulations 2 and 6 (when $n_0 = 2$), the agbiotechnology firm set p_L at \$5.09. The price of the conventional herbicide, p_0, decreases by 31% in this case, from \$11.94/lb in simulation 2 to \$8.94/lb in simulation 6. Farmers benefit from competition and product diversity. Farmer surplus increases from simulation 2 to 6, but it is mostly shifted from conventional farmers to those farmers that adopt RRW. Conventional farmer surplus decreases from \$121 million to \$58 million, while surplus to those farmers who adopt RRW was \$107 million post introduction of RRW. 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 RRW agbiotech firm has a payoff of \$39 million in simulation 6. 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 result in some farmers adopting a new technology while others continue using the conventional technology. Such interactions allow for farmers with a low level of willingness-to-pay for the GM technology to accrue surplus because of the price decreases of the competing conventional pesticide associated with the release of the GM trait. The variations in surplus measure was used to compare farmer surplus as the market shifts from conventional wheat to a market with conventional wheat and GM wheat.

Farmers with the highest willingness-to-pay for the GM trait shift from adopting the conventional pesticide to adopting the GM solution. Some farmers continue adopting the conventional protection. Some farmers that did not adopt any plant protection when only conventional protection was available may purchase the conventional pesticide in the new market because of their low need or willingness-to-pay. The variations of farmer surplus and also changes in firm profits and sector welfare in both market configurations are illustrated in Table 3.

The variations of surplus show the changes in surplus for one group of farmers as the market moves from conventional to either conventional plus GM FRW or conventional plus RRW. For example, moving from simulation 1 to 3, $\Delta S_{\phi \to 0}$ is the change in surplus of those farmers who purchase no plant protection solution in simulation 1 then purchase technology choice *0* (conventional fungicide) in simulation 3. In simulation 1, 50% of farmers adopt no protection solution and 50% adopt the conventional protection solution. In simulation 3, 36% of farmers with the highest θ adopt GM FRW, 32% adopt the conventional fungicide, and 32% adopt no protection solution. This indicates that 18% of farmers moved from purchasing no protection in simulation 1 to purchasing the conventional protection in simulation 3 (50%-32%). Introducing GM FRW,

Table 3. Variations of Surplus ($ million)

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	8.84	12.76	41.60	63.20	-80.31	83.20	66.09
#2	#4	2.46	19.70	20.34	42.50	-60.60	56.50	38.40
#1	#5	8.10	15.02	36.43	59.55	-77.72	76.92	58.75
#2	#6	2.72	20.26	20.70	43.68	-63.40	53.39	33.67

the surplus for the 18% of total farmers that switched from nothing to conventional fungicide protection increased by $8.84 million.

The surplus to farmers who purchased conventional protection technology in both simulations 1 and 3 ($\Delta S_{0\to 0}$) increases by $13 million. Conventional adoption in simulation 1 was 50% and in simulation 3 was 32%. Adoption of the GM FRW was 36% in simulation 3. Thus, farmers with the highest willingness-to-pay for the new technology become adopters in simulation 3. This leaves 14% of farmers purchasing conventional fungicide in both simulations. Therefore, the increase in surplus to those 14% of farmers is a direct result of the price decrease of the conventional fungicide.

The surplus to farmers who purchase the conventional fungicide in simulation 1 and then adopt the GM FRW in simulation 3 ($\Delta S_{0\to 1}$) increases by $42 million. Adoption of the conventional fungicide in simulation 1 was 50% and adoption of the GM FRW was 36% in simulation 3. Those 36% of total farmers with the highest willingness-to-pay for the GM FRW variety are the ones who moved from conventional to GM FRW. So, the change in farmer surplus for those 36% of total farmers was an increase of $42 million.

The total variation in surplus from simulation 1 to 3 increased by $63 million. Because of the price decrease of the conventional fungicide, the total change in payoff for the conventional fungicide producing firms ($n_0 * \Delta\pi_0$) was a decrease of $80 million from simulation 1 to 3. The total change in payoffs for the fungicide producing firm and the GM FRW agbiotech firm ($\Delta\pi_1 + \Delta\pi_B$) increased by $83 million. Thus, sector welfare increased by $66 million from simulation 1 to 3.

The variation of surplus solidifies the notion that adopters of a new GM wheat trait are not the only group to gain surplus. In fact, from simulation 2 to 4, and from simulation 2 to 6, 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 GM technology are similar. From simulation 2 to 4, $\Delta S_{0\to 0}$ = $20 million and $\Delta S_{0\to 1}$ = $20 million. From simulation 2 to 6, $\Delta S_{0\to 0}$ = $20 million and $\Delta S_{0\to 1}$ = $21 million. This indicates that farmers who continue to use conventional protection post introduction of a GM wheat variety benefit almost equally as those who adopt the new GM variety.

Summary

In hard red spring (HRS) wheat, the two GM traits nearest to commercialization are fusarium resistant wheat (FRW) from Syngenta and Roundup Ready wheat (RRW). Monsanto announced that it has deferred the

commercialization of RRW until issues of market acceptance are alleviated. Monsanto acknowledged that it might reconsider its position if another agbiotechnology firm enters the GM wheat market.

Typically, adoption estimates of GM crops examine the cost-benefit of the GM variety compared to the conventional variety. However, release of a GM variety would impact prices of competing pesticides used on the conventional varieties, making the conventional variety less costly than prior to the GM variety. The release of RR soybean in 1996 resulted in a 40-50% decline in price of two leading conventional soybean herbicides in 1997 and 1998. Considering such price decreases results in lower than expected adoption rates for the GM variety. This causes an increase in surplus for those farmers who adopt the GM variety, as well as those who plant the conventional variety. This also poses major strategic questions for agbiotechnology and conventional pesticide firms in their estimates of adoption rates, prices, and profits.

A Cournot quantity competition model was developed to determine the equilibrium quantities of conventional pesticide and agbiotechnology firms. The Cournot model was used because firms that must make production decisions ahead of the selling period, and firms with extensive research and development costs are not able to aggressively set prices. Rather, the conventional and agbiotechnology firms determine Nash equilibrium quantities and then determine a market clearing price for their respective products. The agbiotechnology firm determined a profit for conventional varieties, and 30% for RR wheat adoption.

Likewise, the release of GM FRW would result in a price decrease of 30-36% for conventional fungicides. Again, this price decrease allows farmers with a low willingness-to-pay for the GM FRW variety to benefit from lower fungicide prices. The surplus to farmers who continued to produce conventional varieties, post-introduction of a GM fusarium resistant HRS wheat variety, increased by $15-20 million. Assuming competition in the conventional maximizing technology fee ($/acre) for its GM trait. The market with conventional wheat only was compared to the market with conventional and GM wheat varieties to determine the price decreases of the conventional pesticide as a result of the GM trait introduction. Changes in farmer surplus, tech firm payoffs, and sector welfare were also analyzed.

This study provides contributions in that it develops 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 price impact model can also be applied to different GM traits and crops, as well as any problem involving the release of new technology and its effects on the pricing of an incumbent competing technology.

Under the stylized assumption, the results suggest the release of a RR HRS wheat variety would result in a price decrease of 31-35% for conventional herbicides. This price decrease allows farmers with a low willingness-to-pay for the GM variety to realize cost savings in the production of conventional HRS wheat. The surplus of farmers continuing to produce a conventional variety post-introduction of RR HRS wheat, increased by $13-20 million. Assuming market equilibrium quantities of the conventional and RR wheat technologies, adoption rates were determined as 23% for no product adoption, 47% fungicide sector and market equilibrium quantities of the conventional and GM technologies, adoption rates were determined to be 23% for no product adoption, 46% for conventional varieties, and 31% for GM FR wheat adoption. Introduction of either the RR or GM FR wheat traits improved welfare for both growers who adopt the new GM variety and those using the conventional variety (due to the price decline), as well as the agbiotechnology firm.

Using the actual number of firms with conventional herbicides labeled for use on HRS

wheat in North Dakota (11) and marginal production costs ranging from one to three dollars, introduction of RRW would cause a 20-25% price decrease for conventional herbicides. Similarly, four firms produce conventional fungicides labeled for the suppression of FHB in HRS wheat. This value, combined with per acre marginal production costs ranging from one to three dollars, would more likely cause a 19-22% price decrease for conventional fungicides, post introduction of GM FRW.

As the number of generic glyphosate-producing firms increase, the price of the glyphosate would decrease and the agbiotechnology firm would increase the technology fee for the RRW trait. Because RRW involves a bundle of the trait and the glyphosate herbicide, the decrease in price of the glyphosate allows the agbiotechnology firm to capture remaining willingness-to-pay for the bundle through the technology fee. This results in lower payoffs to conventional herbicide and glyphosate-producing firms, whereas the agbiotechnology firm experiences an increase in payoffs. This is akin to recent announcements by Monsanto that the cost of its RR soybean system will not change; however, it also announced that the price of its Roundup Original Max herbicide has been lowered by 25-30% (Burchett, 2004). Since the cost of the RR soybean system is unchanged and the cost of the Roundup Original Max herbicide has decreased, it can be inferred that the technology fee for the RR trait has increased.

Several implications arise from these results. First, adoption of a new GM wheat variety may not be as high as expected due to likely concurrent price decreases of conventional pesticides. The price decrease leads to a lower production cost of conventional varieties, and some farmers who would likely adopt the GM variety, if there were no price decrease, do not adopt because of the lower cost of conventional production. 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 did 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.

The results of this study provide important policy contributions, in that all producers of hard red spring wheat benefit from the introduction of a GM wheat variety because of price decreases of the conventional pesticides. Thus, agbiotechnology firms are not the only entities to benefit from GM wheat introduction. This is an important issue to convey when addressing market acceptance concerns.

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How to Obtain Additional Information

This document is a summary of a more comprehensive report which contains additional information. Copies of this summary and single copies of the main report, *Impacts of Genetically Modified (GM) Traits on Conventional Technologies*, are available free of charge. In addition, *Strategic Analysis Of Trait Commercialization In Genetically Modified (Gm) Grains: The Case Of Gm Wheat,* Research Rpt. No 560 is also available. Please address your requests to Carol Jensen, Department of Agribusiness and Applied Economics, North Dakota State University, P.O. Box 5636, Fargo, ND 58105-5636, (phone 701-231-7441, fax 701-231-7400), E-mail cjensen@ndsuext.nodak.edu, or these documents are available on the world wide web at http://agecon.lib.umn.edu.