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Costs and Risks of Testing and Segregating GM Wheat*

Abstract

Development of genetically modified crops is challenging the functions of the grain marketing system with many participants arguing for Identity Preservation (IP) systems prior to release of GM varieties. In this study, a stochastic optimization model was developed 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 estimation of the risk premium required for sellers to undertake a dual marketing system with GM/Non-GM segregations over the current Non-GM system. Elements of costs (testing costs, rejection costs, and risk premium) were estimated for a base model representing a grain export chain. The model includes elements of costs and risks for uncertainties within the marketing chain including risk of adventitious commingling at all stages of the marketing chain, grower truth-telling, variety declaration, and accuracy of testing technologies. Sensitivities were evaluated for effects of GM adoption, risk parameters, variety declaration, tolerance levels, and for a domestic market case.

Introduction

Development and commercialization of genetically modified (GM) crops has challenged the functions and operations of the grain marketing system. The adoption of GM corn and soybeans in the United States has resulted in numerous interventions to ease the transition to marketing of these crops. The path taken in the case of GM wheats is more elongated for numerous reasons. In contrast to the other grains and oilseeds, commercialization of GM wheats is evolving concurrent with a fairly extended process of public scrutiny and commercial concerns. One of the more important concerns is that of testing and segregation. Given there will no doubt be market segments adverse to GM content in wheat shipments, adoption and efficient marketing of GM wheat will require protocols for contractual limits, testing and segregation.

Implicit in these insinuations are that some buyers, for varying reasons including regulations and product marketing, may choose or have no recourse but to limit the content of GM wheat in Non-GM wheat purchases. Presumably, these buyers would do so by specifying in their purchase contracts some limit on GM content and/or more precise prescriptions regarding production/marketing/handling processes. This is what has evolved in the

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commercialization of other GM crops. At least initially, or indefinitely, one could envision a marketplace of buyers with differentiated demands for their aversion to GM content. Hence, it is critical to have a prescribed system that conforms to these requirements.

Within the micro-structure and economics of the grain marketing system, some of the important concerns with respect to GM crops marketing center on added costs and risks. Additional testing involves added costs of conducting the tests, of which there are several technologies and varying accuracies. The risk is that of GM wheat varieties being commingled and detected in customers' shipments who place limits on GM content. This is indeed 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 and assess the distribution of costs amongst participants. In addition to testing costs, other costs include the cost of selling in a discounted market if rejected, and the seller's risk premium for handling GM grain. We capture all of these in our model. The model is a cost function, inclusive of these costs, and is solved using stochastic optimization to determine the optimal location, frequency and technology for testing.

The primary focus is on testing and tolerance strategies confronting the U.S. marketing system, producers, processors and foreign processors. The contribution of this research is that it provides a quantitative model that can be used to assess costs and risk of alternative strategies for marketing GM crops. The distribution of costs and risks in the case of GM wheat have come to be an important prerequisite to further commercialization of this trait. Most important, we provide estimates of the risk premium necessary for suppliers 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, characteristics (e.g., vomitoxin) and production processes.

Background

This section provides a background description to the problem and some detail to its various elements.

GM Wheats

Development of GM wheats has lagged other grains and oilseeds for varying reasons. Most important is likely the more complex genetics. Other contributing factors include: 1) wheat is a smaller volume crop within North America; 2) exports are of greater relative importance; 3) import country regulations vary much more for wheat and are less well-defined; and 4) competition amongst exporting countries is likely more intense and compounded by radically different marketing systems regarding quality and trade practices, etc.

These points notwithstanding, there are several initiatives for the development of GM wheats. In North America these have been primarily on the *Round-up Ready®* wheat trait, though there is extensive research elsewhere on a wide range of GM traits in wheat (e.g., fusarium resistance by Syngenta, drought resistence by DuPont, among others). Virtually all development in North America is currently on Hard Red Spring (HRS) wheats. Experimental trials are being planted in South Dakota, North Dakota, Minnesota (and no doubt elsewhere), as well as in selected Canadian prairie provinces.

Round-up Ready® wheat (RRW) is an example of 1st stage benefits. Other 1st generation benefits should be commercially available by 2005 (Bloomer). However, 2nd and 3rd generation effects will not be accessible until 2006 and beyond. In the case of wheat, 2nd generation effects would likely include enhanced protein quality, novel starch types (functionality), enhanced nutritional content, reduced allergens and improved freshness and shelf-life for baked products. These observations were echoed by Biane indicating that consumer benefits in the case of wheat include extending shelf life, improved nutrition, and reduced allergens. The pressures for adopting GM wheat, specifically RRW, come from a combination of cost reduction, reduced dockage, increased profitability of competing crops (being recipients of GM technology), and the prospect of 2nd and 3rd phase benefits associated with GM wheats.

In all cases, there is an insinuation that development of a GM wheat is good and should be pursued. However, it is very clear that GM wheats should not be commercialized, in whatever fashion, until some type of IP and testing system is developed to mitigate risks to buyers.

The asynchronous regulations, along with selected buyer resistance and indigenous differentiated demands, ultimately suggest that a dual marketing system (or a marketing system to facilitate coexistence) is inevitable. This is likely true in the domestic market even though labeling would be voluntary with different approaches likely adopted by buyers for branded versus non-branded (e.g., private label, food service, etc.) products. This would also occur internationally between countries with and without tolerance limits, and/or other requirements for the traits, and those with approved traits.

Finally, inevitably, tolerances will need to be defined and/or those proposed will be needing refinement. There are two forms in which tolerances are applied. One would be those defined by regulatory agencies (e.g., the FDA, and like agencies in other countries). Second, would be as commercial tolerances.[1] Most important in establishing these tolerances are that costs increase as tolerances are tightened, and that risks are mitigated by the use of tolerances. Risks are defined as buyers receiving a product that should be rejected and sellers having a product rejected that should have been accepted. There is a fundamental tradeoff between risks and costs. Tighter tolerances result in increased costs and decreased risks.

Elements of a Dual Marketing System and Sources of Risks

Ultimately, an alternative to a regulated system is a system with dual market channels. Such a system (as envisioned in the model later) is represented in Figure 1. All the basic elements are included from grower delivery, handling at country and export elevators, and the potential for testing at each of these functions. Thus, the system only involves movement to the point of first

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[1] The experience of vomitoxin in wheat and barley is analogous. Vomitoxin is regulated by the FDA with limits placed on its presence in the semi-processed crops (e.g., flour, malt). However, individual firms can and do adopt different tolerances, subject to the FDA regulations. Similarly, some importing countries adopted tighter tolerances than others and, in fact, tolerances may vary across firms within a single importing country.

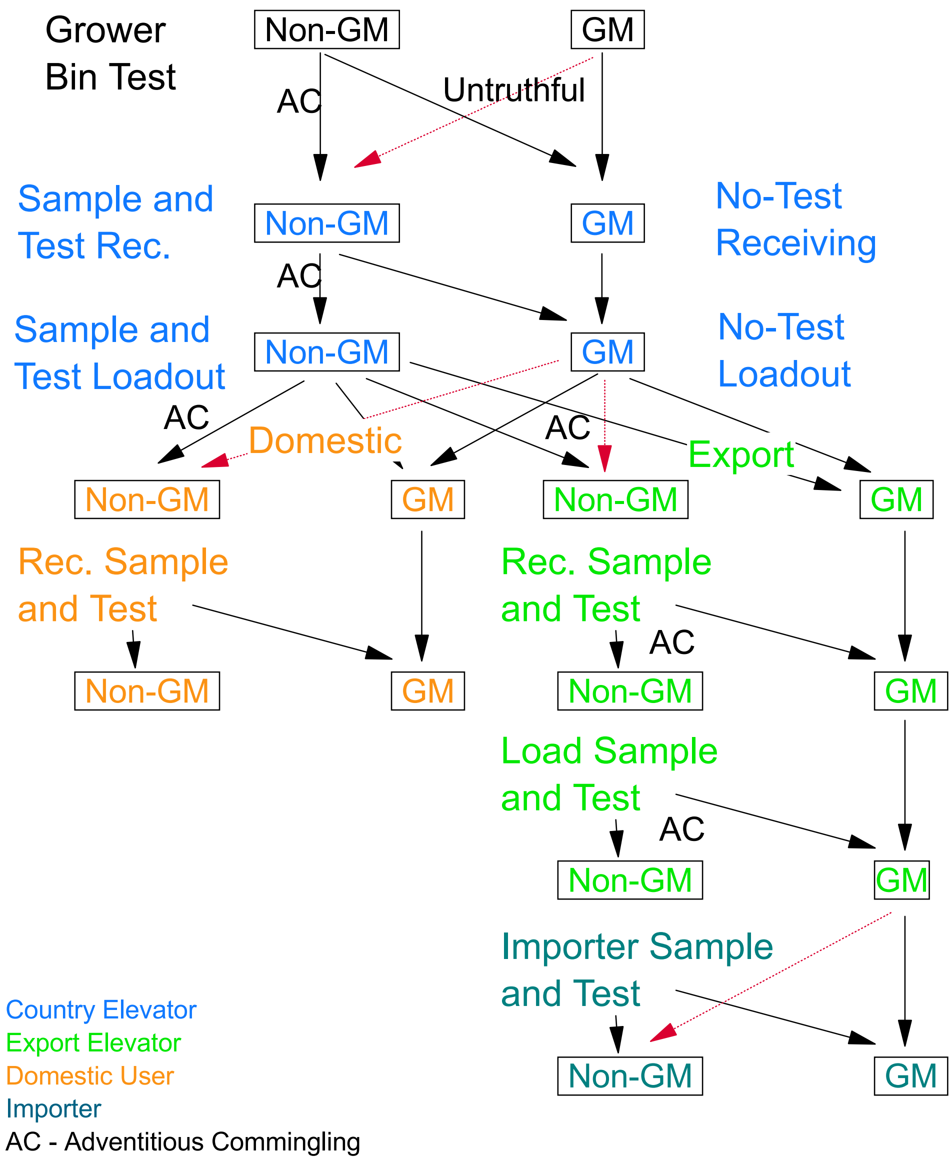

Figure 1. Grain Handling Subject to Adventitious Commingling.

processing.[2] An important and non-traditional practice reflected here is that growers declare GM content at point of first delivery. That is, subject to their own uncertainty about the GM content, growers would declare (i.e., as in some type of contract or affidavit) whether the content of the grain includes GM varieties. This is commonly referred as GM declaration and has been an important element of the evolution of the market of GM grains (Harl).

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 it could be elevators specialized in handling GM versus Non-GM. Or, it could be a

[2] In concept, the model could be extended to cover and assess risks and costs within the processing sectors. However, the current state of knowledge, with respect to risks and costs in these functions and testing technology, is not available and would preclude extending the model empirically.

vertically integrated firm with some elevators specializing in GM versus Non-GM handling. Each type of adoption has occurred in the marketing of other GM grains.

<u>Sources of Risks</u>: Risks are incurred throughout this system. Each are described here briefly and the actual distributions used in the model are explained in a later section.

There are three sources of grower risk. These include volunteers in subsequent crops, pollen drift, and on-farm adventitious commingling. Experience with volunteers has been limited in these crops for obvious reasons. Current literature suggests the level of risk of volunteers to be in the area of 31% of fields infested with an average density of 9 plants/sq. meter in the first year (Thomas and Leeson). The percent of fields infested and densities decline as years since the last wheat crop increase. By year 5, only 9% of fields were infested with an average density of less than 1 plant/sq. meter. These results indicate that there is a positive incidence, and this declines through time and is dependent on variety and agronomic practices. Using reasonable assumptions about planting rates etc., these risks translate to a probability of about .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 the years following.[3]

Pollen drift, in the case of self-pollinated GM wheats, is relatively modest compared to cross pollinated crops like corn. Previous studies for wheat have suggested that the rate of outcrossing is generally less than 1% but can range as high as 5% with pollen drifting from 5 to 48 meters. Hucl and Matus-Cadiz indicate this may result in higher than acceptable levels of off-types occurring in isolation strips of 3 to 10 meters. They indicated outcrossing varies by variety with Oslo and Roblin having higher outcrossing rates which may require isolation strips larger than for low-outcrossing varieties. Finally, Hurburgh (in the case of corn) indicated on-farm handling risks of adventitious commingling to have a probability of about .016. The most likely sources of mixing errors at the farm level were: planter box .6, combine .6, transport .2, handling-on-farm .3 or .017 excluding pollen drift.

While handlers routinely segregate and blend grains as a primary function of their business, there is added risk of handling GM grains due to the possibility of adventitious commingling. A recent published study by USDA/ARS found that if running elevators non-stop, contamination is 4%; after 3 minutes, it declines to .2%. (i.e., probability=.002) (Casada, Ingles, and Maghirang). These are corroborated by Hurburgh who suggested the sources of adventitious commingling at the elevator/handling function to be: handling .3%, shipping .3%, and mixing 1% for a total of =1.6% or a probability of .016.

Another source of risks is testing. Throughout the system there are risks associated with testing. Tests are not 100% accurate. However, the level of risk can be determined and varies with technology and tolerance. These are described below. Finally, inevitably a contract penalty may be imposed by the buyer if GM content is

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[3] If we assume average infestation rate of 9 plants/sq. meter, this equals 36,434 plants/acre. If we convert this to a seed equivalent at 14,000 seeds/lb., then 2.6 lbs. or 0.04 bu would be required to generate 36,434 plants/acre. Assuming a normal seeding rate of 1.5 bu/acre, the rate of infestation is equivalent to 2.89% of planting rate. If infestations are likely to occur with a probability of .31, then the expected infestation rate is 2.89%*.31+0*.69=0.9% in year 1, and declines thereafter.

found in a Non-GM shipment. This may be a simple penalty, or a rejection of the shipment by the seller. In either case, costs to the seller would be accrued.

Testing and Tolerance

There are several aspects of testing that are important. Most important is that testing would only apply to Non-GM shipments. It would be unnecessary to conduct tests on those shipments/lots already known to be GM. Thus, testing would only occur for those shipments/lots that are thought to be Non-GM.

There are two basic tests that could be used for analyzing for the presence of RRW. These are commonly referred to as strip tests and PCR tests.[4] Characteristics of these tests and their costs are shown in Table 1. These tests are for "single-trait" events. The PCR test is based on DNA technology and is more commonly used in international contracts. Strip tests are or would be more commonly used domestically. Table 2 shows the cost of these tests as they would typically be applied at different points in the marketing system, and converts them to cents/bushel (c/bu).

Trade Practices

The grain marketing system is evolving and beginning to adopt these protocols in GM corn and soybeans. Of importance in each case, as it would be in wheat, are tolerances, testing technologies, frequency at which tests are applied, declaration of GM content at the country elevator, and associated added costs and risks.

[4] However, the PCR tests may be less appropriate in GM wheat because unlike corn, there is no need at present for a single PCR test to identify several biotech events that use the same marker gene. Further, there is no need to test for event GA21 which in corn currently requires a PCR test because strip tests are not accurate (Tobin).

Table 1. GM Testing Tolerances, Costs, and Accuracies

GMO Tolerance Tested for (%)	% Confidence Level (%)	Seeds	Cost per Test ($)
		PCR Tests	
1	99	600	120
.1%	95	3000	300
.1%	99	4650	400
		Strip Tests	
1	95		7.50

Source: Communications with Danny Giggax. Based on batch testing in 150 seeds/batch.

Table 2. GM Cost per Test by Location

	Testing Cost $/test	Lot Size	Testing Cost c/bu
Farmer Bin Sample	7.50	5000 bu	.15
Country Elevator Receiving	7.50	800 bu	.94
Country Elevator Loading	7.50	3300 bu	.23
Domestic User Receiving	120-400*	3300 bu	3.64-12.12
Export Elevator Receiving	120-400*	3300 bu	3.64-12.12
Export Elevator Loading	120-400	33000 bu	.36-1.21
Importer Receiving	120-400	33000 bu	.36-1.21

* Depending on tolerance required and test applied.

Contract Specifications: End-users and buyers express their needs and aversion to GM in contracts with tolerances. This is critical. Ultimately, it is incumbent on those buyers wanting to limit GM content in Non-GM shipments, for whatever reason (commercial or regulatory), to specify limits/restrictions in their purchase contracts. Those not averse to GM would not have to do anything special.

This can be implemented in existing contract forms, and in a way similar to other factor limits. Specifically, for non-grade determining factors (e.g., dockage, vomitoxin, etc.) buyers specify limits in their contracts. This could be similarly accomplished for GM content. For example, a buyer may specify a limit simply as: not to exceed X% GM content and/or a discount may apply if the tolerance is exceeded. In addition, an acceptable test/sampling procedure would have to be concurred. Presumably, that would be standardized in such a way to make the contract language and implementation common across transactions.

Declaration of Known GM Content or Variety: Growers declare varieties (i.e., whether the shipment contains GM varieties) at time of delivery (Harl). It is important that the grower knows the variety being delivered or at least has the capability of knowing. This provides a wealth of information that needs to be conveyed to the marketing system. Not only does this provide the essential information for segregation and testing requirements, it has several other positive benefits.[5]

Empirical Model

A model of grain flows reflecting the structure of a dual system with testing and segregation of GM/Non-GM flows (similar to that depicted in Figure 1) from growers to either importers or domestic end-users was developed. The model assumes adventitious commingling can occur at various stages of the grain marketing chain with given probability distributions. A level of GM/Non-GM adoption by farmers is assumed and farmers may/may not identify grain lots delivered as GM/Non-GM with a probability of "truth-telling." Tests are conducted at various stages to determine if grain indicated as Non-GM contains levels of GM exceeding tolerances. Non-GM flows exceeding the tolerance are diverted to GM flows at the stage of the marketing chain where they are identified and subjected to a penalty.

An important and innovative feature of the analysis relates to the risks the handler/shipper is exposed to and the consequence of violating a tolerance. For example, if a ship is being loaded with Non-GM wheat, and even though the shipper is taking grain from a segregated Non-GM flow, it is possible that the ship may be found to have a detected level of GM content (for example, BT or RRW corn materials in wheat). In practice this would be interpreted as a contract violation and subject to either rejection, penalty, or renegotiation, all at a loss to the shipper. Any of these would be terms of the purchase agreement.

In any case, the shipper would be subject to an implicit cost or "risk premium" associated with this type of content. We estimate the value of this risk premium (π) as the expected costs for a Non-GM system (EV_{NGM}) less the certainty equivalent (CE) of the utility of additional costs of a system containing both GM and Non-GM segregations and include it in our cost function.[6] This premium reflects the point at which decision makers would be indifferent to the current Non-GM system or

[5] Ultimately, this would provide a precursor to marketing by variety or, more likely, restricted varieties. This would be a fundamental paradigm shift in grain marketing and would be similar to that in France and other exporting countries using variety in varying ways for marketing and classification

[6] In this case, we assume the expected costs for the current Non-GM system are unchanged and examine only the marginal costs of testing and rejection. Thus, the expected costs for the Non-GM system are assumed zero.

a system handling both GM and Non-GM segregations.

Model Specification

The model is developed as a stochastic optimization model of a grain marketing chain. The model utilizes an objective function presented by Saha and used earlier by Serrao and Coelho. 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 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 is comprised of the weighted disutility of additional system costs for handling both GM and Non-GM segregations.

The model estimates the additional system costs due to testing and segregation for each of the segregations (states of nature) separately. Additional system costs are impacted by:

C_{NGM} is additional testing and segregation costs added to Non-GM shipments to maintain GM separation,
C_{GM} is additional costs for GM bushels (assumed zero),
k is location in the system where tests can be applied (country elevator receiving, local elevator loading, export elevator receiving, export elevator loading, importer receiving, domestic user receiving),
T_k is cost of individual test applied at location k,
S_k is sampling intensity at location k,
V_{NGMk} 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, and
V_{DGMk} is bushels diverted from Non-GM to GM flows at location k.

The model derives additional system costs at each stage of the marketing chain, tracks segregation flows throughout the system, and derives statistical properties on the proportion of shipments with GM exceeding specifications within end-use flows.[7]

Distributions and Parameters Used in the Model

The model incorporates risk in a number of random variables. These include farmer "truth-telling;" adventitious commingling which occurs at several locations (farm, country elevator, export elevator, and transportation equipment) due to various factors (inadequate cleaning, etc.); sampling and inspection plans; and test accuracy.

Sources of information were from other published research, a survey of market participants, and/or industry judgement. These were supplemented by information contained in recent studies on adventitious commingling. The distribution of grower risks (inclusive of volunteers, pollen drift, and on-farm handling) were derived to reflect the risks depicted in previous studies. Similarly, handling risks were taken to depict those reflective in Hurburgh and Casada, Ingles, and Maghirang. Testing risks were from the test specifications and are contained in Table 1.

To get some judgement of the distributions about grower and handler "truth-telling," we conducted a survey of

[7] System costs excludes other costs for IP verification, segregation, which would be highly autonomous.

participants knowledgeable on this topic as it pertains to marketing of GM corn and soybeans. Results from this were used to derive a triangular distribution on truth-telling.

The penalty for GM contained in a Non-GM shipment was assumed to be uniformly distributed within a range of 40-90 c/bu in the export market and 2-20 c/bu in the domestic market. Given the grains in this study are not currently traded, we cannot use observed values. There are several aspects of the cost components. First, it is a result of a contract specification agreed between buyer and sellers. Second, it is important whether the test is evaluated at origin (i.e., export port) or destination (import port). If the former, being out of contract is not as great. Finally, some export elevators (e.g., with shipping bins) may be more capable of testing prior to loading than others.

The logic to the export penalties 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 c/bu. However, in some cases, rejection may entail re-shipping the grain to some other market at a cost to the shipper. In many geographical locations internationally, this would be about the equivalent of 50 c/bu. For the domestic market, these would reflect handling costs and possible shipment to alternate destinations. Thus, these likely reflect a worst case scenario. The final distributions used in the base case simulations are contained in the Table 3.

For all the important and interesting random variables, we conducted and present simulations to illustrate their effect on the solutions.

Results

A base case was defined and simulated. Results from this are described first. Simulations and sensitivities are then evaluated relative to this base case. Sensitivities were conducted to examine affects of risk attitudes, tolerance, variety declaration, level of GM adoption, level of discounts for rejection of Non-GM shipments, and choice of test type by location. A second model is developed to also examine impacts for shipments to domestic users.

Base Case

The base case was defined to reflect the most likely system and protocols. These include:

- Export shipment to importers;
- GM adoption by farmers of 20% (based on market distributions of GM aversion of buyers);
- Grower declaration of GM content at the country elevator;
- Testing was allowed at any or all of the following: Country Elevator (CE) at receiving and/or loadout and at the Export Elevator (EE) at receiving and loadout;
- Testing technology at the export/import level was required restricted to the PCR tests.[8]

[8] 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. This could 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.

Table 3. Base Case Distributions

	Distribution	Minimum	Most Likely	Maximum	Corroboration
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	
Handlers	Triangular	0.95	0.99	1.00	
Price Penalty	Uniform				
Export		40 c/bu		90 c/bu	
Domestic Users		2 c/bu		20 c/bu	
Testing		Cost	Accuracy		Test Type
Country Elevator		$7.50/Test	0.95		Strip Tests
Export Elevator		$120/Test	0.99		PCR

In addition, a PCR 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 results identify the optimal testing strategies which maximize utility (minimize disutility) of GM/Non-GM system versus the current Non-GM system. The optimal strategy would be to test every 5^{th} railcar at the country elevator when loading and to test every ship sublot when loading at the export elevator. This testing strategy results in average rejection rates at the importer of 1.75% with less than .02% of lots containing adventitious commingling remaining in importer flows after testing at the importer (due largely to test accuracy).

The proportion of flows in the Non-GM channel declined from .80 at the farm level to an average of .696 at the importer. Thus, on average, over 10% of Non-GM shipments are diverted to the GM segregation throughout the handling system. This illustrates the risk of incorrectly rejecting shipments throughout the system. Most of this occurs after unloading at the export elevator. Further, we are 95% confident that diversions of Non-GM to GM shipments should range from about 8% to 17% of shipments. This diversion takes place due to large samples containing units with both adventitious commingling and Non-GM which are represented by a single test, adventitious commingling which occurs in the system, and through effects due to test accuracy.

Additional system costs for testing and discounts for rejection at the importer in the base case were 1.4 c/bu. The approximate components of these costs are: testing of every 5^{th} railcar loaded at the country elevator, .037 c/bu; testing of every ship hold at the export elevator, .282 c/bu; testing of every ship hold at the importer, .259 c/bu; and rejection cost at the importer of .808 c/bu.

If this cost was absorbed solely by the Non-GM bushels, the costs average 2.0 c/bu. The cost of the system includes both additional system costs and the risk premium. Adding these two cost elements results in total costs of 2.4 c/bu when measured across all bushels and 3.4 c/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. Other costs could include costs for additional segregation, monitoring, etc., but were not included here.

Variety Declaration and Testing

In the base case, mechanisms are used to elicit information from growers on the GM content of their grains. In fact, this function would normally be included in "closed loop" marketing plans. This 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). If such a mechanism were not developed, initial handlers would have greater uncertainty upon receipt, which in turn could 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 which included a higher rate of adventitious commingling (20%, which is equal to the percent of GM adoption) at the point of first receipt.

With no variety declaration, the optimal testing strategy included testing of every 5th unit at the country elevator, both when receiving grain from growers and when loading railcars; and testing every 5th railcar when received at the export elevator and every hold when loaded at the export elevator (Table 4). Rejection rates at the importer increased from 1.75% for the base case to 2.34% with no variety declaration. The largest impact was on the proportion of Non-GM in the system. When flows reach the importer, only 30.6% of flows were Non-GM. Thus, a system with no variety declaration results in significant diversion of flows from Non-GM to the GM segregation. This occurs throughout the system, but is concentrated at the country elevator level. These are reflected in the costs when attributed to Non-GM bushels. Costs of testing and rejection for Non-GM bushels increased from 1.99 c/bu for the base case to 4.38 c/bu with no variety declaration. Total costs for Non-GM bushels similarly increased from 3.36 c/bu for the base case to 5.70 c/bu with no variety declaration.

A case was also developed where no testing and no variety declaration was allowed. This was used to reflect the risks inherent in the system and the value of testing. With no testing allowed, rejection rates at the importer were 10.10% (Table 4). This is significantly higher than either the no variety declaration case or the base case. Total costs per Non-GM bushel were also significantly higher than either of the other cases (13.42 c/bu).

Effect of Price Differentials (Discounts)

In corn and soybeans discounts have evolved to be about 10% of the value of grain. In the base case, discounts were applied which represent 10% of the value of wheat and added logistical costs to go to an alternative market. However, these are determined in part by contract specifications of individual buyers and by cumulative interaction of all buyers, sellers, and impacts of technology costs. To illustrate, we varied discounts to determine how these impacted testing strategies and also examined a case where discounts representative of additional handling costs were applied if rejected for country and export elevator loading. Two cases were developed, one with lower

Table 4. Effect of Variety Declaration and No Testing

Variety Declaration	Base Case Variety Declaration	No Variety Declaration	No Testing & 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
Probabilities			
GM in Importer Flows	.02%	.01%	0.10%
Rejection at Importer	1.75%	2.34%	10.10%
Costs			
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
Percent of Flows Non-GM by Location			
Adoption Rate	80.0%	80.0%	80.0%
Farmer in Bin	80.0%	80.0%	80.0%
Country Elevator in Store	81.7%	77.7%	81.7%
Country Elevator Loaded on Track	76.8%	51.1%	81.7%
Export Elevator in Store	77.2%	39.0%	82.0%
Export Elevator after Loading	70.8%	31.3%	82.0%
Importer after Test	69.6%	30.6%	73.7%

penalties (0-10 c/bu) and a second with higher penalties (100-150 c/bu). A third case was developed to examine effects of additional discounts applied at loading locations (country and export elevators) when lots are identified as GM and diverted.

Lower penalties resulted in an optimal testing strategy which was less intensive. Optimal testing occurred at the same locations (both country elevator and export elevator loading); however, sampling at the export elevator was less intensive (every 5th 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 (Figure 2). Higher penalties resulted in the same optimal testing strategy as the base case.

The third case applied additional penalties at loading and resulted in a more intensive testing strategy. Tests were conducted at the same locations; however, every unit was tested at both the country and export elevator when loading. The effect of this more intensive testing strategy for this case resulted in lower rejection rates at the importer (1.68% versus 1.77% in the base case).

Total costs (Additional + Risk Premium) when attributed to the Non-GM bushels increased as the level of the penalty for rejection increased. With the higher penalty (100 to 150 c/bu), total costs per Non-GM bushel were 5.19 c/bu while the low penalty rate had total costs of only 1.6 c/bu. This indicates 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, decision makers respond with strategies which include greater testing intensities and lower rejection rates. Costs would be higher per Non-GM bushel and require higher risk premiums (Figure 2).

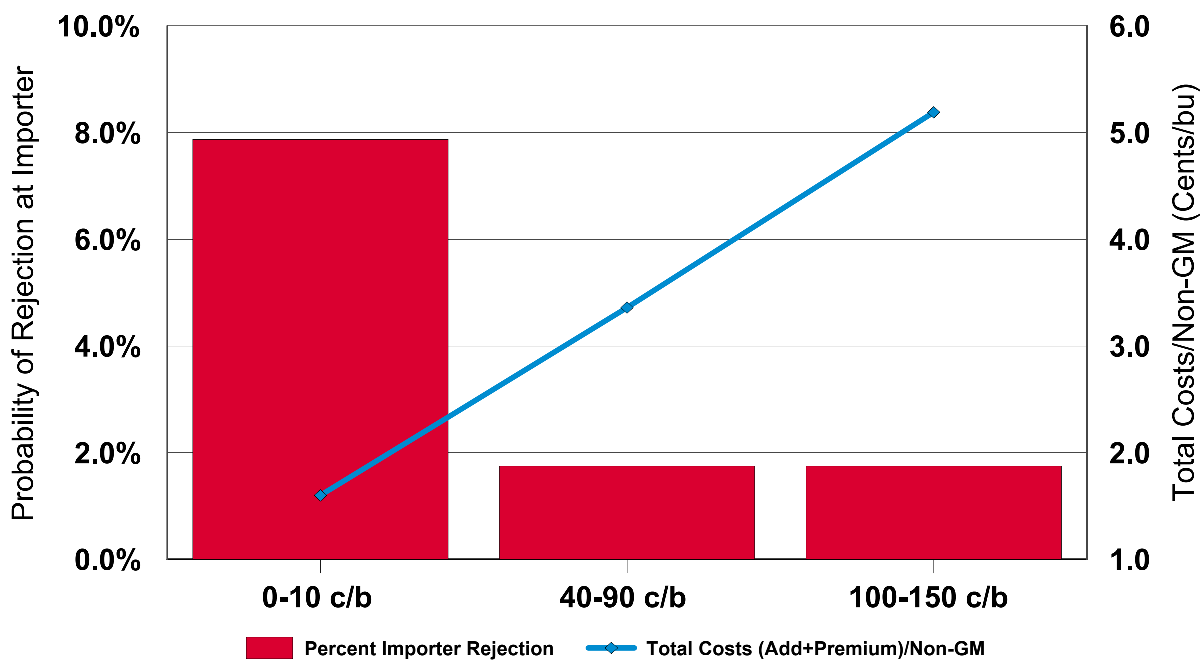

Figure 2. Effects of Penalty for Rejection on Rejection Rates and Total Costs per Non-GM Bushel.

Other Simulations[9]

GM Adoption Rate

Adoption for GM in the base case was assumed to be 20% and was parameterized based on expected buyer aversion. However, this will vary with market forces, and most important, will vary geographically, both of which would impact the optimal testing strategy. Thus, the range of GM adoption was examined for cases with 10% and 50% GM adoption and compared to the base case.

Optimal testing strategies for 10% GM adoption were the same as for the base case. However, with GM adoption of 50%, the optimal testing strategy included testing at the country elevator and export elevator when loading and added additional testing (every 5th unit) when grain is received at the country elevator. As the level of GM adoption increased, the proportion of samples rejected at the importer also increased from a low of 0.17% for the 10% GM adoption to 2.12% with 50% GM adoption.

Costs of testing and rejection, when estimated over all bushels, declined as the level of GM adoption, increased. For GM adoption of 10%, additional costs attributed to all bushels were 1.53 c/bu and declined to 0.97 c/bu with 50% GM adoption. When costs are attributed only to Non-GM bushels, the additional testing and rejection costs increased from 1.94 c/bu for 10% GM adoption to 2.56 c/bu for 50% GM adoption. This occurs largely due to the lowering of the proportion of samples that are tested as the rate of GM adoption increases.

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 contractual relations and/or elevator imposed mechanism. In the base case, farmers were truthful in their declaration 95% of the time (range from 80% to 100%). This was represented in the model by a triangular distribution with a minimum value of 80%, most likely 95% and maximum of 100%. Two cases were developed to examine the effect of reductions in farmer truth-telling. One case has truth-telling represented by a triangular distribution with minimum of 40%, most likely value of 50% and maximum of 60%, while the second case has a minimum of 65%, most likely value of 75% and maximum of 85%.

As farmer truth-telling declines, optimal testing strategies results in increased testing. Both cases with lower truth-telling included testing of every 5th unit at the country elevator when receiving in addition to testing at the country and export elevators when loading. Rejection rates at the importer increased from 1.75% in the base case to 1.91% for the lower truth-telling case (Figure 3). Also, the proportion of flows at the importer that were Non-GM declined from 69.6% in the base case to 58.0% with the lower truth-telling case. Thus, there is greater false rejections in the system as grower truth-telling decreases. Total costs for Non-GM bushels also increased as farmer truth-telling declined. Total costs for the lowest farmer truth-telling were 3.81 c/bu for Non-GM bushels versus 3.36 c/bu for the base case.

[9] Details of these simulations are provided in the full research report.

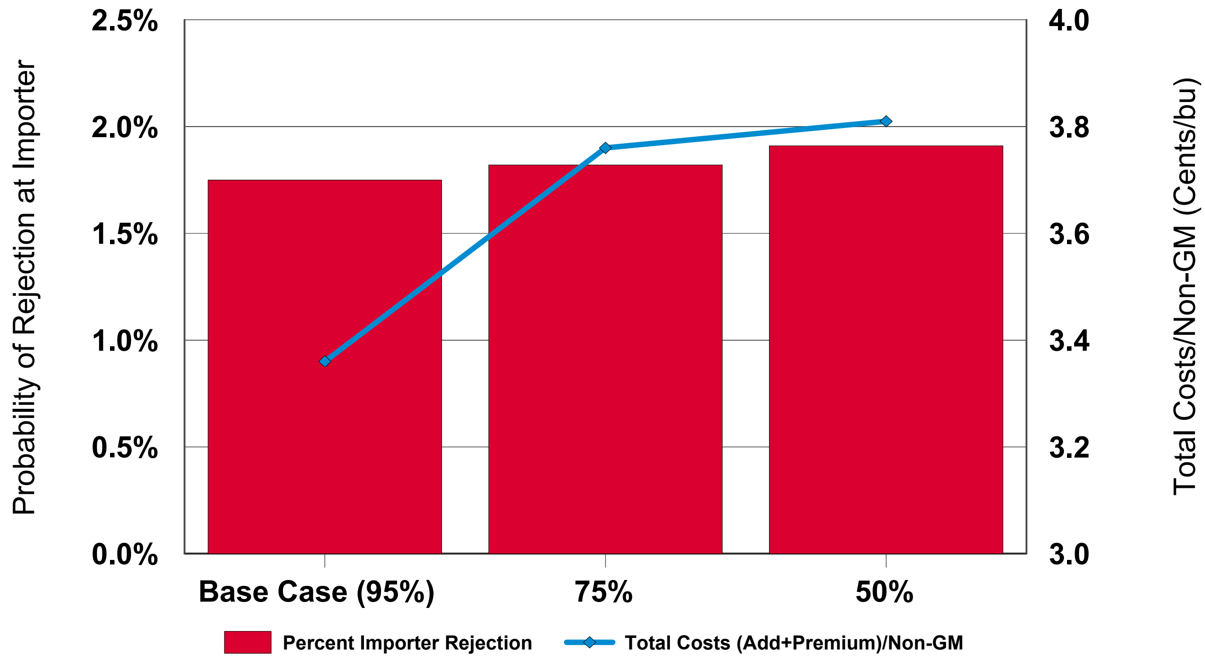

Figure 3. Effect of Grower Truth-telling on Rejection Rates at Importer and Total Costs per Non-GM Bushel.

Choice of Testing Technology

In the base case the type of test was assumed to be a strip test at the country elevator and PCR tests at the export elevator and for importers. This assumption was relaxed and a case developed which in addition to choosing where and how often to test, the model also chooses what test to apply based essentially on the cost and risk. In this case, the choice of test was limited to choice at the country and export elevators. A PCR test was still required by the importer.

The optimal testing strategy when there was a choice of test included testing every 5th unit at the country elevator when loading, every 5th unit at the export elevator when receiving, and every unit at the export elevator when loading. At all locations the strip test was chosen, which has a lower cost and test accuracy than the PCR test. This is reflected in a lower proportion of flows in the Non-GM segregation at the importer (65.4%) than in the base case (69.6%) and a higher rejection rate at the importer (2.08% versus 1.75% in the base case).

Costs on all measures declined when the choice of test type was allowed. Testing and rejection costs across all bushels declined from 1.39 c/bu in the base case to 1.23 c/bu when choice of test was allowed. The risk premium required for decision makers to be indifferent between a dual handling system and a Non-GM system declined from 0.96 c/bu in the base case to 0.80 c/bu when the choice of test is allowed. Total costs for Non-GM bushels declined from 3.36 c/bu in the base case to 3.12 c/bu when choice of test is allowed.

Effect of Testing Tolerance

Buyers choose the tolerance which in turn defines testing protocols. In the base case a 1% tolerance was assumed. It is well recognized that tolerance tightening has the impact of raising costs and prospectively raising risks of not conforming. There are three elements of costs that are critical in evaluating effects of differing tolerance limits. These include testing costs, risk of not conforming, and adventitious commingling in the system. The first two are clear. As tolerance is tightened, testing costs increase and risk of rejections increase.

However, it is not known how adventitious commingling in handling (either through residual grains remaining in handling equipment or through cross-contamination of lots) would be impacted by increasing/decreasing tolerance levels. To approximate for this, we developed two cases. One has a tolerance level of 0.5% (50% of the base case value) in which we increased the levels of adventitious commingling that would be identified at this tighter specification so parameters of the distribution were twice that in the base case. A second case was developed in which the tolerance level was assumed to be 5%. In this case, 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 effect of tolerances on the level of adventitious commingling is indicated and as such, results are illustrative but should be viewed with caution. In both cases, alternative tests which achieve these desired tolerance levels and their associated accuracies and costs were utilized rather than the parameters for the base case test accuracies and costs. For the 0.5% tolerance level, a strip type test was assumed having a cost of $40/test and accuracy of 99%. For the 5% tolerance level model, choice of tests was between two strip type tests costing $20/test with one having accuracy of 95% and the other 99%. Costs and accuracies of these prospective tests were obtained from Giggax.

Results indicate increased testing as tolerance levels tighten from 5% to 1% (Base case). Increasing the tolerance further (0.5%) results in testing of every 5th unit, but changes from the country elevator when loading to the export elevator when receiving. The rejection rate at the importer increased as the tolerance became tighter. Rejection for a 5% tolerance was 1.07%, while at a 0.5% tolerance was 3.00%.

Costs and risk premiums also increased as tolerances tightened. Tightening the tolerance from 5% to 0.5% increased testing and rejection costs from 0.63 c/bu to 1.67 c/bu for all bushels and from 0.83 c/bu to 2.60 c/bu for Non-GM bushels. The risk premium increased from 0.47 c/bu with a 5% tolerance to 1.06 c/bu with a 0.5% tolerance. Total costs for Non-GM bushels increased from 1.45 c/bu with the 5% tolerance to 4.25 c/bu with a 0.5% tolerance.

Summary and Implications

Development and commercialization of genetically modified (GM) crops has challenged the functions and operations of the grain marketing system. While these have already been confronted and (partially) resolved in other grains and oilseeds, none of these issues have been resolved regarding the anticipated commercialization of GM wheats. While the focus of the GM debate currently in North America is on the *Round-up Ready*® wheat trait, there is extensive research suggesting that other traits will be similarly proposed in the coming years. The purpose of this paper is to determine the optimal testing strategy and to quantify the costs and risks of the system.

Problem

Pressures for adopting GM wheat, specifically RRW, come from a combination of cost reduction, reduced dockage, increased profitability of competing crops (being recipients of GM technology), and the prospect of 2nd and 3rd phase benefits associated with GM wheats. Virtually all of the major stakeholder groups have taken positions essentially pointing to the desirability of GM wheats, conditional upon developing a system involving Identity Preservation (IP) and testing to satisfy needs of buyers. In addition, in this case the technology developer has indicated not commercializing the trait until such a system is adopted. Beyond these positions, the asynchronous regulations and indigenous differentiated demands resulting in buyer resistance ultimately 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 measured using some type of prescribed test. Then, 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 fundamental tradeoff confronting shippers and buyers. In light of this, there are important operational questions such as the optimal location to test, how intense, the test type, and how numerous factors impact these strategies.

Analytical Model

A stochastic optimization model was developed of the export and domestic marketing system. All the elements of the system, including costs and risks, were included in the model. Of particular importance were the costs and risks at each node of the system, as well as the risk imputed upon the shipper. Specifically, we had a focus on the risk premium necessary to induce a shipper to handle Non-GM wheat and to be exposed to the risks and penalties of being out of contract.

The model was posed as the utility for a portfolio representing additional testing and rejection costs of a combined Non-GM/GM system. The results indicated the optimal testing strategies for supplying export and domestic 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. A model was developed for the export market and sensitivities conducted to evaluate impacts of risk attitudes, variety declaration, levels of rejection costs, GM adoption rates, grower truth-telling, and tolerances. A second model was developed for the domestic market to evaluate differences between optimal testing strategies and costs for export and domestic markets. Sensitivities of all the critical variables were conducted.

Major Conclusions

The base case was defined to represent a likely set of situations. Important amongst these were: GM adoption by growers in a region was 20%; growers declared GM content at delivery, subject to some uncertainty; and testing was allowed at varying intensities and locations throughout the system. Alternative testing technologies were also included, as well as penalties for being out of contract.

Results indicated the optimal testing strategy was to test every 5th unit at the country elevator when loading and every unit loading at the export elevator. This results in additional costs of testing and rejection for Non-GM bushels of 1.99 c/bu. Adding the risk premium increased total costs per Non-GM bushel to 3.36 c/bu. The risk premium in this case was 0.96 c/bu which is interpreted as 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.

Several factors were examined using sensitivity analysis. Dropping variety declaration at the country elevator increased the intensity of the optimal testing plan, increased costs and premiums, and resulted in a higher proportion of Non-GM flows being diverted to GM within the marketing chain. Increasing the risk aversion of the decision maker increased the risk premium required, but resulted in the same optimal testing strategy. Decreasing the risk aversion resulted in more testing, a higher proportion of flows being diverted to GM, a lower risk premium, and lower total system costs. Decreasing the cost of rejection at the importer reduced the intensity of testing, increased rejection rates to 7.9% at the importer, and lowered costs and the risk premium. Adding additional costs at interior loading points representing additional handling charges increased the intensity of testing, test costs, and the risk premium, while lowering the proportion of flows diverted from Non-GM to GM within the system.

Changes in prospective tolerance levels of tests for adventitious commingling indicated changes in optimal testing strategies as tolerances tightened. More testing was required for tighter tolerances, and tests were shifted from the country elevator when loading to the export elevator when receiving as tolerances tightened from 1% to 0.5%. Costs, premiums, rejection rates, and the proportion of flows diverted to GM within the system increased as tolerances tightened. Total costs including the risk premium increased from 1.45 c/bu with a 5% tolerance to 4.25 c/bu with a 0.5% tolerance. While the results for tolerance are illustrative, more research would be useful on the effects of tolerance tightening on adventitious commingling, rejection rates, and their effects.

The optimal testing strategy for the domestic market had higher rejection rates, costs, and risk premiums than did the export market. Additional costs, when measured over all bushels or over Non-GM bushels and risk premiums, were about double those for the export market. These were higher for the domestic market largely due to increased testing costs arising from smaller lot sizes for domestic users (railcars) versus importers (ship holds).

Implications

There are several implications from these results. First, a system based on testing and segregation can very efficiently assure buyers of GM content at a quite low cost. While nil tolerance cannot be achieved through a system based on testing, the GM content can reasonably be assured at levels of .5% and 1%. Second, the cost of a system based on optimal testing and segregation inclusive of a risk premium are much less than most systems that have been proposed on IP and other means to control GM content. Third, there are many factors that will affect the elements of an optimal testing system, costs, and risks. Most important amongst these include price discounts/costs for being out of contract and GM declaration at delivery. Fourth, strict interpretation of the risk premium would indicate that this is the premium required for grain handlers to be indifferent between a dual system of Non-GM and GM or the current Non-GM system. In order for Non-

GM to gain a premium, sellers will have to provide proof that it is in fact Non-GM, buyers must be willing to pay this cost and, eventually through competition, price differentials will emerge to approximately reflect these costs. Fifth, an IP system to resolve marketing of GM would be much more elaborate in terms of monitoring, administration, etc., than a system involving tolerances and testing, and, as a result, would be much more costly.

Finally, these results are suggestive of 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 the costs and risks in the system. These risks are summarized in Table 5. The most crucial elements of the system would be: declaration of GM content at delivery, testing for GM throughout the Non-GM system, buyers' aversion to GM, contract specifications for some tolerance level, and the test(s) adopted.

Table 5. Risks and Mitigating Strategies for Introducing/Marketing GM Wheat

Risk Factor	***Mitigation Strategy***
Breeding, seed production contamination	Breeding protocols
Volunteers	Contract requirements about sequential planting
Pollen Drift	Buffer requirements in planting
On-Farm Risks	Grower education, contract terms, monitoring
Farmer Accountability (truth-telling or retention/leakage)	Contract terms/obligations, incentives
Handling (receiving, segregating, loading, and transport)	Variety declaration, testing, car tagging, and other protocols
Testing/Accuracy	Protocols requiring testing at some (though selected) points; frequency/intensity of testing. Not important for known RRW shipments

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