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Grower Response to Contracts and Risk in Genetically Modified (GM) Crops

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

Contract strategies can resolve some of the challenges that exist for property rights conformance of genetically modified (GM) crops. The purpose of this research is to determine how contract terms impact adoption decisions related to GM grain production and marketing. A simulation model was developed for prospective GM introduction in hard red spring (HRS) wheat, and distributions of net returns for growers were analyzed using stochastic dominance and stochastic efficiency. Results illustrate that contracts can be designed to induce desired behavior. Technology fees, probabilities of detection, and the level of non-GM premiums were the most notable factors influencing adoption decisions. In addition, point-of-delivery pricing and premiums for non-GM production impact adoption decisions.

Key words: adoption risk, GM crops, incentives contracting, stochastic dominance

Introduction

Agbiotechnology companies use contracts in numerous crops to protect their intellectual property and earn a return from their research. Contracts for genetically modified (GM) crops normally include terms for technology user fees, seed planting, and replanting restrictions (e.g., growers cannot keep seed for the following year for replanting purposes). Contract provisions allow monitoring of acres planted, and stewardship guidelines provide growers with agronomic recommendations and requirements for technology use. In response, growers can choose from a range of alternatives including adoption and complying or not complying with the contract terms, adopting it illegally, or not adopting the technology.

The purpose of this research is to examine how contract terms and pricing strategies impact adoption decisions related to GM grain production and marketing, in this case wheat. The analysis determines how technology agreements impact incentives to conform to contract terms, the size of non-GM premiums to discourage adoption, and point-of-delivery pricing. Stochastic dominance and stochastic efficiency are used to identify how contract terms affect efficient choice sets for growers and risk-efficient adoption strategies. This article contributes to the growing literature on contracting strategies, risk, and GM crops marketing.

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Background and Previous Literature

There has been an escalation in research on contracts in the economics literature (e.g., as discussed in Dutta, 1999; Laffont and Martimort, 2002; Molho, 1997; Rasmusen, 1994; and Salanié, 1997; among others). In agriculture, there has been an increase in the use of contracts to govern production and marketing in agriculture (MacDonald et al., 2004; Key and MacDonald, 2006). However, in grains (and small grains in particular), use of contracts has not been common, comprising only about 12% of the production.

Contracts are more critical for GM crops. The contracts examined here would be considered production contracts in the paradigm of MacDonald et al. (2004). Production contracts detail specific farmer and contractor responsibilities and typically specify particular inputs and production guidelines, and allow the contractor to give technical advice and make field visits. Sykuta and Parcell (2003) describe the terms of the agbiotechnology contract used by DuPont, and the contract terms used by a broad spectrum of agbiotechnology firms are discussed by Maxwell, Wilson, and Dahl (2004). With increased use of agbiotechnology in crop production, undoubtedly there has been an increase in use of production contracts (e.g., as analyzed in Hurley, Mitchell, and Rice, 2004). Further, as GM output traits are developed, the need for contracting will become essential (Riley and Hoffman, 1999; Shoemaker et al., 2001).

Contracts define fees, agronomic stewardship recommendations,[1] penalties, incentives, and premiums. The agbiotechnology firm establishes the technology fee, but must consider the tradeoff between higher fees versus the disincentive they provide growers to adopt the technology and/or comply with contract terms. Technology fees traditionally are identified in the contract, paid when seed is purchased, and assessed on the area seeded. More recently, this strategy is changing for some companies and crops. The agbiotechnology firm uses random checking, fines, and other penalties to induce desirable behavior. Potential legal initiatives against violators (discussed below) are used by agbiotechnology firms as a mechanism of enforcement. In evaluating decisions regarding these devices, it is critical to estimate how growers would respond to varying contract terms, penalties, fines, and so on.

Technology use agreements (TUAs) are a feature of GM contracts and have similar principles as stewardship agreements. Contracts can be designed with incentives to adhere to the terms of the agreement. In some cases, TUAs stipulate that the farmer is subject to random checking of fields and storage bins for up to three years following the last planting of the GM crop to ensure the grower does not keep seed for replanting. The technology provider may require that only its herbicide be applied over the crop for weed control purposes. Penalties may be imposed if these rules are violated. Most companies require that seed is not "brown bagged" or "bin run," meaning seed cannot be replanted or supplied to anyone else for replanting.[2] Monitoring through random audits is intended to induce compliance among growers (*Agweek*, 2003).

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[1] An example of a stewardship agreement is the refuge options for insect resistance management with Bollgard Cotton. Farmers currently have two options for planting Bollgard Cotton as it relates to insect resistance management. They can plant 80% of the area in a given field to Bollgard and 20% to conventional cotton. They are allowed to spray the 20% with conventional insecticides to control insects, or they can plant 95% of the field to Bollgard and leave 5% of the field unsprayed for insects (Gigax, 2005).

[2] A comprehensive summary of current contract terms used by agbiotechnology companies is presented by Maxwell, Wilson, and Dahl (2004).

Agbiotechnology firms also confront "piracy" risk due to users obtaining seed illegally by either purchasing black-market seed or purchasing from users who initially obtained the seed legally but ignored replanting restrictions (Gurton et al., 2005). Piracy results in loss of revenue to the agbiotechnology firm and varies across regions and countries. As an example, 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. Piracy has also resulted in a number of confrontations and strategic initiatives. 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).

A recent study indicated Monsanto had initiated legal proceedings 90 times against 147 farmers and 39 agricultural companies over issues related to technology piracy (Center for Food Safety, 2005; also reported by Elias, 2005). Monsanto claims this is a necessary component of its strategy for recouping revenue from technology users. In Brazil, Monsanto implemented a mechanism to collect royalties on Roundup Ready® soybeans where growers planted Roundup Ready® soybeans in prior growing seasons without paying a technology fee until the 2004 crop (*Farmers' Independent Weekly*, 2003). Prior to the 2004 crop, since it was illegal to produce GM soybeans, there was no mechanism to collect technology fees (akin to charging a fee for an illegal drug). Commencing with the 2004 crop, legislation changed, making it legal to produce the crop, and Monsanto initiated a royalty scheme in which the fee was collected at the point of delivery by grain firms (Monsanto, 2004, p. 43). In Argentina, illegal purchases of Roundup Ready® soybeans induced Monsanto to halt sales in that country because of the lack of royalty collection (Gray, 2004).

Model Overview

A model is developed to evaluate how growers respond to different contract provisions in terms of the adoption strategies of GM technology. The distribution of payoffs was evaluated using stochastic dominance with respect to a function (SDRF) and stochastic efficiency with respect to a function (SERF). Kingwell (2000) applied a similar model to cotton contracts in Australia using a utility framework. Our model expands on Kingwell's work with explicit treatment of risk by considering the distribution or return from each adoption strategy across a range of risk aversions.

Growers have four choices, including whether to grow non-GM (*NA*), to legally adopt GM (*LA*), to improperly adopt GM (*IMP*), and to illegally adopt GM (*ILL*). Each choice would have a different expected return and risk. Legal adopters acquire the GM seed legally. Improper GM adoption involves legally purchasing seed, signing a technology agreement, but violating contract terms (as applied here, it is assumed to be from under-reporting of GM acres which results in a loss of technology fees to the agbiotechnology firm on the under-reported acres). Illegal GM adoption occurs when a grower purchases the seed illegally and does not pay the technology fee. This includes use of bin-run GM seed from prior growing seasons and/or seed purchased illegally. The hypothesis is that contract strategies impact grower decisions about their choice. There are numerous sources of risk related to the grower's adoption decision, discussed below.

The analysis was applied to GM traits in hard red spring (HRS) wheat. A number of GM traits are under development for wheat (Wilson, Janzen, and Dahl, 2003) and even though Monsanto has temporarily withdrawn its Roundup Ready® (RR) trait from commercialization, others are being developed, including fusarium resistance, among others. Indeed, U.S. Wheat Associates and other organizations recently passed resolutions encouraging commercialization of these traits (U.S. Wheat Associates, 2006). In all cases, GM traits will result in a bifurcated market making contracting and segregation an integral component of marketing and commercialization. RR is a trait with a yield advantage over conventional (Blackshaw and Harker, 2002), as well as lower chemical application costs, but would encompass a TUA and technology fees.

Stochastic simulation is used to simulate payoffs for each of the four strategies. Distributions of net returns are then compared using SDRF and SERF to determine risk-efficient decisions and to examine effects of risk aversion on preferences. Risk is a result of variability in yield, price, quality (protein, falling number, test weight, and vomitoxin), in addition to the chance of being detected for violating a term of the TUA, testing, and the probability of commingling. Sensitivity analyses were conducted to evaluate the impact of contract parameters (technology fees, probability of violation detection, fines for violation), as well as the effect of point-of-delivery pricing and non-GM wheat premiums on producer preferences. Government program payments were not included because of decoupling, which should not impact planting decisions.[3]

Mathematical Description of Model

A payoff function is defined as net returns over direct costs per acre, or: Π_i = gross revenue less direct costs for choice i, where $i = 1, \ldots, 4$, for each of the alternative grower strategies (*NA*, *LA*, *IMP*, and *ILL*), as described above. Costs are defined below, and price is a function of protein, falling number, vomitoxin, test weight, and transportation costs. In the base case, price excludes a non-GM premium. The model for net returns is defined as:

$$(1) \qquad E(\Pi_i) = \hat{Y}_i * \hat{P}_i - C_i - \hat{T}_i,$$

where $E(\Pi_i)$ is the expected net return per acre of choice i; a "hat" ($\hat{}$) indicates the notation is a random variable, and $\hat{Y}_i$ is the yield for choice i (bushels/acre), $\hat{P}_i$ is price for choice i ($/bushel), and $\hat{T}_i$ represents the technology costs for choice i. C_i is the direct cost for producing choice i and includes seed, herbicides, volunteer control costs, fungicides, insecticides, fertilizers, crop insurance, fuel, repairs, drying, miscellaneous, and operating interest—each on a $/acre basis. Volunteer control costs were assumed applied on all but the no-adoption (*NA*) strategy, and herbicide costs varied by alternative. The remaining costs are assumed the same across strategies and are derived from Swenson and Haugen (2002). Indirect costs such as land and taxes are excluded because they are fixed and constant across crops and choices. Yield for GM wheat has an 11%–14% yield benefit (uniformly distributed) over conventional wheat due to superior agronomics (Blackshaw and Harker, 2002).

[3] Further, as noted below, our data consist of a limited time period (1993–2001) consistent with availability of data on vomitoxin distributions. During that period, loan deficiency payments (LDPs) were made in three years and there was no correlation between annual price levels.

Price ($\hat{P}_i$) is defined as follows:

$$\hat{P}_i = \left(P^M + P^H * (PRO_i) - P^L * (1 - PRO_i) - D^T * TW - D^{FN} * FN - D^{Vom} * VS\right), \tag{2}$$

where P^M is the base price (units and descriptions are reported later in table 2); P^H is the premium for protein > 14% (random); PRO_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./bushel 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 2 ppm and 0 otherwise.

Technology costs are defined as:

$$\hat{T}_i = TF_i - VC_i - p(V_i) * F_i, \tag{3}$$

where TF_i is the technology fee for choice i; VC_i is the cost of volunteer control (assumed only for RR wheat adopters); $p(V_i)$ is a discrete variable where 1 = detection and 0 = non-detection for scenario i (where $i = IMP, ILL$), which occur with specified probabilities; and F_i is the fine applied if detected. Conventional growers do not incur a technology fee, legal adopters pay the technology fee on all acres, improper adopters pay the technology fee on a reduced portion of their acres, and illegal adopters do not pay the technology fee. Mechanisms influencing deterrence of improper and illegal use include increasing the probability that an improper or illegal grower is detected and increasing the fine for violation (F_i). Varying technology fees change the expected payoff from the legal adoption scenario. The expected yield benefit, ease of use, and less herbicide use also impact revenues and costs, as depicted in equation (1).

TUAs require growers to agree to random audits for up to three years following the first planting of the technology. Auditing involves ensuring the number of reported acres is correct and making certain seed is not being reused. It also involves checking that the grower applied Monsanto's Roundup brand herbicide over the crop instead of a generic glyphosate substitute by contacting the retailer where the herbicide was purchased. Illegal users are more difficult to detect as they have not signed a technology agreement and the company would not have a record of their existence.

Data Sources, Distributions, and Simulation Procedures

The base case is defined for a grower in Crop Reporting District (CRD) 2, located in the north central region of North Dakota, and is typical of yields and prices in the HRS wheat-producing regions. The base period was 1993–2001, and was chosen to encompass a period containing available data of some of the critical variables.[4] Table 1 provides a summary of the data sources. Distributions for premiums and discounts for test weight, protein, falling number, and vomitoxin are taken from Dahl et al. (2001).

[4] The data on vomitoxin were only available from 1993–2001, which restricted our time period.

Table 1. Data Sources

Variable	Data Source
Historic Wheat Yield	North Dakota Agricultural Statistics Service (2003)
Roundup Ready® Wheat Yield Benefit	Blackshaw and Harker (2002)
Wheat Prices	Minneapolis Grain Exchange (1993–2001)
Quality Data (Test Weight, Protein, Falling No.)	ND State University, Department of Cereal Science and Food Technology (1993–2001)
Vomitoxin Losses	Nganje et al. (2004)
Quality Premiums and Discounts	Dahl et al. (2001)
Transportation Cost (CRD #2 to Minneapolis)	Burlington Northern Santa Fe Railway (2003)
Crop Production Costs	Swenson and Haugen (2002)

Distributions for the random variables were determined using *BestFit*™ (Palisade Corporation, 2000) which estimates parameters for each possible distribution using maximum-likelihood estimators. Different fit statistics (Anderson-Darling and Kolmogorov-Smirnov) were used to evaluate the distributions. Assumptions and distributions are reported in table 2. Correlations were estimated between yields, price, protein, test weight, falling number, and vomitoxin. The correlations between protein with yields (−0.79) and protein and test weight (−0.72) were statistically significant and incorporated within the stochastic simulation model.

Detection probabilities [in equation (3)] were equal to those used by Kingwell (2000) and were represented as discrete distributions. An improper user is detected with the likelihood of 0.30, while illegal users have a detection probability of 0.06. These were represented as binomial distributions ($p(V_i)$) indicating the illegal/improper activity was detected ($p(V_i) = 1$) or not detected ($p(V_i) = 0$) with probabilities equal to those above. If detected, fines were assessed. An illegal adopter has a much smaller likelihood of being detected—i.e., because this user has not signed a TUA, the company is less likely to be aware of the grower's existence. Improper users face a $10/acre fine if detected, reflecting a typical cost to cover the loss of technology fee revenue due to incorrect acreage reporting. Illegal users face the possibility of losing revenue realized from adopting GM wheat illegally. Therefore, fines for illegal use when detected were assumed equal to total revenue ($Yield * Price$) for illegal production. A greater fine is allocated to deter illegal use because "brown bagging" seed is more serious than inaccurate reporting of planted acres.

Equations (1)–(3) were the basis of the simulation of net return distributions of alternative adoption strategies, simulated in *@Risk* (Palisade Corporation, 2000). Variables in each were defined as random or nonrandom, and whether correlated or not. One thousand iterations were conducted, at which the stopping criteria were satisfied. Random draws were correlated where statistically significant to assure consistent cross-variable relationships are reflected in the random draws.

Stochastic Dominance and Stochastic Efficiency Analysis of Choice Sets

There are four steps in our analytical methodology. First, we derive the Π_i for each alternative $i = 1, \ldots, 4$. Second, we use stochastic simulation to iterate 1,000 outcomes of Π

Table 2. Base Case Assumptions, Distributions, and Logic

Variable/Parameter	Assumptions/Description	Distribution	Logic
Yield (bushels/acre)	Mean = 27.56, SD = 3.54	Normal	Mean and std. dev. in ND CRD #2 (1993–2001)
Yield with RR wheat	11%–14% benefit over conventional yield	Uniform	Monsanto field trials
Price	Mean = 3.43, SD = 0.41	Extreme Value	Minneapolis less freight (1993–2001)
Quality	Quality variables equal to distributions accrued over period 1993–2001	Test Weight: Extreme Value Protein: Logistic Falling Number: Logistic	Quality characteristics represent realistic distributions for quality premiums/discounts
Vomit Damage	Min. = 0.000 Mean = 0.000 Max. = 0.123	Triangular	Used to estimate level of vomitoxin and determine if discounts applied
Quality for RR wheat	(same as above)	(same as above)	Results confirm quality is not different for RR wheat vs. non-RR wheat
Premiums/Discounts:			
Test Weight ($/bu.)	Mean = -0.04, SD = -0.05	Normal truncated at 0	Quality discounts/premiums
Protein > 14% ($/bu.)	Mean = 0.40, SD = 0.34	Normal truncated at 0	
Protein < 14% ($/bu.)	Mean = -0.14, SD = 0.19	Normal truncated at 0	
Falling Number ($/bu.)	Mean = -0.26, SD = 0.37	Normal truncated at 0	
Vomitoxin ($/bu.)	Mean = -0.20, SD = 0.44	Normal truncated at 0	
Technology Fee ($/acre)	Value = 8	NA	Similar to value used in other crops
Improper Use (prob. of detection and fine)	Values = 0.3 and $10/acre	NA	Prob. of detection from Kingwell (2000); fines derived as value to regain lost technology fee revenue plus small penalty
Illegal Use (prob. of detection and fine)	Values = 0.06, net revenues from RR wheat	NA	

for each $i = 1, \ldots, 4$. Results from these simulations are collected and used to define distributions for each choice. Third, SDRF is used to analyze and create rankings among the choices across a range of Arrow-Pratt absolute risk absolute coefficients (ARACs). Fourth, SERF is used to estimate the certainty equivalent that decision makers would place on a risky alternative relative to a no-risk investment. Certainty equivalents are estimated across a range of risk attitude coefficients. They are utilized to rank alternatives and determine where preferences among alternatives change, and to estimate the risk premium for alternatives relative to the no-adoption case.

SDRF was used to determine risk-efficient decisions among grower choices. It allows growers' behavioral assumptions to be explicitly modeled to compare among risky alternatives. Outcomes are based on expected utility from a distribution of net returns. Growers' choices are measured at the endpoints of a range of risk-aversion levels. Growers are considered "amoral calculators," following Lataez-Lohmann and Webster (1999), 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 adoption choices.

SERF was used to estimate and rank risky choices based on certainty equivalents assuming a negative exponential (CARA) utility function for a range of ARACs (Hardaker et al., 2004), following Sangtaek, Mitchell, and Leatham (2005); Babcock and Hennessy (1996); Kaylen, Loehman, and Preckel (1989); and Lambert and McCarl (1985). For different ARACs, certainty equivalents were estimated and ranks compared. An advantage in using certainty equivalents is that "the absolute differences in the certainty equivalent values between risky alternatives represent the risk premium that decision makers place on the preferred alternative over another alternative" (Ribera, Hons, and Richardson, 2004, p. 419). The risk premiums indicate the magnitude of differences in relative preferences among choices. The premium indicates the change that would have to occur in the certainty equivalent of net payoffs in order to induce a change in preferences. The sign of the premium indicates the preference relative to the no-adoption case. Positive premiums indicate the alternative is preferred to the no-adoption case, while negative premiums indicate the no-adoption case is preferred.

The range of ARACs utilized for both the SDRF and SERF was from -0.1 to 0.117. Values for the upper bounds were chosen following McCarl and Bessler (1989) and are within a reasonable percentage of income standard deviation (Babcock, Choi, and Feinerman, 1993) and within the range implied by methods applied by Hardaker et al. (2004). SDRF and SERF procedures were conducted using *Simetar* (Richardson, Schumann, and Feldman, 2005).

Results

The simulation is of net returns of alternative adoption strategies. The preferred adoption strategy was identified using SDRF/SERF, and the impact of varying the underlying parameters including fees, probabilities, etc., of the adoption strategy was examined. Results from the base case are discussed first, and then sensitivities are conducted on these terms.

For the four alternatives (no adoption, legal, improper, and illegal), illegal has the highest mean return over direct costs ($26.90/acre), followed by legal ($24.02/acre), improper ($23.71/acre), and no adoption ($23.34/acre) (table 3). Illegal adoption also has the largest standard deviation of net returns ($27.98/acre), while no adoption has the lowest standard deviation ($16.97/acre). The cumulative distribution functions for the alternatives are shown in figure 1. The expected value of net returns is positive for all four choices at probabilities exceeding about 0.2. For probabilities exceeding 0.1, illegal is the most rightward alternative. For probabilities less than 0.1, illegal net returns shift to the left-most distribution.

The SDRF results show that the risk-efficient sets change across the range of ARACs examined (table 3) as rank orderings at the endpoints of the range of ARACs differ. For the most risk-averse growers, no adoption is preferred. For risk-neutral and risk-preferring growers, illegal is preferred.[5]

The SERF analysis indicates where preferences shift and the value of preferences across the range of ARACs. Shifts are reflected in changes in the ordering of certainty equivalents and resulting risk premiums (figure 2) as ARACs increased.[6] There were

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[5] Results for SDRF beyond the base case were not reported as they are replicated by SERF analysis which provides results by ARACs instead of just at endpoints and allows calculation of risk premiums.

[6] Further details of these simulations and stochastic dominance results are available from the authors upon request.

Table 3. Base Case Results for Grower Adoption Strategies of GM Technology

	Grower Adoption Strategy			
Description	No Adoption	Legal	Improper	Illegal
Mean Return ($/acre)	23.34	24.02	23.71	26.90
Standard Deviation	16.97	19.28	19.77	27.98
Preferences by ARAC—Ranking of Preferences: (1 = most preferred, 4 = least preferred)				
ARAC = −0.1	4	3	2	1
ARAC = 0	4	2	3	1
ARAC = 0.117	1	2	3	4
Certainty Equivalent by ARAC ($/acre):				
ARAC = −0.1	49.68	60.65	62.66	68.53
ARAC = 0	23.34	24.02	23.72	26.90
ARAC = 0.117	9.25	5.82	5.07	−31.39
Risk Premium for Alternative Relative to No Adoption, by ARAC ($/acre):				
ARAC = −0.1		10.97	12.98	18.85
ARAC = 0		0.68	0.38	3.55
ARAC = 0.117		−3.43	−4.18	−40.64

Note: ARAC = absolute risk absolute coefficient.

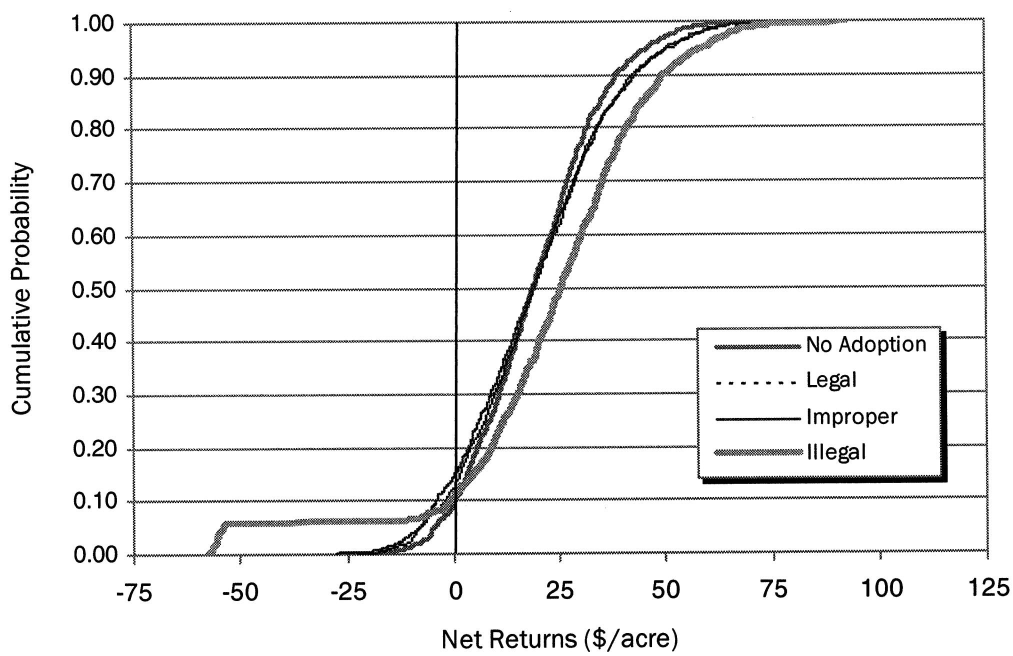

Figure 1. Cumulative distribution of net returns for no, legal, improper, and illegal adoption—base case

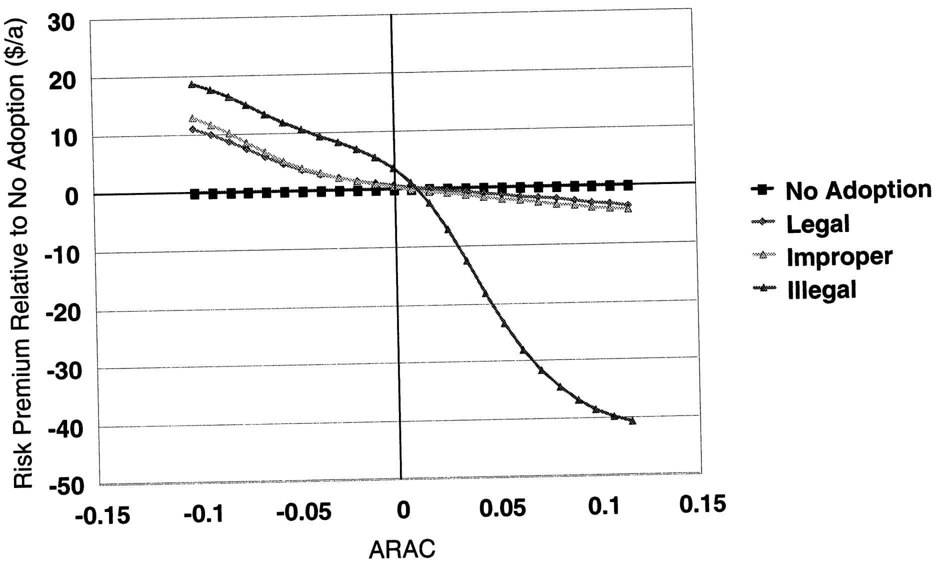

Figure 2. Risk premium relative to no adoption, by alternative and risk attitude

two shifts in the preferred alternative across risk attitudes. Illegal adoption was preferred by risk-preferring to less risk-averse growers with ARACs from −0.1 to 0.0109, then legal adoption was preferred over a narrow range of ARACs (0.0109 to 0.01738). At ARACs higher than 0.01738, no adoption is the preferred alternative.

Risk premiums decline as growers become more risk averse, and become negative for legal, improper, and illegal adoption as growers become moderately to highly risk averse (figure 2). Illegal adoption has the highest risk premium for risk-preferring ($18.85/acre) and risk-neutral growers ($3.55/acre). Risk premiums for illegal, improper, and legal adoption were negative across most of the range of risk-averse growers, indicating no adoption was the preferred alternative by as much as $3.43/acre over legal adoption and $40.64/acre over illegal adoption for the most risk-averse growers. In general, these results suggest that no adoption would be the dominant choice for more risk-averse growers, with the least risk-averse to risk-preferring growers preferring illegal adoption. Only growers with ARACs within a narrow range of risk aversion (0.0109 to 0.01738) would prefer legal to the other alternatives, and the preference over the next best alternative for these growers was less than $1/acre.

Technology Fee

The technology fee in the base case was $8/acre and varied from $0–$12/acre in simulations. If it is less costly to legally adopt, growers are likely to avoid the risk of improper and illegal use and adopt the technology.[7] As technology fees increase, net returns for legal and improper decline, but variability is unchanged (figure 3).

[7] This result was 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 prohibitive.

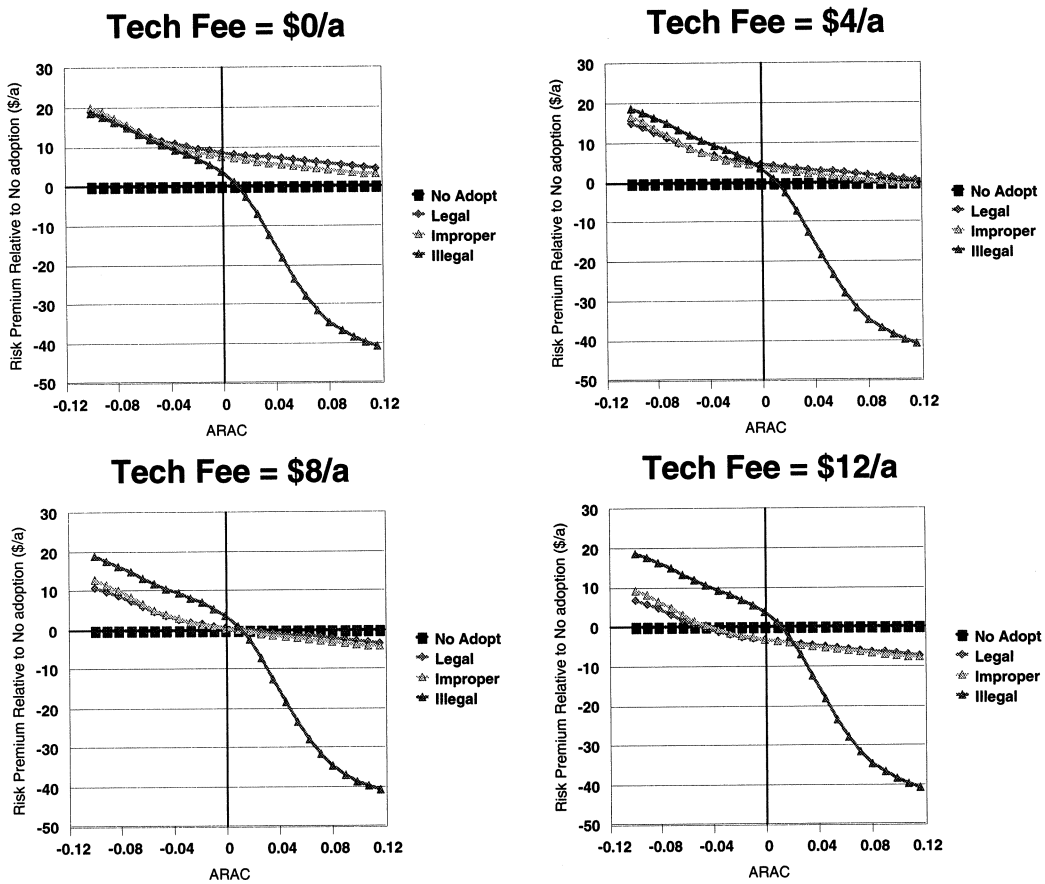

Figure 3. Risk premiums for alternatives relative to no adoption, by level of technology fee and ARAC ($/acre)

Increasing the technology fee results in lowering of certainty equivalents and risk premiums (figure 3) for both legal and improper adoption. Declines in certainty equivalents and risk premiums are roughly equivalent to the increase in technology fees for legal and less for improper adoption, reflecting the proportion of actual planted area reported to the technology firm and occurring similarly across the range of risk attitudes. As technology fees increase, ordering of legal and improper alternatives shifts. The ARACs where growers shift from illegal to legal, shift rightward (toward risk averse). For the most risk averse, no adoption becomes preferred and continues to shift leftward, further reducing the range of ARACs that would prefer legal adoption. At a technology fee of $10/acre, legal is not the most preferred choice for any ARACs. Thus, as technology fees increase, first risk-preferring growers shift from legal to other alternatives, and growers who are less risk preferring switch, followed by the most risk averse. Moderately risk-averse growers are the last to change from preferring legal.

Risk premiums were positive for risk-preferring growers at technology fees up to $12/acre (figure 3). For more risk-averse growers, risk premiums shift from positive to negative as technology fees increase. Risk premiums for improper adoption reflect the same pattern as those for legal adoption; however, the change in risk premiums is less than the change in technology fees. With no technology fee, risk-neutral growers prefer improper adoption by $7.58/acre, and risk-averse growers prefer improper adoption by $3.02/acre. At a technology fee of $12/acre, risk-preferring growers prefer improper by $9.38/acre, while risk-neutral growers would require an additional $3.22/acre, and more risk-averse growers require an additional $7.78/acre to be indifferent.

Detection Probability and Fines

Agbiotechnology companies affect the detection of inappropriate use by monitoring growers to ensure they comply with technology use requirements and, when detected, assessing fines for such behavior. Increasing the likelihood of detecting improper and illegal users affects growers' decision making. A grower may be hesitant to adopt improperly or illegally when there is a higher probability of being detected and subsequently fined. Violation of the TUA also results in a fine. A higher fine can be administered to perpetrators for a range of contract violations including: planting of saved seed, selling saved seed, or not reporting planted acres accurately. A higher fine reduces violations because it reduces the expected utility for these scenarios. This sensitivity also varied fines for improper and illegal use. No adoption and legal adoption expected utilities are unchanged from the base case in these sensitivities, as detection probabilities and fines do not apply to them.

Probabilities of detection for improper use were varied from 0.10 to 0.50, and 0.04 to 0.20 for illegal use. Results for these sensitivities only impact net revenues for illegal and improper adoption individually. Thus the effects on each are compared to base values for the remaining alternatives. SERF analysis [results presented in figure 4a where the left and right panels examine the effects alternative fines have on improper (left panel) and illegal (right panel) vs. the remaining alternatives at their base values] reveals that changing the probability of detection for improper and illegal use affects risk premiums over no adoption for improper and illegal across the range of risk aversion. As detection probabilities increase, risk premiums for improper adoption decline (left panel of figure 4a). As growers become more risk preferring, the effect on risk premiums of changing the probability of detection levels declines. The net effect of this is to shift the risk attitude where improper use would be preferred to no adoption from moderately risk averse to slightly risk preferring as the detection probability for improper use increases.

Increasing illegal detection probabilities have larger impacts on the risk premium for moderately risk-averse growers and less for risk-preferring to less risk-averse and more risk-averse growers (right panel of figure 4a). The effect of increasing the probability of detection for illegal use shifted the risk attitude, where growers would prefer illegal adoption to the other alternatives, from slightly risk averse to moderately risk preferring. Thus, increasing the probability of detection for both illegal and improper use results in a widening of the range of risk attitudes where legal adoption would be the preferred set over illegal, improper, and no adoption for slightly risk-averse to slightly risk-preferring growers.

Fines for improper use were varied from $10–$90/acre, and those for illegal use from $84 (which is the gross return over direct costs from the average yield and price) to $160/acre. Effects of changes in fines on improper and illegal use varied by risk attitude.

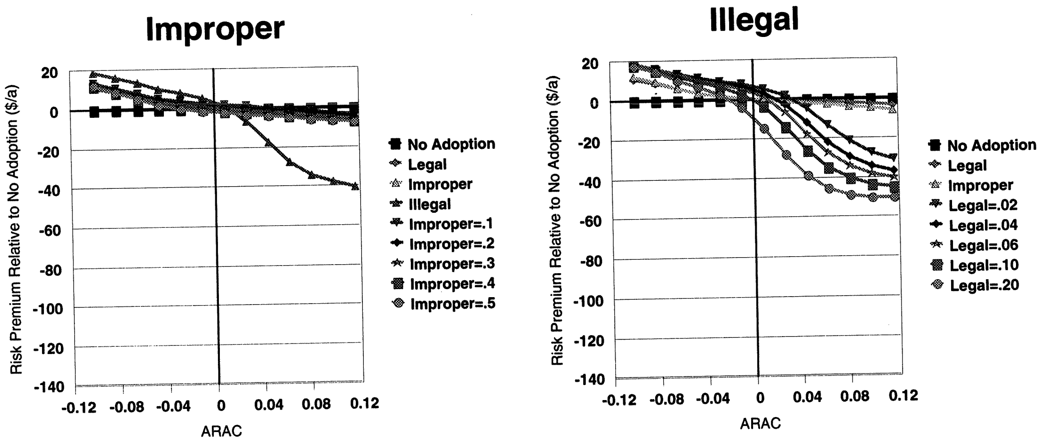

Figure 4a. Sensitivity of risk premiums over no adoption for changes in the probability of detection for improper and illegal use, by grower risk attitude

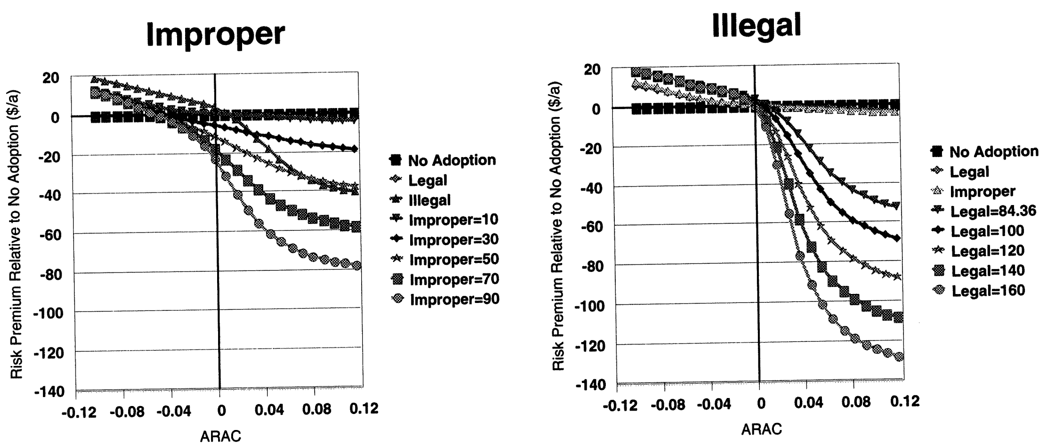

Figure 4b. Sensitivity of risk premiums over no adoption for changes in the fines for detection for improper and illegal use, by grower risk attitude

In both cases, as fines increased, changes in risk premiums were larger for risk-averse than risk-preferring growers (figure 4b). Risk premiums over no adoption were greater for highly risk-averse growers than less risk-averse growers (right panel of figure 4b). This finding is important as the effect of increasing fines on illegal use is to shift the point that illegal adoption becomes preferred. However, for most or all risk-preferring growers (depending on the level of fines), illegal use remains the preferred option. Thus, increasing fines has the effect of further intimidating those growers least likely to consider illegal adoption (most risk averse) and having minimal or no impact on growers most likely to prefer illegal adoption (most risk preferring).

Increasing fines for improper use affects risk premiums for improper over no adoption differently based on the level of risk aversion (left panel of figure 4b). As fines for improper detection increase, risk premiums for improper adoption decline more for highly risk-averse growers than for less risk-averse to risk-preferring growers. For risk-averse growers, improper adoption shifted from the third preferred alternative to the least preferred at improper use fines of $70/acre or more.

Changes in fines have limited to no impact on risk premiums for risk-preferring growers, while increasing the detection probabilities has small and increasing impacts for moderately risk-preferring to risk-neutral growers. This suggests that for firms where illegal use is a problem, increasing the probability of detection may have better results in reducing illegal use than increasing fines. In contrast, both increasing the probability of detection and increasing fines for improper use impacted risk premiums for risk-averse to moderately risk-preferring growers. The effect of increasing fines for improper adoption on risk premiums for moderately risk-preferring to risk-averse growers was larger than the effect of increasing the probability of detection. This finding suggests that where improper use is a problem, the choice of increasing detection probabilities or fines to reduce improper use is less clear.

Non-GM Premium

Non-GM wheat would have a premium over GM wheat due to restrictions in some countries and due to segregation costs. This sensitivity determines how changes in the value of non-GM wheat influence growers' decisions. Tests were applied to all deliveries and there is a probability of commingling of 0.025 (Wilson and Dahl, 2005) which was represented as a binomial distribution.

As the premium for non-GM increases, the rankings of the preferred choices change. No adoption is preferred across an increasingly wider range of risk attitudes (figure 5). The range of risk attitudes where growers prefer legal adoption in the base case is shifted to no adoption with a non-GM premium as little as $0.06/bushel. As premiums decrease, the risk attitude where growers shift preferences from no adoption to illegal adoption shifts leftward (more risk preferring), until reaching a non-GM premium of $0.60/bushel. No adoption is preferred across all risk attitudes except for the most highly risk-preferring growers. This sensitivity indicates that even a small non-GM premium would preclude legal adoption from being a preferred option.

Point-of-Delivery Pricing of Technology Fees

An alternative pricing mechanism to technology fees and enforcement mechanisms is point-of-delivery pricing. Typically technology fees are applied on a per acre basis and mechanisms used to enforce the integrity of the contract. Every adopter pays the same price for the technology regardless of the benefits. An alternative is point-of-delivery pricing in which the technology fees are deducted from price at delivery (as introduced commencing with the 2004 Brazil soybean crop). Testing on all shipments at the delivery point and/or some form of variety declaration would likely be required. The advantage of this strategy is that the agbiotechnology company extracts revenues from growers who "brown bag" seed and pricing links technology fees to yields. At higher yields, the amount paid in technology fees is higher.

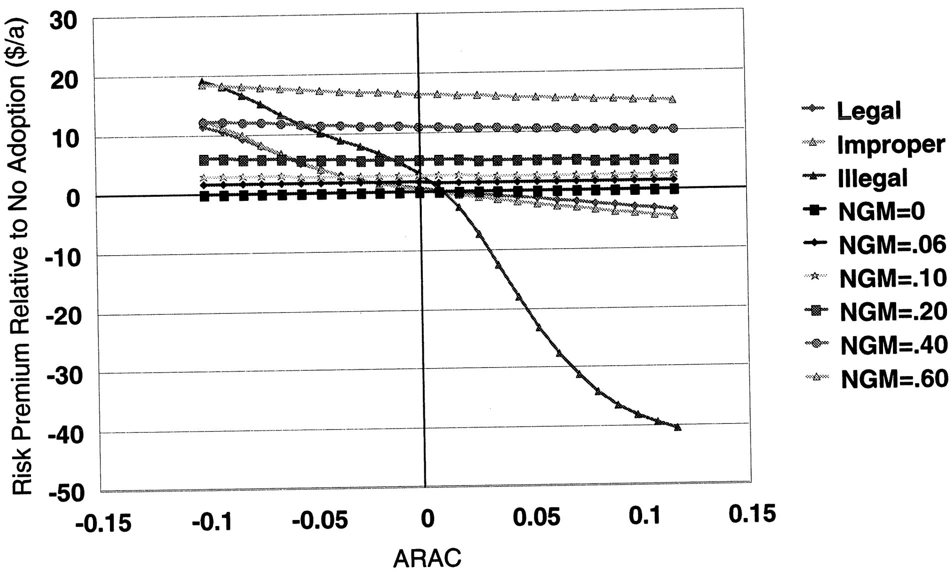

Figure 5. Sensitivity of risk premium over no adoption (base case) to changes in non-GM premium, by grower risk attitude

The effect of this strategy is to change the expected payoff in (1). The modified model for returns is defined as:

$$E(\Pi_i) = \hat{Y}_i * (\hat{P}_i - TB_i) - C_i, \tag{4}$$

where the variables are as previously defined, but now the technology fee is TB_i and applied on a per bushel basis. In this case, implicitly, the area-based technology fee is charged per unit and deducted from the commodity price. For this sensitivity, a point-of-delivery discount (TB_i) was implemented on the price of all GM wheat bushels ranging from $0.10–$0.40/bushel.

The result for $0.20/bushel indicates the benefits of illegal and improper adoption are eliminated across a wide range of risk-averse to risk-preferring growers. The most risk-averse growers would prefer no adoption to legal adoption, and the most risk-preferring growers would prefer improper to legal adoption. As the point-of-delivery technology fees decrease to $0.15 and $0.10/bushel, risk premiums for legal, improper, and illegal adoption increase relative to the no-adoption alternative. This decrease in technology fees results in legal adoption being preferred over a wider range of risk attitudes, and at the $0.10 technology fee, legal is preferred for all risk-averse and the less to moderate risk-preferring growers. At $0.30/bushel, only a small range of risk-preferring growers would prefer legal adoption, with risk-averse growers preferring no adoption above the others.

It is interesting to compare the impact of traditional technology fees (figure 3) with point-of-delivery fees (figure 6). Using traditional fees, illegal adoption becomes the preferred alternative as technology fees increase for larger portions of risk attitudes. For point-of-delivery technology fees ranging from $0.10 to $0.40/bushel, illegal adoption never ranks higher than the third best alternative.

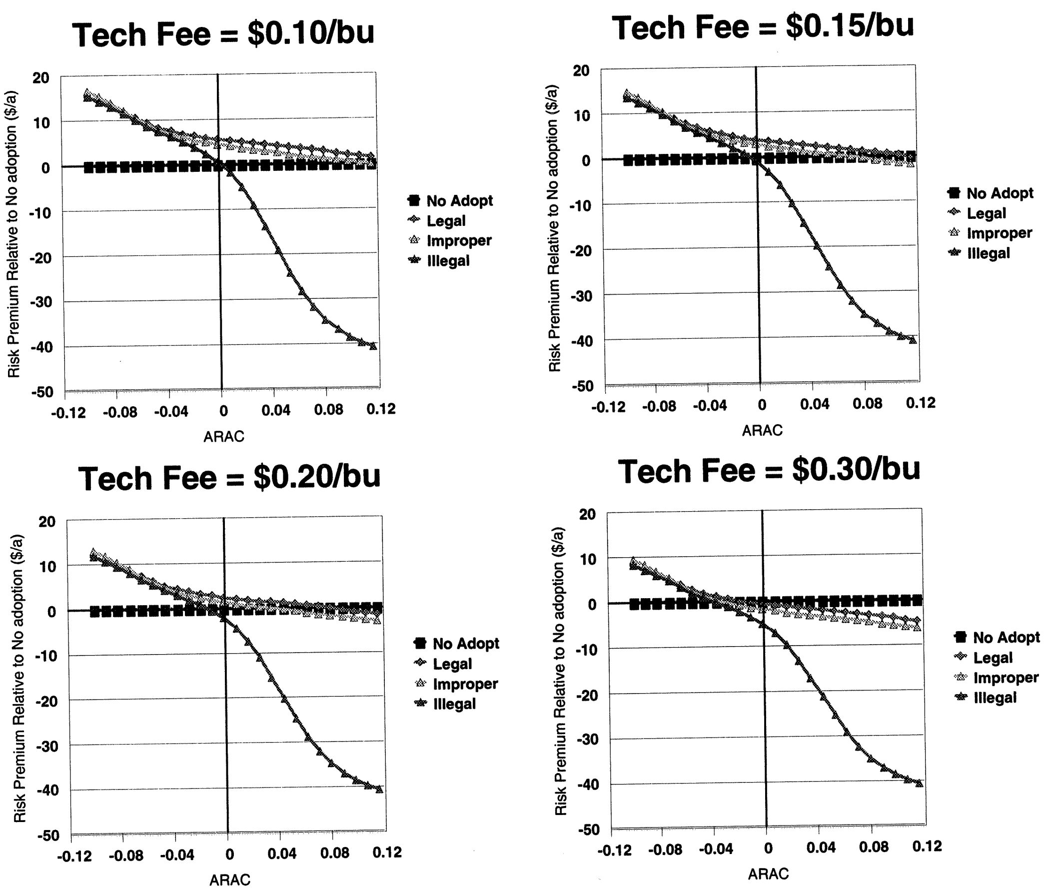

Figure 6. Sensitivity of risk premiums to point-of-delivery technology fees, by ARAC ($/acre)

Applying technology fees at the point of delivery has implications. Loss of technology fee revenue is eliminated and there is less need for auditing growers. Costs and inconvenience of auditing are lower and revenue from the technology likely higher because more growers' technology fees are collected. This strategy would be particularly beneficial in markets where the regulation of GM crops is minimal, as with some developing countries where illegal planting of GM crops is rampant. Growers may also prefer this pricing strategy because it eliminates auditing, which is onerous, and may reduce their concerns about unwittingly reporting acres incorrectly and being subsequently fined. Although point-of-delivery pricing collects fees from legal and illegal growers, it does little to deter "brown bagging," and this system requires a relationship between the agbiotechnology company and all delivery elevators.

Summary

Contracts between agbiotechnology firms and growers are used to define technology use, pricing, and to ensure that the firm receives royalties. Contracts can be developed with provisions designed to mitigate illegal and improper use of GM technology. This research identifies how contract terms impact grower adoption preferences (no, legal, improper, or illegal adoption) related to GM grain production and marketing, in this case wheat. The analysis determines how technology agreement terms, the size of non-GM premium, and point-of-delivery pricing impact grower adoption preferences. Stochastic simulation was used to measure risk, and stochastic dominance and stochastic efficiency were conducted to rank among alternatives and to evaluate impacts of grower risk aversion on choices. This study contributes to the growing literature on contracting strategies and illustrates how risk can be included in contract decisions.

Technology fees have an important effect on grower adoption preferences. In the base case, no adoption is the dominant choice for most risk-averse growers. In fact, legal adoption is dominant for only a narrow range of risk preferences. The premium for non-GM wheat impacts adoption, and the results indicate that even a small non-GM premium would preclude legal adoption from being a preferred option. Increasing technology fees reduces the range of risk attitudes where legal adoption is the preferred set. As technology fees increase, risk-averse growers shift from legal to no adoption.

The effect of increasing fines or the probability of detection is different for illegal and improper adoption. Increasing fines for illegal use has the effect of intimidating those growers least likely to prefer illegal adoption. For improper adoption, increasing fines has a larger impact on risk-neutral to moderately risk-preferring growers. Increasing the probability of detection has a larger impact on more risk-preferring growers. If there are only a small number of growers who illegally adopt the technology, 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 growers 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.

Point-of-delivery pricing of technology eliminates the advantage of illegal use because all producers pay if they deliver GM. Point-of-delivery pricing affects preferences across the range of grower risk attitudes, whereas other contract terms generally impact only a portion (usually the most risk-averse growers). As technology fees increase, the range of risk attitudes where legal adoption is preferred shifts; in contrast, for traditional technology pricing, the range narrows. Consequently, when piracy is a problem, point-of-delivery technology fees provide a better incentive to choose legal adoption than would traditional technology pricing, fines, and increasing the probability of detection.

The results reported here have implications for growers, agbiotechnology firms, and buyers. Agbiotechnology firms will continue to seek means to price their technology.[8] For growers, numerous factors impact their adoption decisions—including technology fees, fines, and penalties, as well as premiums for non-GM production. For GM-averse buyers, these results indicate they could pay a relatively modest premium for non-GM production and effectively deter legal adoption of the technology. Finally, as technology firms analyze among alternatives, it is important to assess the likely grower response

[8] As evidenced in Argentina, Monsanto halted sales of Roundup Ready® soybeans due to illegal use. Also, in a Supreme Court case in Canada involving a Saskatchewan farmer over illegal use, Monsanto expressed the need to enforce protections over illegal use.

to each. For this particular technology, legal adoption at what were proposed technology fees would only be dominant over a narrow range of risk aversions. Further, contracts can be designed to deter illegal and improper use of GM crop technology without discouraging adoption. The results also suggest that nonconventional, point-of-delivery pricing can be used as an alternative to traditional technology fees to encourage legal adoption over a broader range of risk aversions among farmers.

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