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Cost Implications of Alternative GM Tolerance Levels: Non-Genetically Modified Wheat in Western Canada

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Modern agricultural biotechnology is leading to the creation of supply chains involving identity preservation of genetically modified (GM) and non-GM crops. Cost differences are estimated for three selected supply chain systems for Canadian non-GM wheat at different levels of tolerance for GM material. The selected systems extend from the farm to export port and include use of both mixed and dedicated country and export elevators as well as farm-level containerization of wheat. There is an appreciable increase in the costs of identity preserved marketing of non-GM wheat within each system as threshold levels tighten from 5% to 0.1%.

Key words: genetically modified (GM) wheat, GM thresholds, identity preservation, supply chain systems, tolerance-sensitive costs.

Introduction

Numbers of Canadian farmers have adopted licensed genetically modified varieties of such widely grown crops as canola, corn, and soybeans. Nonetheless, there has been hesitancy to accept foods based on GM technology in many export markets (Philips & Foster, 2000). This apprehension hinges on perceptions by numbers of consumers that food products made from GM crops may be unhealthy, have harmful effects on the environment, or be associated with ethical or social concerns (Veeman, 2001). The most recently proposed introduction of a GM crop in Canada involves Roundup Ready wheat, which has been under consideration for regulatory approval in both Canada and the United States. In May 2004, Monsanto announced that it would defer its pursuit of regulatory approval for Roundup Ready wheat due to considerable market resistance. Monsanto representatives have indicated that the company is not abandoning the technology for wheat but will wait until market resistance decreases.

Wheat is grown on more than 20 million acres in the western Canadian prairies; production exceeds 20 million tonnes annually. Almost 19 million tonnes of western Canadian wheat is sold annually to more than 70 countries, generating between $4 and $6 billion (US dollars) in export sales revenues and accounting for over 18% of the world's exported wheat—the second highest in the world (Canadian Wheat Board [CWB], 2003). Because Canada is a large player in wheat export markets, commercialization of GM wheat has become an issue of much debate among grain farmers and grain marketing organizations.

According to press reports and information given on the web page of the Canadian Wheat Board, buyers representing more than 80% of Canada's current wheat export markets have indicated that they would not purchase GM wheat if it were to be grown in Canada (CWB, 2004; Grenier, personal communication, March 18, 2003; Wilson, 2003). Concerns have also been expressed about the market acceptability of GM wheat produced in the United States (Wisner, 2002). These reactions lead to interest in and pressure for commodity segregation through identity preservation (IP) supply-chain systems. It is expected that IP supply chains will involve higher marketing costs than those of the current wheat bulk-handling system. It is also expected that the allowable tolerance standard for accidental (adventitious) commingled GM materials will be an important element of designing and costing an IP supply chain for non-GM wheat, because IP costs are likely to vary significantly under various tolerance levels, and tolerance levels for GM content within non-GM wheat consignments set by different import countries are likely to vary. Consequently, the impact on costs of different levels of tolerance is an important issue. This study is directed to that issue.

Identity Preservation for Non-GM Wheat

Identity preservation is a management system that is designed to distinguish the source and nature of products as they move through the supply chain (Buckwell, Brookes, & Bradley, 1998). Such systems must satisfy stringent protocols for production, handling, and testing procedures that require documentation from the producer to the end user (Dobson, 2002). Identity preservation is a well-established practice in the production and marketing of crops with various distinctive and desired

characteristics, such as with certified seed, malt barley, white corn, food-grade soybeans, organically produced crops, or crops with a specific oil composition (Kalaitzandonakes & Maltsbarger, 1998). Although there may be motivations to maintain the segregation of particular GM crops having desired characteristics, the major purpose currently expected for segregation of non-GM wheat within an IP supply chain will be to assure the segregation of non-GM wheat from possible commingling with GM wheat, which is evidently viewed by numbers of buyers as an undesirable trait.

Tolerances and Thresholds for GM Content in a Non-GM Identity Preservation System

From the perspective of the grain industry, "a tolerance for non-GM is referred to as the maximum allowable GM content to still be considered non-GM" (Wilson & Dahl, 2002). The associated threshold is the set point beyond which non-GM wheat can no longer be considered to be non-genetically modified, and would be rejected by the customer. In the context of this study, the terms *threshold* and *tolerance levels* refer to an expressed percentage of allowable GM content in non-GM products. The different tolerance levels considered in this study are 5%, 3%, 1%, 0.5%, and 0.1%. These particular levels were chosen because they represent or encompass most of the existing labeling specifications for declaration of GM content that may apply internationally. For example, a 5% level of tolerance has been discussed for Japan, Hong Kong, and Canada, whereas a threshold of 3% was proposed for South Korea and Thailand. A maximum level of 1% of accidental inclusion of licensed GM content originally applied as the threshold for labeling requirements in the European Union, but this has been reduced to a level of 0.9%. The threshold level of 0.5% is included because it currently applies in several non-GM IP programs for soybeans in Ontario. The lowest specified threshold, 0.1%, is included because it is currently viewed as a scientifically feasible level for GM testing (T. Demeke, personal communication, May 9, 2002; Maltsbarger & Kalaitzandonakes, 2000; Philips & McNeil, 2000; Veeman, 2003).

The Approach of the Study

We consider three alternative western Canadian supply chain systems for wheat, within which identity preservation of non-GM wheat may be applied, and analyze the impacts of the different threshold levels within each of these situations (Figure 1). In System 1, segregation must occur within elevators, because these are assumed to handle both GM and non-GM wheat. By contrast, in System 2, elevators are designated to handle solely either GM or non-GM grain. System 3 involves the use of containers for GM wheat; we assume that these are sealed and loaded at the farm for shipment to the purchaser.

In this study of IP non-GM wheat, the postulated scenario assumes that although GM wheat is widely grown commercially in western Canada, approximately half the Canada Western Red Spring (CWRS) wheat crop that is grown for export is specified as non-GM IP wheat. This general assumption allows abstraction from the possibility of added costs and inefficiencies that might be associated with the marketing of a much smaller proportion of non-GM wheat. These cost components could, for example, involve limitations on the efficient utilization of elevator space or usual blending practices; these have been termed "hidden costs" by Maltsbarger and Kalaitzandonakes (2000). Similarly, the IP scenarios that we consider abstract from and do not consider any added or "hidden" costs that might be incurred should farmers need to transport their non-GM IP wheat over relatively long distances to non-GM dedicated country elevators (this could potentially occur in Supply System 2 if the total wheat crop were to include only a small proportion of non-GM wheat). Thus, inefficiencies that could be introduced into the marketing system through the introduction of non-GM IP supply chains are not considered in this study.

In analyzing the on-farm cost consequences of the range of alternate tolerance levels, we assumed a standardized farm model that involved standard equipment for some major items. Representative western Canadian country and export elevators were also assumed to operate in the context of the current export marketing procedures for western Canadian wheat. Specialists suggested three types of GM tests currently used in non-GM soybean IP systems—polymerase chain reaction (PCR) tests for containers and ships and strip tests or ELISA tests at the elevator level—as likely to be used for non-GM wheat, depending on the tolerance level and the size of shipments. Other specific assumptions are summarized in Appendix 1.

Initial interviews with knowledgeable industry representatives were conducted in order to determine the tolerance-sensitive points and activities in each of the three supply-chain systems. Tolerance-sensitive points are indicated in Appendix 2. Subsequently a set of surveys was developed, pretested, and administered to knowledgeable people within the grain industry in order

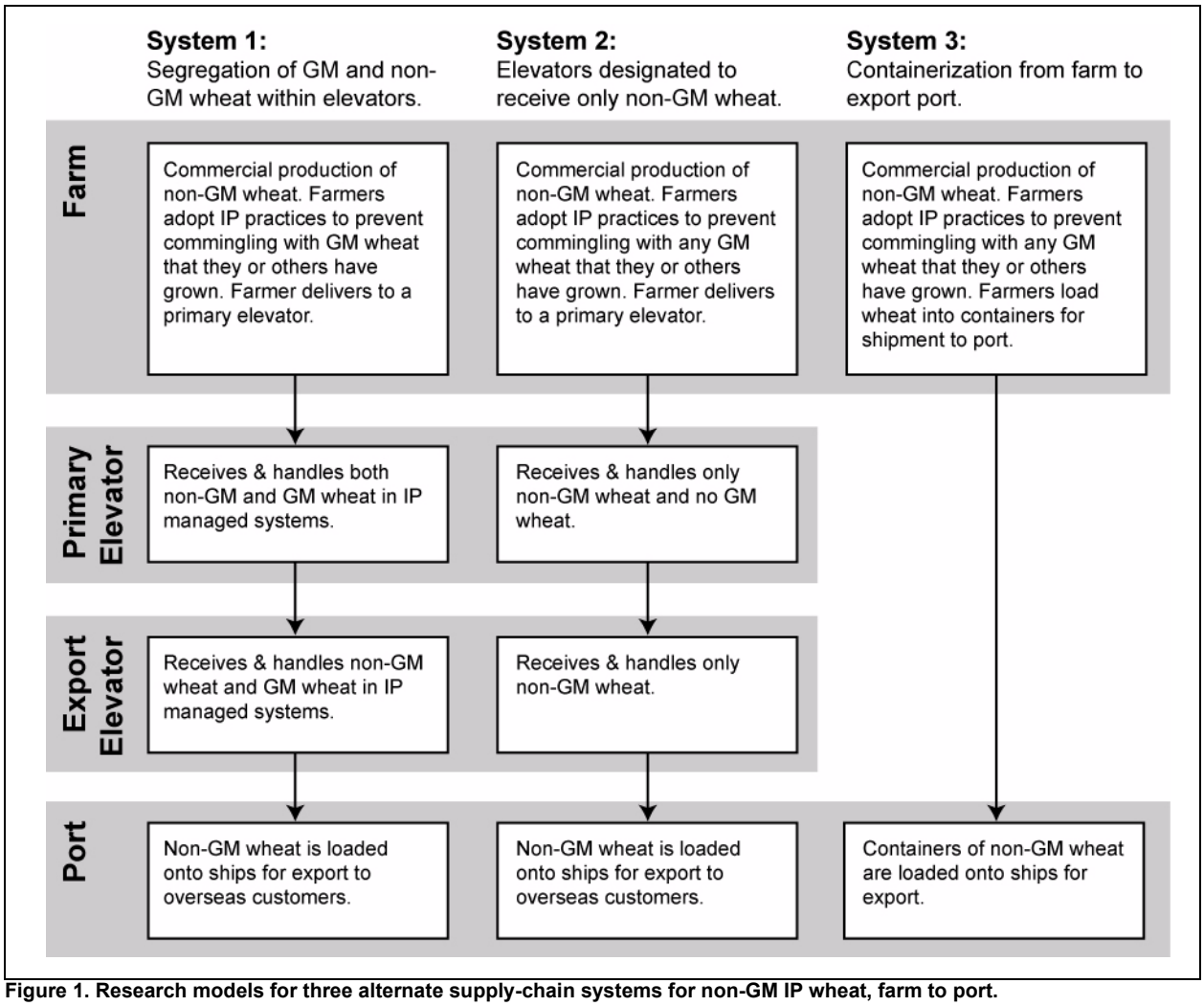

Figure 1. Research models for three alternate supply-chain systems for non-GM IP wheat, farm to port.

to generate data to develop estimates of incremental costs of tolerance-sensitive components of IP systems for non-GM wheat within each of the three specified supply-chain systems for the specified tolerance levels. The incremental costs that we consider and estimate are the costs that vary with changes in tolerance levels.

Each person interviewed had expertise in IP systems and protocols. Detailed interviews were conducted with five plant scientists/agronomists, fourteen seed growers (identified as farmers familiar with threshold levels and IP protocols), seven primary elevator managers, three export elevator managers, twelve GM testing specialists,[1] three container shipping experts, and three individuals associated with the commercial development of agricultural biotechnology. These interviews, which were the source of the data for the study, were conducted from February through May 2003. The cost estimates reported in this paper are all in Canadian dollars.[2]

The respondents were queried on the feasibility of achievement of the specified threshold levels and operational procedures to achieve these levels. With the use of structured surveys, respondents also provided estimates of incremental time and associated costs to undertake IP protocols associated with the different threshold levels, such as the time spent in cleaning items of machinery and equipment or the costs of applying GM-content

1. *Half of this group provided price information for various GM tests; the others provided information on likely testing protocols for each threshold level and for each of the three alternate IP supply chains.*
2. *During February–March 2003, the United States-Canada exchange rate averaged US$1.00:C$1.46.*

Table 1. Tolerance-sensitive IP cost summary at the farm level—estimated mean costs by tolerance levels ($/tonne).

	Tolerance level				
Farm IP cost points	**5%**	**3%**	**1%**	**0.5%**	**0.1%**
Isolation zone	$0.07	$0.07	$0.18	$0.42	$0.72
Volunteer control	0.84	0.84	2.09	4.15	5.15
Cleaning:					
Seeder	0.02	0.02	0.03	0.06	0.08
Combine	0.06	0.06	0.13	0.21	0.26
Truck	0.01	0.01	0.02	0.02	0.03
Semi	0.01	0.01	0.02	0.02	0.03
Bin	0.01	0.01	0.03	0.05	0.08
Dryer	0.01	0.01	0.02	0.03	0.04
Auger	0.00	0.00	0.01	0.01	0.02
Combine flush	0.02	0.02	0.03	0.04	0.04
Total farm costs	**$1.04**	**$1.06**	**$2.55**	**$5.03**	**$6.45**

Note. Data from fourteen seed growers.

tests. Based on the estimates of time and other associated costs at each stage of the different supply chains, incremental cost estimates were developed for each supply-chain system. The sensitivity of a number of these cost estimates was assessed (for example) in terms of potential variations in the protocols for on-farm isolation zone practices and for farm yield variations. Subsequently the tolerance-sensitive incremental cost estimates associated with the different tolerance levels were combined with information, for 2002–03, on other (i.e., non-tolerance-sensitive) IP costs to give general estimates of the aggregate costs of achieving the specified tolerance levels in the three IP supply-chain scenarios. The mean values of the various estimates are for 2002–03 and are reported in terms of Canadian dollars per metric tonne of non-GM wheat.

Tolerance-Sensitive IP Costs

Farm Level

We assumed that farm-level costs would not differ for the three supply chains, because these systems effectively diverge only beyond the farm gate. Mean farm-level tolerance-sensitive cost estimates for the various threshold levels of tolerance are reported in Table 1. These indicate the importance of volunteer control of GM wheat amongst the various farm-level IP cost components and show an appreciable increase in tolerance-sensitive costs as threshold levels become more stringent.

Table 2. Mean incremental tolerance-sensitive cost estimates at the primary elevator level for System 1 (non-GM and GM wheat are received within the same elevator; $/tonne).

	Tolerance level				
	5%	**3%**	**1%**	**0.5%**	**0.1%**
Clean receiving	$0.00[a]	$0.01	$0.01	$0.02	$0.02
Clean storage	0.01	0.01	0.01	0.02	0.02
Clean shipping	0.00[a]	0.00[a]	0.00[a]	0.01	0.01
Capital expenditure	0.05	0.05	0.12	0.19	0.19
GM test (receiving)	0.03	0.03	0.06	0.14	0.28
GM test (shipping)	0.02	0.02	0.08	0.19	0.39
Total	**$0.11**	**$0.11**	**$0.27**	**$0.57**	**$0.91**

Note. Data from seven primary elevator operators, six IP coordinators, and six GM-testing specialists.
[a] Values greater than zero but less than $0.01/tonne.

Table 3. Mean incremental cost estimates at the primary elevator level for System 2 (elevator designated to receive only non-GM wheat; $/tonne).

	Tolerance level				
	5%	**3%**	**1%**	**0.5%**	**0.1%**
Clean receiving	$0.00	$0.00	$0.00[a]	$0.00[a]	$0.00[a]
Clean storage	0.00	0.00	0.00	0.00[a]	0.00[a]
Clean shipping	0.00	0.00	0.00[a]	0.00[a]	0.00[a]
Capital expenditure	n/a	n/a	n/a	n/a	n/a
GM test (receiving)	0.03	0.03	0.06	0.14	0.28
GM test (shipping)	0.00	0.00	0.00	0.00	0.00
Total	**$0.03**	**$0.03**	**$0.06**	**$0.14**	**$0.28**

Note. n/a = not applicable. Data from seven primary elevator operators, six IP coordinators, and six GM-testing specialists.
[a] Values greater than zero but less than $0.01/tonne.

Primary Elevator Level

Reported incremental IP costs at the primary elevator level include GM-content testing, cleaning of the receiving, storage, and shipping components of the elevator system, and capital expenditures for devices to aid in the prevention of commingling of non-GM and GM wheat (such as lock-out systems). Table 2 indicates the mean incremental tolerance-sensitive cost estimates across the five tolerance levels for a primary elevator, which receives and must segregate non-GM and GM wheat (Supply System 1). Table 3 gives similar cost estimates for a designated non-GM elevator (Supply System 2). Incremental costs for these IP systems are less for the dedicated elevator system than for dual-handling elevators. In both cases the costs of GM testing are a major component of the tolerance-sensitive IP costs; these costs appreciably increase as the threshold levels dimin-

Table 4. Mean incremental tolerance-sensitive cost estimates at the export elevator level for System 1 (non-GM and GM wheat received within the same elevator; $/tonne).

	Tolerance level				
	5%	**3%**	**1%**	**0.5%**	**0.1%**
Clean receiving	$0.01	$0.01	$0.01	$0.02	$0.02
Clean storage	0.00[a]	0.00[a]	0.00[a]	0.01	0.01
Clean shipping	0.00[a]	0.00[a]	0.01	0.01	0.01
Capital expenditure	0.01	0.01	0.05	0.05	0.05
GM test (receiving)	0.08	0.08	0.08	0.08	0.08
GM test (shipping)	0.01	0.02	0.03	0.06	0.21
Total	**$0.11**	**$0.12**	**$0.18**	**$0.22**	**$0.38**

Note. Data from three primary elevator operators, six IP coordinators, and six GM-testing specialists.
[a] Values greater than zero but less than $0.01/tonne.

ish. The lower levels of tolerance-sensitive costs for a primary elevator that handles only non-GM grain arise because of lower costs of cleaning and GM testing at shipping, reflecting the lower risks of commingling with GM grain for a facility dedicated for non-GM grain handling.

Export Elevator Level

At the export elevator level, tolerance-sensitive incremental costs include testing for GM content, cleaning of various items of equipment, and capital expenditures for lock-out systems and physical barriers that prevent contamination of non-GM consignments with GM crop material. Tables 4 and 5 show the estimated mean tolerance-sensitive IP costs at the export elevator level for Supply Systems 1 and 2. The tables show that incremental IP costs increase as tolerance levels decrease. Similar to the pattern of costs in primary elevators, GM-testing costs make up the largest part of added costs of the IP system for export elevators in both Systems 1 and 2.

Containerization

Information from initial interviews with containerization specialists identified GM testing as the only incremental cost element for non-GM wheat at this stage of Supply System 3. In the scenario considered for this study, the quantity of non-GM wheat that is produced on the representative farm (approximately 220 tonnes) would initially be bin-stored on the farm. At the time of wheat shipment, the farmer would load this into nine containers, each holding a maximum of about 27 tonnes of wheat (L. Daoust, personal communication, July 17, 2003). Containers would then be shipped by truck to the nearest container loading facility, where they would be loaded onto trains for shipment to a container yard near the port location for subsequent loading onto ships. In this scenario, GM testing involves application of PCR tests; this process is not considered to be tolerance sensitive and is estimated to cost $1.43/tonne at each of the five tolerance levels.

Table 5. Mean incremental tolerance-sensitive cost estimates at the export elevator level for System 2 (elevator designated to receive only non-GM wheat; $/tonne).

	Tolerance level				
	5%	**3%**	**1%**	**0.5%**	**0.1%**
Clean receiving	0.00	0.00	0.00	0.00	0.00
Clean storage	0.00	0.00	0.00	0.00	0.00
Clean shipping	0.00	0.00	0.00	0.00	0.00
Capital expenditure	n/a	n/a	n/a	n/a	n/a
GM test (receiving)	0.08	0.08	0.08	0.08	0.08
GM test (shipping)	0.01	0.02	0.03	0.06	0.21
Total	**$0.09**	**$0.09**	**$0.11**	**$0.14**	**$0.28**

Note. n/a = not applicable. Data from three export elevator operators, six IP coordinators, and six GM-testing specialists.

Table 6. Tolerance-sensitive costs for three supply-chain systems.

	Tolerance level				
	5%	**3%**	**1%**	**0.5%**	**0.1%**
System 1: non-GM and GM wheat received within the same elevators					
Farm level	$1.04	$1.06	$2.55	$5.03	$6.45
Primary elevator	0.11	0.11	0.27	0.57	0.91
Export elevator	0.11	0.12	0.18	0.22	0.38
Total System 1	**$1.26**	**$1.29**	**$3.00**	**$5.82**	**$7.74**
System 2: elevators designated to receive non-GM wheat and no GM wheat					
Farm level	1.04	1.06	2.55	5.03	6.45
Primary elevator	0.03	0.03	0.06	0.14	0.28
Export elevator	0.09	0.09	0.11	0.14	0.28
Total System 2	**$1.16**	**$1.18**	**$2.71**	**$5.31**	**$7.02**
System 3: containerization					
Farm level	1.04	1.06	2.55	5.03	6.45
GM testing	1.43	1.43	1.43	1.43	1.43
Total System 3	**$2.47**	**$2.48**	**$3.98**	**$6.46**	**$7.88**

Note. Data and estimates from respondents.

Total Incremental Tolerance-Sensitive IP Costs

The incremental IP costs for each system are based on data and related estimates provided for each stage of the three supply chains and five tolerance levels. Table 6

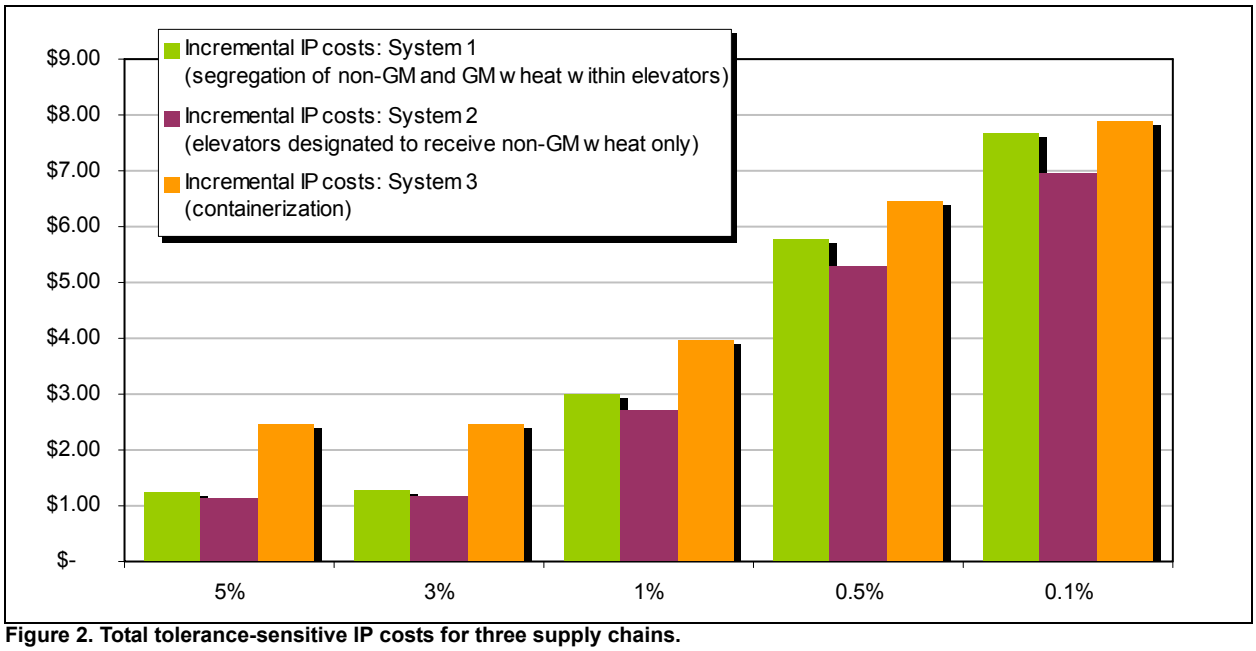

Figure 2. Total tolerance-sensitive IP costs for three supply chains.

shows the incremental costs from each stage of each supply chain, summed by tolerance level.

Figure 2 presents the sum of the incremental IP costs for all three supply chains in a clustered column graph that enables ready comparison across the range of specified tolerances. This figure shows the appreciable effect on incremental costs as lower threshold levels apply in each of the three supply chains. Incremental costs for System 3, the containerization system, are highest overall; System 2, in which primary and export elevators receive only non-GM wheat, has the lowest costs overall. The incremental costs of System 1, in which elevators receive both non-GM and GM wheat, are greater for each threshold level than for System 2 but less overall than for Supply System 3.

The relationships between the incremental costs of the different IP systems change as tolerance levels decrease. Although costs of containerization are appreciably higher than for the other two systems, this is the least sensitive of the three supply systems to changes in tolerance of GM content. At the 5% threshold level, the incremental costs of System 1 amounted to $1.26/tonne, compared to $2.47/tonne for System 3, a difference of $1.21. However, at the 0.1% tolerance level, incremental costs of System 1 increased to $7.74, while these costs for System 3 increased to $7.88, a difference of only $0.14/tonne in incremental tolerance-sensitive costs between these two systems.

Aggregate Supply Chain Costs for Identity Preserved CWRS Wheat: From Farm to Ship

In addition to the incremental tolerance-sensitive costs of segregation in an IP system, there are major other costs in each of the three IP supply systems that are not expected to change at different threshold levels. These are the non-tolerance-sensitive IP costs associated with production, handling, and shipping wheat to export port position. From a variety of sources, we developed an approximation of these particular costs as average costs for the central Alberta area and used these as "base situation costs" in order to interpret the potential overall impacts of different tolerance levels on the total levels of supply-chain costs. The estimates of non-tolerance-sensitive IP cost components are summarized in Table 7 for Supply Systems 1 and 2. Similar information for System 3 is shown in Table 8.

Table 9 shows the related approximation of total aggregate costs for wheat (including the on-farm costs of production in Alberta as well as shipping and handling from Edmonton, Alberta to the point of loading on an ocean vessel in Vancouver) for the different threshold levels. These figures include the estimated tolerance-sensitive IP costs, IP costs that are not sensitive to varying tolerance of GM content, and other relevant costs of production and marketing.

As may be expected from the preceding discussion, aggregate costs in each of the three systems increase

Table 7. Other CWRS wheat cost components (not including tolerance-sensitive IP costs) for Supply Systems 1 and 2, farm to export port.

	Costs ($/tonne)
Farm production[a]	$136.45
Transport to elevator[b]	$4.00
Primary elevator tariff[c]	$11.25
Transport to port (from Edmonton)[d]	$28.35
Export elevator tariff[c]	$7.80
Total base costs: farm to port (Vancouver)	$187.85
Fixed IP: farm (certified seed)[e]	$1.50
Fixed IP: elevators (training, legal costs)[f]	$0.30
Coordination at all levels[f]	$3.75
Total fixed IP costs	$5.55
Farm to port costs before tolerance-sensitive costs	$193.40

[a] *Alberta Agriculture, Food and Rural Development [AAFRD], 2003.*
[b] *AAFRD, 2002.*
[c] *G. Goyeau, personal communication, July 16, 2003.*
[d] *L. Daoust, personal communication, July 17, 2003.*
[e] *D. Haarsma, personal communication, June 5, 2003.*
[f] *Sparks Companies Limited, 2000; R. Vanderkylen, personal communication, April 16, 2003; C. Young, personal communication, April 16, 2003; J. Reid, personal communication, April 29, 2003.*

Table 8. Other CWRS wheat cost components (not including tolerance-sensitive IP costs) for Supply System 3, farm to export port.

	Costs	
	$/container[a]	$/tonne
Farm production costs[b]		$136.45
Total freight, local drayage, etc.[c]	$1,144.00	$42.03
Fuel surcharge (4%)[c]	$45.76	$1.68
Port drayage[c]	$204.00	$7.56
Buy-back (CWB cost element)[d]		$25.00
Fixed IP costs[e]		$5.25
Total		$217.96

[a] *Assumes container holds 60,000 lbs. (27 tonnes).*
[b] *AAFRD, 2003.*
[c] *G. Goyeau, personal communication, July 16, 2003.*
[d] *S. Snider, personal communication, July 22 & 23, 2003; N. Cobb, personal communication, August 12, 2003.*
[e] *Includes estimated cost of certified seed ($1.50/tonne) and IP coordination costs ($3.75/tonne).*

Table 9. Total CWRS farm-to-port aggregate costs—comparison of three alternate supply systems across tolerance levels ($/tonne).

Supply system[a]	Tolerance level				
	5%	3%	1%	0.5%	0.1%
Elevator System 1	$194.66	$194.68	$196.39	$199.19	$201.09
Elevator System 2	194.56	194.57	196.10	198.68	200.37
Container System 3	216.68	216.69	218.19	220.67	222.09

[a] *In System 1, primary and export elevators receive both non-GM and GM wheat. In System 2, primary and export elevators do not receive any GM wheat. System 3 involves container shipment of wheat.*

appreciably as tolerance levels become more stringent. Aggregate cost differences between the three systems narrow, to a relatively minor degree, as tolerance levels become more stringent. The cost difference between Systems 1 (dual-purpose elevators) and 2 (designated elevators) is $1.10/tonne at the 5% level and $0.66/tonne at the 0.1% level. Aggregate costs in System 3 (containerization) are $22.12/tonne higher than for System 2 at the 5% threshold level and $21.62/tonne higher at the 0.1% level of tolerance.

Summary and Conclusions

The main objective of this study was to estimate the effects of different thresholds relative to the tolerance levels for GM content on the costs of supplying non-GM wheat to export consumers. These estimates were developed for three alternative supply chains in the context of potential commercialization of GM wheat. The cost estimates relate to the wheat marketing system and the production and handling facilities for this grain in the central Alberta region of the western Canadian prairies. Respondents viewed each of the specified thresholds (which ranged from 5% to 0.1%) to be feasible, although changes in operations and capital equipment requirements are necessary for some threshold levels to be achieved. The results of the study must be interpreted in the light of its assumptions, which are based on a scenario in which approximately half of the CWRS wheat destined for export is non-GM wheat; this enables abstraction from hidden costs and inefficiencies, as from underutilization of elevators or added costs of transportation to elevators dedicated to non-GM wheat. The estimates are based on the marketing system and infrastructure that apply to export of western Canadian wheat. Risks and liabilities that might be associated with system failure are not included in the costs of the selected systems, because these are not explicit IP costs and are not readily assessed.

Estimated costs increase appreciably with more stringent tolerance levels. System 1, in which both non-

GM and GM wheat are received at the same primary and export elevators, is comparatively the most sensitive to increasing stringency in tolerance levels of GM commingling. The costs associated with identity protection in a mixed handling system increase at a sharper rate than for the other two systems considered in this study. System 3, in which non-GM wheat is containerized on the farm, is the least sensitive of the three systems to changing levels of tolerance of GM content. For System 2 (in which designated elevators receive only non-GM wheat) as well as for System 1 (in which elevators handle both GM and non-GM wheat), handling costs increase with decreases in the levels of tolerance for accidental inclusion of GM content. However, System 2 is less sensitive to changes in threshold levels; as tolerance for adventitious contamination declined, System 2 became increasingly more cost efficient relative to System 1 in handling non-GM wheat.

The containerization process of System 3 is the most expensive of all three systems, at all tolerance levels. However, the cost gap between System 3 and the other two IP systems lessens with tighter levels of tolerance and lower thresholds, reflecting the lower cost-sensitivity of System 3 to reductions in tolerance levels. The container-based system can be viewed to have the lowest risk of accidental contamination by GM material, because the opportunity for post-farm contamination is minimal with containerization technology. As a relatively new technology—at least for the shipment of wheat—it is possible that the handling and shipping costs associated with containerization may lessen over time, making this supply chain option more attractive in future. Similarly, testing protocols and the technologies associated with producing and segregating GM and non-GM wheat may change in future, altering the costs of IP segregation for wheat in the various supply chain systems. Nonetheless, even though the tolerance-sensitive IP costs narrow between containerization and the two elevator-based supply chain systems, total aggregate costs of producing, shipping and handling CWRS wheat from Alberta farms to the export point at the Port of Vancouver are currently higher for containerization. Currently, System 2 is effectively the lowest cost supply system at all the tolerance levels considered in this study.

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Appendix 1: Major Standardizing Assumptions

Supply chain stage	Assumptions
Farm level	A representative western Canadian farm is assumed to grow non-GM IP wheat. 2000 acre farm. Non-GM IP wheat is grown on a 160 acre field. Average wheat yield is 50 bushels per acre. An 8000 bushel (220 tonne) bin is used to store wheat. 14 tonne (500 bushel) farm grain truck. $15/hour wage applies for mechanical cleaning.
Transport from farm	A 40 tonne transport (semi) truck is used for transport from farm.
Primary elevator	Primary elevator is representative of western Canadian elevators. $16/hour wage applies for mechanical cleaning.
Export elevator	The export elevator is representative of Canadian export elevators. $27.29/hour wage applies for mechanical cleaning.
Containers	Containers hold 27 tonnes (60,000 lbs.) of wheat. Wheat is loaded directly into containers at the farm, without the use of a liner or bags. Wheat is assumed to be in condition and placed in temporary storage on the farm before being loaded into containers.

Note. Based on information from Alberta Agriculture and interviews with industry personnel.

Appendix 2: Tolerance-Sensitive Cost Points in the Three Supply-Chain Systems

IP cost points		System 1: segregation within elevators	System 2: elevator only receives non-GM	System 3: containers
Farm:				
Isolation zone		X	X	X
Volunteer control		X	X	X
Cleaning	**Seeder**	X	X	X
	Combine	X	X	X
	Trucks	X	X	X
	Bin	X	X	X
	Dryer	X	X	X
	Auger	X	X	X
GM test		X	X	X
Primary elevator:				
GM test		X	X	
Cleaning	**Receiving**	X	X	
	Shipping	X	X	
	Storage	X	X	
Capital investment		X		
Export elevator:				
GM test		X	X	
Cleaning	**Receiving**	X	X	
	Shipping	X	X	
	Storage	X	X	
Capital investment		X		
Port:				
Bulk		X	X	
Container				X

Note. Data from initial interviews.