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# Producer Contract Strategies in GM Crops

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**Abstract**

A number of challenges exist for genetically modified (GM) crop development at the production level. Contract strategies can resolve some of these challenges. Contracts can be designed to induce legal adoption of GM crops by varying technology fees, violation detection, and penalties. The objective of this research is to analyze contracting strategies to determine terms to induce legal adoption of GM wheat and to minimize technology agreement violations. A simulation model of the prospective introduction of GM technology into hard red spring wheat was developed. Results illustrate that contracts can be designed to induce desired behavior. Technology fees, probability of detection, and the level of non-GM premium were the most notable factors influencing adoption decisions.

**Key Words**: contracts, genetically modified crops

## Highlights

The effect of contract terms on the adoption of GM wheat by producers was evaluated in this report. Four different adoption scenarios were compared: no adoption, legal adoption, improper adoption, and illegal adoption. A producer was assumed to choose the scenario with the highest expected utility of profit. Contract terms such as technology fees, contract violation, and fines for violation were adjusted to determine their effect on the producer's adoption decision. Stochastic simulation was used to account for the uncertainty and risk in the analysis and generalized stochastic dominance was conducted to compare choice sets. A final analysis was conducted to determine the optimal technology fee when the objective is to maximize the technology firm's revenue.

Some important findings were:

- Legal adoption is most preferred with lower technology fees. Illegal adoption becomes more appealing as technology fees increase.
- Improper use declines substantially as the probability of violation detection increases. Illegal use is only marginally deterred with increased probability of detection.
- More risk-averse producers tend to favor legal and no adoption and avoid illegal and improper use.
- Point-of-delivery pricing is useful in eliminating illegal use.
- Premiums for non-GM production deter legal adoption of GM production.
- Increased fines for contract violation will deter improper use substantially, but illegal use marginally.
- The optimal technology fee to maximize technology firm revenue subject to legal adoption being induced is $2.11 per acre.

# PRODUCER CONTRACT STRATEGIES IN GM CROPS

**Brett J. Maxwell, William W. Wilson, and Bruce L. Dahl***

## Introduction

Agricultural biotechnology has led to substantial growth in genetically modified (GM) crops. The technology, most notably gene transfer, has been implemented in a number of crops including corn, cotton, soybeans, and canola. Plants are being bioengineered to be tolerant to herbicides that the plant is normally susceptible to. With these herbicide tolerant crops, producers benefit from lower input costs and increased convenience, quality, and yields over conventional varieties. Protecting intellectual property rights and the subsequent investment associated with technology development is important with these crops. Technology firms use contract mechanisms to protect their investment. Agreements generally include a technology user fee and stipulate that the producer cannot keep seed for the following year for replanting purposes.

Production contracts have been used by technology companies in numerous crops such as corn, cotton, soybeans, and canola. Contracts are a mechanism to monitor how many acres of a variety are planted. Stewardship guidelines provide producers with agronomic recommendations and requirements for technology use. Finally, contracts stipulate seed planting and replanting restrictions, and technology fees that the producer must pay for using the technology. Technology companies design contracts to earn a return on their investment.

GM technology in wheat has not been commercialized anywhere in the world. However, given the potential commercialization of GM wheat, concerns realized in other GM crops apply to GM wheat.[1] Contracts will be necessary to alleviate some of these trepidations. Developing contract terms to address segregation and other contract violations regarding GM wheat is important to the long-term viability of the wheat industry.

The purpose of this report is to analyze the impacts of contract terms for GM grains inclusive of incentives to the producer, technology use rules and protocols, and randomness that minimizes contract abandonment while maintaining returns for the technology company and the producer. Stochastic dominance is utilized to determine the effect of alternative efficient choice sets for growers. The analysis also considers the problem from a technology company standpoint, maximizing technology fee revenue subject to the producer's adoption decision. Hard red spring (HRS) wheat is the focus of this report, but this problem is applicable to other GM crops and traits.

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[1] There are a number of GM wheat traits under development (Wilson, Janzen, and Dahl. 2003) including herbicide, fusarium and drought resistance, as well as quality attributes. Monsanto has recently announced suspending commercialization decisions for at least four years. The results are illustrated in this report in the case of Round-up Ready® wheat in part due to the technical parameters that exist for this trait. Nevertheless, the challenges and opportunities addressed in this report will confront each of the wheat traits, as well as other GM grains and oilseeds.

First, studies on contracting, pricing, and benefits of GM crops are summarized. The next sections present contract mechanisms used in GM crop production. The empirical model, data, and methodology are presented in the following section. Results and summary conclude the report.

## Previous Literature

Technology providers develop contracts to protect their intellectual property and generate a commercial return on their research and development investment. Returns are often in technology fees charged directly to producers. Contracts outline prices, agronomic stewardship recommendations, penalties, incentives, and premiums for a particular grain or oilseed. The technology firm determines terms in the contract to generate a return and to induce growers to adopt the technology.

Several studies have been conducted that examine contracting, pricing, and benefits of GM crops. Some of these are summarized below in Table 1.

Table 1. Previous Studies on Contracting of GM Crops

| Authors | Research |
|---|---|
| Kingwell (2000) | Incentive design in GM crops, determined contract terms can be adjusted to induce legal adoption of GM cotton |
| Giannakas (2001) | Determined pricing paths for GM seed and influence of government regulation of GM crops on technology firms' pricing strategy |
| Kinwa-Muzinga and Mazzocco (2002) | Examined price paths of portfolio of seeds, determining that price of GM seeds influenced by competition from other technologies |
| Alexander and Goodhue (1999) | Examined inter-firm competition effect on technology pricing. |
| Holzman (2001) | Evaluated dynamic net benefits of GM wheat, determined that overall benefit influenced by contract terms such as price |

Technology firms face a risk of "piracy" by potential users (Kingwell, 2000). Usually this piracy occurs due to users obtaining seed illegally by purchasing the seed on the black market or from users who initially purchased the seed legally but ignored replanting restrictions in contracts and kept their own seed. Piracy varies across regions and is extreme in parts of the world. Qaim and de Janvry (2002) estimated that the actual amount of Bt cotton planted in Argentina in the 2001/2002 growing season was five times the official recorded planting area. Their study also indicated that a lower price for the technology would increase benefits for cotton producers and increase profits for the technology provider.

Technology "piracy" has resulted in a number of confrontations and challenges. Saskatchewan farmer Percy Schmeiser challenged Monsanto in the Canadian supreme court regarding a patent violation for which he was found guilty in a lower court (Elias, 2004). Results of the lower court were supported by the Supreme Court (Monsanto, 2004). Monsanto has implemented a mechanism to collect royalties on Roundup Ready® soybeans from Brazilian soybean producers, who until the 2003 crop were growing Roundup Ready® soybeans without paying a technology fee (*Farmers' Independent Weekly*, 2003a). Illegal purchases of Roundup Ready® soybeans in Argentina induced Monsanto to halt sales in that country because of the lack of royalty collection (Gray, 2004).

Pricing strategies for GM technologies are critical. Producers can be monitored but perfect information on their actions is nearly impossible to obtain because of cost constraints (Giannakas, 2001). Kinwa-Muzinga and Mazzocco (2002) examined the prices of a portfolio of GM seeds. Pricing strategies were analyzed for GM corn seed when there was competition between three varieties: one conventional seed, one input-trait variety, and one output-trait variety. Alexander and Goodhue (1999) stressed the effect of competing products on a technology firm's ability to extract profit from their product. If producers have the option of growing a similar herbicide-tolerant crop from a competing firm, then the ability to charge monopolistic prices for the seed or technology is hindered.

## Production Mechanisms for Existing GM Grains and Oilseeds

Technology use agreements are used by major technology firms. The notion behind technology use agreements is to provide long-term intellectual property right protection and sustainability of the GM crop or trait. The agreements are unique to the particular product but, stewardship and technology agreements have similar principles. Information collected from contract agreements are summarized in Table 2.

Monsanto, Syngenta, Dow AgroSciences, Dupont, BASF, and Bayer Crop Science are important GM crop developers. Only the Clearfield® system from BASF is non-GM, but there are stacked traits in some of their varieties that designate them GM. Monsanto is one of the innovators of the "Technology Use Agreement" (Monsanto, 2003a). Stewardship guidelines are included in the "Technology Use Guide" issued to all users (Monsanto, 2003b). All seed is considered GM and, therefore, is subject to the channeling and marketing restrictions associated with GM.

Monsanto's "Technology Use Agreement" (2003a) stipulates that the farmer is subject to random checking of his fields and storage bins for up to three years following the last planting of the GM crop. This is to ensure that the grower does not keep seed for replanting (Kingwell, 2000). In some cases, Monsanto requires that only their Roundup Ready® herbicide, be applied over the crop for weed control purposes. Penalties may be incurred by the producer if these rules are violated.

Table 2. Technology Agreement and Stewardship Guidelines

| Technology Agreement | Monsanto | Syngenta (NK Brand Seeds) | Dow Agrosciences | Dupont/Pioneer | BASF | Bayer Crop Science |
|---|---|---|---|---|---|---|
| Yes/No | Yes | Yes | Yes | Yes | Yes | No |
| Crops | corn, cotton, soybeans, canola, sugarbeets | corn, soybeans, alfalfa | corn, sunflowers, soybeans, | corn | corn, soybeans, canola, sugar beets, rice, sunflowers wheat | corn, rice, canola, cotton |
| Crop System Characteristics | Bt, Roundup Ready® | Bt ( Knockout*), Liberty Link | Bt Corn (Herculex I Insect Protection), Clearfield Sunflower** | Bt (YieldGard, Herculex I) | Clearfield system is a non-GM natural mutent selection herbicide tolerant system | Liberty Link |
| Refuge Zone Requirements (IRM) | All Bt crops require 20% non-Bt in non-cotton growing areas and 50% in cotton belt in U.S. Refuge zones mandated by Environmental Protection Agency. Roundup Ready® crops do not have a refuge zone requirement. Refuge must be within 1/2 mile of Bt corn. | All Bt crops require 20% non-Bt in non-cotton growing areas and 50% in cotton belt in U.S. Refuge zones mandated by Environmental Protection Agency. Liberty Link herbicide system does not have any refuge requirements. All refuge zones must be within 1/2 mile of the Bt crop. | All Bt crops require 20% non-Bt in non-cotton growing areas and 50% in cotton belt in U.S. Refuge zones mandated by Environmental Protection Agency. Refuge must be within 1/2 mile of Bt corn. | All Bt crops require 20% non-Bt in non-cotton growing areas and 50% in cotton belt in U.S. Refuge zones mandated by Environmental Protection Agency. Refuge must be within 1/2 mile of Bt corn. | Herbicide tolerant, so no refuge requirements. Some Clearfield products are stacked with other GM traits that may require refuge requirements. | No refuge zone requirement. |
| Pesticide Requirements | Insecticide applications prohibited in non-Bt refuge zone unless economic thresholds are met. Only Roundup brand herbicides allowed to be applied over Roundup Ready® crops. All other glyphosate brands are not approved and Monsanto disclaims all responsibilities. | Insecticide applications prohibited in non-Bt refuge zone unless economic thresholds are met. Liberty herbicide must be applied over Liberty Link varieties. | Insecticide applications prohibitted in non-Bt refuge zone unless economic thresholds are met. | Insecticide applications prohibitted in non-Bt refuge zone unless economic thresholds are met. | Specific brand Group 2 (ALC inhibitors) not required but strongly encouraged for best results. | All Liberty Link herbicides are tolerant to the group 10 herbicide Liberty (Glufosinate), therefore only this herbicide may be sprayed on the crop. |
| "Brown Bag" Policy | Seed is not allowed to be replanted, supplied for replanting. All planted seed must be purchased and certified from an approved dealer. | Seed is not allowed to be replanted, supplied for replanting. All planted seed must be purchased certified from an approved dealer. | Seed is not allowed to be replanted, supplied for replanting. All planted seed must be purchased and certified from an approved dealer. | Seed is not allowed to be replanted, supplied for replanting. All planted seed must be purchased certified from an approved dealer. | For wheat, growers must purchase new certified seed every year. Other crops having similar guidelines established. | All Liberty Link crops are hybrids so brown bagging is not illegal, but rarely occurs due to the inability of hybrids to reproduce effectively. In "open pollinated" Liberty Link canola varieties, replanting is not illegal. |
| Monitoring/ Auditing Policy | Grower allows Monsanto the right to randomly audit, examining farmers' fields and farm to ensure compliance for up to 3 years following initial contract agreement. Violation of this or any requirement could result in loss of technology growing rights, penalties, and/or fines. | IRM plan allows Syngenta and its dealers the right to monitor farmers' crops and farm to ensure compliance with IRM requirements or face loss of technology use rights and/or penalties and fines. | IRM plan allows Dow Agro Sciences and its dealers the right to monitor farmers' crops and farm to ensure compliance with IRM requirements or face loss of technology use rights and/or penalties and fines. | IRM plan allows Dupont/Pioneer and their dealers the right to monitor farmers' crops and farm to ensure compliance with IRM requirements or face loss of technology use rights and/or penalties and fines. | No specific monitoring policy. | No specific monitoring policy. |

- Continued -

Table 2. Technology Agreement and Stewardship Guidelines (Continued)

| Technology Agreement | Monsanto | Syngenta (NK Brand Seeds) | Dow Agrosciences | Dupont/Pioneer | BASF | Bayer Crop Science |
|---|---|---|---|---|---|---|
| Yes/No | Yes | Yes | Yes | Yes | Yes | No |
| Technology Fees | Technology fees charged on per acre basis for cotton, canola, and sugarbeet traits and included in per bag price for corn and soybeans. The price for the Bt trait is generally higher than the Roundup Ready® trait. In U.S., technology fee historically has included a pint of Roundup bundled with the seed at purchases. | No separate technology fee for Knockout brand or Liberty Link system. | Mycogen seed varieties have a per unit technology fee separate from seed and chemical costs. | Technology fees charged on a per acre or per unit basis for YieldGard and Herculex I varieties licensed by Monsanto and Dow respectively to Dupont. | No separate technology fee charged. | No separate technology fee charged. |
| Patent Protection | Monsanto gene technologies protected by U.S. patent law. Monsanto licenses the grower, allowing use of the technology but not ownership subject to the conditions in the technology agreement. Violators are subject to penalties/fines to cover damages. | Liberty Link and Knockout gene technologies protected by U.S. patent law. Syngenta licenses the grower, allowing use of the technology but not ownership subject to the conditions in the technology agreement. Violators are subject to penalties/fines to cover damages. | Dow AgroSciences (Mycogen) and Herculex I gene technologies protected by U.S. patent law. Dow AgroSciences licenses the grower allowing use of the technology but not ownership subject to the conditions in the technology agreement. Violators are subject to penalties/fines to cover damages. | Herculex I and YieldGard varieties protected by U.S. patent law. | BASF works with a number of private and public institutions establishing varieties protected by U.S. patent law. | Liberty Link crops protected by U.S. patent law. |
| Product Warranty Policy/Notice Requirement | Monsanto warrants product will perform properly in accordance with directions. Roundup Ready® Risk Share program in Canada will refund entire technology fee if crop is removed due to environmental reasons by a specified date within that crop year. In U.S., has guarantees on net per acre benefit of certain varieties over conventional varieties. | No limited warranty policy available. | Dow AgroSciences warrants that the Mycogen gene technology licensed hereunder will perform as set forth in the product use guide when used in accordance with directions. | Dow AgroSciences warrants that the Mycogen gene technology licensed will perform as set forth in the product use guide in accordance with directions. YieldGard varieties will perform as indicated if used in accordance with directions in the technology use guide. | No limited warranty policy available. | No technology agreement, so no specified warranty available. |
| Grain Channeling Restrictions | All grains, including YG corn, RR Corn, canola, sugarbeets, are open to domestic use including on farm feed, feedlots, elevators that agree to accept the grain, or other approved domestic uses. However, RR sugarbeets are not readily used due to most domestic buyers' refusal to buy them. | All Syngenta (NK) corn and soybeans are approved for human food and animal feed use in the U.S, Canada, EU, and Japan. | Dow Agro requires that grain produced from Mycogen or Herculex I technologies is channeled to appropriate areas that accept GM crops. Grain must be consumed for feed or grain purposes in accepted markets. | Grain can be channeled according to YieldGard and Herculex I channeling restrictions. | Clearfield varieties that are not stacked with GM trait are considered non-GM and are available to export to any country as non-GM. | Liberty Link crops are GM so only accepted in markets that accept the Liberty Link GM gene, so should only be distributed to these markets. |
| Stewardship | Technology Use Guide outlines pollen flow prevention recommendations and additional refuge guidelines. | Product use guide indicates non-Bt refuge crop should be similar to Bt variety. 1/4 mile refuge zone distance is preferred over 1/2 mile distance. | Product use guide indicates non-Bt refuge crop should be similar to Bt variety. 1/4 mile refuge zone distance is preferred over 1/2 mile distance. | Product use guide indicates non-Bt refuge crop should be similar to Bt variety. 1/4 mile refuge zone distance is preferred over 1/2 mile distance. | Clearfield system relies on herbicide application. Recommendations include herbicide and crop rotation practices to avoid weed resistance. | No specific stewardship recommendations available. |

* Knockout is a Sygenta Seeds brand. Liberty Link is from Bayer CropScience.

**Dow AgroSciences Seeds produced by Mycogen Seeds, a subsidiary of Dow AgroSciences. Herculex I is a DAS trademark.

Most companies require that seed is not "brown bagged" or "bin run," meaning seed cannot be replanted or supplied to anyone else for replanting. Monitoring producers through random audits induces compliance among most producers as over 300,000 growers in the United States and 30,000 in Canada adhere to the contract stipulations (*Agweek*, May 26, 2003). Compliance is not just important for protecting intellectual property rights, firms also want to instill responsible agronomic practices for use of their products to maintain the long-term viability of the technology.

**Refuge, Channeling, and Stewardship Requirements**

In most grower agreements, firms outline patent protection laws associated with their crop. Patent numbers are indicated, and agreements stipulate that the technology is protected by U.S. patent law and that the agreement represents a license to the grower to use but not own the gene.

The most common stipulation for GM crops involves a refuge requirement[2] for Bt crops. The Environmental Protection Agency (EPA) mandates that a Bt crop must have at least a 20% refuge of non-Bt corn in non-cotton growing areas and a 50% refuge of non-Bt corn in the cotton belt (Butzen, 2003). Additionally, the producer agrees to allow firms to monitor fields to ensure compliance. Violators are subject to penalties including loss of technology growing rights and subsequent damages (Dow AgroSciences, 2003). Producers must comply with refuge options that firms set forth in their Integrated Resistance Management (IRM) requirements. Refuge zones in Bt crops decrease the occurrence of insect resistance by allowing susceptible insects to mate with the rare resistant ones to maintain Bt effectiveness in subsequent years (Butzen, 2003).

However, the Center for Science in the Public Interest indicated that 19% of corn farms in Iowa, Minnesota, and Nebraska did not follow the refuge zone requirements (Farmers' Independent Weekly, 2003b). This furthers the necessity to implement enforceable contracts including incentives to producers to comply with refuge zone requirements.

Due to the refusal by some markets of GM crops and their products, technology firms may indicate available export markets. Most agreements outline the importance of delivering to the appropriate marketing channels. Some companies distribute a list of elevators that will accept GM products. The product use guide also outlines other information such as restrictions on where the product is registered to be planted.

Stewardship recommendations are common and describe potential use inclusive of herbicide and crop rotations, pollen flow considerations, spraying and application timing, among other recommendations. Stewardship guidelines are not enforced, but producers are strongly urged to adhere to guidelines to ensure subsequent continuous benefits of the technology.

[2] Refuge requirements do vary across different crops but the basic requirement is to have a zone where non-GM crops are planted next to or in conjunction with GM crops to reduce the likelihood of pest resistance.

## Model Overview

A model is developed to evaluate incentive and contract terms on grower's decision about prospective contract terms for GM and technology agreements for HRS wheat.

Producers have four adoption choices: grow non-GM wheat, legally adopt GM wheat, improperly adopt GM wheat, or illegally adopt GM, denoted by A, B, C, and D (Figure 1). Following Lataez-Lohmann and Webster (1999), producers are considered amoral calculators, meaning that their chief interest is profit and they will abide by or violate technology agreements whenever it is profitable to do so. As amoral calculators they select the most profitable of the four choices.

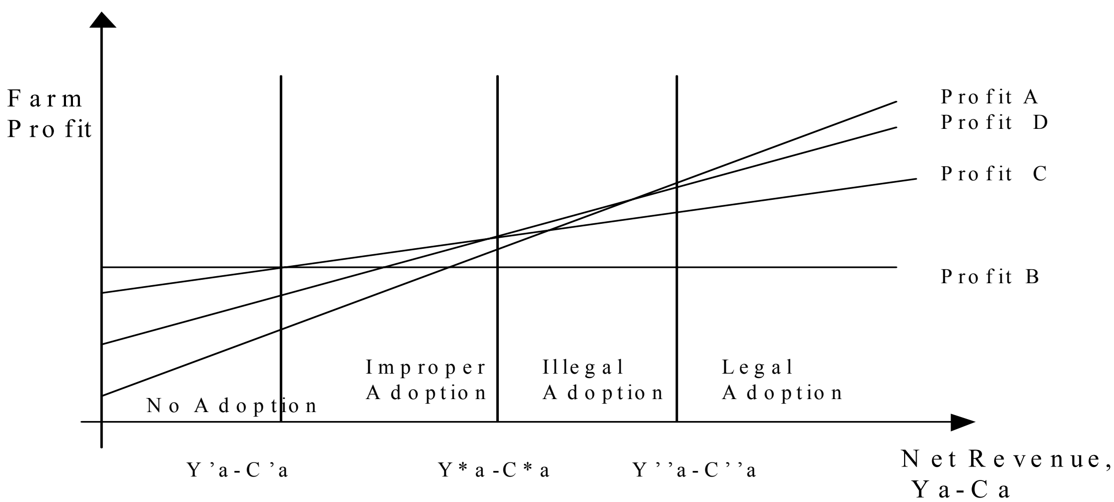


**Figure 1. An illustration of Farmer's Decision Problem**
**Source: Kingwell (2000) Incentive Design for Introducing GM Crops**

Adoption scenarios are representative of decisions that a producer would face if GM HRS wheat is commercialized. A producer may opt to grow non-GM wheat. Legal adopters acquire and use the GM seed legally. Improper GM adoption involves legally purchasing the seed and signing a technology agreement, but knowingly or unwittingly violating the contract terms. Illegal GM adoption occurs when a producer purchases the seed illegally and does not pay the technology fee. Illegal adoption includes bin running GM seed from previous growing seasons. There are numerous sources of risk related to the producer's adoption decision. Risks include prices, yields, wheat quality, and the monitoring and detection probability which influence the producer's adoption decision.

GM wheat is represented as Roundup Ready® hard red spring wheat (RR wheat). RR wheat is assumed to have an 11%-14% (Blackshaw and Harker, 2002) yield advantage over conventional wheat, as well as lower chemical application costs. Adoption would encompass signing a technology use agreement and a payment of a per acre technology use fee.

Stochastic simulation is used to determine adoption and compliance decisions for producers by accounting for production variability and shifting parameters. Variability is implemented into the model through yield, price, wheat quality (protein, falling number, test weight, and vomitoxin), and input costs. Volunteer control accounts for the cost of controlling volunteers in subsequent crop years. Parameters evaluated include the effect of risk aversion, technology fees, probability of violation detection, fines for violation, yield, price, and some alternate marketing sensitivity's such as point-of-delivery technology fee pricing, non-GM wheat premiums, GM/non-GM co-mingling probability, and point of delivery testing frequencies.

## Mathematical Description of Model

A profit (total revenue – direct costs) function is derived for choice i, where i = 1...4, for non-adoption, legal adoption, improper adoption, and illegal adoption, respectively. The producer selects choice i with the highest expected profit. The utility of profit is calculated to account for different risk aversion levels. Costs include seed, herbicides, technology fees, volunteer control costs, fungicides, insecticides, fertilizers, crop insurance, fuel, repairs, drying, miscellaneous, and operating interest. Indirect costs such as land and taxes are excluded because they are fixed and constant across crops and choices. Price is a function of protein, falling number, vomitoxin, test weight, and transportation costs. In the base case, price does not account for a non-GM premium. The model is defined as:

$$E(\Pi_i) = Y_i \bullet P_i - C_i - T_i$$

where: $E(\Pi_i)$ is equal to the expected profit of choice *i*, $Y_i$ is equal to the yield for choice i (bushels/acre), $P_i$ is price for choice i ($/bushel), $C_i$ is agronomic costs for choice i, and $T_i$ represents the technology costs for choice i.

Yield for GM wheat is assumed an 11%-14% yield benefit (uniformly distributed) over conventional wheat due to superior agronomics. Price $P_i$, is defined as:

$$P_i = [(P^M + P^H \bullet(C_i) - P^L \bullet(1-C_i) - D^T \bullet TW - D^{FN} \bullet FN - D^{Vom} \bullet VS - T)]$$

where, $P^M$ is the base price (Minneapolis in $/bushel), $P^H$ is the premium for protein>14% (random), $C_i$ is the protein content (correlated with yield), defined as 0 if <14 and 1 otherwise, $P^L$ is the discount for protein<14% (random), $D^T$ is the discount for test weight (random), $TW$ is test weight (defined as 1 if test weight is <58 lbs/bu and 0 otherwise), $D^{FN}$ is the falling number discount, $FN$ is the falling number (defined as 1 if lower than limit of 300 and 0 otherwise), $D^{Vom}$ is the vomitoxin discount, and $VS$ is vomitoxin (defined as 1 if vomitoxin is greater than 2ppm and 0 otherwise).

Agronomic costs are defined as:

$$C_i = \sum(S_i, FU_i, H_i, I_i, F_i, C_i, I_i, FL_i, R_i, D_i, OI_i, Misc._i)$$

where, $S_i$ is the seed cost, $FU_i$ is fungicide costs, $H_i$ is the conventional herbicide costs, $I_i$ is the insecticide costs, $F_i$ is the fertilizer costs, $C_i$ is the crop insurance costs, $FL_i$ is fuel and labor costs, $R_i$ is cost of repairs, $D_i$ is drying costs, $OI_i$ is operating insurance, $Misc_i$ is miscellaneous costs, and all are in $/acre.

Conventional growers have no technology fee, legal adopters pay the technology fee, improper adopters pay a reduced portion of the technology fee, and illegal adopters do not pay the technology fee but plant the GM wheat. Technology costs are defined as:

$$T_i = (TF_i - VC_i - p(V_i) \bullet F_i),$$

where $TF_i$ is the technology fee for choice i, $VC_i$ is the cost of volunteer control (assumed in only RR wheat adopter), $p(V_i)$ is the probability of detection for scenario i (where i = IMP, ILL), and $F_i$ is the fine for scenario i (i = IMP, ILL).

Mechanisms that influence deterrence of improper and illegal use include increasing the probability of detection, $p(V)$, and increasing the fine for violation $V$. The size and type of technology fees charged are important components of the cost of growing GM wheat, and varying these change the expected profit from the legal adoption scenario. The expected yield benefit from GM wheat, ease of use, and less herbicide use, also affect the adoption decision.

Technology use agreements require the grower agrees to random audits for up to three years following the first planting of the technology. Auditing involves ensuring the correct number of reported acres, making sure no seed is being reused. It may also involve checking that the grower applied Roundup Ready® brand herbicide over the crop instead of a generic glyphosate substitute by contacting the retail store where the herbicide was purchased. Illegal users are more difficult to detect, as they have not signed a technology agreement, and the company presumably does not have a record of their existence.

Detection probabilities in the base case equal those used by Kingwell (2000). Improper and illegal users have probabilities of 0.3 and 0.06, respectively, of being detected. An illegal adopter has a much smaller likelihood of detection because the company is less likely to be aware of this producer. The illegal adopter has not signed a technology use agreement and the company has no record or knowledge of their growing operation. In later sensitivities these parameters are altered to determine their effect on the producer decision.

Improper users face a $10/acre fine for their violations if detected. This fine was selected to reflect the most likely fine to cover the loss of technology fee revenue due to incorrect acreage reporting. Illegal users face the possibility of losing the net revenue realized from adopting the GM wheat illegally. A steeper fine is allocated to deter illegal use because “brown bagging” seed is a much more serious offense than inaccurate reporting of planted acres.

A utility function with a coefficient of relative risk aversion[3] (Fraser, 1991) was assumed for grower's utility of profit to account for different risk aversion levels. It is represented as function:

$$U(\Pi) = \Pi^{1-R}/1\text{-}R ,$$

where,

$\Pi$ = profit, $U(\Pi)$ = utility of profit, and R = relative coefficient of risk aversion.

The base case for this model is Crop Reporting District (CRD) 2, located in the North Central Region of North Dakota and represents average yields and prices between the western and eastern part of the state. All of the data sources are from CRD 2. The average yield benefit is observed across field trials from a variety of geographies. In the base case and all other sensitivities, the model is simulated at four different risk levels: risk neutral and coefficients of relative risk aversion of 0.1, 0.5, and 0.9. To account for risk aversion, expected profit is converted to expected utility for the three levels of risk aversion. A risk-neutral producer is expected to select the scenario with the highest expected profit. This concept is important because producers are likely to vary substantially in their risk attitudes and, therefore, vary in their propensity to violate contract agreements.

## Data Sources and Distributions

Table 3 provides a summary of the data sources used in this research.

Table 3. Data Sources

| Model Component | Data Source |
|---|---|
| Historic Wheat Yield | North Dakota Agricultural Statistics Svc. (1997-2001) |
| Roundup Ready® Wheat Yield Benefit | Blackshaw and Harker (2002) |
| Prices | Minneapolis Grain Exchange (1997-2001) |
| Quality Data (Test weight, protein, falling number, and vomitoxin) | Department of Cereal Science and Food Technology, NDSU, (1997-2001) |
| Quality Premiums and Discounts | Dahl, Wilson, Johnson, and Nganje (2001) |
| Transportation Cost (CRD#2 Mpls.) | Burlington Northern Sante Fe (2003) |
| Crop Production Costs | Swenson and Haugen (2002) Crop Budgets, NDSU Extension Service |

[3] See Sadoulet and de Janvry (1995) for difference between relative risk aversion and absolute risk aversion. Relative risk aversion, R = -y*U''(y)/U'(y) and absolute risk aversion, A = -U''(y)/U'(y).

Distributions for the yield, price, and quality variables were determined using fitting capabilities in *@Risk* (Palisade, 2000a) and are summarized in Table 4. Distributions for premiums and discounts for test weight, protein, falling number, and vomitoxin are from Dahl, Wilson, Johnson, and Nganje (2001). Table 5 summarizes the model parameters and Table 6 summarizes base case assumptions.

Values for risk aversion, technology fees, and fine severity were nominally assigned as a prescribed value and not simulated. This is because subsequent sensitivities were simulated to determine their effect on the producer decision. The probability of detection was represented as a discrete distribution. A producer who is an improper user is either detected or not detected by the technology company with the likelihood of being detected 0.30. Illegal users have a similar detection probability, but at a 0.06 probability.

Table 4. Random Variable Distributions

| Variable | Distribution | Mean | Std.Dev. | ($\alpha_1$ $\alpha_2$) | (Min, Max) | Correlation |
|---|---|---|---|---|---|---|
| Yield | Normal | 24.26 | 3.38 | NA | NA | NS† |
| Yield Increase GM Wheat | Uniform | NA | NA | NA | (.11, .14) | NS |
| Market Price | Extvalue | 3.60 | 0.27 | NA | NA | NS |
| Test Weight | Extvalue | 58.67 | 0.37 | NA | NA | NS |
| Protein | Beta | NA | NA | (0.14, 0.20) | (14.60, 15.10) | NS |
| Falling Number | Logistic | 353.53 | 55.14 | NA | NA | NS |
| Vomitoxin | Extvalue | 0.03 | 0.03 | NA | NA | NS |
| Test Weight Premium/Discount* | Normal | -0.04 | 0.05 | NA | NA | NA |
| Protein > 14% Premium* | Normal | 0.40 | 0.34 | NA | NA | 0.85 with protein 13% |
| Protein < 14% Discount* | Normal | -0.14 | 0.19 | NA | NA | 0.85 with protein 14% |
| Falling Number Discount* | Normal | -0.26 | 0.37 | NA | NA | NA |
| Vomitoxin Discount* | Normal | -0.20 | 0.44 | NA | NA | NA |

Source: Distributions for premiums and discounts are from Dahl, Wilson, Johnson, and Nganje (2001) and were truncated at zero.
†NS – Not statistically significant (P= 0.05).

Table 5. Parameters

| Parameter | Base Case Value | Distribution |
|---|---|---|
| Risk Aversion coefficient | R = 0.5 | NA |
| Technology Fee | $8.00 | NA |
| Detection Prob. Improper | 0.30 | Discrete (Detected/not detected) |
| Detection Prob. Illegal | 0.06 | Discrete (Detected/not detected) |
| Fine Severity Improper | $10 | NA |
| Fine Severity Illegal | $Yield*Price | NA |

Table 6. Base Case Assumptions

| Variable/Parameter | Mean | Std. Dev | Distribution | Logic |
|---|---|---|---|---|
| Yield (bushels/acre) | 24.25 | 3.38 | Normal | Mean and std.dev. in ND CRD 2 (1997-2001) |
| Yield with RR wheat | 11-14% benefit over conventional yield | | Uniform | Monsanto field trials |
| Price | 3.60 | 0.27 | Extreme value | Minneapolis less freight (1997-2001) |
| Quality | Quality variables equal to distributions accrued over period 1997-2001 | | Test weight: Normal<br>Protein: Betageneral<br>Falling no:logistic | Quality characteristics represent realistic distributions for quality premium/discounts |
| Quality for RR wheat | Same as above | | Same as above | Results confirm quality is not different for RRW vs. non-RRW |
| Premium/Discount for Test $/bu | -0.04 | -0.05 | Normal | Quality premium/discounts |
| Premium/Discount for Protein > 14% $/bu | 0.40 | 0.34 | Normal | |
| Premium/Discount for Protein < 14% $/bu | -0.14 | 0.19 | Normal | |
| Premium/Discount for Falling Number $/bu | -0.26 | 0.37 | Normal | |
| Premium for Vomitoxin $/bu | -0.20 | 0.44 | Normal | |
| | <u>Value</u> | | | |
| Risk Aversion | 0.5 | | NA | Relative coefficient of risk aversion |
| Technology Fee $/acre | 8.00 | | NA | Similar to value used in other crops |
| Improper Use: Prob. detection and fine | 0.3 and $10/acre | | NA | Prob. detection from Kingwell (2000) and fines derived as value to regain lost tech fee revenue plus small penalty |
| Illegal Use: Prob detection and fines | 0.06, Net revenues from RR Wheat | | NA | |

## Simulation Procedures

Simulations were conducted using @*Risk* (Palisade Corporation, 2000a). One thousand iterations were conducted, at which time appropriate stopping criteria were indicated. A base case model is developed to simulate the most likely situation.

## Results

There are several sources of risk of adopting a GM crop. One is co-mingling and the other is being detected by the technology company for improper or illegal actions. Some producers may unwittingly violate terms outlined in the technology agreement and be subject to fines or penalties. Incorporating a risk aversion parameter into the analysis accounts for how different producers will react to these situations.

The base case represents a likely situation and provides results for comparison. Base case results for all risk attitudes are illustrated below (Table 7). For risk neutral, the results are in profit/acre and are converted to utility of relative risk aversion for risk-averse producers. For a risk neutral grower, the most profitable decision is illegal adoption, but that also has the largest standard deviation.

Table 7. Agronomic Decision Model Results

| R = 0 (Risk neutral) | | |
|---|---|---|
| Choice | Mean Profit ($/acre) | St. Dev ($/acre) |
| No Adoption | 20.22 | 14.87 |
| Legal Adoption | 20.88 | 16.85 |
| Improper Adoption | 20.77 | 17.29 |
| Illegal Adoption | 26.37 | 18.45 |
| R=0.1 | Expected Utility | Std. Dev of Expected Utility |
| No Adoption | 16.17 | 11.04 |
| Legal Adoption | 16.55 | 12.44 |
| Improper Adoption | 16.43 | 12.78 |
| Illegal Adoption | 20.57 | 13.43 |
| R=0.5 | | |
| No Adoption | 8.09 | 3.93 |
| Legal Adoption | 8.02 | 4.38 |
| Improper Adoption | 7.90 | 4.54 |
| Illegal Adoption | 9.26 | 4.44 |
| R=0.9 | | |
| No Adoption | 12.06 | 4.05 |
| Legal Adoption | 11.68 | 4.60 |
| Improper Adoption | 11.46 | 4.83 |
| Illegal Adoption | 12.31 | 4.32 |

For all levels of risk aversion, the highest utility is realized by selecting illegal adoption. For R=0.1, legal adoption is second, but as the producer becomes more risk averse growing conventional wheat becomes more appealing. The expected profit/utility relationship varies across risk aversion levels (Figure 2). For risk neutral producers, illegal adoption yields the highest expected profit. Aside from illegal adoption, there is a slight advantage to legal adoption across all levels of risk aversion, but this advantage narrows as the coefficient of risk aversion approaches 0.9.

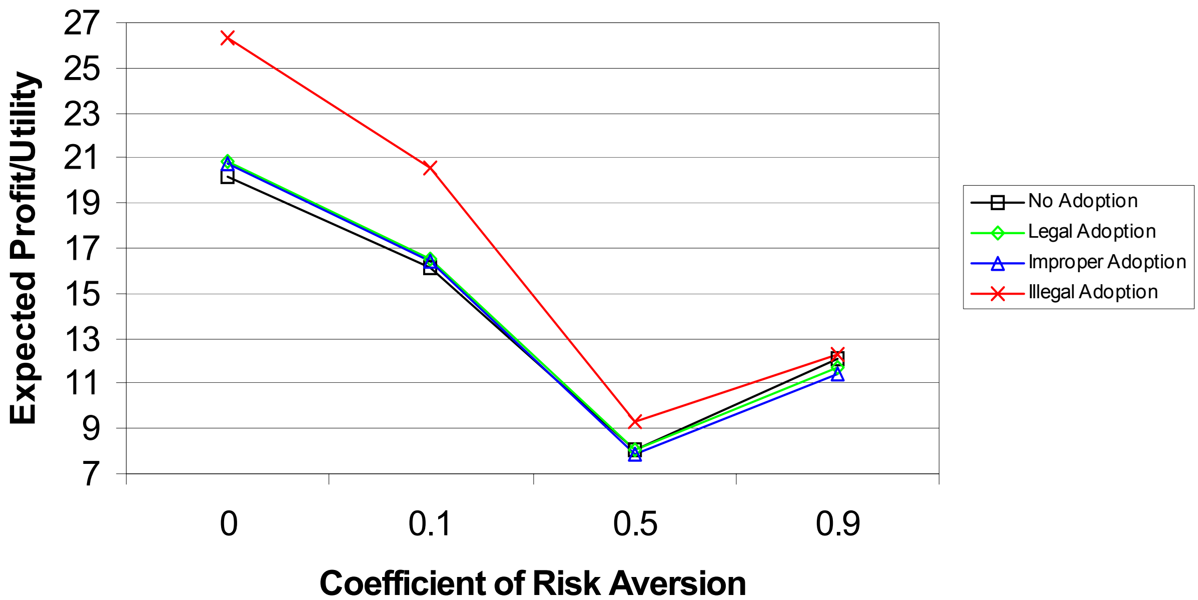


**Figure 2. Expected Profit/Utility and Risk Attitude**

## Sensitivities

Sensitivities were conducted for several parameters including technology fees, detection probability, fine severity, point of delivery technology fee, non-GM premium, and point of delivery sampling. Results are presented for each risk aversion coefficient of 0.5.

### Technology Fee

The technology fee is a key parameter in the producer decision model. The technology fee was varied from $0-$12 to determine the impact of that value on the producer's decision (Figure 3).

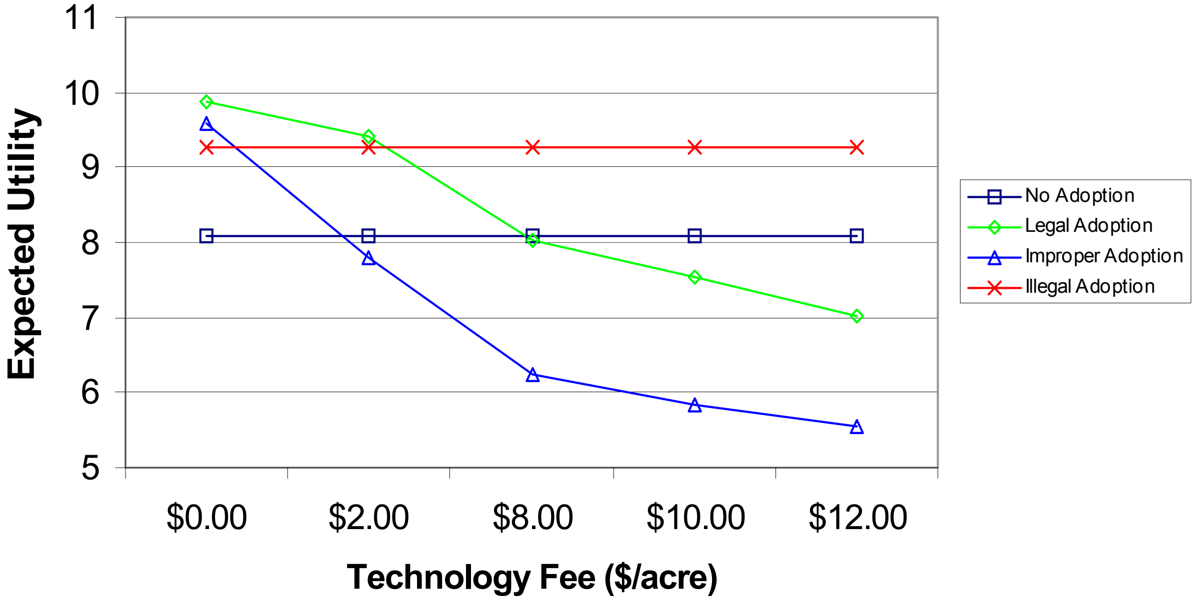


**Figure 3. Expected Utility as Technology Fee Changes, R=0.5**

If it is less costly to legally adopt a technology, most producers are likely to avoid the risk of improper and illegal use and adopt the technology.[4] As the technology fee increases to $8.00/acre, the expected utility for not adopting GM wheat exceeds that for legal adoption. Expected utility for legal and improper adoption falls as the technology fee increases. This is because improper adopters still pay the technology fee on 90% of their acres, but also face the risk of a fine if detected.[5]

### Probability of Detection

Technology companies can affect the level of detection of inappropriate use by monitoring to ensure growers comply with technology use requirements. By increasing the likelihood of detecting improper and illegal users, technology companies deter this use. A producer may be more hesitant to adopt improperly or illegally when there is a higher probability of being detected and then fined.

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[4] This result has shown to be the case with GM cotton in Australia. Monsanto's introduction of Bt cotton at a high price deterred many would be adopters from growing it because the costs were too high.

[5] A number of assumptions need to be mentioned. First, Roundup Ready® wheat is assumed to be introduced with the intent of satisfying all potential growers. There is likely to be producers who fall into the early innovator segment and will adopt the technology regardless of the price. Also, a technology company may skim the market to achieve a certain level of adoption at a higher technology fee to gain high revenues at a lower overall market share. Additionally, this model assumes that any one producer will adopt the technology improperly or illegally given a higher expected utility level. There is likely to be a smaller percentage of potential violators. Expectedly, if only a small segment of producers consider improper or illegal use, then the price for the technology is likely to be higher.

The probabilities of detection for improper use were varied from 0.10 to 0.50 and 0.04 to 0.20 for illegal use, simultaneously. Illegal use is less likely to be detected because these growers have not signed a technology use agreement with the company and monitoring is more difficult. The probability of detection scale shows the probabilities for improper and illegal use (Figure 4). No adoption and legal adoption expected utilities do not change across detection probabilities because it does not apply to these scenarios.

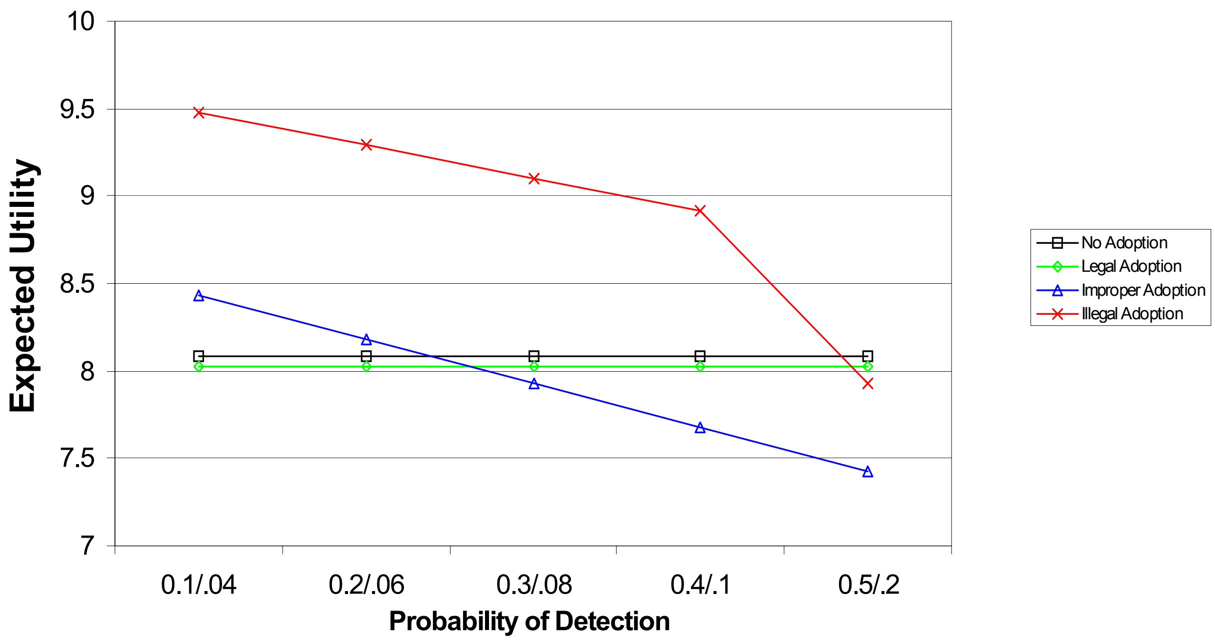


**Figure 4. Expected Utility for No, Legal, Improper, and Illegal Adoption When Detection Probability is Varied, R=0.5**

Illegal adoption has the highest expected utility unless detection probabilities exceed 0.2. Due to the lack of information available to the technology company regarding illegal users, it is very difficult to detect them. Trying to audit 20% of producers who have never signed a technology agreement would be very costly and difficult to achieve. A lower level of detection is more likely. Increasing the detection level on illegal users does not significantly impact the producer decision, unless at the extreme end of the detection spectrum. Therefore, if illegal use is a significant problem, the technology company may want to look at other ways to discourage these actions. Possibilities include paying the grain handler to run spot checks at the point of delivery (not dissimilar from what was adopted in Brazil in the 2004 crop).

Increasing the probability of detection deters improper adoption. Improper users face a higher likelihood of detection than illegal users because they have signed a technology agreement and the technology company is more aware of information such as expected acres planted and location of those planted acres. Large probabilities of detection are required to impact illegal users. Therefore, increasing the auditing probability should expose more improper users and reduce the occurrence of this action but is less effective at reducing illegal use.

An important assumption in this sensitivity involves the information available to the producer and the technology company. The producer is likely to be unaware of the probability of being detected for improper user. All he knows is that the company audits randomly over a time period. A risk-averse producer is likely going to avoid this due to the uncertainty of being detected, but a less averse producer may attempt to use the technology inappropriately. The technology company is unaware of the risk attitude of the producer and, therefore, does not have a method of focusing their auditing on high risk producers. Additionally, the technology company is limited in its ability to detect illegal users even more so than improper users. If improper use is a concern, a strategy for the technology company is to outline in their technology agreements a high likelihood of detection. Even if this likelihood is not as high as the company implies, the signal to producers should deter improper use. Ultimately, the degree of information available to both parties impacts the actions of each.

**Fines**

Violation of the technology use agreement results in a fine. A higher fine can be administered to perpetrators who violate the technology use agreement in any number of ways including planting of saved seed, selling saved seed, or not reporting planted acres accurately. A higher fine is expected to deter violations because it will drive down the expected utility for these scenarios. This sensitivity varies the fines for improper and illegal use. Fines for improper use are varied from $10-$90 per acre. Illegal use fines are varied from $84.36 (base case yield*price) to $160 per acre. No adoption and legal adoption expected utilities are unchanged from base case values in these sensitivities as fines do not apply to them.

Results varied for improper and illegal adoption. For the case of illegal adoption, expected utility declines very marginally as the fine level increases. If illegal use is prevalent among producers, increasing the fine is not likely to reduce these actions. Improper adoption is deterred somewhat by increasing the fine. An increase from $10-$30 per acre results in a lower expected utility for improper use. A technology company that has a frequent occurrence of improper use could use fines as a successful deterrence of these actions. However, it should be noted that signaling of high fines by the technology company may deter illegal and improper actions because producers are unlikely to know the probability of being detected. If a strong message is sent, this alone could discourage illegal and improper actions.

Concerns exist for using this strategy to reduce improper use. First, in some cases, improper users are unknowingly violating the agreement, imposing a huge fine may cause more harm than good. Secondly, the technology company is unlikely to have fines exceed the actual lost revenue from improper reporting of acres planted. Even though there is the argument that higher fines will act as an incentive to producers to be more careful in reporting their acres, the resulting loss of goodwill from being too hard on these producers may not be beneficial. Ultimately, the seriousness of the problem will impact the decision on fine levels for the company. If improper use is common, the resulting technology fee revenue may induce the company to amplify the fines.

**Point of Delivery Technology Fee**

An alternative is a point-of-delivery pricing scheme. Typically technology fees are deducted on a per acre basis. Every technology adopter pays the same price for the technology regardless of the benefits or losses they achieve. Under point-of-delivery pricing, the technology fee is deducted from the price at delivery. Testing would be required on all shipments at the delivery point and some form of variety declaration would likely be required (this is the mechanism adopted by the technology firm for collection technology feed in the 2004 soybean crop. The advantage of this strategy is that revenues can be extracted from producers who "brown bag" seed. Additionally, point-of-delivery pricing links technology fees to yield. At higher yields, the total amount paid in technology fees is higher. Producers pay based on the benefits they receive from the technology.

For this sensitivity, a per bushel point-of-delivery discount was implemented ranging from $0.20-$0.60 per bushel (Figure 5). The point-of-delivery pricing sensitivities are interesting. The benefits of illegal adoption are eliminated with legal and illegal adoption being equally preferred. Improper use would be the same if not for the assumption of lower input costs via generic herbicide (an illegal user may do the same thing and become an improper user). At lower fees, adoption of the technology is more beneficial. Unlike the per acre technology fee sensitivity, at higher fees no adoption becomes more appealing because the pricing strategy eliminates the benefits that illegal users had with the per acre pricing strategy.

Receiving technology fees at the point-of-delivery offers some key advantages and disadvantages. First, loss of technology revenue is eliminated. There is less need for auditing of producers because regardless of how much GM wheat is planted the technology fee is collected. The costs and inconvenience of the auditing process are lower and revenue from the technology likely higher because more producers' technology fees are collected. This strategy would be particularly beneficial in markets where regulation of GM crops is minimal, as with some developing countries where illegal planting of GM crops is rampant. Producers may also prefer this pricing strategy because it eliminates the auditing that some producers see as an inconvenience and may reduce their concerns about unkowningly reporting acres incorrectly and being subsequently fined.

There are concerns with point of delivery pricing. Although it is a method of collecting fees from legal and illegal growers, it does little to deter "brown bagging." Unless the technology company maintains intensive auditing (which it has less incentive to do now that it is collecting all technology fees), the integrity of the GM seed supply may be compromised. Lack of monitoring of the GM seed supply may lead to complications including higher rates of co-mingling of non-GM and GM wheat. The impact of this strategy depends on the amount of illegal use. If a small number of producers are growing seed illegally, then the seed supply concerns are less significant. Additionally, this system requires a relationship between the technology company and all delivery point elevators.

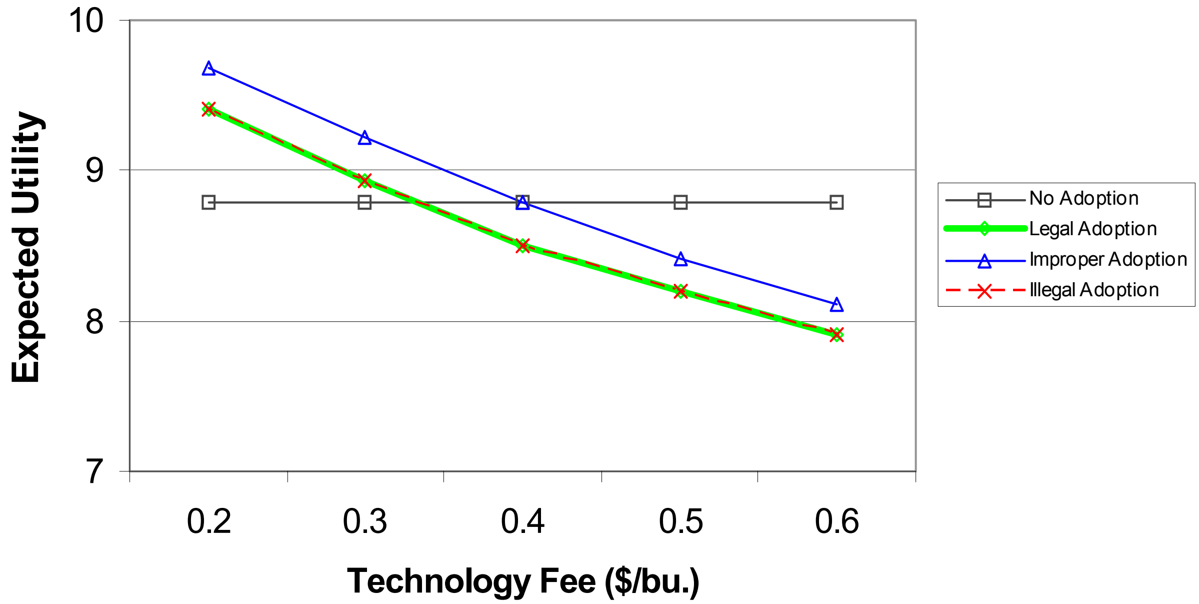


**Figure 5. Expected Utility with Point of Delivery Technology Fee, R=0.5**

**Non-GM Premium**

Non-GM wheat may have a premium over GM wheat due to export restrictions and assuming a feasible segregation system. This sensitivity determines how changes in the value of non-GM wheat may influence the producer's decision. A range of $0.06-$1.00 premium for non-GM is considered. Test samples are taken from all deliveries and there is a probability of co-mingling of 2.5% (Figure 6).

As the premium for non-GM increases, the expected utility for no adoption increases. These results indicate that illegal adoption will still have the highest expected utility up to about a $0.20 premium. Beyond that, conventional wheat is preferred.

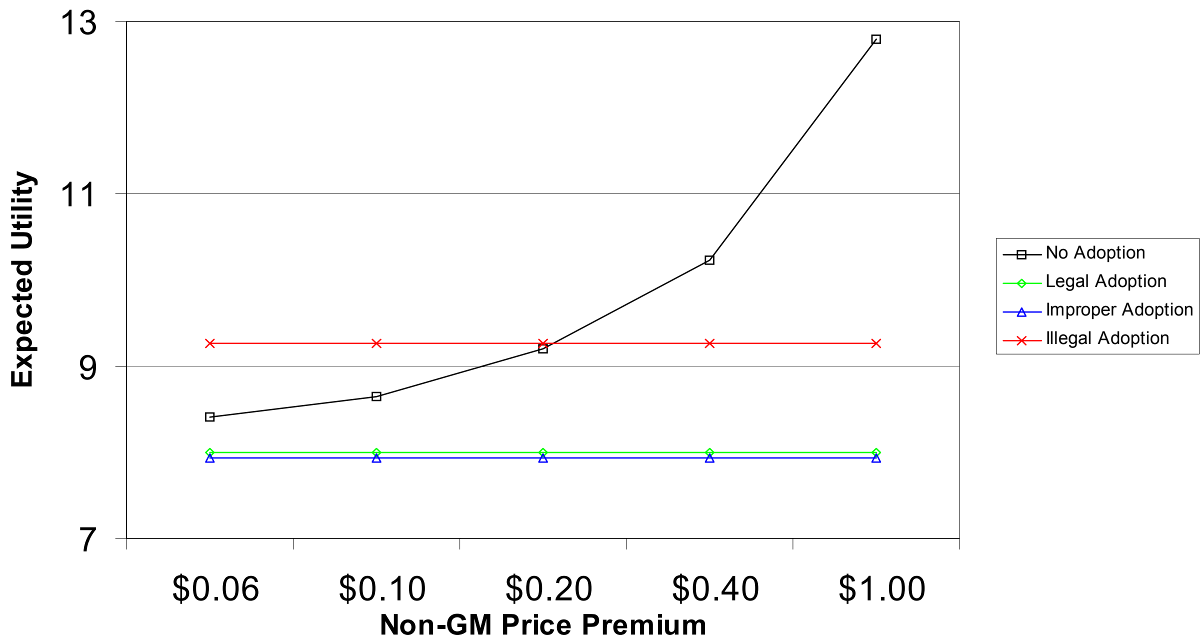


**Figure 6. Expected Utility when Non-GM Price Premiums Exist, R=0.5**

**Roundup Ready® Wheat Yield Benefit**

The 11%-14% yield benefit for Roundup Ready® wheat was an assumption based on results of earlier studies. Blackshaw and Harker (2002) found a 9%-16% yield benefit for Roundup Ready® wheat. Kalaitzandonakes and Philips (2004) found a $4/acre convenience factor. A sensitivity was conducted to account for these factors.

Results of the yield adjustment and convenience factor are concurrent with the base case, offering a similar interpretation of the producer's decision (Figure 7). Differing from the base case, though, is the increased comparative advantage of legal and improper adoption over the no adoption choice. Legal and improper adoption becomes more appealing relative to no adoption than in the base case.

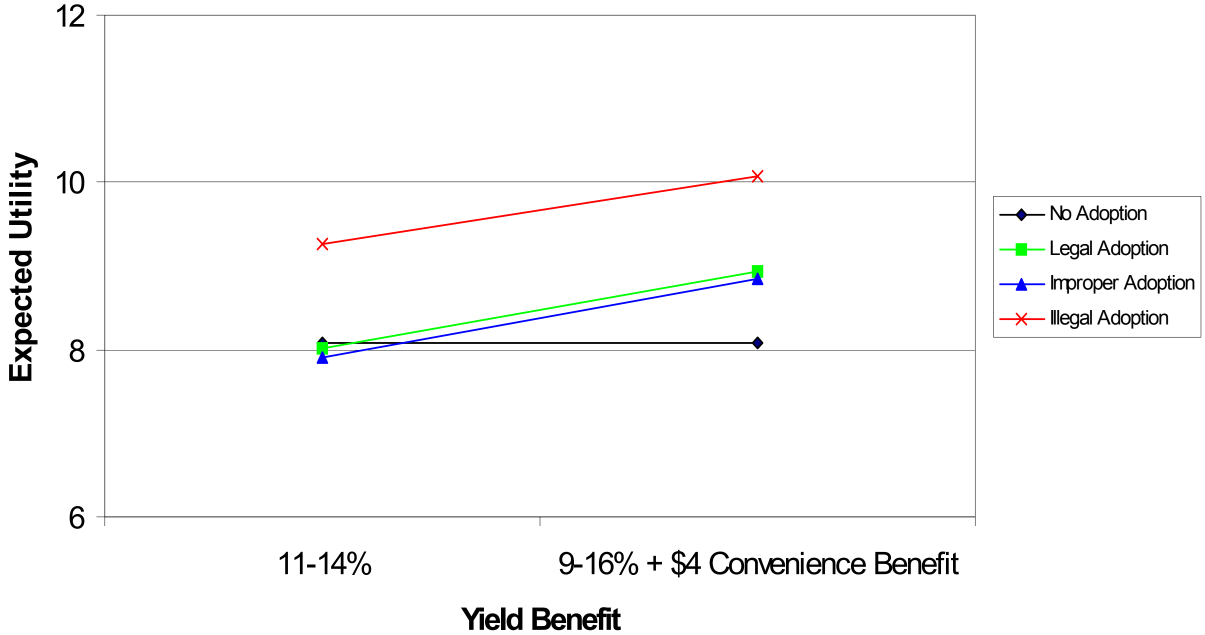


**Figure 7. Expected Utility for Base Case and Alternative Yield Plus Convenience Benefits, R=0.5**

### Stochastic Dominance Analysis of Choice Sets

Stochastic dominance is often used for analyzing risk in agriculture (McCarl, 1990). Originally developed by Meyer (1977a), stochastic dominance guarantees a choice set's dominance as long as the risk aversion coefficient is within a given range.

There have been numerous applications of stochastic dominance in agriculture. Dias, Helmers, and Eghball (1999) used generalized stochastic dominance to determine the risk efficiency of nine different technologies of land application. Another application was in valuing soil test information for crop production (Lukin and Eppline, 1999). A risk management application of comparing grazing versus feeder and option contracts in feeder cattle was conducted by Harrison, Bobst, Benson, and Meyer (1996).

Due to the risk and uncertainty in decision making in agriculture, Meyer's methodology including first-degree (FSD), second degree (SSD), and third degree (TSD), as well as generalized stochastic dominance (GSD), is suitable for such decision making. FSD is a stronger dominance criterion but has less restrictive assumptions. SSD is higher order and GSD methodology differentiates between choice sets of data on account of their risk efficiency. FSD and SSD are incorporated together for GSD, therefore, facilitating implementation of risk aversion coefficient lower and upper bounds and comparing choice sets of data. The methodology was used because it allowed behavioral assumptions by producers to be explicitly accounted and to provide a theoretically sound comparison of the risky alternatives.

Outcomes for this model are based on expected utility from a distribution set. The producer selects the scenario with the highest expected utility. Producer's choices are measured across a range of risk aversion levels.[6]

Generalized stochastic dominance incorporates first and second degree stochastic dominance and higher order stochastic dominance. The methodology is useful because it allows the distribution of outcomes for the four scenarios to be compared to determine the best outcome, while accounting for risk attitudes of the producer. Implementation was achieved using *Astomdom,* which determines rankings of scenarios and allowed sets of distributions to be compared, accounting for the risk in each distribution (Meyer, 1980). The program ranks the distributions according to their risk efficiency and profit. Preferences are based on how the program ranks the distributions.

Generalized stochastic dominance was used to analyze the results of the base case at technology fees ranging from \$0 to \$12 per acre. Results are summarized in Table 8. Results are similar in that illegal use is most preferred at most technology pricing levels. GSD only showed legal use to be exclusively preferred when the technology does not cost anything. At \$2/acre, legal and illegal adoption is equally preferred, meaning that the risk efficient set includes legal and illegal adoption. At every technology fee increment above \$2/acre, illegal adoption is the most preferred, with legal adoption being second, either by itself or with the alternative choices.

Two observations are reflected in the GSD results (Table 8). Legal adoption is preferred at lower technology fees, and illegal adoption is preferred at higher technology fee levels. Also, at the extreme technology fee level of \$12/acre, legal use is still at least as equally preferred to improper and no adoption.

Lower technology fees reduce illegal adoption. Pricing the GM wheat technology low is a suggestive way of curbing illegal activities. Legal adoption is at least second to the risk efficient set when technology fee levels are \$2/acre. Illegal use would be expected to be selected at most technology fee levels. Effectively, it may not be feasible to deter all illegal use. Rather, allow a small amount of it to occur and price at a higher level where revenues can be maximized.

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[6] Generalized stochastic dominance assumes absolute risk aversion coefficient, A= -U''(y)/U'(y) (Zentner et al., 1981).

Table 8. Risk Efficient Sets Using Generalized Stochastic Dominance

| Technology Fee ($/acre) | Most Risk Efficient Set | 2nd to Risk Efficient Set | 3rd to Risk Efficient Set | Last to Risk Efficient Set |
|---|---|---|---|---|
| $0 | Legal | Improper | Illegal | No Adoption |
| $2 | Legal, Illegal* | Improper | No Adoption | |
| $4 | Illegal | Legal | Improper | No Adoption |
| $8 | Illegal | Legal | Improper | No Adoption |
| $10 | Illegal | Legal, No† Adoption | Improper | |
| $12 | Illegal | Legal, No†† Adoption, Improper | | |

* Legal and illegal adoption are both within the risk efficient set.
† Legal and no adoption are both second in the risk efficient set.
†† Legal, no adoption, and improper adoption are all second to the risk efficient set.

**Determining the Optimal Technology Fee**

The model was reformulated as a profit maximizing problem for the technology company. *Risk Optimizer* (Palisade Corporation, 2000b) was used to determine the optimal technology fee for the base case. Sensitivities were conducted on fines and probability of detection for improper use. *Risk Optimizer* allows one to optimize a target cell subject to constraints on other parameters.

The technology company seeks to maximize technology fee revenues by choosing the technology fee ($TF_i$) that maximizes revenues for the growers preferred choice i:

$$Max\ (revenue) = Max\ E\left[\sum_{i=1}^{4} TF_i \cdot FC_i\right]$$

where $FC_i$ is a binary variable equal to 1 when $U(\Pi_i)$ =Max [$U(\Pi_1)$, $U(\Pi_2)$, $U(\Pi_3)$,$U(\Pi_4)$] and zero otherwise; and $TF_i$ is the technology fee for grower choice i.

The technology firm is most concerned with eliminating illegal adoption first because they still gain 90% of their technology fee revenue if producers are improper users. Altering the fines and probability of detection will alter producer's decision making and, therefore, alter the level of the technology fee.

Table 9 shows how changes in fines and probability of detection for improper use influence the optimal technology fee, revenue from technology fees, and proportion of producers legally or improperly adopting GM wheat. Only parameter changes for improper use are presented in the results. This is because even at the upper tail of the parameter ranges for illegal use, the changes in technology fee were essentially zero. Because improper use is closely tied with legal use, the overall proportion of adopters is combined for these two to signify the importance or deterring illegal use first.

Table 9. Sensitivity of Optimal Technology Fees, as Fines and Probability of Detection Vary

| Item Value | Optimal Tech Fee ($/acre) | Expected Tech Fee Revenue ($/acre) | Proportion of Producers Legal/Improper | Proportion of Producers Illegal |
|---|---|---|---|---|
| Fines | | | | |
| $10 /A | $2.11 | $1.35 | 0.7 | 0.30 |
| $30 /A | $2.11 | $1.57 | 0.83 | 0.17 |
| $50 /A | $2.11 | $1.90 | 0.95 | 0.05 |
| Probability of Detection | | | | |
| 0.3 | $2.11 | $1.35 | 0.7 | 0.3 |
| 0.4 | $2.11 | $1.16 | 0.62 | 0.38 |
| 0.5 | $2.11 | $0.99 | 0.52 | 0.48 |
| 0.6 | $2.11 | $0.81 | 0.43 | 0.57 |

Parameters for improper use were varied to determine the influence on the proportion of producers who switch from legal/improper to illegal. The optimal technology fee remained constant at different fine and detection levels. This occurs largely because as tech fees increase, producers prefer legal and illegal adoption to improper (Figure 3). Therefore, increased fines and higher probabilities of detection only further decrease the utility of improper relative to legal and illegal adoption. Although changes in fines and probability of detection did not impact optimal tech fees, the per acre amount received by the technology company changed. This value is less than the actual technology fee because it is the expected mean per acre revenue subject to the level the parameters are set at.

As fines for improper use increase, the mean revenue to the technology company increases. This is because the proportion of legal/improper users is increasing versus illegal users. At higher fines for improper use the company benefits two-fold. First, it deters illegal adoption, as evident by the decreased proportion of illegal users, and deters improper use because of the higher fine. Consequently, the technology fee revenue is higher than at previous fine levels.

While increasing fines for improper use acts as a deterrent for improper use and reduces the amount of illegal use, increasing probability of detection reduces improper use but increases illegal use.

Both fines and probability of detection deter improper use. However, the effect of varying these parameters results in two distinct implications for the technology company. Increasing fines deters improper use and shifts growers from improper and illegal use to legal use, as evident by decreased proportion of illegal use and increased technology fee revenue. In contrast, increasing the probability of detection for improper use appears to shift producers to illegal use, therefore, hindering the effectiveness of increased probability of detection in thwarting in appropriate technology use.

The $2.11/acre technology fee yields the maximum revenue the technology firm can receive if its purpose is to deter illegal adoption. Improper adoption still occurs at this level because allowing some improper adoption to occur will still provide the technology company with revenue. Expending a high effort to deter all forms of contract violation, including improper adoption, may not be the optimal strategy. Instead, allowing some of the improper adoption to occur, while eliminating illegal use, can be carried out by applying the $2.11/acre technology fee.

Results from the generalized stochastic dominance analysis imply that legal adoption is preferred, as much as improper and no adoption, at technology fees up to $12/acre. This implies that if illegal adoption is not a concern for the technology company, a higher technology fee can be charged. This differs in determining the optimal technology fee subject to the legal/improper adoption constraint because illegal adoption is assumed to be a problem and, therefore, the technology company's pricing strategy is to price at the level that will deter illegal use.

## Summary

Contracts between the technology firm and producer are used to define technology use, pricing, and ensure that the firm receives royalties. A problem arises from inappropriate use or "piracy" of the firm's technology by producers. Contracts can be designed to mitigate illegal and improper use of GM technology.

The purpose of this report was to evaluate contract terms to induce legal adoption of GM HRS wheat. An analysis was conducted to compare four different GM adoption scenarios: no adoption, legal adoption, improper adoption, and illegal adoption. A producer was assumed to choose that with the highest expected utility of profit. Contract terms, such as technology fee, probability of detection for contract violation, and fines for violation, were adjusted to determine the effect on the producer's adoption decision. Stochastic simulation was used to account for the uncertainty and risk in the analysis, and generalized stochastic dominance was conducted to compare the choice sets. A final analysis was conducted to determine the optimal technology fee when the objective is to maximize the technology firm's revenue. Results are summarized in Table 10.

Table 10. Summary of Impacts on Contract Terms on GM Adoption

| Sensitivity | Effect on GM Wheat Adoption |
| --- | --- |
| Technology fee | At lower fees, legal adoption is best |
| Risk aversion | Higher risk-averse producers tend to avoid illegal and improper use. Legal and no adoption is more appealing to the more risk-averse producers |
| Detection probability for improper/ illegal use | Improper use declines substantially with increases in probability detection, illegal use declines marginally |
| Fines for improper/illegal use | Improper use declines with increased fines but only marginal decreases in illegal use |
| Point of delivery technology fee | Eliminates illegal use |
| Non-GM price premium | Higher non-GM premium increases likelihood of conventional wheat adoption |

The level of technology fee is most critical to the adoption decision. Charging too high a price will induce illegal and improper adoption. A point of delivery technology fee is an alternative that eliminates the advantage of illegal use because all producers pay if they deliver GM. Point of delivery pricing mitigates illegal use but producers still react to the price level by only adopting if the price is low enough.

Fines for detection and detection probability have variable impact on the producer's decision. An increase in the monitoring deters illegal use marginally and substantially decreases improper use. Increasing fines does not deter illegal use and is marginally effective at decreasing the occurrence of improper use.

Technology firms are unlikely to continue to invest in GM seed technology if their efforts are not compensated.[7] Contracts can be designed to deter illegal and improper use of GM crop technology without discouraging adoption. Monitoring and auditing procedures have to be feasible. If there are only a small number of producers who illegally adopt the technology, then it may not be in the firm's interest to exert substantial effort to deter these actions. It is important not to undermine the value of signaling on the part of the technology firm. A clear message can be directed to producers indicating that contract violators will be punished with a substantial penalty or fine. Without revealing the detection probability, firms can discourage inappropriate technology use through the credible threat of punishment for violation.

[7] As evidenced in recent developments in Argentina where Monsanto has halted sales of Roundup Ready® soybeans due to illegal use and the ongoing supreme court case in Canada between a Saskatchewan farmer and Monsanto over illegal use.

Increasing fines is a better deterrent to illegal and improper use than increasing probability of detection is when maximizing technology fee revenue is the company's objective. This suggests that a technology company, when faced with problems involving illegal use, may be able to increase their revenue without actually changing the price of the technology fee. Raising the price of the technology may influence legal adopters to switch to improper or illegal adoption, as previous results in this analysis suggest.

Results of this analysis can also be used to evaluate contracts by buyers wanting non-GM wheat. By looking at the size of the premium necessary to induce non-GM adoption, buyers can develop pricing terms as an incentive to producers to grow non-GM wheat.

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