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Costs and Risks of Testing and Segregating Genetically Modified Wheat

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Development of genetically modified (GM) crops is challenging the functions of the grain marketing system. A stochastic optimization model was developed in this study to determine optimal testing strategies. The model chooses the optimal testing strategy that maximizes utility (minimizes disutility) of additional system costs due to testing and rejection, and allows the estimation of the risk premium required for sellers to undertake the dual marketing of GM and non-GM segregations over a non-GM system. Costs are estimated for a vertically integrated grain export chain including testing, rejection, and a risk premium. The model includes elements of costs and risks of adventitious commingling at all stages of the marketing chain, variety declaration, grower truth-telling, and accuracy of testing technologies. Sensitivities were evaluated for the effects of GM adoption, risk parameters, variety declaration, and tolerance levels.

Development and commercialization of genetically modified (GM) crops have challenged the functions and operations of the grain marketing system. The adoption of GM corn and soybeans in the United States has resulted in several interventions to facilitate the transition to marketing these crops. The process is taking longer for GM wheat for numerous reasons and a major technology provider has recently at least temporarily withdrawn commercialization of the *Roundup Ready*® wheat trait (Monsanto; Sosland Publishing). In contrast to the other grains and oilseeds, commercialization of GM wheat is proceeding concurrent with a fairly extended process of public scrutiny and commercial concerns (Wilson, Janzen, and Dahl provide a comprehensive summary of the issues related to GM wheat). One of the concerns is that of testing and segregation. Technology providers and the grain industry want to avoid disruptions that occurred with the introduction of biotech traits in other grains. Given there will be market

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segments for GM content, efficient marketing of GM wheat will require protocols for contract limits, testing, and segregation.

Some buyers, for varying reasons including regulations and product marketing, may choose to limit GM content in non-GM wheat purchases. Buyers would do so by specifying in their purchase contracts some limit on the GM content and/or more precise prescriptions regarding production, marketing, and handling processes in their purchase contracts. A marketplace of buyers with differentiated demands based on their aversion to GM content may develop. Exports to Japan, the largest offshore market, and some of the EU countries would be adversely affected if a credible system were not implemented.

Some of the important concerns regarding marketing GM crops center on added costs and risks. Additional testing, of which there are several technologies and varying accuracies, involves costs and risks to buyers and sellers. For buyers, there is the risk that GM varieties would be commingled and detected in shipments that have limits on GM content. For sellers, there is the risk that non-GM shipments that should be accepted are rejected due to false positive test results for GM content. This is an economic problem as agents seek to determine the optimal strategy for testing and other risk mitigation strategies.

The purpose of this paper is to determine the optimal testing strategy and to quantify the costs and risks to market participants. We analyze factors impacting these costs and risks. In addition to testing, other costs include selling in a discounted market if rejected, and a seller's risk premium for handling GM grain. We reflect these in a cost function, which is solved using stochastic optimization to determine the optimal test location, intensity, and technology. The contribution of this research is that it quantifies costs and risks of alternative strategies for marketing the GM crops. The distribution of costs and risks in the case of GM wheat is an important prerequisite to further commercialization of this trait. The use of a utility function within a simulation framework allows us to estimate the risk premium necessary for shippers to expose themselves to tolerances associated with non-GM shipments. Though the problem is focused on wheat, the methodologies would be applicable to other crops, GM traits, characteristics (e.g., vomitoxin), and production processes.

Background

GM Wheats

There are several initiatives for the development of GM wheats. In North America, these have been primarily for the *Roundup Ready*® trait, though there is an extensive research on a wide range of other GM wheat traits (e.g., fusarium resistance by Syngenta, drought resistance, and varying forms of end-use trait enhancement are being developed). Most research in North America is currently on hard red spring (HRS) wheat, but there is recent work on drought tolerance in hard red winter (HRW) wheat.

Monsanto's decision "deferring all further efforts to introduce Roundup Ready wheat" (Monsanto) and to "withdraw regulatory submissions outside the United Sates" (Sosland Publishing) is particularly important. This decision was made for a multitude of reasons, but was influenced by grower groups and others apparently concerned about the inability to segregate GM from non-GM wheat, which was also the maintained assumption of several aggregate-level analyses (Furtan, Gray, and Holzman 2001, 2003; Wisner). This is despite that segregation of other characteristics is routine in these small grains and similar segregation practices have evolved for marketing non-GM shipments in corn and soybeans.

If any GM traits in wheat were approved in the United States and/or Canada, there would be no limits on the adoption of these traits, except to the extent individual companies impose limits or tolerances. If a trait is approved in Japan, imported wheat would be subject to labeling laws. The EU ministers recently agreed to a plan requiring labeling of food as GM if 0.9% of ingredients are GM (down from 1%) and 0.5% tolerance on GM material that is "unavoidable present," but also declared safe by EU scientific advisors or the European Food Safety Authority (European Parliament 2003a, b).

The asynchronous regulations, along with selected buyer resistance and indigenous differentiated demands, ultimately suggest that a bifurcated marketing system (or a marketing system to facilitate coexistence) is inevitable. This would exist internationally between countries with and without tolerance limits. There are two forms in which tolerances are applied. One would be defined by regulatory agencies (e.g., the FDA and similar agencies in other countries) and the other as commercial tolerances. It is important to note that costs increase and risks are mitigated as tolerances are tightened. Risks are defined as buyers receiving a product that should be rejected and sellers having a product rejected that should have been accepted.

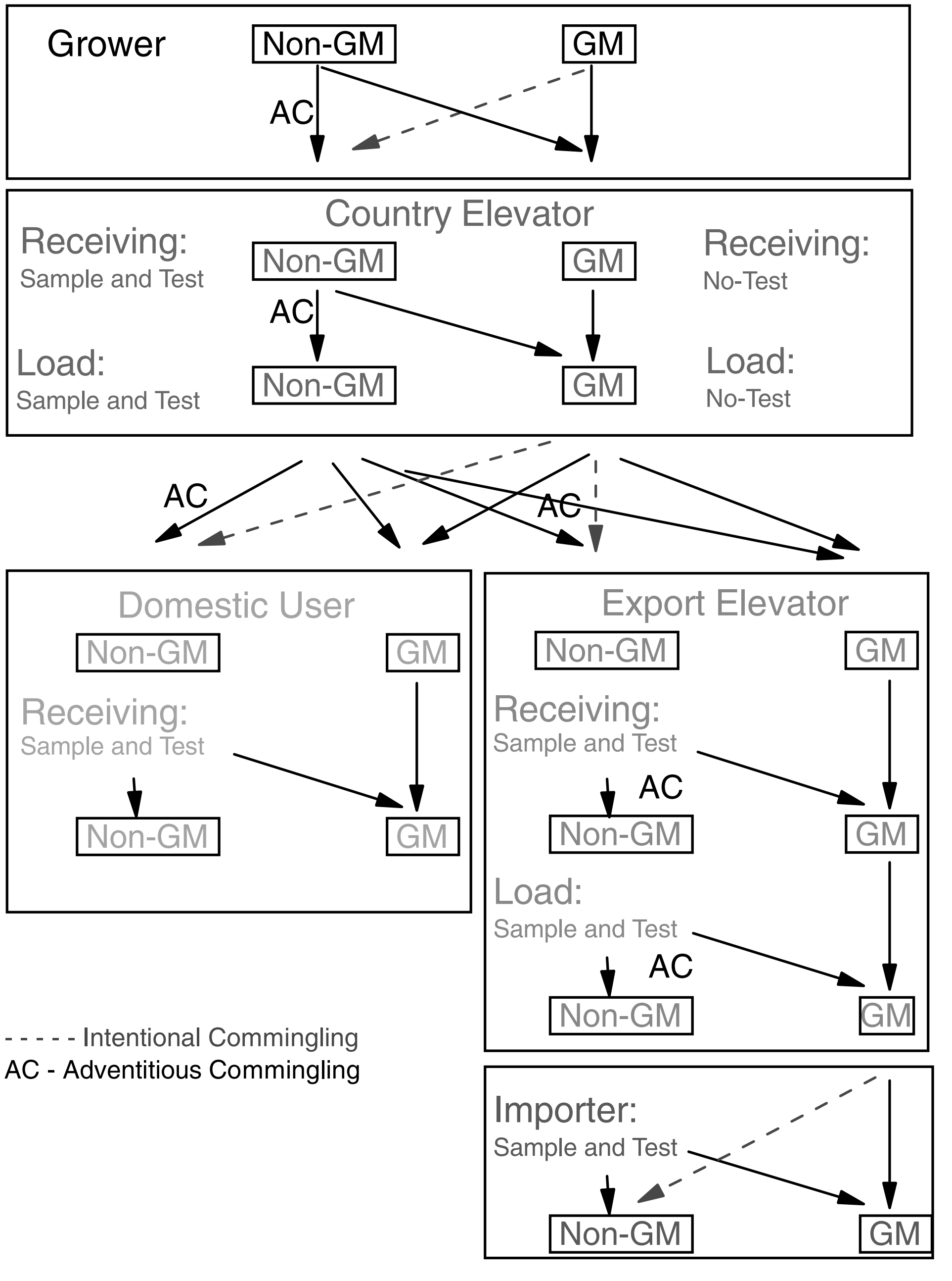
Elements of a Dual Marketing System and Sources of Risks

The economics of Identity Preservation (IP) have been studied extensively in a growing body of literature (e.g., Directorate General; Lin, Chambers, and Harwood; Buckwell, Brookes, and Bradley; Strayer). The IP and traceability systems provide process verification and retain the identity of the product from the farm. Informational flows are critical in these regimes. Unless tests are a prescribed component of the system, the risks of not conforming to desired limits persist.

An alternative is a system of testing and segregation in a dual marketing system. Segregation isolates like products with particular attributes to avoid commingling. Unlike IP, the identity of the grain is lost once it is accumulated with like products. Segregation has evolved in response to international market acceptance of bio-engineered products. Coexistence of transgenic grain and nontransgenic grain has evoked the supply chain to segregate commodities such as high lysine corn and high oleic soybeans to ensure added value beyond the farm gate (Sonka, Schroeder, and Cunningham). However, segregation has been a long-standing practice in the industry for spring-planted grains.

A dual marketing system involves grouping like lots into segregations, but would not necessarily preserve their identities. Basic functions include grower delivery, handling at country and export elevators (EE), and possible testing at each of these functions (figure 1). Wheat would be delivered by growers to a first handler and it may or may not be declared as containing GM, and it may or may

Figure 1. Grain handling subject to adventitious commingling



not be tested for GM content. The first handler would create segregations based on this information. Wheat would be loaded into railcars where again it may be tested. It is then shipped to an export elevator where it may be tested when it is received. On the basis of information about the shipments' GM contents, it would be segregated and may eventually be tested when loaded onto a ship. In all cases, it would be tested by the importer. The risks associated with testing would likely vary with technology and tolerance (described below) and inevitably a penalty may be imposed by the buyer if GM content is found in a non-GM shipment. This may be a penalty or a rejection of the shipment by the seller. In either case, the seller would accrue costs. There are numerous sources of uncertainty in this system, including the levels of adventitious presence of GM content, adventitious commingling, testing accuracy, truthfulness in GM declarations, and penalties for being out of contract.

The testing would only occur for those shipments thought to be non-GM. Concurrent with any test is a tolerance which is normally specified in purchase contracts. Technically, a tolerance is the allowable variability from a standard or requirement. A tolerance for non-GM is the maximum allowable GM content to still be considered non-GM. The end-users and buyers express their aversion to GM in contract with tolerances. Ultimately, it is incumbent on buyers wanting to limit GM content for whatever reason (commercial or regulatory) to specify tolerances and testing methodologies in their purchase contracts. Those not averse to GM would not. For others, restrictions could be implemented in existing contract forms similar to other factor limits.

An alternative to facilitate GM marketing is for growers to declare varieties (i.e., whether the shipment contains GM varieties) at the time of delivery. The variety declaration is a mechanism whereby farmers indicate known GM-content at delivery. This is a common commercial practice for marketing GM grains and oilseeds that have regulatory approval and is anticipated to play a role in traceability systems. Variety declaration provides information that can be conveyed to the marketing system, providing information for segregation and testing requirements.

This system could be envisioned as being adopted with several different scopes. It could reflect an elevator that seeks to segregate within their own facilities, or elevators specializing in handling GM versus non-GM. Alternatively, it could reflect a multi-plant firm with elevators specializing in GM versus non-GM handling. Each type of adoption is envisioned in the marketing of GM grains.

Empirical Model

A stochastic optimization model of grain flows was developed for a vertically integrated firm reflecting the structure of a dual marketing system with testing and segregation of GM/non-GM flows from growers to importers. Adventitious presence and commingling can occur throughout the grain marketing chain with given distributions. A level of GM adoption by farmers is assumed which determines initial flows into the system. There is an uncertainty about whether farmers will identify GM grain lots delivered as such, which we term grower "truth-telling." The tests can be conducted at different stages and at varying sampling intensities to determine if grain indicated as non-GM contains levels of GM exceeding tolerances. Non-GM samples exceeding the tolerance are diverted to GM flows at the stage of the marketing chain where they are identified and subjected to a penalty.

The model estimates the additional system costs due to testing for each of the segregations separately. Additional system costs are defined as

$$C_{\mathrm{NGM}} = \sum_{k=1}^{n} T_k \cdot TC_k \cdot S_k \cdot V_{\mathrm{NGM}\,k} + D_k \cdot V_{\mathrm{DGM}\,k} \tag{1}$$

and

$$C_{\mathrm{GM}} = 0 \tag{2}$$

where C_{NGM} is additional testing and segregation costs added to non-GM shipments to maintain GM separation; k is location in the system where tests can be applied (country elevator [CE] receiving, local elevator loading, EE receiving, EE loading, importer receiving, and domestic user receiving); T_k is binary variable reflecting whether tests are/are not conducted at location k; TC_k is the cost of an individual test applied at location k; S_k is sampling intensity (number of samples per lot) at location k; $V_{\mathrm{NGM}\,k}$ is volume (number of lots) of non-GM handled at location k; D_k is discount or penalty applied to grain diverted from non-GM to GM flows at location k; $V_{\mathrm{DGM}\,k}$ is the volume of bushels diverted from non-GM to GM flows at location k; and C_{GM} is additional costs for GM bushels (assumed zero).

The model derives additional costs at each stage of the marketing chain, tracks the flow and composition of flows for segregations throughout the system, and derives statistical properties on the proportion of shipments with GM exceeding specifications in end-use flows. System costs exclude other costs for IP verification which would be highly autonomous.

Risk Premiums and Utility

An innovative feature of the analysis relates to the additional risks the handler/shipper is exposed to beyond that inherent in the current non-GM system and the consequence of violating a tolerance. In the dual marketing system, it is possible to detect a level of GM content in a non-GM shipment even though the shipper is taking grain from a segregated non-GM flow. In practice, this would be a contract violation and subject to either rejection, penalty, or renegotiation and would result in a loss to the shipper. Each could be a term of the purchase agreement. In any case, the shipper would be subject to an implicit cost or "risk premium" associated with this type of contract. We estimate the value of this additional risk premium (π) required to offset the risks of handling the GM content as the expected costs for a non-GM system ($\mathrm{EV}_{\mathrm{NGM}}$) less the certainty equivalent ($\hat{C}_{\mathrm{GM/NGM}}$) of the utility of additional costs of a system containing both GM and non-GM segregations and include it in our cost function. We assume the non-GM system contains a baseline level of costs and risk and estimate the certainty equivalent for additional costs accrued in a dual handling system.

Model Specification

The model is of a vertically integrated grain marketing firm and solved using a stochastic optimization model to quantify the risk premium (Saha). The objective function contains a von-Neuman-Morgenstern type utility function, with decreasing absolute risk aversion and increasing relative risk aversion. The model chooses the optimal testing strategy (where to test and how often to test) that maximizes utility by minimizing the disutility of additional system costs for a supply chain handling a portfolio of segregations representing two states of nature (GM and non-GM grains). The portfolio utility consists of the weighted disutility of additional system costs for handling both GM and non-GM segregations. The objective is

$$\text{MaxU} = \text{MinDU}(C) = \text{Min}\sum_{i=1}^{2}\delta_i\left(\lambda - e^{(-\phi C_i^{\eta})}\right) \tag{3}$$

$$\text{s.a. } X_j \in Y_j$$

where U is utility; DU is disutility of additional system costs (C); δ_i is the proportion of flows devoted to each state of nature ($i =$ NGM, GM); e is the base of the natural logarithm; λ is a parameter that determines positiveness of the utility function; ϕ and η are parameters which affect the absolute and relative risk aversion of the utility function; C_i is the additional system costs associated with each state of nature ($i =$ NGM, GM), as defined in equations (1) and (2); X_j is the decision variable vectors of the model ($j = T_k$, S_k representing the locations T_k, where tests are conducted and the intensity of testing at locations S_k); and Y_j is the opportunity set of model.

The utility function is appropriate for use within a simulation model as it is flexible, allowing for changes in both absolute and relative risk aversion. Further, it allows us to estimate the risk premium necessary for shippers to be indifferent to the added risks associated with handling GM grains in a dual system. Parameters of the utility function are λ, ϕ, and η. A value of $\lambda = 2$ in the objective function above allows for a positive utility function. The parameters ϕ and η affect absolute and relative risk aversion. We followed Serrao and Coelho and fixed values for λ and ϕ and sensitivities were conducted for η.

The risk premium is derived from the expected value of the dual system of GM and non-GM segregations as follows:

$$\pi = \text{EV}_{\text{NGM}} - \hat{C}_{\text{GM/NGM}} \tag{4}$$

where

$$\text{U}(\hat{C})_{\text{GM/NGM}} = \text{EU}(C)_{\text{GM/NGM}} = E\left(\sum_{i=1}^{2}\delta_i\left(\lambda - e^{(-\phi\hat{C}_i^{\eta})}\right)\right) \tag{5}$$

and EV_{NGM} is the expected additional costs of a non-GM only system (assumed as a baseline or nil from which additional costs/risks are measured),

$\hat{C}$ is the certainty equivalent of additional system costs for a dual GM/non-GM system, $EU(C)_{GM/NGN}$ is the expected utility of additional system costs, and other parameters are as previously defined. The risk premium is the additional revenue necessary for decision makers to be indifferent between the current non-GM system and a dual system handling both GM and non-GM segregations.

Simulation Procedures

The model is solved using *Risk Optimizer* (Palisade Corporation 1998), a program designed to solve optimization problems with uncertainty. The stochastic optimization program uses a genetic search algorithm to identify optimal solutions. Each combination of choice variables (where and how intensively to test) is simulated for 1,000 iterations for which means for objective values and other variables are collected and then the genetic search algorithm identifies the next set of choice values. The model continues selecting sets of choice values until no significant improvement in the best mean objective values has occurred for a significant number of iterations.

The model tracks the volume of flows in the non-GM segregation that are adventitiously commingled at each location in the grain handling system, as well as the proportion of volume in the non-GM and GM segregations. These are utilized to determine the proportion of samples adventitiously commingled for sampling at subsequent locations. Factors affecting the volume of adventitious commingled grain at a location include prior adventitious commingling, grain diverted from non-GM flows to GM due to positive test results for samples, and effects due to accuracy of tests.

Distributions and Parameters Used in the Model

Uncertainty exists in several variables. These include uncertainty about adventitious presence and commingling at several locations (farm, CE, EE, and transportation equipment), uncertainty due to sampling, test accuracy, grower truth-telling, and rejection costs at the importer if GM content exceeds importer specifications.

There are three sources of grower risk. These include the presence of volunteers that germinated from prior crops, pollen drift, and on-farm adventitious commingling. The risk of volunteers germinating from prior years has been limited in these crops for obvious reasons. Current literature suggests the level of risk of volunteers is in the area of 31% of fields infested with an average density of nine plants per square meter in the first year (Thomas and Leeson). By year five, only 9% of fields were infested with an average density of less than one plant per square meter. These results indicate there is a positive incidence that declines through time. Using reasonable assumptions about planting rates, etc., the risk of adventitious presence in subsequent years due to volunteers translates to a probability of 0.009 in year 1 (which would apply if wheat were planted on ground that was planted to wheat in the prior year), and diminishes to virtually nil in following years. Pollen drift is relatively modest compared with

Table 1. Base case distributions

	Distribution	Minimum	Most Likely	Maximum	Source
Grower risks	Triangular	0.01	0.025	0.05	Hurburgh
Country elevator	Triangular				
Receiving		0.001	0.01	0.02	Casada et al.
Loadout		0.001	0.01	0.02	
Export elevator	Triangular				
Receiving		0.001	0.01	0.02	Casada et al.
Loadout		0.001	0.01	0.02	
Truth-telling (retention)					
Farmer	Triangular	0.8	0.95	1.00	Survey
Handlers	Triangular	0.95	0.99	1.00	Survey
Testing		Cost	Accuracy		Test type
Country elevator		$7.50/test	0.95		Strip tests
Export elevator		$120/test	0.99		PCR

cross-pollinated crops such as corn. Studies for wheat suggest that the rate of outcrossing is generally less than 1% but can range as high as 5% with pollen drifting from 5 to 48 m. Hucl and Matus-Cadiz indicate this may result in higher than acceptable levels of off-types occurring in isolation strips of 3–10 m. Finally, Hurburgh (in the case of corn) indicated the probability of on-farm handling risks of adventitious commingling is about 0.016, excluding pollen drift. The distribution of grower risks was derived to reflect risks depicted in these studies (table 1).

Handlers routinely segregate and blend grains as a primary marketing function in HRS wheat. There is added risk of handling GM grains due to the possibility of adventitious presence, though in concept this is not dissimilar from other discrete attributes. Casada, Ingles, and Maghirang found that if running elevators nonstop, contamination is 4%; after three minutes, it declines to 0.2%. (i.e., $p = 0.002$). These results are supported by Hurburgh. Handling risks were represented by a triangular distribution derived to depict risks in both studies (table 1).

To get some judgment on the distributions about grower and handler "truth-telling," we conducted an informal survey of participant's knowledgeable on the marketing of GM corn and soybeans. Results were used to derive a triangular distribution[1] for the probability of grower truth-telling (table 1).

Uncertainties in testing are simulated using hypergeometric distributions, which are discrete distributions used to simulate sampling plans where parameters represent the number of samples drawn, the number of items not meeting specifications, and the population size. Samples drawn are assumed to be representative, reflecting standardized procedures across lot sizes which conform to specifications associated with the accuracy level of the test. The accuracies were from suppliers' test specifications.

The penalty for GM contained in a non-GM shipment was assumed to be uniformly distributed within a range of 40–90 cents/bu. There are several elements of the cost components. First, it is a result of a contract specification agreed to by buyers and sellers. Second, it is important whether the test is evaluated at the origin (i.e., export port) or the destination (i.e., import port). If the former, being out of contract is not as problematic. Finally, some export elevators (e.g., with shipping bins) may be more capable of testing prior to loading than others. The value of the penalty is based on two components. Discounts for GM in non-GM corn have been in the area of 10% of the value, which in the case of wheat would be about 40 cents/bu. In some cases, rejection may entail re-shipping the grain to some other market at a cost to the shipper. In many international locations, this would be about the equivalent of 50 cents/bu. Thus, the level of penalties likely reflects a worst case scenario.

The risk aversion parameter values for λ and ϕ were assumed to be 2 and 0.01, respectively (following Serrao and Coelho). For the risk parameter, η, a base value of 0.5 was utilized, then sensitivities are conducted for values from 0.1 to 0.9, with 0.9 indicating higher risk aversion and 0.1 lesser risk aversion.

Results

Results from the base case are described first. Simulations and sensitivities are then evaluated relative to this base case. Sensitivities were conducted to examine the effects of risk aversion, variety declaration, discounts for rejection of non-GM shipments, and the effect of buyer tolerances.

Base Case

The base case was defined to reflect a likely system and protocols. These include export shipments; GM adoption by farmers of 20% (which determines the partition of initial flows in the marketing system)[2]; and grower declaration of GM content at the country elevator. Testing was allowed at any or all of the following: country elevator (CE) and export elevator (EE) at receiving and/or loadout. Testing technologies were strip tests at the CE and PCR tests at the EE; the risk aversion parameter $\eta = 0.5$; and finally, no additional costs of segregation were included.[3] In addition, a test at the importer is applied at a cost of \$120/test on every unit designated as non-GM and is also used to impose an accept/reject mechanism for deliveries of non-GM wheat not meeting GM content specifications.

The optimal strategy would be to test every fifth railcar at the country elevator when loading and to test every ship sublot when loading at the export elevator (table 2). This results in average rejection rates by the importer of 1.75% and an average of 0.02% of importer flows containing GM content greater than tolerances. This 0.02% represents the buyer's risk of accepting quality that does not meet tolerances.

The proportion of flows in the non-GM channel declined from 80% at the farm level to an average of 70% at the importer. Thus, on average, 10% of non-GM shipments were diverted to the GM segregation throughout the handling system. This illustrates the sellers risk of having shipments rejected throughout the system. Most of the diversions occured after unloading at the export elevator and were due to adventitious commingling that occured in the system.

Table 2. Base case results and effect of variety declaration and no testing

Variety Declaration	Base Case Variety Declaration	No Variety Declaration	No Testing and No Variety Declaration
Utility	1.0097	1.0071	1.02
Test (1 = yes/0 = no, every *n*th unit)			
Country elevator receiving	0–0	1–5	0–0
Country elevator loading	1–5	1–5	0–0
Export elevator receiving	0–0	1–5	0–0
Export elevator loading	1–1	1–1	0–0
Buyers risk of flows exceeding GM tol.	0.02%	0.01%	0.10%
Rejection at importer	1.75%	2.34%	10.10%
Percentange of flows non-GM by location (percent)			
Adoption rate	80	80	80
Country elevator in store	82	78	82
Country elevator loaded on track	77	51	82
Export elevator in store	77	39	82
Export elevator after loading	71	31	82
Importer after test	70	31	74
Costs (cents/bu)			
Additional costs/all bu	1.39	1.33	5.70
Additional costs/non-GM bu	1.99	4.38	7.75
Certainty equivalent (premium)	0.96	0.40	4.17
Total (add + prem)/all bu	2.35	1.73	9.87
Total (add + prem)/non-GM bu	3.36	5.70	13.42

The utility of the base case converts to a certainty equivalent of 0.96 cents/bu. This is the premium that should be required for a shipper to be indifferent to this non-GM/GM system and a system of non-GM only. It represents the value of the additional risk associated with the non-GM/GM system and is the added cost suppliers would implicitly accrue by handling GM and selling to a non-GM contract.

Additional system costs for testing and discounts for rejection were 1.4 cents/bu. If this cost was absorbed solely by the non-GM bushels, the costs average would be 2.0 cents/bu. The cost includes both additional system costs and the risk premium. These cost elements result in total costs of 2.4 cents/bu when measured across all bushels and 3.4 cents/bu when attributed solely to non-GM bushels. These costs only reflect additional costs of testing and rejection within a system of non-GM/GM wheat.

Variety Declaration and Testing

Mechanisms could be used to elicit information from growers on the GM content of their grains in the base case. This function would normally be included in "closed loop" marketing plans and facilitates segregation at the point of first receipt, albeit at an allowed risk of adventitious commingling at the grower level and due to grower truth-telling (below). Without this mechanism, first handlers would have greater uncertainty, which in turn would impact the level of adventitious commingling due to the inability to segregate GM from non-GM without testing. To simulate this impact, we developed a model without variety declaration.

In this case, the optimal strategy is testing of every fifth unit at the country elevator, both when receiving grain and loading railcars; and testing every fifth railcar when received at the export elevator and every hold when loaded at the export elevator. Rejection rates at the importer increased from the base case to 2.34% with no variety declaration. Only 31% of flows identified as non-GM reach the importer. Thus, a system with no variety declaration results in significant misidentification and diversion of flows from non-GM to the GM segregation (i.e., the seller's risk is high). Total costs for non-GM bushels increased from 3.36 cents/bu for the base case to 5.70 cents/bu with no variety declaration.

A case was also developed where testing and variety declaration did not occur. This was used to reflect the risks inherent in the system and the value of testing. With no testing or variety declaration, rejection rates by the importer were 10%, substantially higher than either the no variety declaration case or the base case. Total costs per non-GM bushel were also higher than either of the other cases (13.42 cents/bu).

Grower Truth-Telling

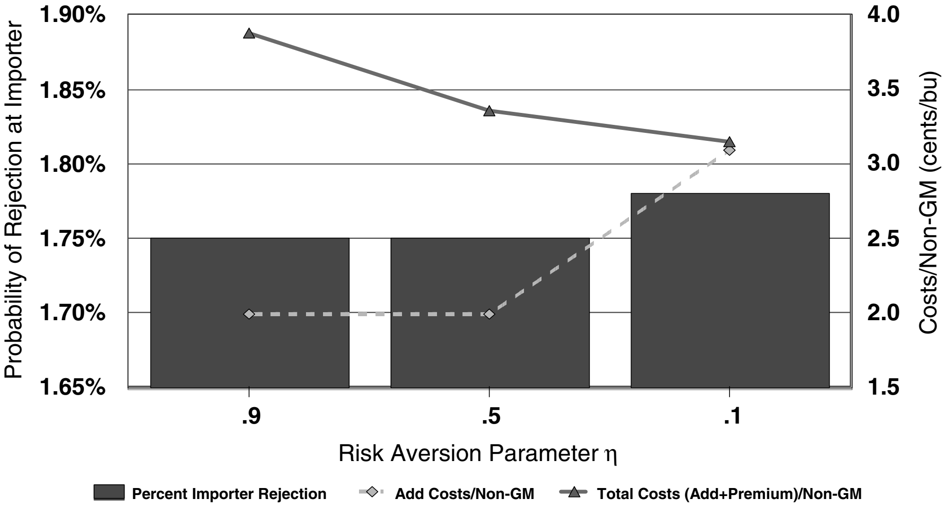
Farmers are assumed to declare GM content at the point of delivery. This allows the first handler to segregate and would be typically governed by some type of contract and/or elevator-imposed mechanism. In the base case, the distribution of farmer truth-telling was assumed to be represented by a triangular distribution with parameters for minimum, most likely and maximum values of [80, 95, and 100]. To examine the effect of reductions in farmer truth-telling, we changed the triangular distribution to [40, 50, and 60].

As farmer truth-telling declined, optimal strategies resulted in increased testing. Lower truth-telling requires testing of every fifth unit at the country elevator when receiving in addition to testing at the country and export elevators when loading. The proportion of non-GM flows at the importer declined from 70% in the base case to 58% with the lower truth-telling case. Thus, there are greater false rejections as grower truth-telling decreases. Total costs for non-GM bushels increased as farmer truth-telling declined. Total costs for the lowest farmer truth-telling were 3.81 cents/bu versus 3.36 cents/bu for the base case.

Effect of Risk Parameter (η)

The risk parameter, η, would likely vary across handling firms, with some more and some less willing to assume risks. To illustrate, we conducted sensitivities for the base case with more/less risk aversion. Two cases, $\eta = 0.9$ (more risk averse) and $\eta = 0.1$ (less risk averse), were developed and optimal solutions derived and

Figure 2. Effect of risk aversion parameter on importer rejection rates, and additional and total costs per non-GM bushel



compared to results from the base case ($\eta = 0.5$). Optimal testing for both the base case and the more risk averse case was the same (figure 2). The less risk averse case requires more intensive testing than the other cases; testing every fifth unit at the country elevator when receiving and loading and every fifth unit at the export elevator when receiving and every unit when loading.

Utility declined as the risk parameter, η, declined. This resulted in a decline in the risk premium at which decision makers would be indifferent to a system of non-GM/GM or a non-GM system. With $\eta = 0.9$, the risk premium was 1.3 cents/bu, but declined to 0.04 cents/bu when $\eta = 0.1$. Less risk averse shippers discount additional testing and rejection costs less than the more risk averse shippers and, therefore, require less of a premium to accept additional costs of operating a non-GM/GM system.

Effect of Price Differentials (Discounts)

We varied discounts to determine how these impacted testing strategies. Two cases were developed, one with lower penalties (0–10 cents/bu) and the second with higher penalties (100–150 cents/bu), each represented as a uniform distribution. Lower penalties resulted in a less intensive testing strategy. Optimal testing occurred at the same locations, but sampling at the export elevator was less intensive (every fifth unit versus every unit in the base case). This less intensive testing is reflected in a higher rejection rate, which increased from 1.75% in the base case to 7.87% with lower discounts (table 3). Higher penalties resulted in the same optimal testing strategy as the base case. The results indicate that if the penalty for being out of specification for GM is minimal, the optimal response of decision makers is to test less often and accept higher rejection rates. As the penalty increases, shippers respond with more testing and lower rejection rates.

Table 3. Sensitivity to alternative rejection penalties

	Base Case		
Penalty	**0–10 cents/bu**	**40–90 cents/bu**	**100–150 cents/bu**
Utility	1.0063	1.0097	1.012
Test (1 = yes/0 = no, every *n*th unit)			
Country elevator receiving	0–0	0–0	0–0
Country elevator loading	1–5	1–5	1–5
Export elevator receiving	0–0	0–0	0–0
Export elevator loading	1–5	1–1	1–1
Buyers risk of flows exceeding GM tol.	0.08%	0.02%	0.02%
Rejection at importer	7.87%	1.75%	1.75%
Percentage of flows non-GM by location (percent)			
Adoption rate	80	80	80
Country elevator in store	82	82	82
Country elevator loaded on track	77	77	77
Export elevator in store	77	77	77
Export elevator after loading	71	71	71
Importer after test	65	70	70
Costs (cents/bu)			
Additional costs/all bu	0.63	1.39	2.13
Additional costs/non-GM bu	0.97	1.99	3.07
Certainty equivalent (premium)	0.41	0.96	1.47
Total (add + prem)/all bu	1.04	2.35	3.60
Total (add + prem)/non-GM bu	1.60	3.36	5.19

Effect of Testing Tolerance

Buyers choose the tolerance, which in turn defines testing protocols. In the base case, a 1% tolerance was assumed. Tightening tolerances raises costs and prospectively raises risks. Three elements of costs are critical in evaluating the effects of differing tolerance limits: testing costs; risk of not conforming; and adventitious commingling in the system. The first two are clear. However, it is not known how adventitious commingling would be impacted by increasing/decreasing tolerance levels. To account for this, we developed two cases. The first involves tolerance levels of 0.5% in which we increased the levels of adventitious commingling that would be identified at this tighter specification, so the parameters of the distribution were twice that in the base case. In the second case, tolerance levels were assumed to be 5% and the parameters for the distributions for adventitious commingling were assumed to be 50% of base case levels. These cases illustrate the potential effect of increasing tolerances. However, further empirical research on the level of adventitious commingling is required. As such, results are illustrative only.

Tightening tolerances (e.g., 5% to 1%) resulted in more testing. Tightening the tolerance further (0.5%) resulted in the location of tests of every fifth unit shifting from the country elevator when loading to the export elevator on receiving. The rejection rate at the importer increased as the tolerance tightens. Rejection for a 5% tolerance was 1%, while at a 0.5% tolerance it was 3%. Costs and risk premiums increased as tolerances tightened. Tightening the tolerance from 5% to 0.5% increased testing and rejection costs from 0.83 cents/bu to 2.60 cents/bu for non-GM bushels. The risk premium increased from 0.47 cents/bu with a 5% tolerance to 1.06 cents/bu with a 0.5% tolerance. Total costs for non-GM bushels increased from 1.45 cents/bu with the 5% tolerance to 4.25 cents/bu with a 0.5% tolerance.

Summary and Implications

The development and commercialization of GM crops are challenging the functions and operations of the grain marketing system. While these have already been confronted in other grains and oilseeds, none of these issues have been resolved regarding the anticipated commercialization of GM wheats. The purpose of this paper is to determine optimal testing strategies and to quantify the costs and risks of a dual system for marketing GM and non-GM wheat.

The asynchronous regulations and indigenous differentiated demands resulting in buyer resistance suggest that some type of dual marketing system will need to evolve to facilitate coexistence. Ultimately, this will likely be a system in which buyers specify limits or a tolerance on GM content. Testing would be adopted at varying points in the marketing system to facilitate segregation and assure contract conformance. Given that testing and segregation entail costs and risks, there is a tradeoff confronting shippers and buyers and there are operational questions, such as, where are the optimal locations to test, how intensively to test, and how numerous factors impact these strategies.

A stochastic optimization model was developed of a vertically integrated export marketing system. The results indicated the optimal testing strategies for supplying export markets and provided an estimate of the additional risk premium required for decision makers to be indifferent to the non-GM/GM system and a non-GM system. Results identified the optimal testing strategies, costs and risks. The risk premium is the implicit cost accrued by the shipper to be indifferent between a handling system involving non-GM and GM wheat, versus the current non-GM system. The testing strategy would result in minimal GM content at the import market, and only 1.75% of the shipments would be rejected.

There are several implications from these results. First, a system based on testing and segregation can efficiently assure buyers of GM content at a low cost. While nil tolerance cannot be achieved through a system based on testing, the GM content can reasonably be assured at 1%. Second, the cost of a system inclusive of a risk premium is less than that estimated by others for IP systems and other means to control GM content, as well as assumed in aggregate welfare analysis of GM wheat. Third, many factors will affect the elements of an optimal testing system, costs, and risks. Fourth, given the added risk for a dual system, shippers should increase their margins to reflect the risk premium. In order for non-GM to gain a premium, sellers will have to provide proof that it is non-GM, buyers must be willing to pay this cost and, eventually through competition, price differentials will emerge to approximately reflect these costs.

Finally, these results suggest some mitigation strategies that could be adopted in the wheat marketing system. Ultimately, the purpose of these would be to facilitate conditioning of probabilities assumed in this study and would involve a number of contract-type mechanisms necessary to control costs and risks in the system. The most crucial elements would be the declaration of GM content at delivery and testing for GM throughout the non-GM system. With continued operation of dual GM/non-GM systems, the costs for non-GM wheat may diminish over time as the market adjusts.

The model was developed as a vertically integrated firm. An extension would be to reframe the analysis with multiple intermediary agents, each with their own utility function and parameters, and solved as a sequence of contracts. The results derived would depend on assumptions for tolerances, adventitious commingling risks, GM adoption levels, etc., as well as parameters of the utility function.

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Endnotes

[1] A triangular distribution is specified by points which represent the minimum, most likely, and maximum values where the probability of occurrence for minimum and maximum values are zero and the direction of skew is set by the relative value of most likely to the minimum and maximum values (Palisade Corporation 1996, p. 189).

[2] A survey of buyers by the Canadian Wheat Board indicated 82% nonacceptance for GM wheats (Canadian Wheat Board).

[3] Additional segregation costs are somewhat elusive, and are certainly autonomous and highly situation specific. To support this, most country elevators in the HRS area already segregate by grade, protein, test weight, dockage, falling numbers, and vomitoxin. Thus, segregating GM wheat should be viewed as an additional segregation, or alternative segregation to others. Or, in a very practical case, it would be viewed as a dedicated facility handling only GM (or non-GM) shipments.

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