OPTIMAL TESTING STRATEGIES FOR GENETICALLY MODIFIED COMMODITIES

A Thesis
Submitted to the Graduate Faculty
of the
North Dakota State University
of Agriculture and Applied Science

By

Eric James Jabs

In Partial Fulfillment of the Requirements
for the Degree of
MASTER OF SCIENCE

Major Department:
Agribusiness and Applied Economics

May 2003

Fargo, North Dakota

North Dakota State University
Graduate School

Title

Optimal Testing Strategies For Genetically

Modified Commodities

By

Eric James Jabs

The Supervisory Committee certifies that this ***disquisition*** complies with North Dakota State University's regulations and meets the accepted standards for the degree of

MASTER OF SCIENCE

SUPERVISORY COMMITTEE:

Chair

Approved by Department Chair:

May 23, 2003
Date

Signature

ABSTRACT

Jabs, Eric James; M.S.; Department of Agribusiness and Applied Economics; College of Agriculture, Food Systems, and Natural Resources; North Dakota State University; May 2003. Optimal Testing Strategies for Genetically Modified Commodities. Major Professor: Dr. William W. Wilson.

In this study, a stochastic optimization model was developed to determine optimal testing strategies, costs, and risks of a dual-marketing system. The model chooses the optimal testing strategy (application, intensity, and tolerance) that maximizes utility (minimizes disutility) of additional system costs due to testing and quality loss and allows simulation of a risk premium required to induce grain handlers to undertake a dual marketing system versus a non genetically modified (GM) system. Elements of cost, including test cost, quality loss, and risk premium, were estimated for a base model representing a grain export chain. Uncertainties were incorporated and include variety declaration, test accuracy, and risk of adventitious commingling. Sensitivities were performed for effects of variety risks, penalty differentials, re-elevation discounts, import tolerances, variety declaration, risk aversion, GM adoption, and domestic end-user.

ACKNOWLEDGMENTS

I would like to express special appreciation to Dr. William W. Wilson who has provided a wealth of knowledge on the issues of genetically modified organisms, testing, and segregation. Recognition is given to my committee members: Dr. William Nganje, Dr. John D. Bitzan, and Dr. Rodney D. Traub; your knowledge, insight, and willingness to provide assistance are greatly appreciated. I would like to thank Bruce L. Dahl for his unwavering commitment and valuable suggestions throughout this research.

The Mountain-Plains Consortium/University Transportation Centers Program provided funding for this research.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Figure Page

CHAPTER 1
STATEMENT OF PROBLEM

Introduction

Biotech commodities have become increasingly important in recent years because of their potential to provide agronomic benefits to producers and specific, quality-based attributes to end-users. Concurrent with the adoption of transgenic grains, development of genetically modified (GM) wheat has evolved with GM varieties potentially available by 2005.

Consequently, development of testing, tolerance, shipping, and segregation strategies is imperative to commercial firms throughout the production and marketing supply chains. Biotech enlargement will predicate itself dependent upon the evolvement of testing, tolerance threshold, identity preservation, traceability, and channeling; and will vary depending upon the time, accuracy, and costs involved.

Testing procedures involve detection of genetic modification, and the determination of quality and composition in an attempt to assign a component price. Shipping procedures will vary depending upon the investment in infrastructure, which currently is oriented towards high-volume, low-cost homogenous commodity flow. Segregation strategies will be important to avoid adventitious commingling of grain and to ensure effective incentive schemes.

Commercialized and regulatory tolerance limits vary substantially, indicative that conformance will reside with tolerance policy. This thesis addresses production and marketing supply chain participants, which ultimately include the entire value chain: input suppliers, production, handling, processing, market distribution, and the consumer. Alternative scenarios, which encompass testing location, method, cost, risk, contract liability, and specified tolerance, will be evaluated to determine the optimal strategy to employ. Ultimately, this thesis analyzes economic costs and risks associated with testing, segregation, and the establishment of an optimal tolerance.

Elements of the Problem

Growth of GM Grains

GM varieties for production have been embraced by producers globally in an effort to reduce input costs, create ease in production, and fulfill specialized output characteristics specific to particular markets. First-phase benefits have been developed for the producer's behalf, but second-phase benefits, when instituted, would provide additional opportunities for producers. The provision of GM wheat would include first-phase benefits by 2005 with second-phase and third-phase benefits to ensue. These benefits could encompass enhanced protein quality, novel starch types, enhanced nutritional content, reduced allergens, and improved freshness and shelf life for baked products (Wilson, Dahl, and Nganje 4). Adoption of GM wheat, however, lags that of row crops for numerous reasons, including its pronounced export proportion. Foreign Agricultural Service (FAS) and National Agricultural Statistics Service (NASS) indicate that corn and soybean percentage exported are 19.76% and 36.51%, respectively, while wheat percentage exported is 40.91%. Furthermore, over half of wheat exports are destined to Japan and/or European countries that are averse to GM wheat.

Traditionally, production and marketing were designed for major commodity crops in the United States to provide maximum value through delivery of large amounts of homogeneous grains and oilseeds (Sonka, Schroeder, and Cunningham 23). Today, the interaction between agricultural biotechnology, and production and marketing is highly correlated, which foreshadows the need to incorporate them concurrently. The realization of value from biotech commodities involves research and development of a biotech product, new marketing and business arrangements to redistribute value, the utilization of information technologies, evolution of testing, segregation, identity preservation, technology, public acceptance of differentiated products, and the development of transportation and handling infrastructure (Sonka, Schroeder, and Cunningham 3).

Entities Taking Positions

In the past year, several major wheat-marketing associations have released positions that are imperative to the evolution of transgenic grain, specifically GM wheat. The biotechnology positions address issues concerning adoption, testing, identity preservation, segregation, financial obligation, and potential benefactors in the proliferation of biotechnology. The positions are briefly summarized below.

The U.S. Wheat Associates/National Association of Wheat Growers position is that they will "work with all segments of the industry to develop and ensure that a viable identity preservation system and testing program is instituted prior to commercialization of biotechnology products" (U.S. Wheat Associates 1). In addition they "support an establishment of a reasonable threshold for adventitious commingling of biotech traits in bulk wheat or products derived from bulk wheat in both U.S. and international markets" (U.S. Wheat Associates 1). Furthermore, they "urge the adoption of a nationally and internationally accepted definition of biotechnologically derived products" (U.S. Wheat Associates 1).

The National Grain and Feed Association encourages the adoption of biotechnology crop development via three main objectives. The registration process and protocols for segregation, testing, and identity preservation must be provided to entrust segregation. Second, analytical tests must be defined and approved by the United States Department of Agriculture (USDA) for purposes of determining the presence of GM content. Finally, the U.S. government should work toward commercially attainable thresholds for adventitious presence of GM grains in non-GM grain shipments (National Grain and Feed Association 2-3).

The American Bakers Association (ABA) believes "all biotech crops and ingredients must be accompanied by an efficient, inexpensive trait identification system with accuracy of detection to meet USDA, Food and Drug Administration (FDA), Environmental Protection Agency (EPA) guidelines, and foreign customers labeling or purity requirements" (American Bakers Association 6). The ABA will "work with all segments of the grain and cereal foods processing industry to develop and assure that a viable segregation and testing program is instituted prior to commercialization of biotech products" (American Bakers Association 6). In the event that a biotech crop or ingredient is released, ABA feels that the sole financial responsibility should reside with the technology developer (American Bakers Association 6).

The North American Grain Millers Association advocates that technology providers and regulators place close consideration to 1) the adoption of reasonable thresholds to facilitate the movement of grains with adventitious admixture; 2) testing; and 3) identity preservation, in which technology providers and regulators question the feasibility of marketing biotech-based grains (North American Grain Millers Association 2-4).

Monsanto is committed to working conjunctively with the North American wheat industry to develop grain-handling systems prior to commercialization of GM wheat. In adherence to this policy, Monsanto has formed a wheat industry advisory committee to provide advice and counsel on the proper inducement of biotechnology. The objectives of the committee are to provide direction on the feasibility, strategy, and standards for market acceptance, development of grain handling protocols, and the commercialization process while leaving the commercialization decision to Monsanto (U.S. Wheat Associates 2).

The USDA-Grain Inspection, Packers and Stockyards Administration (GIPSA) play a prospectively important role in the facilitation of biotechnology. In response to continued growth in biotechnology, USDA-GIPSA invited comments related to alternatives for marketing grain that houses biotech and non-biotech products in November 2000. The agency is in the process of determining how to facilitate the evolution and commercialization of biotech grains (USDA-GIPSA, Notice 50853-50854).

Recently, USDA-GIPSA introduced a new process verification program designed to meet the marketplace's rapidly evolving needs. Process verification is currently under review in the Federal Register and expected to commence in 2004. Process verification provides producers, marketers, suppliers, and processors alike with third-party verification of their quality processes and standards in an effort to assure buyers and sellers of marketing claims, such as type, production practice, and quality attributes. The program is based on ISO 9000 principles, an internationally recognized set of quality standards, to ensure international objectivity and to provide a means to conduct a document review, review audit, conditional audit, and surveillance audit. GIPSA, recognized internationally for reliability and integrity, will provide technical knowledge through its grain expertise and integrity through mandatory auditor certification by the American Society of Quality (ASQ). Collectively, GIPSA, and more broadly USDA, will provide a "USDA

Certification" label to enhance buyers' confidence in process-verified products, whether domestic or foreign (USDA-GIPSA, Process Verification 1-4).

In addition to the aforementioned biotechnology statements, positions have been established in primary competitor countries. The Canadian Wheat Board's (CWB) objective is to ensure that the introduction of GM wheat and barley varieties for production, handling, and marketing will be accomplished in a manner that will satisfy customer requirements and result in net beneficial benefits to western Canadian farmers. However, the CWB believes that GM wheat should not be made available until proven technologies, associated protocols, and procedures are intact to avoid commingling of transgenic and non-transgenic varieties. Furthermore, the CWB believes that the segregation system should have the ability to test accurately, quickly, and economically for transgenic presence (Canadian Wheat Board 1).

The Australian Bureau of Agricultural and Resource Economics (ABARE) has not taken a formal position on biotechnology; however, research is ongoing to determine the feasibility of GM adoption and the policy implications that arise via the emergence of crop gene technologies. ABARE believes market access barriers, and price premiums or incentives should be considered concurrently with agronomic and environmental factors when assessing GM feasibility. The Australian government currently has a major study (3.65 million dollars over 4 years) to assess costs of segregating products. ABARE notes that the additional marketing cost of keeping GM grain separate during production and distribution is not inconsequential, even in a country with extensive controls. ABARE recognizes that long-run competitiveness in Australia may hinge on consumer acceptance of GM grain because negligible premiums on non-GM grain may evolve if no incentives exist (ABARE 9). Each position insinuates that the continued development of biotechnology is desirable but is contingent upon development of a viable segregation, identity preservation, and testing strategies in order to mitigate risks to supply chain participants.

Labeling

A perverse and confrontational issue facing the food industry involves labeling foods. Labeling concerns have surfaced in response to consumer attitudes towards process benefits, but they may be lessened as biotechnology is utilized to develop product-based GM goods with desirable attributes for segmented niche markets. Labeling can assume a voluntary (public) or a mandatory (private) role in the marketplace that mitigates risk and uncertainty for consumers. A voluntary labeling policy would be at the discretion of the industry, whereas a mandatory labeling policy would be instituted if the industry were unable to identify risks inherent in GMO products.

Voluntary

Under a voluntary labeling policy, the industry may assist participants with standard development and consistent, credible labeling systems. Canada, the United States, Argentina, and Hong Kong have initiated this labeling framework and support efforts to develop standards for voluntary labeling of GM foods (Phillips and McNeill 2)

Mandatory

Under a mandatory labeling policy, the government acts in the interest of constituents to ensure consumer protection from potential health and safety hazards (Phillips and Isaac 3-4). Prior to August 2001, a delegation of the EU and 22 additional countries adopted or declared its intention to implement mandatory labeling systems. As of

August 2001, only a sub-set of these countries revealed the full structure of proposed labeling rules, and only the United Kingdom (UK), Japan, China, and South Korea formally implemented labeling statutes. Australia and New Zealand, Thailand and Brazil, and South Africa implemented labeling laws in September 2001, December 2001, and 2002, respectively. A persistent problem that has plagued the industry is the identification of a tolerance level for GM content that will drive mandatory labeling policies (Phillips and McNeill 2).

European Union

The five regions that regulate genetically modified organisms (GMOs), Canada, the United States, Mexico, Japan, and the EU, have contemplated the appropriate role of labels in signaling new production methods to consumers. While the EU agriculture council currently requires labels, adoption in the future may facilitate a technical barrier to trade, posing challenges to producers, consumers, and governmental agencies (Phillips and Isaac 1). The EU has an extensive labeling policy that varies distinctly from the United States and includes pre-market authorization via the Novel Foods Regulation, which requires that the consumer be informed of genetic properties that are differentiated from their conventional counterparts.

In addition, the consumer must be informed of the presence of GMO and any material in the novel food that is not present in its respective conventional counterpart. Directive 90/220 initialized labeling requirements in the EU through required GM crop variety labeling and was enhanced in 1997 with the enacting of the EU Novel Foods Regulation 258/97 that set a 1% tolerance level for whole or processed foods (Phillips and McNeill 4). Furthermore, Regulation 1139/98, passed in 1998, governs labeling of EU-approved corn and soybeans released prior to Regulation 258/97 if they contain GM protein or DNA. Finally, Regulation 50/2000 extends biotech labeling requirements to any food product that contains GMO additive or flavoring, or is processed from a GMO (Mansour and Bennett 4). Recently, a regulation addendum was instituted via an agreement among EU farm ministers to set a level of 0.9% for labeling of all food and feed containing GMO material. They also agreed on a threshold for incidental traces of authorized and unauthorized GMOs at 0.5%. These extensive provisions enacted by the EU will inevitably necessitate a segregation, identity-preservation, and genetic testing program to facilitate trade (Elliott 1, 4).

United Kingdom

The United Kingdom (UK) has taken a proactive approach to labeling as the only EU member state to enact legislation and establish enforcement mechanisms. Numerous provisions since 1999 have sustained the UK's initiative for labeling systems, including a March 1999 provision that requires all foods, additives, and flavorings that have entered the market since September 1, 1998, and contain greater than 1% GM content to be labeled. The UK Food Safety Agency extended that provision in April 2000 to include all GM foods, additives, and flavorings irrespective of their market entrance. In addition to primary provisions, the UK requires labeling of restaurant meals containing GM foods. Financial penalties and authoritative supervision assure strict adherence to UK labeling policies and statutes (Phillips and McNeill 4).

Japan

The Japanese implemented mandatory labeling regulations, requiring products to be assessed prior to market entrance as of April 1, 2001. The Ministry of Agriculture, Forestry, and Fisheries (MAFF) in corroboration with the Ministry of Health, Labor, and Welfare (MHLW) assessed 24 food products made from biotech corn and soybeans, and processed foods where the ingredient is one of the top three food ingredients and comprises over 5% of the total weight (Phillips and McNeill 4). Three classifications, contains GMOs, may contain GMOs, or GMO free, characterize bulk shipments with more than 5% GM content, between 1 and 5% GM content, and less than 1% GM content, respectively (Phillips and McNeill 4).

United States

In contrast, the U.S. Coordinated Framework and the FDA's 1992 policy support the principle that the predominant consideration in evaluating biotech food safety should be the impartial characteristics of the food and its ingredients, not the process used to produce the food or its ingredients (Mansour and Bennett 5). Consequently, the FDA has determined that a food product should be labeled as a product of biotechnology only if it has been altered in a significant way. This policy ensures product availability, while providing consumers with pertinent information about food safety and compositional changes in a simple, meaningful, and consistent manner (Hoban 3).

A national survey of American consumers conducted in 1997 elicited a 75% approval rating of FDA proceedings (Hoban 3). The United States supports a voluntary labeling strategy; consequently, the USDA has provided guidance for the industry through publications outlining acceptable wording for interested manufacturers. In response to changing global preferences, the GE Right to Know Act was introduced in Congress in 1999, providing for mandatory labeling of genetically modified foods (GMFs) although support has been sparse. As of May 2000, sixteen U.S. states have introduced bills that require labeling for GM foods (Phillips and McNeill 2).

Precautionary Principle

The establishment of precautionary measures to avert potentially dangerous effects on environmental, human, animal, or plant health warrants objective scientific evaluation or precautionary principle (Apel 1-2). U.S. involvement began in 1992 with the Rio Declaration although the concept was extrapolated from the fundamental principles of German environmental law in the early 1970s, which sought environmental damage aversion via forward planning and blockage of potentially harmful activities (Tickner and Raffensperger 2). While the precautionary principle is not expressly mentioned in U.S. laws or policies, it underlies many early environmental statutes.

Conversely, the European Union (EU) has proactively maintained the precautionary principle as a risk management tool in its statutes, and seeks to employ it when inconclusive or divergent scientific conclusions are drawn to avert health and environmental risks (Tickner and Raffensperger 11). The EU maintains that the precautionary principle is inscribed in the European Commission treaty and is the underlying subject for judgments on behalf of the European Court of Justice. The court defines the conditions for the application of precautionary measures as follows: "where there is uncertainty as to the existence or extent of risks to human health, the institutions may take protective measures without having to wait until the reality and seriousness of those risks become fully apparent" (Tickner and Raffensperger 2).

In addition, health and environmental protections within European Commission law are explained for the application of precautionary measures as follows:

> Article 130r(1) of the EC Treaty, according to which Community policy on the environment is to pursue the objective inter alia of protecting human health. Article 130r(2) provides that policy is to aim at a high level of protection and is to be based in particular on the principles that preventative action should be taken and that environmental protection requirements must be integrated into the definition and implementation of other Community policies. (Tickner and Raffensperger 2)

The precautionary principle encapsulates EU concerns with respect to health and environmental protection; ultimately, employment of precautionary measures may be a detriment to exportation of transgenic grains to the EU. Barriers to trade include diverse and complex socioeconomic conditions, scientific inconclusiveness, WTO transparency of the precautionary principle, and discrepancies within the WTO Sanitary and Phytosanitary (SPS) Agreement's concept of the "appropriate level of protection" as it pertains to health and the environment (Tickner and Raffensperger 4-11).

Substantial Equivalence

Substantial equivalence (SE) is an internationally recognized standard that evaluates health and nutritional characteristics between a biotech food or crop, and its conventional counterpart. Prior to SE evaluation, gene products are assessed for allergenicity, and tested for acute toxicities and major compositional components. If the expressed protein in the biotech food or crop is deemed to be safe, SE testing ensues via key nutrient and nutritional composition analysis. SE has been embraced globally and endorsed by many national food health agencies, including the Canadian Food Inspection Agency, Japan's Ministry of Health and Welfare, and the U.S. Food and Drug

Administration ("Substantial Equivalence" 1). Despite the widespread acceptance, concerns have been raised about the SE premonition that genetic engineering is synonymous to breeding and that animal, human, and allergenicity testing should diverge from a scientific-based approach ("Inadequate" 3).

Guidelines for SE have been elaborated by the World Health and the Food and Agriculture Organizations (WHO and FAO), the Organization for Economic Cooperation and Development (OECD), the International Food Biotechnology Council (IFBC), the International Life Science Institute (ILSI), the U.S. Food and Drug Administration (FDA), the UK Advisory Committee on Novel Foods and Processes (ACNFP), the Nordic Council, the German Research Community (DFG), and additional national bodies ("The Concept" 1). In the United States, the OECD bases SE on the premise that existing products can be used as a basis to compare new or genetically modified foods and food ingredients, and once a novel food or novel food component is found to be SE, no further tests are needed. In contrast, under regulation (EC) No 258/97, the EU requires notification to the European Commission for market placement of a SE product describing its composition, nutritional value, metabolism, intended use, and undesirable substance levels. Furthermore, if the novel food contains or consists of GMOs, authorizations and safety assessments are mandatory. In cases where the GMOs can reproduce and transfer genetic material, Directive 90/220/EEC provides for an environmental risk assessment.

While the United States has not established any specified criterion except for molecular, compositional, toxicological, and nutritional data usage, the European Commission published recommendations for applicants and authorities concerning novel food placement. The European Commission recommends providing competent authorities with general information about the product, process, and dietary exposure. Chemical compositional information, including the genetic construct, and DNA sequence transfer to the host organism to assess environmental risks and health hazards, must also be identified. Finally, the toxicity and allergenicity should be evaluated through new gene identification and new proteins that are expressed from the GMOs. Under these guidelines, the European Commission hopes to support novel food ingredient applications and placements ("The Concept" 2). Corroboration among national bodies with respect to SE will facilitate the growth of transgenic grains, create transparency of potential risks and hazards, and mitigate undesirable health uncertainties ("The Concept" 4).

Identity Preservation

Identity Preservation (IP) is an important aspect of biotech development, but existing IP systems have proved to be inadequate (Wylie 44). IP is inevitably going to play a major role in providing nutritional benefits to consumers when adoption of second-generation biotech products evolves. In an attempt to capture forthcoming premiums associated with transgenic crops, IP must ensure quality, and retain economies of scale and efficiencies for all operations. IP hinges on purity risk (e.g., the risk of contamination) first originating with the producer through isolation, clean equipment, and pure seed; and ultimately transgresses throughout the marketing chain to the end-user. Infrastructure, including new bins and gentler handling systems, may need to be erected because of physical delivery requirements that counter traditional marketing patterns (Wylie 45-46). Geographic concentration of biotech production around an end-user is one technique that can be used to minimize cost (Sonka, Schroeder, and Cunningham 27).

Segregation

Segregation is the isolation of like products with particular attributes to avoid commingling. Unlike identity preservation, the identity of the grain is lost once threshold is attained and accumulated with like products (Sonka, Schroeder, and Cunningham 26). Segregation has evolved in response to international market acceptance of bioengineered products and the lack thereof. Coexistence of transgenic grain and non-transgenic 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 7). As thresholds are revolutionized in the biotech industry, strict purity limits may be instituted, requiring totally distinct handling systems to conform to regulations (Sonka, Schroeder, and Cunningham 27).

Although considerable debate has endured about segregation, the feasibility is questionable given negligible premiums for non-transgenic grain, adoption rates, storage, testing, and logistical implications. Initially, a survey of elevator managers dispersed throughout the United States evoked a substantial negative connotation about segregation benefits, costs, and/or risks, but a recent survey conducted by the American Corn Growers Association rebuked earlier connotations. The survey of 1,149 elevators in 11 Midwestern states conveyed that more than half of grain elevators preferred segregation of GMO and non-GMO grains this year, and in addition, one-fifth offered premiums for non-GMO corn and/or soybeans. The rationale for this rebuttal can be attributed, in part, to the Starlink corn incident, which fueled widespread fears associated with allergic reactions and the reduction in export sales due to consumer confidence issues (Konsor 1). Ultimately, segregation will depend on premium incentives, added costs, and the evolvement of the international market outlook on transgenic grain.

Logistical Implications

Development of transportation and handling infrastructure concurrently with biotech development will be imperative to generate realized value from biotech commodities. Research and development of transgenic commodities has been immense because of the projected benefits and the reinforcement aspect for creating additional value beyond the producer. While biotech research is definitely pertinent, additional system components need to be implemented to facilitate the full adoption of biotech grain (Sonka, Schroeder, and Cunningham 3). A key system component includes development of transportation and handling infrastructure, albeit with huge investment, which exasperates long-term payoff perceptions that constitute the industry. Compounding the issue is that transportation and handling infrastructure has been historically characterized as highly competitive with very narrow margins. Currently, production and marketing for major commodity crops are oriented towards providing maximum value through low-cost delivery of massive amounts of homogenous grains and oilseeds; consequently, evolvement of a dedicated channel has lagged that of conventional counterparts (Sonka, Schroeder, and Cunningham 4-6). In the future, output trait enhancement oriented towards value-chain participants may inundate the industry, forcing logistically distinct channels of transportation to fully realize value. Concurrent with infrastructure evolvement will be adjoining developments in measurement technology and dynamic underlying investment analysis (Sonka, Schroeder, and Cunningham 20-21).

Objective

The objective of this study is to determine optimal testing strategies for commercial and regulatory applications for GM commodities including GM wheat. Specific objectives include 1) development of a model to determine optimal test application, intensity, and tolerance; and 2) evaluation of how critical factors impact optimal testing strategies. Critical factors may include testing costs and accuracies, quality loss, price differentials in different market segments, supply chain costs, and/or spatial considerations. The model and analysis will include 1) evaluation of various supply chain testing points according to frequency, type, place, and cost; 2) definition of the system and cost function to identify alternative testing strategies at different stages of the marketing system; and 3) assessment of cost and quality loss resulting from non-conformance.

Methodology

The methodology in this research entails stochastic simulation of the cost function. Results will include costs and risks. Simulations of various strategies will be compared. Finally, stochastic optimization procedures will be used to determine the optimal system strategy (Palisade). The model will be defined to minimize system costs subject to conforming to a specified tolerance. The model will be used to simulate various *ex ante* strategies, which will be compared to a base case with respect to cost and risk. Most likely, *ex ante* strategies will include testing at various locations in the system, different sampling intensities, and tolerances. In addition, the impact of grower uncertainty about the distribution of grain delivered into the system will be explored.

Organization

Chapter 2 provides background information that is pertinent to this study. In addition, previous studies related to segregation cost, tolerance allotment, and product loss functions are reviewed. The Theoretical Model is described in Chapter 3. The Empirical Model and data sources constitute Chapter 4. Results are presented in Chapter 5. The Conclusions and limitations of this research are discussed in Chapter 6.

Summary

A viable testing and segregation strategy must accompany the imminent evolution of biotech grain in order to mitigate risks to buyers and sellers alike. Adoption of new transgenic varieties will likely persist in the future, offering first-phase benefits to producers while second-phase benefits may be exploited to increase consumer value. Labeling in the United States hinges on product characteristics at present and will continue to be a controversial issue among nations as biotech evolution continues. Identity preservation will command dedicated handling, distinct logistical pipelines, and traceability from the producer to the end-user. Segregation relies on non-GMO premiums in the marketplace and the capacity to house differentiated grain. Logistical implications will unfold as GMOs promoting consumer value are exploited and/or premium incentives entice the supply chain to segregate grain.

Challenges and sources of opposition continue to confront biotech evolvement; however, these impediments must be mitigated in order to reduce buyer and seller risk. The challenges are to segregate GM from conventional seed, preserve the identity of commodities, test for genetically altered seeds at various points in the supply chain, and provide product labeling as recommended by Mark Singer (Cotterill 20).

CHAPTER 2
BACKGROUND INFORMATION AND PREVIOUS STUDIES

Introduction

Supply chain coordination plays an integral role in the production, handling, storage, and export of GM grain. Effective supply chain management for GM grain relies on a multitude of factors that include testing and sampling procedures, segregation practices, identity-preservation techniques, logistical strategies, and conformance to tolerances in order to satisfy consumer demand. An increasing amount of research has been conducted on segregation and identity preservation in response to the exportability of transgenic grains to importing countries with specified tolerances. The function of identity preservation and segregation is to provide assurances between the buyer and seller within the marketing channel; consequently, it encompasses the majority of the literature.

Testing in the supply chain to ascertain conformance to contract specifications and export criteria is critical to the viability of identity preservation and segregation strategies. In light of the coexistence of biotech and non-biotech grain, testing equipment and procedures need to assess the critical factors in a rapid, economical, and accurate manner to facilitate marketing and trade. A number of studies quantify testing costs, accuracies, and time involved for an array of genetic events across all commodities. In addition, sampling techniques, analytical methods, and preparation considerations assess the importance of obtaining a representative sample to minimize measurement error.

Logistics plays a pivotal role in the exportation and movement of grain across the supply chain. Inspection policies, testing procedures, and transportation mode choice deviate immensely from those of a high volume, high-speed bulk commodity system that currently characterizes the industry, resulting in gravitational pressures for change and logistical implications.

Tolerances, both regulatory and commercial, govern the intensity of supply chain decisions. In general, as tolerances tighten, the risk of non-conformance becomes greater; necessary modifications become apparent; and fewer elevators are able to preserve GM grain.

This chapter focuses on the importance of identity preservation and segregation for the coexistence of biotech and non-biotech commodities. Testing and sampling methods are presented along with their respective impacts on logistics, costs, accuracies, and tolerance limits. In addition, both commercial and regulatory tolerances, and their significance in GM commodities are explored. Finally, logistical impacts are examined through inspection policies, testing frequencies, and tolerance thresholds.

Identity Preservation

Numerous studies address identity-preservation costs within the supply chain and the factors that comprise them. Buckwell, Brookes, and Bradley identify identity preservation as a system of management and trade that allows the source and nature of materials to be identified as they move through the supply chain. Wilcke refers to IP as separate storage, handling, and documentation of separation; Lin defines it as a production-handling-distribution system by which crops are required to be kept separate to avoid commingling at planting, harvesting, loading and unloading, storage, transportation, and manufacturing in order to preserve the crops' identity in terms of the end-use quality genetic makeup or a unique production process. Sonka, Schroeder, and Cunningham define it as a coordinated transportation and identification system to transfer product and information that makes product more valuable; Dye refers to it as a traceable chain of custody that begins with the farmer's choice of seed and continues through the shipping and handling system. Irrespective of the definition of identity preservation, it remains a formidable exercise unless the premiums extracted from the marketplace exceed the costs incurred. Inherent to identity preservation are the additional costs in a variety of dimensions, including production, storage, handling, and logistics (Kalaitzandonakes, Maltsbarger, and Barnes 605).

Identity-Preservation Cost

Kalaitzandonakes, Maltsbarger, and Barnes corroborate that identity preservation results in additional costs in two general categories: direct and indirect (hidden) costs. The increased need for market coordination between buyers and sellers, changes in operations due to newly adopted product identity practices, and increased risks and liabilities stemming from threshold conformance at destination comprise direct costs (607). Overwhelmingly, threshold limits govern the rigorous nature of an identity preservation system, thus they comprise the largest portion of direct costs (606). Indirect or hidden costs result from the underutilization of production, storage, and transportation assets (Maltsbarger and Kalaitzandonakes 1). Transportation assets and storage facilities are discrete units, exacerbating identity preservation costs due to their discontinuous or less fungible product stream nature.

Kalaitzandonakes, Maltsbarger, and Barnes present post-harvest identity preservation costs and their variability relative to selected shifters both exogenous and endogenous to the firm. Empirical data from three case study elevators representing a small, medium, and large size and function within the Midwest; and five efficient high oil corn identity preservation scenarios ranging in volume from 100,000 to 500,000 bushels delivered during harvest and via buyer call while adhering to a 5% threshold are used to estimate costs.

The first case involves delivering an identity-preserved commodity to the elevator where it is aggregated, stored, and delivered to the end-user. In the second case, a farmer network stores the identity-preserved crop and delivers it directly to the end-user. A hybrid economic engineering simulation model, Process and Economic Simulation of IP (PRESIP) is used to estimate identity preservation costs.

In the intermediated supply chain, a combination of two integrated models conjunctively works together to capture costs from the farm network through the elevator and to the end-user. The elevator assets module simulates physical characteristics of the elevator, including number, capacity, dumping pit elevation rates, elevator scale, queue time, storage bin capacity, storage availability, and other grain-handling assets. Concurrently, the elevator grain flow module captures the stochastic nature of grain movements through the elevator. Numerous variables are monitored during simulation in the process model, including storage bin utilization, number of daily incoming trucks, and their respective daily volume. Statistics are exported to the economic analysis module based on their relevancy to evaluate direct and indirect identity-preservation costs. In PRESIP, direct costs include testing and monitoring costs, coordinated costs with respect to end-user demand and contracting acres, annualized capital investment expense for identity preservation, and additional labor. Indirect costs included are forfeited storage, spread margin when the market signals a carrying charge, and grind margin loss due to lost feed sales (Kalaitzandonakes, Maltsbarger, and Barnes 608).

Total identity-preservation costs averaged 35 cents (c)/bushel (bu.) and ranged from 19.85 c/bu. to 52.11 c/bu. for the first case representing a medium elevator with 500,000 bu. of high-oil corn during peak harvest and a large elevator with 200,000 bu. of high-oil corn via buyer call, respectively. Total costs for the direct farmer network ranged from 9.98 c/bu. to 27.99 c/bu. for 500,000 bu. of high-oil corn during peak harvest and 100,000 bu. of high-oil corn via buyer call, respectively. The results highlight that, even for a loose threshold, identity-preservation costs can be significant, particularly hidden costs (efficiency losses) which comprise, on average, 55% of identity-preservation cost and range from 29 to 75%.

The results indicate that identity preservation costs are highly subject to volume and the physical configuration of assets, which suggests that scale economies are not present within the modeled supply chain. In addition, delivery options impact cost; for example, the buyer call reduces indirect cost as it pertains to underutilized elevator storage, but has a corresponding increase in coordination cost and storage premium. Furthermore, transportation mode choice, and direct or intermediate supply chain utilization affect identity-preservation costs, resulting in a direct relationship between cost and miles for direct delivery, and an increase in efficiency when transporting via rail (truck) for long (short) distances in the intermediate delivery.

Lin examines the economics of segregating U.S. non-biotech corn and soybeans for shipments to Japan, the primary non-biotech export market for U.S. grains and oilseeds. Estimations of price premiums that buyers in the U.S. domestic and Japanese export markets are willing to pay for the 2000 and 2001 crops are explored. Additionally, implications are drawn from non-biotech premiums paid by both U.S. domestic and

Japanese export markets in relation to the cost of segregation. Finally, a determination of who bears the cost is examined (3).

Non-biotech corn, IP corn, constitutes 1-2% of U.S. corn production while non-biotech, IP soybeans account for 2% of domestic soybean production. The majority of non-biotech corn and soybeans, approximately 90%, is exported to Japan through identity-preservation techniques. Underlying Japan's interest in non-biotech products is changing sentiment among consumers and government-imposed labeling restrictions on 26 food items. Domestically, non-biotech corn and soybeans have been used by food processing firms such as Gerber; Heinz; Bestfoods, Inc.; and Frito-Lay Inc. (Lin 5).

Japanese buyers' specification of a 95% purity requirement for non-biotech corn can effectively be met by patterning corn segregation after high-oil corn (HOC) handling procedures, although other methods exist such as the Association of Official Seed Certifying Agencies (AOSCA) 99% purity level plan which allows no more than 1% biotech. In addition, Cargill segregates non-biotech corn under *Innovasure*, a process-based identity-preserved system albeit without a specified tolerance. In contrast, the identity-preserved system for soybeans has followed the more rigid, Synchrony-treated soybean (STS) requirements. STS soybeans are a non-biotech, herbicide-tolerant variety developed by DuPont; and marketed by ADM, Protein Technologies, and various grain companies. A purity level of 98 to 99.9% characterizes the STS identity-preservation program; however, in 2001, STS lost its appeal because of its biotech content rigidity. Currently, a non-STS identity-preserved system patterned after HOC is being adopted for soybeans to meet threshold requirements.

The segregation costs presented are extracted from a University of Illinois study which estimated segregation costs for 84 U.S. handlers of specialty grains and oilseeds. The study revealed that additional segregation and handling costs for handling HOC and STS were 6 c/bu. and 18 c/bu., respectively (Bender et al. 17). Concurrent with Bender, Lin examines the various costs unique to segregation including additional costs of storage, handling, risk management (i.e., conformance risk), analysis and testing, and marketing along three points in the marketing chain: country elevator, sub-terminal, and export elevator. Segregation cost for non-biotech corn from the country elevator to export elevator was estimated at 22 c/bu. if the segregation follows the HOC system (USDA-ERS, Biotechnology 32). In comparison, other researchers in the grain-handling industry have estimated segregation costs at 20 c/bu. (Miranowski et al.; Lence and Hayes; Moss, Schmitz, and Schmitz; Krejci). Non-biotech soybeans patterned after HOC and STS resulted in additional costs of 18 and 54 c/bu., respectively (USDA-ERS, Biotechnology 32-33). The segregation costs reported reflect the cost associated with the needed adjustments or modifications to accommodate non-biotech commodities and include both real and hidden costs, estimated at two-thirds and one-third, respectively (Lin 11).

Additional costs that are not inclusive of previous estimations are added freight expense, and producer premiums and incentives. Freight expense surcharges are assessed to volumes less than 8,000-9,000 tons and are unique to corn (13 c/bu.) where complications arise from multiple biotech events and the existence of varieties that have not been approved by importing countries. In contrast, soybeans typically do not incur additional freight expense because herbicide-tolerant soybeans are the only approved biotech trait (Lin 11).

According to USDA's Value Enhanced Grain Survey performed by NASS' Illinois Market News in 2000 and 2001, producer premiums and incentives offered to producers for non-biotech corn ranged from 8 to 10 c/bu. for the 2000 crop and approximately 10 c/bu. for the 2001 crop. Non-biotech soybean price premiums were 15 to 20 c/bu. for the 2000 crop and 20 to 25 c/bu. for the 2001 crop. Total segregation cost for non-biotech soybeans from the U.S. farm gate to final destination in Japan is approximately 62 c/bu. and 40 c/bu. for the 2000 and 2001 crops, respectively, whereas total non-biotech corn segregation costs are approximately 45 c/bu. for both cropping years. These estimates are reflective of all factors pertaining therein to segregation cost, including producer premiums and incentives, handling costs at country elevator, sub-terminal and export elevator locations, and transportation considerations (Lin 12).

The demand price elasticity for non-biotech commodities ultimately determines who will bear segregation costs. Inelastic demand for non-biotech commodities is supported by strong consumer preferences for non-biotech, a lack of substitutes, and/or the nature of a commodity's market demand. Lin examines the willingness of Japanese buyers to bear the additional cost of segregation and shows that Japanese buyer premiums covered 93-111% and 89-111% of the 2000 and 2001 non-biotech corn crop, respectively, and 85-94% and 71-77% of the 2000 and 2001 non-biotech soybean crop, respectively (Lin 23). These estimates infer that demand for non-biotech commodities in Japan is inelastic, although less than perfectly inelastic. Inferior substitutes and inelastic demand for food-grade corn and soybeans underscore the inelasticity of demand for non-biotech products and allow U.S. grain handlers to pass on the majority of segregation costs to the Japanese market; however, U.S. grain handlers, exporters, and identity-preservation producers must bear any remaining costs not borne by Japanese buyers (24).

Bullock, Desquibet, and Nitsi estimate the costs of segregation and identity preservation of GM and non-GM grain along the supply chain for supply chain participants. The integral steps in maintaining the purity of non-GM grains from seed to export are outlined, including production, transportation, testing, incentive, exportation characteristics, and the costs contained therein. Each step in the segregation and identity-preservation process will be explored, and cost estimates included when pertinent.

Seed purity is the foundation for segregating GM from non-GM grain and is attained through quality assurance programs such as the Association of Official Seed Certifying Agencies (AOSCA) and/or third-party services. Although 100% purity is unattainable, it can be approximated at 99.8 to 99.9% for soybeans due to their self-pollination nature and approximately 99% for corn due to its cross-pollination nature. Additional seed purity can be obtained for corn through the following practices: 1) increasing isolation distances between seed-producing or contaminating fields, 2) planting to ensure different silk and pollen release among fields, 3) increasing the number of all-male border rows in seed-producing corn fields, and 4) manually roguing fields to remove undesirable variations (Bullock, Desquibet, and Nitsi 4).

Once seed purity is established, grain production commences with the planting, growing, and harvesting phases. If the farmer chooses to plant both GM and non-GM varieties, he or she will need to take appropriate measures to mitigate contamination risk. Planters need to be sufficiently cleaned between GM and non-GM planting runs to prevent inadvertent commingling of seed. Planter cleaning for 99% and 99.9% purity is 15 and 40 minutes for an 8-row planter, respectively, and 25 and 55 minutes for a 12-row planter, respectively (Hanna and Greenlees). Assuming the value of farm labor is $15 per hour, the total cleaning cost would be less than $15 between GM and non-GM production runs. Coordination of GM and non-GM runs would further reduce planter cleanout cost to virtually nil when configured on a per bushel basis.

The growing phase entails discouraging cross-pollination in transgenic varieties such as corn and potentially available commodities such as wheat; however, soybean contamination risk is nil because of self-pollination. Practices tantamount to those of seed purity should be followed, including temporal, spatial, roguing, border, and isolation zone considerations (Bullock, Desquibet, and Nitsi 6).

The harvesting phase presents additional contamination possibilities because of internal cleanout or flushing costs associated with the combine when alternating between GM and non-GM fields. The first procedure is detailed in a video produced by South Dakota State University and takes two people around four hours to remove literally every kernel of grain. Alternatively, the operator can flush the combine via two steps including light cleaning and harvesting 60 to 70 bu. of the non-GM variety to obtain approximately 99.8% purity (Greenlees and Shouse). The cost of the 2 alternative methods is disparate; the first method results in a total cost of $120, assuming labor is $15 per hour, while the second method results in a total cost of $18.85 assuming it takes 2 laborers 15 minutes to clean the combine and the 70 bu. is discounted at 15 c/bu. Currently, contracts between farmers and grain handlers recommend the use of the second method. For example, Consolidated Grain and Barge Company (CGB) and Protein Technology International, Inc. (PTI) stipulate "Combine was blown or swept clean and visually verified to be free of all other grain and soybeans" (DuPont, 2000 PTI). Archer Daniels Midland (ADM) verifies STS variety purity with the farmer statement "I used reasonable care to clean all harvesting equipment to ensure it was free from any contaminants to the STS grain" (DuPont, Purchase).

After the culmination of harvest, production will either be stored or marketed. Transportation off the farm costs include sweeping the truck clean and implicit harvesting costs if a truck shortage is realized due to excessive queuing at the country elevator. Transportation from the country elevator to a domestic processor or an export elevator is done primarily via rail whereby federal grain inspectors issue each car a certificate, called its origin grade (Bullock, Desquibet, and Nitsi 7). River elevators out of the gulf ports export approximately 75% of the whole grain U.S. soybean and U.S. corn production (USDA-Foreign Agriculture Service (FAS), Oilseeds, Grains; USDA-FGIS). Consequently, additional barge costs are incurred because river elevators typically move grain from truck to barge; therefore, they incur a barge cleaning cost that is mandated by law and is approximately $300. Conversely, export elevators incur a minimal segregation cost tantamount to that of a country elevator associated with segregating varieties and grades among shipping and storage bins (Bullock, Desquibet, and Nitsi 9). Grain not exported in bulk form is transported to domestic processors where GM and non-GM segregation is sustained through dedicated facilities or staggered production runs (ADM 1-2).

Testing occurs throughout the supply chain, but typically, the first testing point is at the country elevator to detect the presence of GM or non-GM grain in a declared variety. Testing intensity will depend upon the number of events that have to be recognized to validate GM content. Currently, soybeans have been granted 11 transformation events for environmental, feed, and food release in the United States, but only glyphosate-resistant soybeans are presently available for commercial planting. In contrast, corn has been granted 16 transformation events, many of which are available for commercial planting exacerbating testing costs (Bullock, Desquibet, and Nitsi 11). GM events can be detected either quantitatively or qualitatively through an array of testing methodologies, including herbicide tolerance bioassay; immuno assay, which encompasses Enzyme Linked Immunosorbant Assay (ELISA) and strip test; and Polymerase Chain Reaction (PCR). Selection of an appropriate testing method is contingent upon the number of events to detect, time constraints, sample size, and result specification.

Bullock, Desquibet, and Nitsi estimate testing costs at the handling stage for export of non-GM soybeans and non-GM corn to Japan by CGB. The soybeans are delivered to the river elevator via truck where two strip tests are used per truck. The soybeans are stored in shipping bins until loaded onto a barge; a representative sample is obtained; and a quantitative ELISA test is performed. Finally, the barge unloads into an ocean vessel at New Orleans where samples are drawn and ELISA tests are reiterated. Total testing costs are 2.31 c/bu.; however, corn testing costs increased to 4.87 c/bu. due to PCR versus ELISA testing and the requirement to test for additional events not approved for import in the EU or in Japan (15).

Production of GM or non-GM grains to meet importer specifications ultimately begins with the farmer; consequently, quality incentives and contracts must be offered to offset additional incurred costs and risks. Typically, grain handlers stipulate accepted farm production practices, premiums, and the delivery window with the farmer; for example, CGB, ADM, and PTI all offer grower contracts via the OSCAR internet-based contracting system developed by DuPont Specialty Grains, where approximately 800,000 acres of non-GM STS soybeans and 700,000 acres of non-GM soybeans are contracted (DuPont, OSCAR 1). Farm premiums vary between $0.10 and $0.30 depending upon variety and contract obligations; for example, ADM offers elevators a $0.25 premium for STS soybeans, whereby a $0.20 premium is allocated to the farmer (ADM 2). Another example is the 22 c/bu. premium received for non-GM soybean shipments to Japan; 10 c/bu. premium is allocated to the farmer who must account for extra costs related to cleaning, logistics, and technology, and 12 c/bu. is available for the elevator to compensate for additional testing and reshuffling costs (Bullock, Desquibet, and Nitsi 21).

Identity-Preserved Production and Marketing (IPPM)

Hobbs, Kerr, and Phillips explore the role identity-preserved production and marketing (IPPM) systems are playing in bridging the gap between differentiated consumer demands and traditional agri-food production of homogenous commodities. Buckwell, Brookes, and Bradley; and Lin define IPPM as a "closed loop" channel that facilitates the production and deliverance of an assured quality by allowing traceability of a commodity from the germplasm or breeding stock to the processed product on a retail shelf. Numerous pressures that are driving IPPMs are identified and include consumer preference changes, advanced technology, globalization, and domestic consumer concerns about new foods and technologies (Hobbs, Kerr, and Phillips 568).

International trade agreements, governed through the World Trade Organization (WTO), have attempted to establish international regulations regarding GMOs; however, a multilateral trade agreement has not been attained. In the absence of an internationally recognized set of rules, nations will establish and contour domestic trade regimes to address consumer concerns. Inevitably, huge disparities arise among trade nations, thus an effective IPPM system may be needed to track product attributes and facilitate trade (Hobbs, Kerr, and Phillips 571). Currently, there is a wide range of IPPM systems operating in Canada and around the world varying in their degree of specificity, although commonalities exist among IPPM systems. All IPPM systems start with certified seed; are handled and transported through special arrangements (e.g., containers and dedicated trucks); and are segregated at the handler or processor, for movement to the wholesaler, processor or retailer in an attempt to preserve value-added attributes (Hobbs, Kerr, and Phillips 575). The value-added attributes inevitably will be ascertained through third-party verification and certification because of incentives to cheat. The principal-agent problem is readily apparent because *ex post* verification may not be possible or costly; however, the incentive will hinge on a subjective assessment of detection and penalties relative to potential gains. Third-party verification will maintain credibility and integrity of the IPPM system and assure the buyer and seller of process attributes (Hobbs, Kerr, and Phillips 576).

A related study by Smyth and Phillips estimates costs, explores reasons, and evaluates government statutes regarding the establishment of an IPPM. The additional cost of operating an IPPM for small niche market products, excluding other endogenous variables that raise cost such as testing and conformance risk, is estimated at 15-20% above the cost of moving conventional products through a supply chain (2). The added cost suggests that scale economies have not largely existed and that a priori demand for IPPMs on a large-scale basis has not subsided. However, the continuity of exports to over 28 countries that have developed or declared GM labeling legislation, and the establishment of quality assurances predicated by food safety concerns and the rapid commercialization of GM products underscore the need for an IPPM system (Smyth and Phillips 2).

Numerous reasons for IPPM systems are highlighted and include consumer demand, producer premiums, and regulatory requirements. An increasing number of consumers, namely the European Union, have expressed reservation with regard to GM products. North American industries are forced to adopt an IPPM system to meet restrictive tolerances established by the government or forgo exports to countries that employ labeling restrictions, which effectively reduces export quantity. Producer premiums are captured through predefined contract specifications in the IPPM system, which ensures that value-added attributes are measured and realized. Finally, adherence to government regulation necessitates the development of IPPM systems for certain novel varieties to ensure containment of the variety to avoid commingling (Smyth and Phillips 3-4).

National regulatory systems have responded divergently towards biotechnology due to varied public confidence, communications, and government intervention. Numerous safety failures in the United States, Europe, and other countries have prompted widespread skepticism among consumers about their respective food safety institutions and their ability to handle emerging biotech products. However, the general populace in the United States exhibits a higher level of trust than its European counterparts because of the disparate reactionary efforts between the United States and Europe (Smyth and Phillips 15).

Communication of biotechnology risks and benefits through an established medium is essential to avert misleading information from undisclosed sources. Media in Britain and Canada have exploited anti-biotechnology sentiment towards consumers, resulting in misrepresented factual information. A survey of 1,200 people in Australia found that 80% of polled participants reported that their main informational source for biotechnology was newspapers and magazines, albeit their overwhelming preference was for the Internet (Biotechnology Australia 1). Smyth and Phillips asserts that additional efforts need to be made that will assure consumers, industry, and government agencies of factual information (15).

Government intervention or lack thereof in biotechnology can result in serious implications for exporting countries. Once GM varieties are approved, regulatory agencies have limited ability to control or manage GM production; consequently, IPPM systems and guidelines cannot be established to segregate and preserve GM varieties for export markets. For example, U.S. soybean and corn exports to the EU from 1995 to 1999 fell from U.S.$2.1 billion and U.S.$574 million to U.S.$1.1 billion and U.S.$175 million, respectively. Importers have segmented and classified regions as GM or GM-free; consequently, GM producing regions will lose global markets to countries with nil or strict tolerances as they divert their purchases to GM-free producing regions (Smyth and Phillips 18). Kuntz estimates that the impact of GM wheat adoption on Canadian agriculture will be a net loss of $185 million per year, or 70% of the annual premium attained in the global wheat trade. The continued proliferation of GM wheat and other transgenic varieties accentuates the need for an IPPM system to preserve identity and capture value-added attributes.

Efficiency

Krueger et al. examine costs and efficiencies associated with multiple grain type deliveries to a prototypical elevator in Indiana. The economic-engineering model utilizing stochastic simulation uses 1999 harvest delivery data, including costs, quantities, and time intervals to simulate operations for a single harvest day, while EXTEND is used to model stochastic elevator processes associated with receiving grain. Two alternative cases are contrasted with a baseline case, which models the elevator receiving two types of grain, No. 2 yellow corn and No. 1 soybeans. The first case proposes that the elevator only handles one commodity, which will demonstrate bulk commodity cost when compared to the baseline case. The second case assumes that the elevator will handle GMO and non-GMO corn and soybeans, which requires an additional testing allotment from two to ten minutes. All cases examined include the incidence of wet or dry characteristics based on a moisture test (4-5).

The model specifies that the prototypical elevator has total capacity of 6 million bu. and can accommodate an average of 200 trucks per day. Truck arrival is modeled through an exponential distribution with a mean arrival interval of 10 minutes. Two truck types are allowed, hopper-bottom and hoist axle, with associated probabilities of 72% and 28%, respectively. The unloading area within the weigh station/grain testing area has a maximum capacity of 11 where first in first out (FIFO) queuing practices is exercised. Additional assumptions include GMO testing at a cost of $7 per truck; 2 available pits with a maximum capacity of 1,250 bu.; flow rate of 400 bu./minute; and a cleanout time of 4 minutes.

The results indicate that increased complexity from handling additional commodities increases time requirements and cost. Cost estimates are quantified in average cost per truck, but inferences can be made from truck arrivals to infer additional costs to the elevator. The addition of non-GMO grains increased the average cost/truck from $23.13

to $26.17 and decreased capacity utilization from 96.5% in the baseline to 64.5% due to additional testing time requirements. The average wait time for truck entry also increased from 25 minutes in the baseline to 305 minutes in the non-GMO case (Krueger et al. 8). The increase in the number of commodities handled increases costs in the first and second cases, but reduces efficiency only in the latter. Efficiency losses can be attributed to switching costs, testing, and clean down time, which increases product complexity and, therefore, decreases elevator efficiency (Krueger et al. 10).

Segregation

Crop segregation is a supply chain strategy that abates contamination risk and assists in ensuring that crops are kept separate during loading and unloading, storage, and transportation. Numerous studies have been done on segregation that estimate cost, explore contamination issues, and investigate strategy implications. USDA-ERS, Biotechnology defines segregation as the process by which crops are kept separate to avoid commingling at harvesting, loading and unloading, storage, and transporting phases. Sonka, Schroeder, and Cunningham refer to segregated systems as crops with particular attributes that are accumulated with like products, but are kept separate from other product streams throughout handling and transportation to avoid commingling. Dye asserts that segregation involves a separate marketing system for GM and non-GM crops.

It should be noted that identity preservation and segregation refer to two distinct types of channels, although they are often used interchangeably to describe similar events. Unlike identity preservation, segregation involves the accumulation of like products kept separate from other product streams to meet a threshold requirement (Sonka, Schroeder, and Cunningham 26). The review of studies encompasses an investigation of segregation costs, contamination risks, and strategy implications.

Segregation Cost

Hurburgh et al. utilize an engineering-economic model to estimate the costs of segregating grain by composition. Operating inputs and coefficients are derived from a 3-year, on-site test at 1 elevator and a survey of 50 elevators in 3 Iowa counties. The country elevator is used as a basis for estimating segregation cost because the maximum variability of quality in grain procurement occurs at this stage in the supply chain. The three main objectives in this study are as follows: 1) development of a model to estimate segregation and testing cost, 2) determination of sensitive variables, and 3) estimation of segregation cost for two selected case-study areas (1).

A number of factors that comprise segregation cost are inclusive in the model; therefore, detailed explanations of each factor and its contribution to total segregation cost on an after income tax basis will be explored. At the culmination of factor explication, a case study will be analyzed to arrive at cost estimates, and all sensitive variables will be examined. Factors one through nine can be categorized as grading costs and factors eleven through seventeen as handling costs. As previously mentioned, segregation cost consists of implicit (hidden) and explicit (known) cost, hence each factor will be assigned a hidden cost classification where applicable.

Test equipment cost is defined as the annualized ownership cost for new testing equipment, and includes salvaged equipment and annual repair costs. In this context, testing apparatus represents equipment used for current U.S. grade factors such as moisture content and test weight. Although GM varieties will still utilize these measurements, it should be noted that additional costs arise to detect GM presence. Operator additional time refers to the extra labor required to administer and apply new tests and is calculated by multiplying the wage rate by the change in testing time (Hurburgh et al. 2).

Data transmission, commonly referred to as interfacing, is the additional technology upgrades required to accommodate automated data handling that will evolve with GM technology. The cost estimate includes the annualized data equipment cost and needed repair cost (Hurburgh et al. 3).

Waiting time for test is a hidden cost due to the inability to delegate an explicit cost to the factor, albeit it is a customer relations cost. The addition of GM testing will increase waiting time due to the inherent nature of currently available tests and the elevator's intent to separate grain lots by variety. It is configured as a function of the time to make a new test, and the travel time between the dispatch and the test site (Hurburgh et al. 3).

Storage of samples currently takes place, but if new tests dictate price, additional samples must be retained for disputes and/or appeals. It is assumed that additional samples will be retained in the existing infrastructure and that building maintenance, property tax, and insurance cost will remain constant. Accounting and record keeping alludes to supplementary dispatcher responsibilities and paper backup (Hurburgh et al. 3-4).

Check testing and standardization of equipment refer to calibration costs that will be incurred to maintain and update sophisticated equipment that is price determining. Typically, the Federal Grain Inspection Service conducts this service for official standards, but currently, U.S. grain standards have not been amended to include GM content; consequently, elevators will submit equipment to federal inspectors or analytical laboratories to ensure conformance (Hurburgh et al. 4).

Modifications of in-house computer software require upgrades in settlement and inventory control software to support the addition of GM products, thereby increasing costs for amortization of test equipment over its useful life. Inevitably, disputes with sellers over grade determinations and variety declarations will exacerbate with the inception of GM grain. Arguably, additional time will need to be allotted in order to explain testing protocols, and discuss questioned results and submitted appeal samples. Currently, U.S. grain standards are the basis for testing protocols, which are highly understood and not highly contestable; hence, elevator operators may tend to resist new testing procedures to avert a higher frequency of disputes (Huburgh et al. 5). The aforementioned factors comprise the grading portion of segregation costs; handling costs will be described in a similar context in the next section.

Additional waiting time at the dump involves additional queuing costs for customers to properly differentiate grain via pit clean-outs and spout redirections. However, if a pit is permanently designated to be variety specific, additional waiting times are nil. Waiting time is a hidden cost and will not be explicitly realized by the elevator, but may affect overall customer satisfaction (Hurburgh et al. 5).

Additional labor at the dump area involves the utilization of employees for tasks specific to segregation. Laborers will be compensated with an hourly wage, which when multiplied by the number of represented bushels in the test equates to an additional pit cost (Hurburgh et al. 6).

The modification of the handling system will hinge on the design and configuration of the elevator, which varies significantly among regions and annual capacities. The number of pits, legs, conveyers, etc. to be modified and the ease of redirecting grain among storages will depend upon existing infrastructure and will be key parameters in determining cost (Hurburgh et al. 6).

Underutilized storage, commonly referred to as "storing air," increases as grain is segregated by end-user specifications; however, segregation decisions should be made based upon the storage layout of the elevator. Uncertainties such as producer deliveries and spot market transactions can conceptually reduce storage efficiency or eliminate underutilized storage cost by providing excess storage capacity. This factor contributes to hidden cost and does not explicitly affect elevator cost, but does implicitly through diminished alternatives (Hurburgh et al. 6).

The risk of misgrading may be elevated if testing apparatus produces large variances and is inaccurate or if data are erroneously entered. Differentiated grain may be commingled with substandard quality, thereby negating segregation efforts and reducing the premium received at resale (Hurburgh et al. 6).

The addition of new storage space to accommodate segregations is not exclusively determined by storage shortages, but, in part, by the inherent nature of differentiated grain and its subjectivity to commingling. An increase in "storing air" may accompany new storage facilities, thereby reducing storage efficiency and increasing hidden cost (Hurburgh et al. 7).

The loss in receiving capacity cost approximates customer loss due to additional receiving and testing time allowances. Opportunity costs as well as direct cash costs are considered when assessing customer loss to competitors (Hurburgh et al. 7).

Hurburgh et al. explore a case study analysis to further emphasize and highlight the magnitude of segregation costs across Iowa regions depending upon statistical averages such as grain production, elevator capacity, storage ratio, elevator design parameters, and a subjective assessment from 1 (worst) to 5 (best). Actual observations of a large north-central Iowa elevator indicated that the cost of soybean testing and segregation at harvest on the basis of oil and protein content was approximately 4.8 c/bu. with 70% representing handling characteristics and 30% representing grading characteristics.

Conversely, cost estimates from the survey of 50 elevators across Calhoun, Webster, and Marshall Counties in Iowa indicated that 50% of the elevators representing 75% of the storage capacity could segregate for less than 3 c/bu., 36% of the elevators representing 19% of storage could segregate for less than 4 c/bu., and only 14% of elevators representing 3% of storage had costs greater than 4 c/bu. (Hurburgh et al. 9, 15). Segregation cost is based on the total volume tested; therefore, the actual segregation cost could conceivably be amplified depending upon the concentration factor of segregated grain. Ultimately, the elevator will have to elect whether to pursue a differentiated grain marketing strategy, or a combination thereof, which will hinge on market premiums available (Hurburgh et al. 8).

Several cost factors varied with volume tested (V) and load size (B), whereas other factors were unaffected by either V or B. Highly sensitive variables include the number of dump pits, elevation capacity, storage efficiency, tester cost, tester time, labor cost, interest rate, bushels tested, volume, and quality premium. An increase in dumping pits, elevation capacity, storage efficiency, bushels tested, volume, and quality premium will decrease segregation costs ceteris parabis. Conversely, a decrease in tester cost, tester time labor cost, and interest rate will decrease segregation costs ceteris parabis. It is important to note that a large portion of the key cost elements is directly controllable by the operations and financial management of the elevator, such as interest rates and labor cost, and will largely determine the feasibility of handling differentiated grain (Hurburgh et al. 9). Variances and cost estimates for the aforementioned north-central Iowa elevator are included in Table 2.1.

Table 2.1. Grain Segregation Cost

Cost Category	Cost Basis	Variable ID	Item	By Item ($/bu.)	Cumulative ($/bu.)
Grading	V	C1	Tester cost	0.007	
	B	C2	Operate tester	0.000	
	V	C3	Data equipment	0.002	
	B	*C4	Wait time	0.001	
	V	C5	Sample storage	0.001	
	B	C6	Accounting	0.000	
	B	C7	Standardization	0.000	
	V	C8	Software	0.000	
	B	C9	Disputes	0.003	
Subtotal grading					0.014
Handling	A	*C11	Waiting time	0.003	
	A	C12	Pit labor	0.001	
	V	C13	Modifications	0.000	
	V	*C14	Underutilized	0.020	
	A	C15	Storage	0.005	
	V	C16	Misgrades	0.000	
	V	*C17	New storage	0.004	
			Loss in receiving		
Subtotal handling					0.033
Total ($/bu.)					0.048
Cost Basis	Cost	Total (%)			
V=Volume based	0.034	0.720			
B=Load size based	0.004	0.087			
A=Across-the-board	0.009	0.194			
* Hidden cost	0.028	0.584			

Source: Hurburgh et al.

The model seeks to explore cost estimates for segregating grain by quality; generally, larger elevators are more suited to handle differentiated grains with the exception of small elevators containing multiple dump pits. Although the model is not directly applied to GM grain, inferences can be made that GM segregation will encompass similar factors, albeit with a specified tolerance (Hurburgh et al. 9-10).

Contamination Risk

Casada, Ingles, and Maghirang explore residual and cross-contamination of grain at handling to address the imminent evolvement of segregation strategies to segment GM and non-GM grain to meet stringent threshold requirements. A USDA-Agricultural Research Service (ARS) Engineering Research Unit 55,000 bu. grain structure is utilized to determine identity-preservation procedures for commercial grain storage facilities and contamination levels that may be realized. The research elevator has two legs, each with a capacity of 3,000 bu. per hour. Cross contamination and residual estimates will be evaluated under three scenarios: 1) red wheat followed by white wheat, 2) yellow corn followed by white corn, and 3) corn followed by wheat; however, only the second scenario has been analyzed thus far. Contamination and residual estimates, and implications for modification will be detailed in the successive sections (Casada, Ingles, and Maghirang 2).

Residual estimates will be ascertained after loading and unloading transfers by individually cleaning out each piece of equipment, sweeping and vacuuming, and then weighing the grain and dust concurrently. Residual grain measurements will be tabulated for three replications to assure accuracy, and critical contamination control points will be identified. The elevator leg is assumed to operate at 2000 bu. per hour at testing, thus results will indicate possible contamination levels for a 1-hour run. Specific equipment analyzed includes the dump pit, cross-conveyor, and elevator boot for loading; and the elevator boot, scalper, and scale for unloading. The preliminary residual results indicate that contamination in the elevator boot and receiving pit was 0.21% and 0.04%, respectively, inferring a total contamination level of 0.25%; however, this figure represents potential contamination since much of the grain will not dislodge and contaminate subsequent grain lots (Casada, Ingles, and Maghirang 3).

The cross-contamination test requires all equipment in the grain stream to be swept and vacuumed prior to grain elevation of one color or type. Grain is elevated until an equilibrium has been established and maintained for a period of five minutes, wherein the leg is shut down following normal procedures entailing equipment self-clean accompanied by a subjective assessment usually based on sound. A second lot of grain of contrasting color or type is subsequently run, and equilibrium is maintained for 15 minutes. Samples are drawn at regular intervals to verify reduced contamination levels to the desired lower limit of detection (one kernel per sample). Correspondingly, a curve of contamination percent versus time after second grain commencement was constructed and normalized based on contrasting grain sample estimates and the bushel percentage of leg elevation per hour, respectively. Three consecutive replications unequivocally indicate that only the first 15 to 20 bu. of grain were contaminated at a level greater than 1% and that only the first 40 to 50 bu. of grain were contaminated at a level greater than 0.5% (Casada, Ingles, and Maghirang 2-3).

The study reveals that the conformance to a rigorous tolerance limit at the elevator location is attainable through pragmatic clean-out procedures which rely on employee adherence to an established protocol. However, the contamination estimates presented assume that delivered grain is homogenous; consequently, identity-preservation practices must be followed throughout the production, growing, and harvesting phases. In addition, the elevator analyzed is smaller than the prototypical commercial elevator, thus revealed contamination estimates must be correlated to commercial elevator operations depending on elevator size and layout (Casada, Ingles, and Maghirang 2).

Strategic Implications

Several strategic implications are notable when contemplating the segregation of GM and non-GM grain in the supply chain. Currently, the demand for non-biotech corn and soybeans is weak in the international arena, constituting a mere 1% of U.S. corn production and 2% of U.S. soybean production; hence, supply chain strategies have been contoured to accommodate these circumstances. A survey by Sparks Company of 100 Midwestern grain elevators in September 1999 indicated that 11% were differentiating for non-biotech corn and 8% for non-biotech soybeans while only 1 to 3% offered premiums for non-biotech corn and soybeans, respectively. However, if international food and proposed feed labeling requirements for bio-engineered foods continue to proliferate, a more rigorous approach to segregation across the supply chain may be imminent to ensure adherence (USDA-ERS, Biotechnology 29).

Effective segregation throughout the supply chain necessitates enhanced coordination among supply chain participants and adherence to established protocols. A recent straw poll in January 2000 indicated that 15% of farmers are making the necessary adjustment to handle or segregate biotech crops in the future (USDA-ERS, Biotechnology 30). Segregation at the farm level requires farmers who grow both biotech and non-biotech crops to preserve identity through the growing, harvesting, transportation, and storage phases via buffer zones, clean equipment, and on-farm storage (USDA-ERS, Biotechnology 31).

The elevator's ability to segregate depends on the tolerance level, layout, location, scale, and management of elevator operations. The National Grain and Feed Association estimated that, at a 1% or lower biotech tolerance, only 5% of the nation's elevators are capable of segregating without major new investments; therefore, the incentive for elevators to segregate will depend on established tolerances (1).

Elevator layout in this context refers to the number of pits, varying bin capacities, bin size distribution, and its effect on grain segregation potential. Generally, multiple pits, large capacity, and a range of bin sizes give the elevator great flexibility in dedicating channels and segregating numerous commodities.

Location may determine grain segregation cost and its feasibility since river terminals can eliminate repetitive elevations through direct grain loading onto vessels, whereas inland terminals are subjected to an increased probability of inadvertent commingling.

The practice of segregation reduces the volume the elevator can handle due to increased testing, queuing, and storage inefficiencies; however, the size of the elevator is instrumental in determining accrued costs because larger elevators may be able to divert biotech grain to satellite locations, originate larger shipments, and create higher grain turnover. Management practices such as dedicating facilities and designating biotech delivery dates may enable the elevator to prevent commingling, minimize queues, and maintain a clean environment for effective crop segregation.

The segregation of biotech commodities raises logistical concerns with respect to increased transportation costs resulting from the anticipated migration from unit train shipments towards smaller unit shipments such as single rail cars. According to the USDA-

ERS, Biotechnology, a 5% biotech threshold presents modest increases in segregation practices; however, a 1% threshold entails identity preservation and evokes substantial costs (31).

In addition to the aforementioned studies, numerous studies quantify identity-preservation and segregation costs for a range of commodities utilizing different methodologies, including surveys of elevator managers (Nelson et al. 1-119; Jirik 1-25; Dahl and Wilson 1-40; Wilson and Dahl 1-83), cost accounting methods (Askin 1-2; McPhee and Bourget 1-8; Hurburgh et al. 1-15; Bullock, Desquibet, and Nitsi 1-27; Sparks Company 1; Smyth and Phillips 1-72), and simulation (Hermann, Boland, and Heishman 1-9; Maltsbarger and Kalaitzandonakes 1-2). IP segregation costs range from 1 72 c/bu. in these studies and are summarized in Table 2.2.

Sampling

Sampling for the detection of biotech grains introduces risk to exporters and importers alike. The inherent risk can be classified into three basic categories: 1) sampling, 2) sample preparation, and 3) analytical method. Sampling encompasses establishment of a quality level, protocol selection, sample size, and sampling tools. Sampling protocols are available to mitigate risks to buyers and sellers, including single, double, and multiple sampling plans that incorporate Acceptable Quality Level (AQL) and Lot Tolerance Percent Defective (LTPD). Sellers select a quality level that they want to have accepted most of the time (e.g., 90% or 95%) called an AQL, whereas buyers select a quality level that they want rejected the majority of the time (e.g., 90% or 95%) referred to as LTPD. The probability of rejection of a satisfactory batch where quality actually equals the AQL is referred to as seller's risk, whereas the probability of accepting a lot where quality is unsatisfactory is referred to as buyer's risk.

Table 2.2. Previous Studies on IP and Segregation Costs

Researcher	*Methodology/Scope of Analysis*	*Estimated Cost of Segregation/IP*
Askin (1988)	Econometric model of costs for primary elevators	Increase of 2 grades handled increased costs < 0.5 c/bu.
Jirik (1994)	Survey of elevator mgrs. and processors	11 to 15 c/bu.
Hurburgh et al. (1994)	Cost accounting model for high-oil soybeans	3.7 c/bu.
McPhee and Bourget (1995)	Econometric model of costs for terminal elevators	Increasing grades handled increases operating costs 2.6%
Hermann, Boland, and Heishman (1999)	Stochastic simulation model	1.9 to 6.5 c/bu.
Maltsbarger and Kalaitzandonakes (2000)	Simulation model for high-oil corn	1.6 to 3.7 c/bu.
Nelson et al. (1999)	Survey of grain handlers	6 c/bu. corn, 18 c/bu. soybeans
Bullock, Desquibet, and Nitsi (2000)	Cost accounting	30 to 40 c/bu. soybeans
Dahl and Wilson (2002)	Survey	25 to 50 c/bu.
Wilson and Dahl (2001)	Survey of elevator mgrs. for wheat	15 c/bu.
Smyth and Phillips (2001)	Analysis of GM IP system for canola in Canada, 1995-96	21-27 c/bu.
Gosnell (2001)	Added transportation and segregation costs for dedicated GM elevators	15-42 c/bu. high throughput 23-28 c/bu. wooden elevators
Sparks Company (2000)		Non-GM canola 38-45 c/bu. Non-GM soybeans 63-72 c/bu.

Source: Wilson and Dahl, "Costs" 8.

In order to quantify seller and buyer's risk, the hypergeometric distribution utilizes lot size, sample size, and defectives concurrently. A more complex method is the double sampling plan, which has defective ranges for accept or reject, and an intermediary range where the decision is indeterminate. In order to ascertain this indifference, a larger sample size is analyzed. If the sum of the total defectives is greater than the upper bound, the lot is rejected; otherwise, it is accepted (Winston 205). A multiple qualitative sampling plan utilizes a specified number of independent samples to assign a positive or negative indicator. The maximum allotted positive results are determined to accept or reject the lot; hence, the higher the allotment for positives, the higher the probability of accepting the lot for any given percentage concentration (USDA, Sampling 8-9).

Sampling size can elicit disparities in the estimation of percent concentration of a lot. Generally, an increase in the sample size will reduce both buyer's and seller's risk of a designated percent concentration threshold; however, lot size and sample cost can diminish that intent. Acceptability of a sample size is contingent upon the AQL and LTPD that are admissible to both parties (USDA, Sampling 7). Grain sampling methods prescribed by the Department of Agriculture include techniques to sample moving grain streams and static grain lots. A diverter type (DT) sampler has been prevalent in the industry for electronically sampling grain streams while manual means have relied on pelican samplers and Ellis cups. In contrast, static lots necessitate grain probing in a specified pattern to eliminate potential stratification within the lot. In addition to sampling tools, dividers such as the Boerner, Cargo, and Gamet allow for correct subdivision of grain in a random manner to facilitate testing (USDA, Sampling 2-3).

Sample preparation and analytical method are two additional sources of error in the detection of biotech grains. The current analytical testing methods include the PCR and ELISA, which have inherent difficulties in producing consistent and accurate quantitative results (USDA, Sampling 6). Sample preparation plays a significant role in representation of a grain lot; for example, a representative sample that is prepared through kernel division versus a ground and mixed sample will provide a disparate distribution of the analyte (USDA, Sampling 10-11). Consequently, variability of quantitative results will inevitably rely on analytical methods and sample preparation in addition to sample size.

Testing Methods

Testing procedures vary widely and may be conducted during several stages of production and movement of agricultural product through the supply chain. Compliance to a certain threshold level of genetic material is a major concern for supply chain management, hence efforts to mitigate risks will undoubtedly evolve to ascertain conformance. These efforts will proliferate through the evolvement of testing protocols and procedures. Factors to consider when testing include cost, limit of detection, time required to complete the test, and the level of technical skill and knowledge required to conduct the test (Stave and Durandetta 4; Sonka, Schroeder, and Cunningham 28). An overview of testing apparatus, required time, and costs measured at 95% accuracy are summarized in Table 2.3. Component measurement, which measures the level of various traits or components, can be disaggregated into two categories: conventional wet chemistry testing and rapid measurement technology testing (Sonka, Schroeder, and Cunningham 22).

Conventional Wet Chemistry Testing

This method is conducted under laboratory conditions, requiring ground samples of grain to measure each individual component. Generally, this form of testing is very accurate and has the ability of measuring low concentrations down to 1%. The disadvantages of this method are high cost, timeliness, mandatory technically inclined

Table 2.3. Testing Method, Cost, Limit of Detection, and Duration

Event	*Testing Method*	*Testing Cost Per Sample*	*Limit of Detection*	*Testing Duration*
Canola				
35S, CP4/EPSPS,NPT11	PCR	$25/1000 seeds	Qualitatively detects 1of 1000 seeds, Quantitatively detects .01% GM presence	3 Days
RR, Liberty Link	Herbicide Bioassay	$30/600 seeds	Depends upon minimum herbicide tolerance requirements	7 Days
Corn				
35S, NOS, CP4/EPSPS, Cry1Ab, Cry1AC, Bt 11, Bt 176	PCR	$25/1000 seeds	Qualitatively detects 1of 1000 seeds, Quantitatively detects .01% GM presence	3 Days
RR, Liberty Link	Herbicide Bioassay	$25/1200 seeds	Depends upon minimum herbicide tolerance requirements	7 Days
Mon 810, 176, CBH351 (Cry9c)	ELISA Microtiter Plate	$65-$70/90 seeds	Cry9c, detection .04% and above Mon810/176,detection .15% and above	9 Days
PAT/pat protein	ELISA Microtiter Plate	$195.00	Detection .2%	2.5 Hours
Cry9C	ELISA Microtiter Plate	$16.00	Detection .01%	3 Hours
CP4/EPSPS	ELISA Lateral Flow	$3.50	Detection .5%	5-10 minutes
Mon 810, Bt11	ELISA Lateral Flow	$3.50	Detection 1%	5-10 Minutes
Cry9C	ELISA Lateral Flow	$3.50	Detection .125%	5-10 minutes
Soybean				
35S, NOS, RR	PCR	$25/1000 seeds	Qualitatively detects 1 of 1000 seeds, Quantitatively detects .01% GM presence	3 Days
RR, Liberty Link	Herbicide Bioassay	$18, $30, $50 (400,1200, 2000 seeds)	Depends upon minimum herbicide tolerance requirements	7 Days
CP4/EPSPS	ELISA Lateral Flow	$3.50	Detection .1%	5-10 minutes

Sources: Midwest Seed Services, Inc. 1-7; EnviroLogix, Inc. 1-6.

operators, and its destructive nature to the sample (Sonka, Schroeder, and Cunningham 22).

Rapid Measurement Technology Testing

This procedure helps to overcome some of the limitations of the previous method. It encompasses two spectroscopic techniques: Nuclear Magnetic Resonance (NMR) and Near Infrared Reflectance (NIR). Both methods utilize light for reflection and absorption in order to assign frequencies to each component. The NIR is more widely used due to its lower cost, ruggedness, accuracy, and robustness for larger components such as protein in wheat and protein and oil in soybeans (Sonka, Schroeder, and Cunningham 22).

GM Testing

GM testing is performed through detection of novel DNA or novel protein that modifies the grain or oilseed. Available tests include herbicide tolerance bioassay, immuno assay encompassing the strip test and ELISA, and PCR. GM testing provides assurances to domestic end-users and importers about the presence or absence of GM content, and facilitates marketing between supply chain participants. In response to changing market demand, USDA-GIPSA recently initiated a proficiency program designated for organizations testing for biotechnology-derived grains and oilseeds to help identify areas of concern. Participation in the program is voluntary and is designed to alert organizations of testing deficiencies to make corrective actions to improve testing capability and reliability in order to unify supply chain participants (Proficiency 1).

The designation of a testing methodology depends upon the number of transformation events that have to be detected and the preference for qualitative or quantitative results; for example, corn has 16 transformation events that have been granted environmental, feed, and food release in the United States while soybeans have 11, one of which is available commercially. Consequently, divergent testing methodologies are employed based on the number of transformation events and if they are approved for importation (Bullock, Desquibet, and Nitsi 11). Each testing methodology will be explained in detail in the following sections.

Herbicide Tolerance Bioassay

The herbicide tolerance bioassay is a pre-emergence quantitative GM test that identifies whether seeds or grains are tolerant to a specified herbicide by imbibing test plots with a herbicide solution, allowing germination for seven days, and then conducting an evaluation to assess seed development. Currently, the test exists for both herbicide tolerance traits commercialized in soybeans and corn: Roundup Ready and Liberty Link (Bullock, Desquibet, and Nitsi 11). In general, the test is simple and inexpensive to perform, but time constraints eliminate it as a possibility among several supply chain participants (USDA-ERS, Implications 24).

Protein Tests

Immuno Assay

The immuno assay test detects proteins created or expressed by the modified gene by locating the antibodies that attach to each respective protein. Immuno assay manifests itself through two types of tests: the strip test and the ELISA test.

Strip Test

A strip test is rapid, accurate, cost-effective, and can be utilized in qualitatively assigning a "yes-no" response. It is the cheapest and easiest method of qualitative testing available and indicates a positive or a negative depending upon the pre-set level of novel protein. The process involves a ground sample, insertion into a tube, and a color change for positive or negative (Stave and Durandetta 4). Several companies market strip tests, including EnviroLogix, Inc.; Strategic Diagnostics, Inc. (SDI); and Neogen Corporation.

To evaluate and assess testing kit performance, USDA-GIPSA provides test kit performance verification via Directive 9181.2 to detect the presence of biotechnology events in grains and oilseeds and to assign a qualitative measurement. Concurrent with approval, manufacturers are successively listed on GIPSA's website along with the event/protein analyte, test sensitivity, and test format characteristics intrinsic to each approved test kit. Although test kit approval does not establish appropriate criterion for official use, it aids in facilitating market transactions between supply chain participants who are ascertaining product information to comply with market demands (Test 1). The total cost for a strip test depends upon the desired event detection, but is approximately $3.50 plus labor; for example, the total cost for detection of glyphosate-resistant soybeans is $6.00 assuming $3.50 for the test kit and 10-minutes labor at $15.00 per hour (Bullock, Desquibet, and Nitsi 12).

ELISA (Enzyme Linked Immunosorbant Assay)

The ELISA test is a laboratory test that quantifies GM content of a sample for a given transformation event. ELISA testing can be applied to raw agricultural products or slightly processed products to reveal a quantitative approximation of novel protein content (Bullock, Desquibet, and Nitsi 12). Novel protein percentage is determined through the examination of various hues with a plate reader that analyzes specific antibody reactions and indicates the concentration of the proteins that are created in conjunction with the genetic event (Strategic Diagnostics, Inc.). Several laboratories offer ELISA tests, and both EnviroLogix, Inc. and Agdia, Inc. provide Bt corn testing, although no ELISA test currently exists for detecting herbicide-tolerant varieties in corn. Both immuno assay tests can only be utilized to detect one event; consequently, several tests may be needed to test for exporter restrictions on several events; however, their simplicity and low cost make them ideal candidates for grain elevator or processing plant utilization (Bullock, Desquibet, and Nitsi 12).

DNA Grain Tests

PCR (Polymerase Chain Reaction)

The PCR test is a laboratory test used to detect modified DNA by selectively multiplying targeted sections of a DNA molecule, identifying the novel DNA, and magnifying it over 1 million times. PCR testing can be applied to raw materials, processed materials, and mixed products; however, its susceptibly to containments or DNA degradation requires testing to be performed under rigorous laboratory conditions with appropriate controls. Several organizations have combated these shortcomings by modifying PCR tests to extend novel DNA detection to processed foods, including Cepheid and Qualicon, Genetic ID, and LawLabs (USDA-ERS, Implications 24).

PCR testing can be measured both quantitatively and qualitatively depending upon the desired sensitivity. The quantitative PCR test uses a DNA probe to produce a fluorescent signal which allows the progress of the PCR reaction to assign a reliable GM detection rate within 0.1%. A qualitative test allows even more sensitive results which can detect traces of target DNA, albeit results are reported as detected or not detected (Bullock, Desquibet, and Nitsi 13).

Synchronous Testing

Several events can be tested for simultaneously through the use of several primers, small DNA molecular sequences corresponding to DNA sequences present in GM commodities. However, primer utilization presents antagonistic results for simultaneous detection of multiple GMOs or detection of a typical event. For example, a primer corresponding to a DNA sequence present in many GMOs can be used to detect multiple GMOs but does not state the modification type, whereas a primer corresponding to a DNA sequence of a given event allows us to recognize an unequivocal determination of one individual transformation, but requires several primers to recognize all transformations (Bullock, Desquibet, and Nitsi 13). Importer event restrictions require individual quantification of GM transformations; for example, 12 of 16 events approved in the United States are not approved for import in the EU while 8 of 16 events are not approved in Japan. Consequently, a qualitative test adding $75 per event is needed to ascertain conformance to importer specifications, which amounts to $600 and $900 for Japan and the EU, respectively (Central-Hanse Analytical Laboratory, LLC 1-7). Since PCR is not readily adaptable for rapid onsite testing, it is better suited for laboratory examinations and export certifications where a large sample size exists (USDA-ERS, Implications 24).

Government Role in Testing

The first United Grain Standards Act was established in 1916 to facilitate the trading of grain in a timely and orderly manner. In 1976, the Federal Grain Inspection Service (FGIS) was commissioned to regulate grain inspection and weighing systems. The merger of FGIS and the Packers and Stockyards Administration in 1994 led to the formation of the Grain Inspection Packers and Stockyard Administration (GIPSA). GIPSA mediates issues involving grain testing, laboratory accreditation, and testing methods to facilitate evolution and commercialization of biotech grains (Shlecht 54).

Logistics

Logistics plays a vital role in determining realized value from biotech commodities through corresponding transportation and handling infrastructure. Currently, the production and marketing system for major commodity crops is designed to deliver maximum value through a low-cost delivery mechanism for large amounts of homogenous grain and oilseeds (Sonka, Schroeder, and Cunningham 2-3).

Investment in transportation and handling infrastructure for biotech commodities has lagged that of its counterpart, biotechnology; consequently, first-phase value-added incentives have not been fully captured. However, the most significant impact will likely occur with the inception of secondary phase benefits, where crops with quality-related traits will provide utility to specific end-users (Sonka, Schroeder, and Cunningham 7). Quality in an attribute system (e.g., biotech grain) will rely on maximizing the absolute level of quality while maintaining a baseline level of volume subject to mutual concession among upstream and downstream partners (Sonka, Schroeder, and Cunningham 26). The Economic Order Quantity (EOQ) framework is imparted in the successive section.

Quality Improvement

Larson explores the integration of inventory and quality decisions in logistics through four inspection/quality cost models in an EOQ framework. All of the models are designed to minimize total annual cost, which is comprised of the summation of purchase cost, order cost, holding cost, backorder cost, and quality cost. The models attempt to quantify available alternatives to a purchasing or procuring entity in the inspection of incoming material and the handling of defective material, which is treated as salvage value, lost product, or rework from the firm. The modified EOQ models include No Inspection

(NI), 100% Inspection with Rework (IR), 100% Inspection with Scrap (IS), and Sampling Inspection with Rework (SI). Each modified EOQ model will be explicitly described in the following sections (108).

In the first model, the purchaser (i.e., importer) decides against the inspection of incoming materials despite an expected defective rate; however, to compensate for defects found downstream, additional units must be procured. It can be modeled as follows: $TC = (C + D_p)U(1+p) + U(1+p)S/Q + hCQ/2$, with an optimal order quantity of $Q(NI) = (2SU(1+p)/hC)^{0.5}$, where C is purchase cost per item, U is the expected annual usage in units, S is cost per order, h is annual holding cost, p is the percent defective, D is cost per defect passed forward, I is inspection cost per item, n is sample size, r is return/rework cost per item, Q is the lot size, w is salvage value, and b is unit cost of backordering per year (Larson 109).

The second model assumes that all defects are reworked and, therefore, have to be backordered. Procurement requirements have not been inflated, thus stockouts and backorders will characterize the ordering cycle; for example, if 100 units are received and 10 are defective, then 10 units are considered stockout and are backordered (Larson 109-110). The IR model is as follows:
$TC = U(C + I + rp) + US/Q + hCQ(1-p)^2/2 + bQp^2/2$ with an optimal order quantity of $Q(IR) = (2SU/(hC(1-p)^2 + bp^2))^{0.5}$ (Larson 109-110).

Similar to IR, the third model assumes that all defects are detected, but differs in that procurement is inflated to cover requirements and defective units are sold for scrap at the salvage rate (w). In this model, backorders are not expected since ordering strategies are inflated to account for defective products and average inventory is reduced by a factor of (1-p) because defects never enter inventory. Total annual cost including scrap salvage rate for p percent of the items and full cost for (1-p) percent of items can be modeled as follows: $TC = U((1-p)C + p(C-w) + I)/(1-p) + US/(1-p)Q + hCQ(1-p)/2$ with an optimal order quantity of $Q(IS) = (2SU/hC(1-p)^2)^{0.5}$ (Larson 112).

The fourth model combines acceptance sampling with lot size decisions and the assumption that accepted lots inclusive of detected defects are advanced forward. Conversely, rejected lots are 100% inspected with all defects reworked analogously to the IR model. The quality cost portion of total annual cost is given by $(P_a(nI + QpD) + (1-P_a)Q(I+rp))$, which assumes all units in accepted lots are passed forward and rejected lots are 100% inspected and reworked. Approximating $P_a nI$ P in the previous equation with $Q(P_a I)n/EOQ$ results in the equation $Q(P_a(pD + n/EOQ) + I - P_a I + rp - P_a rp)$, which is reasonable because n depends on Q; n is constant within a range of Q's under MIL-STD-105, a popular published sampling plan; and $Q(SI) = EOQ$ unless p is large. Total annual cost can then be modeled as follows:

$$TC = [U(C + (P_a(n/EOQ + pD) + (I+rp)(1-P_a)))/(1-pP_a) + [US/(1-pP_a)Q] + [hCQ(1-p+pP_a)^2/2] + bQp^2(1-P_a)^2/2],$$

Optimal order quantity is modeled as follows:

$Q(SI) = (2SU/((1-pP_a)hC(1-p+pP_a)^2 + bp^2(1-P_a)^2))^{0.5}$ (Larson 114-115).

Logistical Implications

Several implications for GM grain movement can be extracted from the previous study, especially those pertaining to NI and IS modeling. NI modeling may occur in the supply chain as a result of identity-preserved containerized shipments, which have been designated as GM or non-GM. Testing protocols may be mitigated as buyers and sellers become increasingly cognizant of grain origin, production practices, handling procedures, and logistical movement of GM commodities. IS modeling may be applied to exported grain shipments that fail to meet conformance standards and are sold in an alternative channel such as non-GM grain sold in a GM channel. Wilson and Dahl estimate that the penalty for GM contained in a non-GM shipment follows a uniform distribution with a range of 40-90 c/bu. in the export market and 2-20 c/bu. in the domestic market ("Costs" 29).

Related Studies

Other logistical studies related to quality improvement include Porter and Rayners' process costing model and loss function, which utilize an advanced TQM method for costing quality, quality improvements, plant, facility, and training investment throughout the entire system. Feigenbaums' PAF model (prevention, appraisal, and failure cost) is utilized in identifying quality costs, which include prevention costs (costs of actions to prevent, investigate, or reduce non-conformity), appraisal costs (costs of evaluation quality accomplishment), and failure costs (non-conformity costs endogenous and exogenous to the firm).

Porteus considers setup cost, rework, and investment requirements inherent to increasing quality and reducing setup costs on economic order quantities. The study indicates that increased logistical costs associated with increased quality uncertainty are borne by system participants.

Ross concurs that variation of product quality (inconsistency) is a major factor in determining customer perception of poor quality. Roy states that variation in product quality (inconsistency) is a major factor in the rejection of parts and that the best way to control quality is through minimizing deviations from a target (increasing conformity). Correspondingly, the magnitude of non-conformance loss is dependent on the manufacturing process, target value, cost or rework, scrap, and warranty.

Roy estimates a Taguchi Loss Function, which measures deviations from ideal values and thus total losses imparted to the system from the time a product is shipped until it reaches the customer. However, the Taguchi Loss Function places more emphasis on customer satisfaction than previous loss functions, which focused on the producer. Roy notes important assumptions of the Taguchi Loss Function, including 1) the quality loss function is a continuous function and measures target value deviations; 2) quality loss is essentially a product performance characteristic minimized by devising quality into the product; 3) quality loss is a result of customer dissatisfaction and should be measured system-wide; and 4) quality loss is a social and financial loss. The nominal value estimation of the Taguchi Loss Function can be modeled as follows: $L(X) = k(X - T)^2$, where $L(X)$ is the quality loss, k is the adjustment factor, X is the observed parameter, and T is the parameter target value. An alternative formulation when higher values are better is $L(X) = k / X^2$ and for lower values is $L(X) = k * X^2$.

Tolerances

Statistical tolerancing is one approach for quantifying a threshold for a specified tolerance. High/low specification provides a range about nominal values which, in the case of transgenic testing, will only provide an upper limit. Statistical tolerance assigns a probability of a mechanism to be nonzero, which allows component tolerances to be defined as probability distributions (Evans, “Background” 189). Components may include the presence of a transgenic attribute, which is important for end-users, processors, producers, and input suppliers. A trial-and-error approach is plausible for discerning between GM and non-GM product. The-trial and-error approach includes the following steps: postulate tolerances for testing, perform an analysis to evaluate postulated tolerances, reiterate results until satisfied, evaluate tradeoffs of varying tolerance levels (i.e., out of contract), cost/benefit analysis, and the assignment of a probability of meeting a contract specification (Evans, “Background” 189-190). Tolerance can be disaggregated into regulatory and commercial tolerances, which comprise the conformance guidelines to which suppliers are subjected.

Regulatory

A regulatory tolerance is a government-imposed tolerance designed to provide the assurance of a nutritional and safe food source derived from GMOs. The origination of regulation in the United States evolved in 1986 in response to the publication of the “Coordinated Framework for the Regulation of Biotechnology” (“Safety” 1). The framework explicitly delegates responsibility among three regulatory agencies: the U.S. Department of Agriculture (USDA), the U.S. Food and Drug Administration (FDA), and the U.S. Environmental Protection Agency (EPA). Each agency is responsible for regulatory oversight of dedicated aspects of biotechnology. In addition, each regulatory body measures biotech regulations through the determination of a conventional counterpart and its corresponding substantial equivalent (“Safety” 1).

The USDA agency APHIS (Animal Plant Health Inspection Service) governs biotech plant potential to become a prevalent plant pest in the environment. APHIS's assessment focuses on possible environment/wildlife consequences and the potential for a biotech crop to become a weed ("Safety" 3-4).

The FDA addresses safety issues pertaining to biotech inception and, more significantly, the impacts associated with changes in the crop. Targeted areas include assessment and testing of new genetic material, and agronomic/compositional changes within the plant that may adversely alter existing genetic material ("Safety" 1-2).

The EPA reviews biotech products containing Plant-Incorporated Protectants (PIP) which protect the plant from perilous pests such as insects, fungi, and disease. The EPA examines several facets within the PIP framework, including characteristics of the product, toxicology, non-target organisms, residual risk, and environmental fate ("Safety" 2-3).

The regulatory stipulations of biotech crops and foods have created impediments to the U.S. food export trade with other major international food markets such as the European Union (EU). Contentious negotiations over biosafety protocol, the release of the European Union's (EU) Communication on the Precautionary Principle, and deadlocked discussions within the Codex Alimentarius Commission's (Codex) Committee on General Principles and Food Labeling highlight differences in regulatory philosophy between the two government bodies. Biotech discussion is rapidly evolving in the regulatory sector via import restrictions, approval processes, and tolerance thresholds.

Although certain elements of regulation foster disparities among competing market nations, a consensus among scientific bodies around the world strongly promotes regulatory procedure in the approval of biotech foods for safety assurance. In May 2000, a joint consultation of the United Nations Food and Agriculture Organization and the World Health Organization reasoned that the substantial equivalence approach "is considered the most appropriate strategy for the safety and nutritional assessment of GM foods" ("Safety" 4). Concurrent with its resolution, the Organization for Economic Cooperation and Development food safety task force reiterated, "Safety assessment based on substantial equivalence is the most practical approach to address the safety of foods and food components derived through modern biotechnology" ("Safety" 4).

As of August 1, 2001, numerous U.S. importing countries have established policies and guidelines about biotech acceptance. Table 2.4 lists national rules, their respective import tolerances, and labeling statutes pertaining to GM foods.

Table 2.4. Status of National Rules for Labeling GM Foods

States	Label	Coverage	Effective Date
Australiasia			
Australia & New Zealand	M	1% Content in processed foods, fruits, vegetables, take-aways, and restaurants.	Sept. 2001
Asia			
China	M	All foods containing GM content.	May 23, 2001
Hong Kong	V/M	All foods containing GM content; 5% tolerance.	Est. 2003
Indonesia	M	Article 41, Provisions on Bio-safety of GM Agricultural biotechnology require product label.	NA
Japan	M	Proposed Ministry of Welfare and Health (MWH) regulations could require all GM products to be labeled, regardless of the tolerances; proposed Ministry of Agriculture, Forestry, and Fisheries (MAFF) regulations exempt additives; animal feeds and any ingredient representing less than 5% of content.	April 1, 2001
Russia	V	Decree No. 12 (1999) refers to labeling of GMOs.	NA

Table 2.4. (Continued)

South Korea	M	GM content for corn, soybean, and bean sprouts (and potatoes in 2002) if 1 of top 5 ingredients; 3% tolerance.	March 1, 2001
Sri Lanka	B	Currently ban production or imports of GM products.	Ongoing
Taiwan	M	Processed foods containing GM corn or soybeans; 5% tolerance.	By 2005
Thailand	M	GM content in all foods and raw products; 3% or 5% tolerance.	End 2001
Africa			
Ethiopia	M	All products.	NA
South Africa	M	New law proposed.	2002
Europe (National)			
Austria	M	Opposed to labeling; wants full ban on GM foods.	NA
Czech Republic	M	All products of GM origin or ingredient.	NA
France, Ireland, Spain	M	Want to label GM additives and preservatives.	NA
Hungary	M	Products containing/derived from GM material (excluding feed and novel food).	July 1, 1999
Netherlands	M	Propose mandatory labeling for animal feed.	NA
Poland	M	Conform to EC 219/90 and 220/90.	NA
Slovenia	M	Conform to EC 219/90 and 220/90.	NA
Switzerland	M	Conforming to EC 219/90, 220/90 and 90/679.	NA
United Kingdom	M	Grocery store and restaurant foods on sale in UK before Sept. 1, 1998; not for additives/flavorings.	March 1, 1999
European Union	M	Directive 90/220: law requiring labeling of all foods and food products containing GMOs; no tolerances set.	1990
European Union	M	Regulation 258/97: 1% tolerance; mandatory labeling of foods; no regulation for chymosin, additives, or feeds.	May 15, 1997

Table 2.4. (Continued)

European Union	M	Regulation 1139/98: specific rules for GM soy and maize.	May 26, 1998
European Union	M	0.9% for all food and feed containing GMO material	Nov. 28, 2002
North & South America			
Argentina	V	No required labels; voluntary labels allowed.	Ongoing
Brazil	B/M	Ban currently in force; propose labels with 4% tolerance.	End 2001
Canada	V	Voluntary standards being developed; labels not used in interim.	2001 or beyond
Mexico	M	Senate has approved a bill for GM foods to be labeled as "transgenic" or "made with transgenic products."	NA
United States	V	GM food must be "substantially equivalent" food; exporters will meet EU standards.	2001

Source: Smyth and Phillips 10-11. Note: M=Mandatory Labeling, V=Voluntary Labeling, and B=Ban on GM.

Commercial

A commercial tolerance is an industry-imposed tolerance designated to meet conformance standards for an individual firm. Commercial tolerances evolve contingent on the adoption of a regulatory tolerance and its specified threshold. Currently, corn and soybeans comprise the majority of discussion pertaining to commercial tolerance discrepancy, but in light of the continual inception of new transgenic varieties, commencement of additional deliberation will be imperative. Although not exhaustive, motivation for establishing thresholds can be attributed to disparity in consumer demands, product differentiation, market share, public perception, and/or consumer awareness. Inevitably as transgression of biotech products evolves, commercial tolerances will be adopted concurrently with regulatory mandates in an effort to minimize biotech acceptance cost.

Summary

The topics discussed in this chapter are important for the determination of testing and tolerance strategies for GM commodities. Most relevant to this research are the procedures, costs, risks, and premiums involved with segregation and identity preservation of GM from non-GM grain. Past research in this area has shown that segregation and identity-preservation practices increase cost, involve rigorous conformance to established protocols, mitigate uncertainties, and intermittently provide premiums or incentives.

Testing procedures and protocols continue to evolve, and their respective costs and risks will determine the optimal testing frequency, type, and place. Sampling, sample preparation, and analytical method can directly impact testing performance. Thus, the value of a representative sample, correct preparation, and analytical technique cannot be undermined.

Logistical implications for supply chain management are extensive and focus on quality incentives, inspection policies, and product losses. The rapidly changing logistical role in the movement of transgenic grains and oilseeds will continue to evolve and impact testing and tolerance strategies.

Regulatory tolerances and the advent of new government regulations may facilitate or hinder exportable production. Commercial tolerances will likely be developed concurrently with alterations in regulatory policy with tolerance specification disparities existing throughout the industry; consequently, thresholds play a pivotal role in determining test frequency, methods, and exportability of commodities.

The studies identified lay the foundation for further research in the areas of segregation, identity preservation, and their respective costs and implications as they pertain to GM commodities; the establishment of an optimal tolerance; and desirable supply chain testing points, frequencies, costs, and methodologies employed to adhere to conformance specifications. Specifically, the costs and risks of testing and segregating GM commodities across the supply chain will be examined with per bushel costs quantified.

CHAPTER 3
THEORETICAL MODEL

Introduction

Tolerances play a pivotal role in the determination of an optimal testing strategy to mitigate the risk of non-conformance. An important consideration is the determination of an optimal tolerance whereby customer and supplier objectives are evaluated. Numerous studies have identified tolerance allocation procedures designed to minimize supplier cost and quality loss. The bulk of the research is dedicated to manufacturing processes and the concurrent design of dimensional components to adhere to an overall assembly tolerance. Tolerance, as defined in this context, refers to grain and its maximum allowable contrasting factor(s) such as percentage GM. The definition of tolerance necessitates identifying the factors that comprise its response function, such as consumers, costs, and risks inherent in tolerance assignment.

In this chapter, the definition of tolerance and the factors that impact tolerance will be explored. Next, models to determine optimal tolerances will be discussed. Finally, pertinent studies will be presented.

Tolerance Defined

Wu, Elmaraghy, and Elmaraghy define tolerance as the maximum deviation from a nominal specification within which the component is still acceptable for its intended purpose. Irianto refers to tolerance as a given parameter known as a specification limit. While there are varying definitions of tolerance, a consensus among scholars identifies a relationship between tolerance and cost. Tolerance defines the maximum, minimum, or range of desired target values while cost is specified with respect to testing cost and market loss resulting from non-conformance. The tolerance-cost relationship can be explicitly shown via a mathematical expression over a desired tolerance range. Various mathematical functions have been proposed in the literature to fit manufacturing cost-tolerance field data, including Sutherland, reciprocal, reciprocal-square, exponential, and Michael-Siddall functions (Wu, Elmaraghy, and Elmaraghy 174). The general representation is modeled in Figure 3.1.

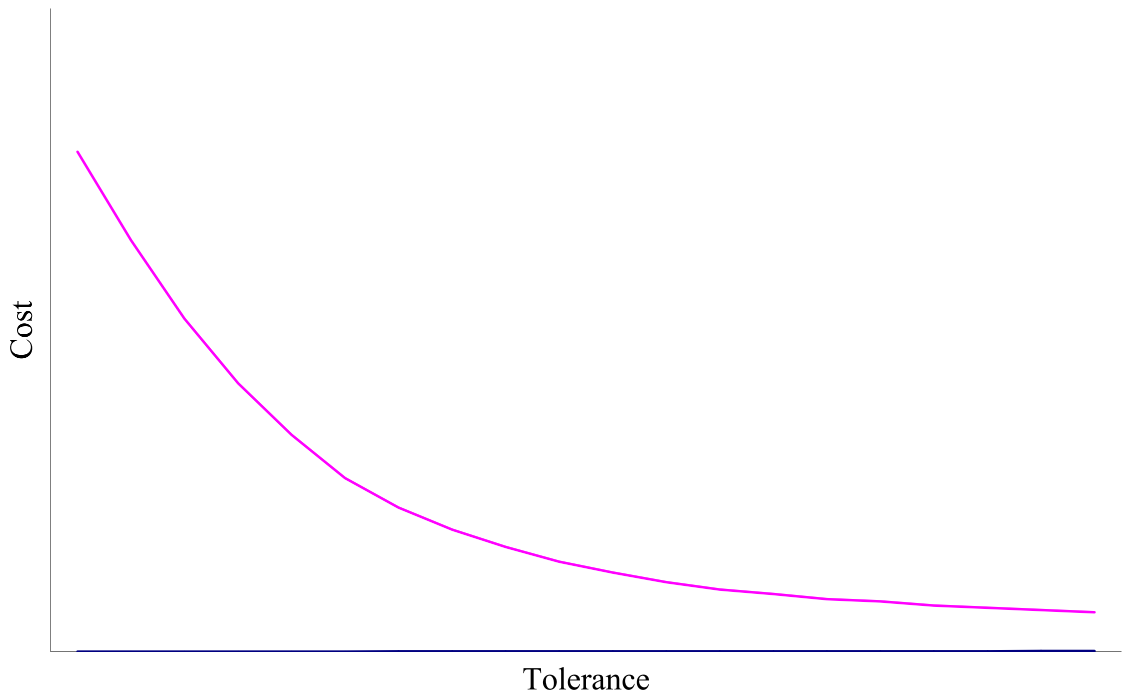

Figure 3.1. Effect of Tolerance on Cost.

Nevertheless, the general relationship exists that, if tolerance is tightened (loosened) it leads to higher (lower) incurred costs because effort is altered to meet specifications (Irianto 588; Jeang, “Optimal” 2188; Jeang, “Tolerance” 28; Wu, Chen, and Tang 227). Tolerances and the specification of an optimal tolerance will ultimately vary depending upon “out of contract costs,” also known as the alternative market discount. Generally, the higher (lower) the discount for non-conforming grain, the tighter (looser) the tolerance specification. The relationship between discounts and tolerances implies that, as non-conformance costs escalate, a more rigorous approach to sampling, testing, and certifying will be adopted. Concurrently, quality loss associated with tolerance specification should be evaluated in conjunction with testing costs to arrive at an optimal tolerance.

Several authors examine tolerance assignment via experimental design techniques utilizing the Taguchi Loss Function, and the concurrent minimization of total cost incorporating manufacturing cost and quality loss costs to determine an optimal tolerance. In addition, other authors attempt to determine least-cost tolerance assignment via computer-aided controlled tolerancing systems, orthogonal array assignment, statistical tolerancing methods, simulation, etc. Pertinent studies will be presented in the following sections and explored in detail to determine optimal tolerances.

Manufacturing Cost Minimization

Wu, Elmaraghy, and Elmaraghy examine numerous dimensional design tolerance synthesis and analysis models to compare tolerance analysis and tolerance allocation methods. Tolerance allocation models are designed to determine what tolerances should be designated along the supply chain in order to adhere to a specified assembly tolerance (i.e., importer tolerance), whereby tolerance analysis models predict assembly tolerances approximating actuality in an attempt to reduce rejects (168). Each model has a significant bearing on optimal tolerance assignment since grain will inevitably be tested throughout many locations along the supply chain to meet an overall tolerance while mitigating the potential for a rejected grain lot.

Tolerance Analysis Models

Engineering dimensional tolerance analysis models reviewed in this study include the following models: worst-case, statistical, Spotts' modified, modified statistical, mean shift, Monte-Carlo, moment, and hybrid (Wu, Elmaraghy, and Elmaraghy 169). The criterion used to discern between the competing models is the ratio of the assembly tolerance calculated by each model when compared to the worst-case models and the percentage rejected due to the difference between the estimated and actual assembly tolerance. The components were assumed to follow one of four distributions, uniform, normal, truncated normal, and Weibull, and to have both equalized and unequalized tolerance chains, where tolerances vary among components (Wu, Elmaraghy, and Elmaraghy 169). Each model calculated different assembly tolerances with varying rejection percentages.

The worst-case model solely guaranteed satisfaction of a specified assembly tolerance with 100% probability for all distributions and tolerance chains. However, individual component tolerances are very tight, and the assembly tolerance is the largest of the group.

The statistical model provided a small rejection percentage for symmetric distributions and the smallest assembly tolerance, but a prohibitive rejection percentage for skewed distributions. Spotts' modified model combines the worst-case and statistical model to reduce predicted rejection percentage for skewed distributions. The modified statistical model reduces the predicted rejection percentage when compared to the statistical model; however, it can still be as high as 16.3%. The mean-shift model is an adaptation of the statistical model and reduces rejection resulting from distribution skewedness (Wu, Elmaraghy, and Elmaraghy 170).

The Monte-Carlo model uses simulation to produce good results when handling skewed, non-normal distributions, but component tolerance distributions must be known with certainty. The moment model's assembly tolerance estimation depends on the component tolerance distribution, and varies from the smallest to largest when using the Weibull and uniform distributions, respectively; however, it has reduced the rejects resulting from skewed and non-normal distributions. Finally, the hybrid model, a combination of the Monte Carlo and moment model, produces results tantamount to those of the latter (Wu, Elmaraghy, and Elmaraghy 171).

The appropriate selection can be made based on the component tolerance distributions employed to predict a tight assembly tolerance range similar to the actual assembly distribution. The statistical and modified statistical are proven candidates when components follow a uniform, truncated, or normal distribution (Wu, Elmaraghy, and Elmaraghy 172).

Cost-Tolerance Functions

The cost-tolerance function aims at optimizing component tolerances while adhering to an assembly tolerance to minimize an overall assembly cost function (Wu, Elmaraghy, and Elmaraghy 173). As previously mentioned, Wu, Elmaraghy, and Elmaraghy examine five functions: Sutherland, reciprocal square, reciprocal, exponential, and Micheal-Siddall. The criterion for evaluation utilizes the nonlinear least square method that is fit to each function whereby the value of the error is minimized and indexed to compare competing functions and indicate goodness of fit and parameter estimations

(174). A tolerance range from 0 to .02 is distributed among three tolerance zones: tight zone (0-.004), medium zone (.004-.015), and loose zone (.015-.02). Results indicate that the Micheal-Siddall function fits the data the best over the entire tolerance range, followed by the exponential function, the reciprocal and reciprocal square functions, and the Sutherland function, which was only suitable for field data in the medium and loose tolerance zones; hence, the Micheal-Siddall function should be used across the entire tolerance range to minimize curve fitting errors (175).

Tolerance Allocation Methods

Wu, Elmaraghy, and Elmaraghy discuss several tolerance allocation methods that have been adopted to minimize total manufacturing costs. Seven methods are considered: proportional scaling, constant precision, Lagrange multiplier, geometric programming, discrete method, linear programming, and nonlinear programming. The exponential cost-tolerance function described previously will be used along with the worst-case tolerance analysis model to compare the seven aforementioned methods. The objective is to minimize manufacturing cost subject to a total assembly tolerance of .05 inches, allocated among 5 component tolerances (175).

Results indicate that the Lagrange multiplier and geometric programming cost-tolerance allocation methods achieve the lowest average cost. However, each function has its shortcomings in its capability to handle cost-tolerance functions. The Lagrange multiplier method does not have the capability to handle the Micheal-Siddall function while the geometric programming method only has the capability to handle the exponential function. Despite these limitations, true optimum solutions can be obtained with simplicity, reliability, and little computational effort. The remaining cost-tolerance allocation methods have the capability to handle all cost-tolerance functions, but remain inferior with respect to average cost, computational effort, simplicity, and/or reliability when compared to the Lagrange multiplier and geometric programming methods (Wu, Elmaraghy, and Elmaraghy 176).

Nagarwala, Pulat, and Raman present a new methodology to solve a tolerance allocation-process selection problem simultaneously. The problem is initially modeled using discrete and continuous variables, and then is transformed into a continuous variable model where an efficient tolerance-cost curve is defined for each component. Subsequently, the tolerance-cost curve is linearly approximated whereby an efficient methodology is employed to solve the problem. Reiteration is performed to minimize the objective function and obtain a feasible solution. The method requires minimal computational effort and proves to be very robust (319).

Gadallah and Elmaraghy present a new method for least cost-tolerance allocation and optimal process selection using an orthogonal-based algorithm. Inner and outer orthogonal arrays are used to represent the tolerance selection domain and the process selection domain, respectively (292). Tolerance allocation is then determined with respect to a range of process precision constraint and an overall assembly functional requirement constraint. Process selection searches for the minimum cost, whereby each design dimension and its resulting cost are required to be greater than zero. The problem is solved using a reiterative approach to the orthogonal-based algorithm until an optimum is reached (294).

Several steps should be followed when designating an appropriate tolerance analysis model, cost-tolerance function, and tolerance allocation method to assess assembly tolerances, to optimize component tolerances, and to minimize the total manufacturing cost, respectively. The proper tolerance analysis model should account for component tolerance distribution functions, data availability, and the a priori criterion aforementioned, including the ability to predict accurate assembly tolerance limits while minimizing estimated percentage rejects (Wu, Elmaraghy, and Elmaraghy 178). Cost-tolerance functions should be chosen to represent cost-tolerance field data in an effort to minimize the value of errors. Resultantly, the value of errors indicates goodness-of-fit and parameter estimations for the function (Wu, Elmaraghy, and Elmaraghy 174). Tolerance allocation methods should achieve two main objectives, the minimization of cost and computational effort, while retaining simplicity, reliability, and the capability of handling multiple cost-tolerance functions (Wu, Elmaraghy, and Elmaraghy 175-176).

Quality Loss

Quality loss is associated with deviation from the target or goal value of a dimension. Several authors regard quality loss as a customer loss when the product or parts do not conform to expectations; consequently, customer loss becomes equivalent to a realized quality loss, manifesting itself through warranty cost, handling cost, customer dissatisfaction, and/or the loss of goodwill (Irianto 589). Hence, the designation of an optimal tolerance must concurrently evaluate the cost of quality loss and testing cost simultaneously to minimize total cost.

Numerous studies identify loss functions that quantify cost of quality loss; however, the Taguchi method has proved to be superior due to its simplicity and good results (D’Errico and Zaino, Jr. 398). Historically, a Lower Allowable Limit (LAL) and an Upper Allowable Limit (UAL) represented the acceptable limits of a design parameter whereby no societal loss was assumed to occur (Roy 11). The goalpost syndrome refers to where no loss occurs within the LAL and UAL region, but where a loss is incurred in the form of an expense whenever the parameter deviates from that range (Ross 4). The Taguchi Loss Function is generally represented with the following notation:

$$L(y) = k(y - m)^2,$$

where

$L(y)$ is the quality loss function,
k is the adjustment factor (constant),
y is the single product quality characteristic,
m is the desired target value.

The aforementioned representation of the loss function assumes that a nominal product quality characteristic is desired so that, if any positive or negative deviation from the nominal occurs, it will be accompanied by a quality loss cost (Irianto 589). The loss function can also be applied in situations in which smaller-is-better and larger-is-better, and is modeled with the notation $L(y) = k(y^2)$ and $L(y) = k(1/y^2)$, respectively.

Experimental Design Techniques

Several studies examine the concurrent optimization of various costs and quality loss to determine an optimal tolerance assignment. The following sections explore the minimization of costs and quality loss in a variety of frameworks.

Inspection and Correction

Irianto explores the Taguchi Loss Function, a quadratic loss function that approximates the balance between customers' loss from performance deviation and producers' effort for performance improvement. In this study, inspection and correction policies are evaluated utilizing two differing policies that represent synchronous and non-synchronous rectification of non-conforming products. The summation of inspection, correction, and hidden quality loss cost, defined via the Taguchi Loss Function, allows the most economical tolerance to be attained while aiding in policy selection. The first policy corrects non-conforming products by using the existing facility, whereas the second policy utilizes a separate correction facility to correct non-conforming products, thereby increasing capacity (588).

Irianto assumed customer dissatisfaction when product quality characteristics deviated from the nominal target value, hence the loss function is defined as follows: $L(y) = k(y-m)^2$. $L(y)$ is the quality loss; k is a constant estimated from claim costs (C_0) and target value (Δ_0) as C_0/Δ^2_0; and y and m are as previously defined. Using X_i to denote a conforming product, the total loss across N_{CONF} conforming products can be represented as $k * \sum_{i}^{NCONF}(X_i - m)^2$. The total value can then be obtained for the cost of quality loss through estimating the distribution of the process as $E[L(y)] = \int_y k(y-m)^2 * f(y)dy$, where $f(y)$ is the probability distribution function of y. When y follows a normal distribution, the expected loss is $k(2\Phi[t]-1-2x\phi(t))$, where $t = (m-\Delta)/\sigma$, $\Phi[-]$ is the cumulative density function, and $\phi(-)$ is the density function of the standard normal distribution.

The second cost component in determining an optimal tolerance stems from inspection of all products and correction of non-conforming products. The total cost can be represented as $TC_\Delta = L_\Delta + C_\Delta$, where L_Δ is the quality loss and C_Δ is the total measurable cost; consequently, the optimal tolerance (Δ^*) minimizes TC_Δ (Irianto 589). Irianto illustrates optimal tolerancing via a numerical example where inspection is assumed to be perfect and the process follows a normal distribution function (591-592). This approach is directly applicable to GM grain and the concurrent determination of an optimal tolerance since quality loss is realized in the form of an alternative market cost when the grain lot is non-conforming, and a measurable testing cost is incurred to meet tolerance specifications.

Manufacturing Optimization

Wu, Chen, and Tang solve the problem of tolerance assignment via a single optimization process to minimize total cost, which includes manufacturing cost and quality loss of assemblies. The authors note that conventional tolerance design lacks a quality factor consideration, but Taguchi's approach ignores variations in manufacturing cost based on tolerances assigned. Thus, a very tight tolerance causes a correspondingly large total cost due to manufacturing, whereas a relaxed tolerance causes a large total cost due to quality loss. Hence, Wu, Chen, and Tang propose a new method whereby quality loss and manufacturing cost are taken into account simultaneously to define an optimal tolerance for both symmetric and asymmetric loss functions (224).

A cost-tolerance curve is determined from the connection between the manufacturing cost of a component and the accuracy level desired. Generally, the manufacturing cost increases as the permissible tolerance decreases and vice versa. Multiple component assemblies require aggregated manufacturing costs of individual components and can be represented as $M = \sum C_i(t_i)$, where M is manufacturing cost, C_i is each individual component, and t_i is the individual component cost. The assembly tolerance is a function of resultant dimensions; therefore, proper tolerance assignments among resultant dimensions assure adherence to the overall assembly tolerance. GM commodities may be represented through the use of resultant dimensions since movement of GM grain across the supply chain necessitates repeated testing at different points to assure conformance (Wu, Chen, and Tang 225). Wu, Chen, and Tangs' interpretation of quality loss is tantamount to that of Irianto, where $L(y) = K(y-m)^2$, and $K = A/\Delta^2$ is determined by estimating an overall loss of A when a product deviates Δ from the target value (226).

The symmetric loss function considers positive and negative deviations from a target value to have equal bearing on quality loss. In order to define an optimal tolerance, the effects of manufacturing cost and quality loss on tolerance assignment must be translated into the same coordinates via a monetary index or resultant tolerance. The following integration, $L = \int_{-\infty}^{\infty} f(y)K(y-m)^2\,dy = Kz^2$, evaluates average loss, L, of a batch product, where f is the density function, y is the resultant dimension, z is the standard deviation of the products' dimension, and m is the target value (Wu, Chen, and Tang 227). It can be rewritten as $L = KAt_r^2$, where A is a constant. Since production data are only available for individual components, the manufacturing cost of the assembly is assumed to be equal to the manufacturing cost of the component and the resulting tolerance to that of the component tolerance. When quality loss and manufacturing costs are plotted, a concave total cost curve is graphically obtained; therefore, the minimum of the curve is the optimal resultant tolerance, t^*. The optimal resultant tolerance, t^*, can also be found algebraically by taking the partial derivative with respect to t of the objective function,

$MinTC = L + M = \sum_{i=1}^{N} C_i(t_i) + KAt_r^2$ (Wu, Chen, and Tang 228).

The aforementioned loss function is only suitable for processes where positive and negative deviations from the target value cause an equivalent loss. An asymmetric loss function can be used to recalculate average quality loss by connecting two segments associated with different constants, K's, at the designed target value where quality loss equals zero. In order to account for differing quality losses that result from positive and negative deviations from the target value, the average quality loss must integrate each loss function separately via the following integrations:

$L = \int_{-\infty}^{m} f(y)K_1(y-m)^2\,dy + \int_{m}^{\infty} f(y)K_2(y-m)^2\,dy,$ where notation is previously defined (Wu, Chen, and Tang 228). If the manufacturing scheme results in symmetrically distributed products on either side of the target value, the integration can be rewritten as $L = 0.5*(K_1 + K_2)*At_r^2$. The objective function minimizes the total cost function: $TC = L + M = \sum_{i=1}^{N} C_i(t_i) + 0.5*(K_1 + K_2)*At_r^2$. Similarly, the optimal resultant tolerance, t^*, can be found by taking the partial derivative with respect to t (Wu, Chen, and Tang 229).

Process-Related Optimization

Wei examines optimal process tolerances by presenting a nonlinear mathematical model that simultaneously considers manufacturing cost, process capability, and quality loss. Historically, process tolerances were maximized to minimize manufacturing costs; however, while wide tolerances reduced manufacturing costs, they concurrently increased quality loss. Therefore, Wei collectively minimizes manufacturing cost and quality loss to arrive at an optimal solution (169). The relationship between tolerance and manufacturing cost is represented by a reciprocal-squared cost-tolerance function,

$C_m = \sum_{i=1}^{n}(A_i + B_i / \Delta_i^2)$, where A_i represents the fixed manufacturing cost, B_i is the cost of producing the component to specifications, Δ_i represents the allowable tolerance, and n denotes the number of components. C_m is modified to $C_m = \sum_{i=1}^{n}(A_i + B_i / \Delta_i^2) * C_{pi}$ to reflect higher manufacturing costs stemming from larger process capabilities (170).

Quality loss is assumed to follow a nominal-is-best Taguchi Loss Function, $L(y) = k(y - m)^2$, where y is the measurement of a quality characteristic, $k = A_c / \Delta_c^2$ is a constant, Δ_c is the consumer's semi-tolerance on either side of the target, and A_c is the loss at either specification limit. The nominal-is-best Taguchi Loss Function can be rewritten as $L = \sum_{i=1}^{n} k_i (y_i - m_i)^2$ when a product is comprised of several components (Wei 170). Denoting μ_i and σ_i for the mean and variation, respectively, the expected overall quality loss for the assembly is as follows, $E(L) = \sum_{i=1}^{n} k_i * [\sigma^2 + (\mu_i - m_i)^2]$. If $\sigma_i = \theta_i \Delta_i$ and $\delta_i = \mu_i - m_i$ when θ is zero to one, and θ is a constant, the former equation can be written as $E(L) = \sum_{i=1}^{n} k_i * [(\theta_i \Delta_i)^2 + \delta_i^2]$, and the total cost equation is as follows:

$$TC = C_m + E(L) = \sum_{i=1}^{n}(A_i + B_i / \Delta_i^2) * C_{pi} + \sum_{i=1}^{n} k_i * [(\theta_i \Delta_i)^2 + \delta_i^2] \text{ (171).}$$

The optimal tolerance is found by minimizing the objective function, $TC = \sum_{i=1}^{n}(A_i + B_i / \Delta_i^2) * C_{pi} + \sum_{i=1}^{n} k_i * [(\theta_i \Delta_i)^2 + \delta_i^2]$, subject to quality constraints. The worst-case constraint requires all components to be produced within the tolerance limit, necessitating 100% inspection, whereas the statistical tolerance constraint allows some non-conforming components. The objective function can be solved via a nonlinear programming solver package such as General Interactive Optimizer (GINO) and/or analytically by taking the first derivative of TC and setting it equal to zero to obtain $dC_t / d\Delta_i = -2B_i\Delta_i^3 C_{pi} + 2k_i\theta_i^2\Delta_i = 0$ and performing substitutions to arrive at $\Delta_i = [(9 * B_i * C_{pi}^3) / k_i],$ where tolerance relates to process capability (Wei 171-172).

Constrained Optimization

Krishnaswami and Mayne employ a procedure for optimizing the allocation of tolerances that considers manufacturing cost and product quality in a constrained optimization framework. They explore a bearing clearance and an overrunning clutch problem to illustrate the effectiveness of their proposed model (211). The Taguchi Loss Function is specified as $L = A / \Delta^2 * (y - m)^2$, where A is the cost of repair when dimensions are non-conforming, m is the dimension target value, Δ is the dimension tolerance, and y is a particular dimensional value. The loss, L, describes the cost of a non-conforming dimension when the target value is not realized; however, full loss does not occur until the assembly tolerance is violated. If the functional dimension is assumed to follow a normal distribution with its mean at the target value, quality loss can be rewritten in terms of the standard deviation of the functional dimension as $L = A / \Delta^2 * \sigma^2$ (212). Manufacturing costs were obtained via the exponential cost-tolerance function utilizing actual cost data for varying tolerance specifications. Then, an optimal tolerance allocation procedure utilizing nonlinear programming techniques is employed to minimize the total cost (213). Similarly, Taguchi examines loss function with smaller-is-better characteristics, where the target value is zero and no negative values are assumed. The loss function can be represented as follows: $L = (A_0 / \Delta_0^2) * \sigma^2$, where Δ_0 is the consumer upper tolerance limit, A_0 is the loss imparted to society when the upper tolerance limit is exceeded, and σ^2 is the variance. The variance for GM lot concentration from zero can be calculated by averaging variance for all bushels within the delivered lot (Taguchi 121-122).

The objective function is Minimize Total Cost = Additional system testing costs (all supply chain points) + Quality Loss $((A_0 / \Delta_0^2) * \sigma^2)$ of non-conformance to a target value of zero GM lot concentration (Taguchi 122). The optimum testing and tolerance strategy can be derived from the preceding enumeration and ultimately depends on the desired importer tolerance specification. The economic tradeoff between testing costs and quality loss is shown in Figure 3.2.

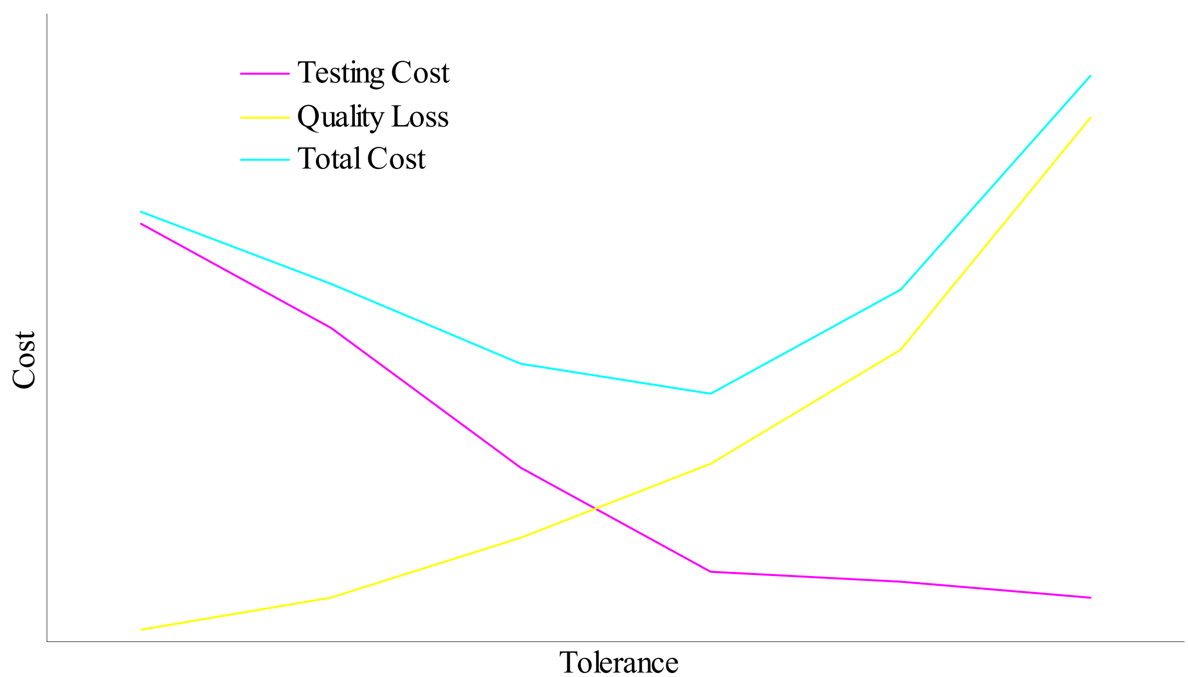

Figure 3.2. Economic Tradeoff Between Testing Cost and Quality Loss.
Source: Krishnaswami and Mayne (214).

Comparative statistics were conducted on critical parameter A_o, which represents the loss imparted to society. Results concluded that, for increasing (decreasing) values of A, the resulting optimal tolerances were tightened (loosened) to avert non-conformance (Krishnaswami and Mayne 214). This study provides evidence that, as "out of contract costs" increase, tolerances will be correspondingly tightened and vice versa. The cost-tolerance relationship presents several implications for testing strategies across the supply chain and/or the testing methodologies that will be utilized.

Objective-Based Optimization

Soderberg examines tolerance allocation with regard for both customer and manufacturer objectives. Essentially, an extended quality loss function is used to model customer objectives while a manufacturing cost function for critical dimensional tolerance is used to consider the manufacturer's objective. The customer's total loss function and the minimum manufacturing cost function are then solved concurrently to determine the optimal tolerance limits of the critical dimension (149).

The total manufacturing cost refers to the sum of different costs that contribute to manufacturing, such as machine payments, maintenance, and/or operator costs. The extent of manufacturing cost depends on tolerance specification because tight tolerances necessitate additional expenses; for example, a tight GM tolerance may require a unique testing apparatus. While manufacturing costs can be estimated with cost data, it is common practice to use a defined mathematical cost-tolerance function such as one highlighted in the preceding sections. Soderberg represents the cost function as $C(t) = k_1 + k_2 /(t + k_3)$, where k_1, k_2, and k_3 are parameters that shape the cost-tolerance curve; and $C(t)$ is the manufacturing cost for a specified tolerance (t) (150). Adding in fixed costs, the equation can be rewritten as $C_m(t) = C_f + \sum C(t),$ where C_f is fixed cost and $\sum C(t)$ is the summation of variable costs (151).

The lowest manufacturing cost can be attained for products involving a tolerance chain (i.e., several dimensional tolerances) by the optimal combination of dimensional tolerances that still adhere to an overall final tolerance. Thus, the minimum manufacturing cost as a function of the critical tolerance depends upon the optimal selection of several dimensional tolerances $(t_i ... t_n)$ and can be written as follows:

$Min(C_m(t_c) = Min(C_{mi}(t_i) + ... C_{mn}(t_n)),$ where $C_m(t_c)$ is the manufacturing cost of the final tolerance, C_{mn} represents n manufacturing costs, and t_n denotes n tolerances. If the individual dimensions are assumed to be normally distributed, the minimum manufacturing cost is a function of the critical tolerance represented as follows:

$t_c \geq \sqrt{(B_i t_i)^2 + ... + (B_n t_n)^2},$ where $B_1 ... B_n$ are relative sensitivities and $t_1 ... t_n$ are individual tolerances (Soderberg 151).

Quality loss is considered via an extension of the method proposed by Taguchi, whereby the definition of quality is altered to refer to the relationship between the critical dimension and the total life of the component. The functional tolerance of a product speaks volumes about its respective quality; consequently, deviations from the target value may result in a quality loss. Costs related to deviations from the expected useful life are alluded to as functionality loss, L_f. The relationship between critical dimensions, and the corresponding loss to the customer allows L_f to be expressed as a function of the critical tolerance, $L_f(t_c),$ where loss decreases with tighter tolerances (Soderberg 151). The second component of quality loss refers to the inflated price that the customer is forced to pay as a result of increased tolerance-related manufacturing costs. It is denoted as $L_p(t_c)$ and includes total manufacturing cost and manufacturing profits. The total loss function is represented as $L(t_c) = L_f(t_c) + L_p(t_c)$ (Soderberg 152).

The optimal tolerance allocation from the customer's viewpoint is $Min(L(t_c))$, where a looser tolerance would lead to functionality loss and a tighter tolerance would lead to higher prices. However, to satisfy both the customer and manufacturer, the sum of the total loss and the manufacturing cost is minimized as follows: $Min(L(t_c) + C_m(t)$. The optimization method ensures that the manufacturer takes responsibility for the customer's satisfaction since the customer's loss is included. When the loss function is asymmetrical around the nominal value, optimal tolerances are determined by separately examining the summated total cost curve on either side of the nominal value. The optimal tolerance limit, t_{opt}, is given for each side or the nominal value as $Min(L(t) + c(t)) = L(t_{opt}) + C(t_{opt})$ (Soderberg 152). The customer is subjected to a quality loss when a product or component suffers a breakdown, commonly referred to as nominal cost, C_n. Sensitivities about the nominal cost corroborate with previous studies in that, as the nominal cost of the total loss to the customer increases, the allowable tolerance correspondingly decreases, and vice versa (Soderberg 156).

Machining Optimization

Jeang derives a mathematical model to minimize both machining cost and quality cost to determine the optimal tolerance specification for machined parts. Jeang concurs that, as tolerance specifications are tightened, machining cost correspondingly increases from attributable factors such the need for additional machining operations, more expensive equipment, and/or reduced cutting rates. Quality cost, which represents the cost of deviating from an ideal target value, also varies with tolerance assignment and can be modeled using a loss function ("Tolerance" 27).

In this study, quality loss refers to the cost of the deviation to society and may include reduced product performance and/or subsequent assembly operation cost. Product quality can be increased through the widening of product tolerance limits while manufacturing variability remains constant or through a reduction in manufacturing variability by improving the quality of materials and processes. Process capability, C_p, relies on the aforementioned procedures and is defined as C_p = (tolerance interval)/6 * (standard deviation), where tolerance interval is determined by the designer and the standard deviation is specified by process and internal quality policies. The standard deviation can be expressed as $p = t/\sigma$, where p is the index that indicates process capability. Since $C_p = 2t/6\sigma$, it is equivalent to $1/3 * p$ or $p = 3 * C_p$; therefore, when C_p is known, p can be estimated and used to specify tolerance. Quality cost is estimated with a loss function that assumes a symmetrical distribution around the target value and is modeled as $L(y) = k(y - T)^2$, where L is the loss function, y is the machined part characteristic, T is the target value, and k is a constant. Since k can be estimated by $k = A/t_0^2$, where A is the cost of repair or rework of the product associated with t_0 and t_0 is the corresponding product tolerance, the loss function can be expressed as $L(y) = A/t_0^2 * (y - T)^2$ (Jeang, "Tolerance" 28).

The product machining cost increases (decreases) as product tolerance ranges for individual characteristics are tightened (loosened). Historical cost reduction charts designated for designers and production engineers indicate that machining cost as a function of tolerance specification decays geometrically and can be expressed as $C_m = b / t_a$, where C_m is the machining cost, t is the tolerance specification, and a and b are constants that vary with different machining operations. A goodness-of-fit exercise is undertaken to evaluate the aforementioned cost-tolerance function, and statistical accuracy indicates that the model approximates an error-free curve (Jeang, "Tolerance" 29).

The optimal machining tolerance is determined across three different models that make use of different assumptions. Each model will be discussed, and the optimal tolerance will be derived accordingly. The first model assumes that the number of non-conforming parts is negligible, thus the part characteristic measurements are represented with a symmetric triangular distribution. The triangular distribution and the specified tolerance utilize the same range, thus the distribution of the process depends upon the tolerance specification. The expected quality cost is expressed as $E[L(y)] = E[k(y-T)^2] = kt^2 / 6$ since the variance is give as $t^2 / 6$. The optimal objective function is $MinC(t) = E[L(y)] + C_m = kt^2 / 6 + b / t_a (k,t,a,b > 0)$, and can be solved by taking the partial derivative with respect to t and setting it equal to zero to obtain $t^* = (3ab / k)^{\frac{1}{a+2}}$ (Jeang, "Tolerance" 30-31).

The second model assumes that the characteristic measurements follow a normal distribution with mean T and standard deviation σ. The expected quality cost is given by $E(L) = E[k(y-T)^2] = kE(y-T)^2 = k\sigma^2$. Substituting t / p for $\sigma, E[L(y)] = k(t / p)^2$, the optimization model can be represented as follows: $MinC(t) = E[L(y)] + C_m = k(t / p)^2 + b / t_a (t,a,b,p,k > 0)$, and solved by taking the partial derivative with respect to t and setting it equal to zero to obtain $t^* = (abp^2 / 2k)^{\frac{1}{a+2}}$ (Jeang, "Tolerance" 31).

The third model assumes that a 100% inspection is performed; consequently, all parts shipped to the customer will be conforming since any non-conforming part will be reworked or scrapped before shipment. It is assumed that any non-conforming part that is reworked or scrapped will not require additional reworking. Since the inspection and correction can be estimated using the machining cost, C_m, the total cost is defined as follows: $C(y) = k(y-T)^2 + C_m$, where $C_m = b / t_a$. The expected total cost can be represented with the integral as follows: $\int_{T-t}^{T+t} k(y-T)^2 f(y)(T, t/p)dy + C_m$, where $fy(T, t/p)$ is the normal probability density function of y with a mean of T and standard deviation of t/p. A search method is typically employed to arrive at the optimal t^*; however, the t^* from model 2 is initially used, and incremental analysis is performed to find the lowest total cost and the corresponding t^* (Jeang, "Tolerance" 31-32).

The models developed in the preceding sections serve a twofold fundamental role: a management tool for determining the optimal tolerance for a part characteristic and a design tool for achieving an economical manufacturing process using a specified tolerance. Input parameters that need to be estimated for the development of the cost function include the target value, T; the manufacturing cost-tolerance function, C_m; and the standard deviation of the manufacturing process, σ (Jeang, "Tolerance" 32).

Comparative statistics are conducted on the critical parameters, t, k, a, and b, to determine their effect on the optimal tolerance, t^*. As the tolerance, t, is tightened (loosened), quality cost decreases (increases), and machining cost increases (decreases), resulting in the tradeoff between quality cost and machining cost for determining the optimal tolerance t^* (Jeang, "Tolerance" 32). The optimal tolerance, t^*, decreases (increases) at higher (lower) values of k, reflecting the value placed on customer satisfaction. An increase (decrease) in the critical parameters, a and b, generate an increasing (decreasing) optimal tolerance. Although each of the critical parameters precipitated a change in t^*, the incremental changes in t^* decreased as the parameters increased, which suggests that there is a reduced sensitivity for higher values of k, a, and b. The aforementioned sensitivities are all important in determining the optimal tolerance, t^*, although t^* is most sensitive to parameter a, hence constants for varying machine operations must be cautiously assigned (Jeang, "Tolerance" 33).

Alternative Tolerance Methodologies

Additional methods have been proposed to deal with tolerance assignment, thus they will be briefly discussed. Evans reviews statistical tolerancing and methods that are applicable for assigning component tolerances (Zhang and Huq 2125). The response of a mechanism and its respective component values are defined as follows: $X = f(y_1, y_2, ...y_n)$, where X is the response vector and y_i are component values (Evans, "Background" 194). Methods for estimating the moments of X are explored and include the following: linear case, extended Taylor-Series approximation, approximation by numerical integration, and Monte Carlo (Evans, "Methods" 1).

D'Errico and Zaino, Jr. examine alternative statistical tolerancing procedures and demonstrate their superiority when contrasted with the Taguchi method (397). A modification of the Taguchi method is employed to estimate moments and provide uniformly better approximations of the distribution of $f(x)$ (400). The method is applied by creating a three-level factorial experiment where the mean of each variable is the center variable and $\mu_i +/- \sigma_i * \sqrt{3}$ are the high and low variables, respectively (400-401).

Kim and Knott use a pseudo-boolean programming approach in determining least-cost tolerances. The approach utilizes both arithmetic and statistical models to specify tolerances on components so that functional requirements are met and cost is minimized (157).

Zhang and Huq compile a comprehensive summary of state-of-the-art tolerancing techniques where theories are examined to link tolerances to process or production cost. Five categories of tolerancing techniques are presented: dimensional tolerance chain techniques, geometric modeling in tolerances, statistical and probabilistic methods in tolerancing, tolerances based on analysis and synthesis, and tolerances based on cost-tolerance algorithms and design methods (2111). Several of the aforementioned studies are included in their analysis; additionally, computer-aided tolerancing techniques and their respective impacts on Computer-Aided Design (CAD) and Computer-Aided Manufacturing (CAM) are discussed (2118).

Summary

The topics discussed in this chapter provide a point of departure for the determination of an optimal tolerance. Although the majority of the literature deals mainly with manufacturing, the methodologies are readily adaptable to the underlying thesis. Most relevant to this research are the proposed methodologies that incorporate cost and quality loss in a framework that accounts for both customers' loss and producers' effort.

Tolerance analysis models were reviewed with regard to their effectiveness in approximating assembly tolerance ranges tantamount to the actual assembly distribution and minimizing the probability of rejection. Four component tolerance distribution functions were utilized: the uniform, normal, truncated normal, and Weibull distribution.

Numerous cost-tolerance functions were evaluated to determine their capacity in the concurrent optimization of component tolerances and the minimization of cost. The general relationship exists that, if a tolerance is tightened (loosened), it results in higher (lower) cost because effort is altered according to specifications (Figure 3.1). The Micheal-Siddall function proved superior due to its adaptability and overall goodness-of-fit.

Tolerance allocation methods were explored to minimize total cost and computational effort. The Lagrange multiplier and geometric-programming cost-tolerance allocation methods achieved the lowest cost while requiring minimal computational effort, albeit certain cost-tolerance functions were not applicable.

Quality loss was expressed using a Taguchi Loss Function when nominal, lower, and higher product-quality characteristics are desired. Subsequently, several experimental design techniques were discussed; models were developed; and optimal tolerances were obtained. Sensitivities of the critical variables were explored, and impacts were examined in relation to optimal tolerance, t^*, specification.

The studies lay the foundation for the development of an optimal tolerance and testing strategy for GM grain. Non-conformance of GM grain may be modeled using the Taguchi Loss Function because it estimates the loss due to a non-conforming product. Furthermore, testing costs and accuracies may be accurately depicted using a manufacturing cost tantamount to the aforementioned studies since testing cost increases as tolerances are tightened. As tolerance changes, quality loss cost and testing cost vary antagonistically with one another; consequently, an optimal tolerance that minimizes the summation of the two can be achieved (Figure 3.2).

CHAPTER 4
EMPIRICAL MODEL

Introduction

This chapter describes the development of a dual-marketing system with testing and segregation of GM/non-GM flows along the grain marketing chain from growers to either importers or domestic end-users. An inherent assumption in the model is the rate of GM adoption. Grain marketing locations included in the model are the country elevator, export elevator, importer, and domestic end-user.

The model utilizes *Risk Optimizer™* to minimize disutility of additional system costs, which are comprised of testing cost and quality loss for all marketing locations. It allows calculation of the risk premium required for grain handlers to undertake a dual-marketing system versus a non-GM system (Palisade 1). Testing costs commensurate with respect to application point, intensity, and applied tolerance. The handler/shipper is subjected to an implicit risk for participating in a dual-flow system; consequently, a risk premium is required to provide indifference between the current non-GM system and a system handling both GM and non-GM segregations. Quality loss is incurred at change of ownership points and is calculated based on the deviation from the target value for GM lot concentration, which is assumed to be zero. Model assumptions include level of GM/non-GM adoption, probability distributions for adventitious commingling, variety declaration, and binomial distributions to explain the probability of acceptance given varying tolerances and percentage concentration in the lot. Tests are applied at various grain marketing locations when received and loaded to identify non-GM grain flows that exceed GM tolerances. The lots identified are correspondingly diverted to GM flows and subjected to quality loss. Non-GM and GM flows are tracked throughout the system to identify the quantity of non-GM grain delivered and the amount of GM grain diverted.

A grain flow diagram and a general description of model components are presented in the first section. Succeeding sections examine the Mathematical Model Description, model elements, parameter specifications, data sources, and simulation procedures. Figure 4.1 provides an illustration of grain flows in a dual-marketing system. Grain flows are tracked throughout the system as non-GM clean, non-GM commingled, and GM. Non-GM grain is subjected to adventitious commingling risk via farmer variety declaration and handling functions inherent in the system. GM lots are diverted at the marketing chain point when they are identified in the non-GM stream and subjected to quality loss. The distribution of grain flows upon arrival at the importer or domestic end-user determines the allocation of additional system costs for non-GM grain.

Model Overview

The model simultaneously determines the optimal testing strategy (application, intensity, and tolerance) to employ for a dual-marketing system encompassing non-GM and GM grain flows. Incentives to adopt in a dual-marketing system are provided to market chain participants via a risk premium, which is specified as $\pi = EV_{NGM} - CE$, where π is the value of the risk premium, EV_{NGM} is the expected costs for a dual system, and CE is the certainty equivalent of the utility of additional costs for a dual-marketing system. The premium, π, represents the point at which decision makers would be indifferent between a non-GM and dual system.

Testing locations in the grain marketing chain include country elevator receiving, country elevator loading, export elevator receiving, export elevator loading, and either

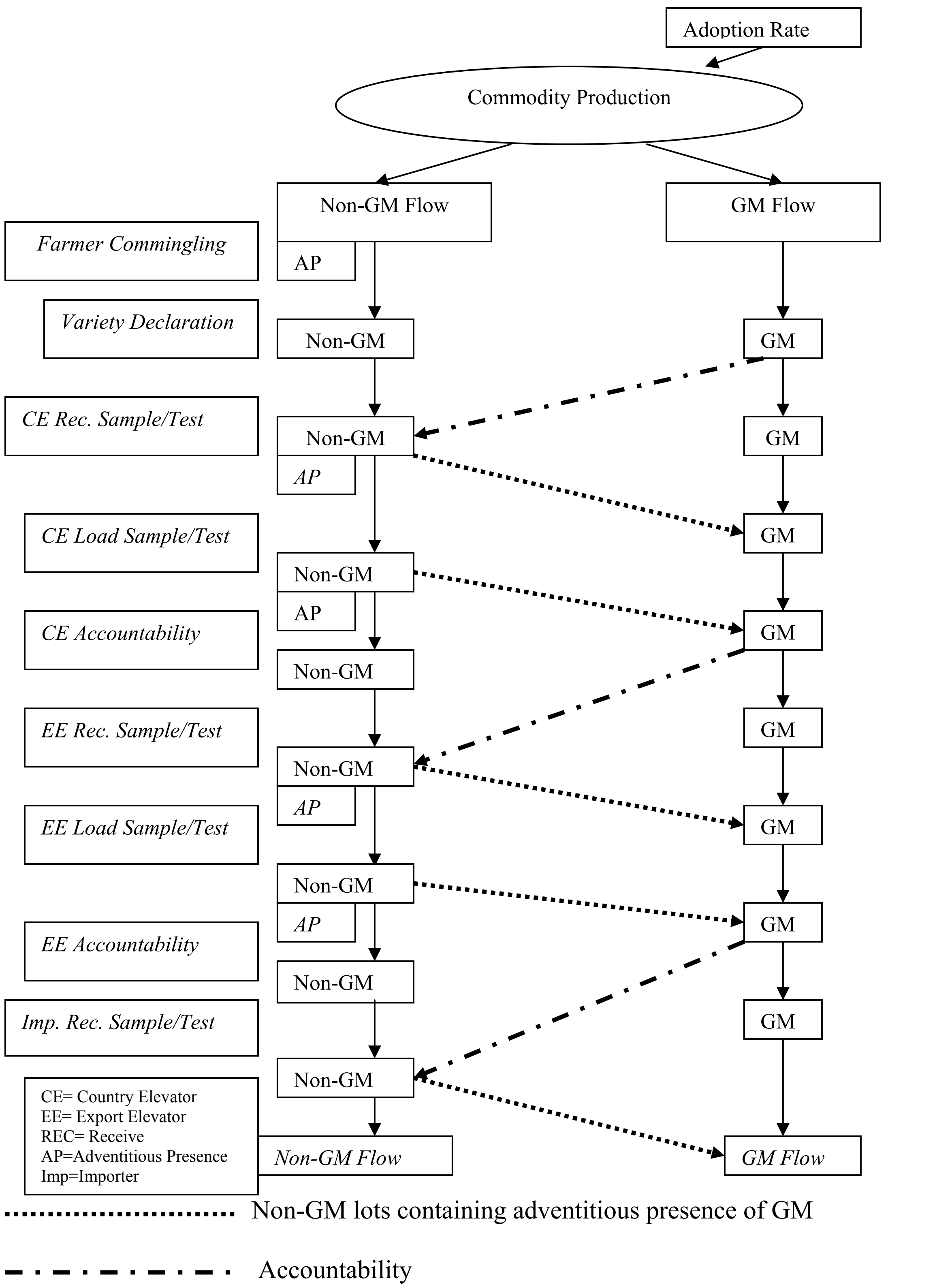

Figure 4.1. Grain Handling Subject to Adventitious Presence.

importer or domestic end-user receiving. Tests can be applied at any of the aforementioned points with varying discrete intensities (1:1 to 1:5) and tolerances (.04% to 5%). Strip tests are utilized at country and export elevators to provide low cost, accurate, and timely results while PCR tests are employed at the importer and domestic end-user to reflect industry practices (EnviroLogix, Inc.). Tests are required on every lot at importer and domestic end-user locations at a predetermined tolerance concurrent with industry procedures.

Mathematical Model Description

Utility Specification

The mathematical model developed is a stochastic optimization model of a grain marketing chain that utilizes an objective function to quantify a risk premium (Saha). Expo-Power Utility, a flexible form for absolute and relative risk aversion, was developed initially by Saha and previously used by Serrao and Coelho to determine optimal cropland allocation and risk premiums for crop insurance programs. The objective function contains a von-Neumann-Morgenstern type utility function with decreasing absolute risk aversion and increasing relative risk aversion. The model chooses the optimal testing strategy (where to test, test intensity, and test tolerance) that maximizes portfolio utility (minimizes portfolio disutility) by minimizing additional system costs for a supply chain handling a portfolio of segregations representing two states of nature (non-GM and GM). The portfolio utility is comprised of the weighted disutility of additional system costs (testing and quality loss) for handling both states of nature. The objective function can be expressed by the following equation:

$$MaxU = Max(C) = \sum_{i=1}^{2} \delta_i (\lambda - e^{(-\phi C_{ij}^{n})})$$

$S.T.\ X_j \in K_j$,

where

δ_i is the proportion of flows devoted to each state of nature i;

e is the natural logarithm;

λ is a parameter that determines positiveness of the utility function;

ϕ and η are parameters that affect absolute and relative risk aversion of the utility function;

C_{ij} is additional system costs for each state of nature i;

X_j is the decision variable vector of the model;

K_j is the opportunity set of the model;

i is states of nature: Non-GM, 1 and GM, 2;

j represents test application, T_μ, and sampling intensity, $S_{\mu i}$, at location μ and tolerance i.

Parameters of the utility function are λ, ϕ, and η. A value of $\lambda = 2$ corroborates with Saha and guarantees positiveness of the utility function. Parameter ϕ linearly affects the absolute risk aversion coefficient when parameter η is held constant. Hence, the variation of parameter ϕ amplifies the risk aversion coefficient without altering the solutions. However, parameter η exhibits a nonlinear behavior relative to the absolute risk aversion coefficient when ϕ is held constant. Since the objective function is more sensitive to η versus ϕ, parameter ϕ is fixed at 0.01, and η is allowed to vary from 0.4 to 0.9. Thus, λ and ϕ are fixed, and sensitivities are conducted about η.

Additional System Cost

The additional system costs of a dual-marketing system are composed of testing and quality loss costs. Risk premium is an additional system cost to compensate grain handlers. The risk premium utilizes λ, ϕ, η, and portfolio utility to define the additional revenue required for decision makers to be indifferent between a non-GM and a dual-marketing system.

Testing costs are summed across grain marketing points. A strip test is used at all intermediate points (i.e., country elevator and export elevator) and a PCR test is used at the importer or domestic end-user.

Quality loss cost is incurred at change of ownership points when grain is delivered. A Taguchi Loss Function with smaller-is-better characteristics is employed to calculate loss imparted to society, which emanates from production and customer costs. In the case of an integrated firm, quality loss only occurs at the final destination point (importer or domestic end-user) and is calculated based on the deviation from a target value of zero. The following sections provide detailed additional system cost calculations.

Risk Premium

The risk premium compensates the handler/shipper for potential risks emanating from detection of GM content in a non-GM flow, which is subject to quality loss. The risk premium is derived from the expected value of the system as follows:

$$\pi = EV_{NGM} - \hat{C}_{GM/NGM},$$

where

$$U(\hat{C})_{GM/NGM} = EU(C)_{GM/NGM} = E(\sum_{i=1}^{2} \delta_i (\lambda - e^{(-\phi \hat{C}_{ij}^{n})})$$

π is the risk premium for the dual system, EV_{NGM} is the expected additional cost of a dual system assumed to be zero, $\hat{C}$ is the certainty equivalent of additional system costs for a dual system, and other parameters are as previously defined.

Testing Cost

Testing costs are incurred at grain marketing locations where tests are applied and vary with testing intensity and tolerance. Strip tests are utilized at receiving and loading functions of the country and export elevator locations while PCR tests are used at the domestic end-user and importer locations. Testing technologies and their respective costs, accuracies, and tolerances are presented in Table 4.1.

Table 4.1. GM Testing, Tolerances, Costs, and Accuracies

Tolerance (%)	Accuracy(%)	Required Seeds	Cost per Test ($)
Strip Tests			
0.04	95	8000	28.0
0.05	95	6000	21.0
0.075	95	4000	14.0
0.10	95	3000	10.5
0.25	95	2000	10.5
0.50	99	1000	3.5
0.75	99	1000	3.5
1.00	99	1000	3.5
2.00	99	400	3.5
3.00	99	400	3.5
4.00	99	125	3.5
5.00	99	125	3.5
PCR Tests			
0.01	99	10000	275
0.05	99	10000	275
0.075	99	10000	275
0.10	99	7500	262
0.25	99	5000	250
0.50	99	2500	250
0.75	99	2500	250
1.00	99	2500	250
2.00	99	2500	250
3.00	99	2500	250
4.00	99	2500	250
5.00	99	2500	250

Source: Strategic Diagnostics, Inc. (Strip) and Midwest Seed Services, Inc. (PCR).

Additional system costs arising from testing are defined as follows:

$$C_{NGM} = \sum_{\mu=i=1}^{n} T_{\mu} * TC_{\mu i} * S_{\mu i} * V_{NGM\mu}$$

$$C_{GM} = 0,$$

where

C_{NGM} is the additional testing cost accrued to maintain GM separation for non-GM shipments;

C_{GM} is the additional cost for GM bushels;

μ is the location within the system where tests can be applied (country elevator receiving, country elevator loading, export elevator receiving, export elevator loading, importer receiving, or domestic user receiving);

T_{μ} is the binary variable reflecting whether tests are applied at location μ;

$TC_{\mu i}$ is the cost of individual test for location μ and tolerance i;

$S_{\mu i}$ is the sampling intensity (number of samples per lot) at location μ and tolerance i;

$V_{NGM\mu}$ is the volume (number of lots) of non-GM grain handled at location μ.

Quality Loss

A Taguchi Loss Function with smaller-is-better characteristics is utilized to calculate quality loss imparted to society. The function does not take on negative values and has a target value of zero (Taguchi 121). The loss imparted to society is composed of costs incurred by the handler/shipper and the end-user. The handler/shipper is exposed to rejection cost and loss of future business, etc. by the end-user while the end-user is exposed to substandard grain quality (Ross 3). Thus, the handler/shipper utilizes testing to reduce quality loss, and the end-user specifies a tolerance to assess quality deviations. Quality deviations from the target value of zero represent an implicit cost to the system, thus shipments containing minimal GM content incur quality loss. Quality loss is incurred by the handler/shipper at the importer (40-90 c/bu.) and domestic end-user (2-20 c/bu.) when non-GM shipments contain a GM lot concentration equivalent to the buyer upper tolerance limit. Shipments containing lower (higher) lot concentrations incur smaller (larger) quality loss. Figure 4.2 illustrates the effect of GM lot concentration on quality loss.

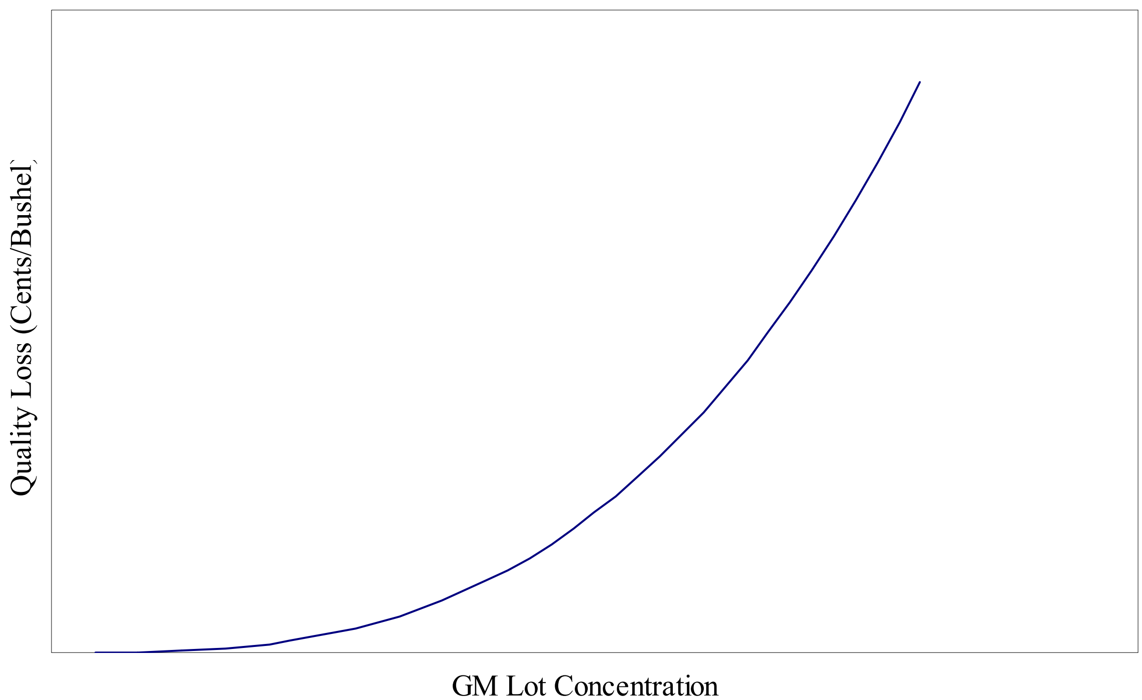

Figure 4.2. Effect of GM Lot Concentration on Quality Loss.

Additional system costs attributable to quality loss are defined as follows:

$$L = \frac{A_o}{\Delta_{o^2}} * \sigma^2,$$

where

L is the Taguchi Loss Function with smaller-is-better characteristics;

Δ_o is the imposed buyer upper tolerance limit;

A_o is the loss imparted to society when the upper tolerance limit is exceeded;

σ^2 is the average lot variance for the distribution of GM lot concentration at change of ownership points from a target value of zero.

The summation of the aforementioned components of additional system costs is represented as follows:

$$C_{NGM} = \sum_{\mu=i=1}^{n}(T_{\mu} * TC_{\mu i} * S_{\mu i} * V_{NGM\mu}) + (\frac{A_o}{\Delta_o} * \sigma^2),$$

where C_{NGM} is the additional testing and quality loss cost added to non-GM shipments to maintain GM separation, and other parameters are as previously defined.

Total Cost

The risk premium, testing cost, and quality loss constitute total cost for a dual-marketing system. Total economic cost includes a direct cost component and an indirect cost component. The direct component accounts for testing costs along the supply chain, and the risk premium required to induce the handler/shipper to handle both GM and non-GM grain. The indirect component accounts for quality loss incurred at any deviation above the target value of zero. The aggregation of both components equates a total economic cost that the organization can expect to incur through cash outlay, customer dissatisfaction, loss of future business, goodwill, etc. (Ross 3).

Detailed Description of Model

This section provides a more detailed description of the model. The flow of grain and how additional system costs are calculated is included in the following sections.

Country Elevator Receiving Details

An underlying GM adoption rate is assumed for GM wheat. Total production is partitioned into a non-GM and GM grain stream. Non-GM lots are further apportioned as non-GM clean and non-GM adventitious presence (AP) depending upon the level of on-farm adventitious commingling. Adventitious commingling at the farm level stems from planter, combine, cross-pollination, and logistical risks (Bullock, Desquilbet, and Nitsi 5-6). Non-GM and GM lots are originated at the country elevator subject to farmer variety declaration. Subsequently, a binomial distribution is utilized to confer operating characteristic (OC) curves that identify the probability of accepting a non-GM lot given its underlying lot concentration and a specified tolerance. Sampling parameters within the non-GM stream are population size, sample size, and defective units. The two former parameters are based on lot specification and sampling intensity, respectively, while the latter is calculated from the binomial distribution.

The model chooses whether to apply a test at each grain marketing point and its accompanying intensity and tolerance. Hence, if a test is applied, samples are drawn, identified, and diverted accordingly. Non-GM and GM flows are partitioned at the commencement of testing. Identified GM flows are diverted to the GM grain stream. Non-GM flows are divided into non-GM clean and non-GM AP by accounting for sampled and rejected, unsampled and rejected, and misidentified lots. Sampled and rejected lots are lots that have been sampled and identified as GM. Unsampled and rejected lots are lots that have not been sampled but are equally represented by a sampled lot when testing intensities are less than 1:1. Misidentified lots are sampled and rejected lots that contain a Type I error due to test accuracy less than 100% (Mendenhall and Sincich 54). The proportion of GM and non-GM grain is recorded as country elevator stored percentage.

Country Elevator Loading Details

Grain of contrasting variety (GM and non-GM) segregated together through a lack of farmer variety declaration increases the adventitious commingling potential. The StarLink corn incident provides an estimate of adventitious commingling potential for a dual system. Aventis submitted adventitious commingling rates for 33 off-farm elevators in 7 states that indicated StarLink corn was present at concentrations ranging from 0.25 to 62.5% with an average of 3.5%. The Environmental Protection Agency (EPA) concurred that the degree of mixing will vary from lot to lot depending upon delivered StarLink percentages, size of storage facilities, and the number of elevations. Jenkyn corroborates these findings through the investigation of flow patterns within storage facilities, indicating that grain cohesiveness, internal friction, and outlet eccentricity affect adventitious commingling rates (1). The EPA estimated an upper bound for StarLink adventitious commingling potential at 1.2 and 1.5% for 1999 and 2000, respectively. The estimated percentage represents an adventitious commingling rate 3 to 4 times the overall percentage acreage planted to StarLink of .32 and .43% in 1999 and 2000, respectively (EPA 17-18). Hence, a conservative adventitious commingling rate applied to grain received at the country elevator is three times the percentage of unidentified GM lots plus adventitious commingling risk for handling. The binomial distribution is employed akin to country elevator receiving; sampling and testing commence; and flows are diverted and apportioned accordingly. The proportion of GM and non-GM grain is recorded as country elevator loaded percentage.

Export Elevator Receiving

Grain shipped to export is subjected to adventitious commingling risk from shipping and country elevator export accountability. The binomial distribution is similarly applied; sampling and testing are performed; and flows are diverted and apportioned accordingly. The proportion of GM and non-GM grain is recorded as export elevator received percentage.

Export Elevator Loading

Grain loaded at export is exposed to adventitious commingling risk from elevating grain to appropriate shipping bins. The binomial distribution is applied; sampling and testing are conducted; and flows are diverted and apportioned accordingly. The proportion of GM and non-GM grain is recorded as export elevator loaded percentage.

Importer Receiving

Non-GM shipments arriving from export elevator origination points are subject to adventitious commingling risk from export shipping and export elevator accountability. Grain received at the importer represents a change of ownership point; consequently, quality loss is calculated based on the delivered grain lot. A tolerance range is specified from 0% to 100%, and the probability of accepting the lot is calculated using the aforementioned binomial distribution. The relative percentages from 0 to 100% are multiplied by the amount of non-GM grain to obtain the number of observations in each tolerance range. The average between successive tolerances is calculated, squared, and multiplied by the change in successive observations to configure individual tolerance variances. Subsequently, tolerance variances are summated to arrive at average lot variance for the distribution of GM lot concentration for the importer. The resulting variance, upper tolerance limit, imparted loss, and non-GM quantity are utilized to calculate quality loss from exceeding the target value of 0%.

In addition, sampling and testing identify GM lots exceeding tolerance to be diverted (seller's risk) from the non-GM flow. The remaining non-GM bushels are apportioned into non-GM clean and non-GM AP (buyer's risk). Buyer and seller risk represents a direct cost; alternatively, quality loss represents an indirect cost. The seller's risk is the probability of a lot being rejected at the importer, whereas the buyer's risk is the probability that an unsatisfactory lot (non-GM AP) is accepted at the importer (Winston 205). The proportion of GM and non-GM grain is recorded as importer percentage and used to calculate costs for non-GM bushels.

Domestic End-User

Grain shipped to the domestic end-user via the country elevator is subject to domestic shipping adventitious commingling risk and country elevator accountability. Additionally, quality loss and buyer/seller risk are calculated as previously mentioned. The proportion of GM and non-GM grain is recorded as domestic percentage and used to calculate costs for non-GM bushels.

Detailed Description of Model Elements and Parameter Calculations

The following sections define distributions and parameters used in the model. Parameter calculations are described, and distributions are specified. The model incorporates risk in several random variables. They include adventitious commingling risks at several locations (farm, country elevator, export elevator, and transportation equipment); variety declaration; binomial; test accuracy; and quality loss. Additional model elements examined include transportation modes and optimal testing parameters.

Adventitious Commingling Distributions

Adventitious commingling distributions used in the model emanate from variety risk studies conducted by the EPA on StarLink corn and handling risk studies by Hurburgh et al.; Casada, Ingles, and Maghirang. A trianglular distribution was utilized to reflect the minimum, most likely, and maximum value. Farm-level adventitious commingling was estimated from grower risks (inclusive of volunteers, pollen drift, and on-farm handling). Country elevator receiving adventitious commingling rate includes variety and handling risk. Country elevator loading adventitious commingling rate includes shipping/handling risk. Export elevator receiving and loading adventitious commingling rates include handling and shipping/handling risk, respectively. The distributions are presented in Table 4.2.

Table 4.2. Base Case Adventitious Commingling Distributions

Location	Distribution	Minimum	Most Likely	Maximum
Grower Risk	Triangular	0.01	0.025	0.05
Country Elevator	Triangular			
Receiving		0.001+3*GM	0.01+3*GM	0.02+3*GM
Loading		.001	.01	.025
Export Elevator	Triangular			
Receiving		0.001	0.01	0.025
Loading		0.001	0.01	0.025

Source: Hurburgh et al.; Casada, Ingles, and Maghirang (shipping/handling risk); and EPA (variety risk). Note: GM = unidentified GM percentage.

Variety Declaration Distributions

Variety declaration indicates farmer, country elevator, and export elevator accountability when declaring grain shipments. The base case scenario assumes variety declaration at the farmer level is zero (i.e., no variety declaration). Conversely, variety declaration assumes contractual relations and/or elevator-imposed mechanisms govern farmer deliveries. Variety declaration estimates are solicited in a survey of market participants knowledgeable of GM corn and soybean marketing. Subsequently, results were used to derive a triangular distribution for variety declaration. Each distribution includes a minimum, most likely, and maximum value that represents the probability that farmers will tell the truth (i.e., accountability) when delivering non-GM or GM grain. Table 4.3 summarizes variety declaration distributions.

Table 4.3. Variety Declaration Distributions

Location	Distribution	Minimum	Most Likely	Maximum
No Variety Declaration (Base Case)				
Farmer	NA	0	0	0
Country Elevator	Triangular	0.95	0.99	1
Export Elevator	Triangular	0.98	0.99	1
Variety Declaration				
Farmer	Triangular	0.8	0.95	1
Country Elevator	Triangular	0.95	0.99	1
Export Elevator	Triangular	0.98	0.99	1

Source: Wilson and Dahl, “Costs” (19).

Binomial Distribution

A binomial distribution is utilized to determine the probability of accepting various lot concentrations with specified tolerances. In general, tightening (loosening) tolerance decreases (increases) the probability of accepting a given lot concentration. The model utilizes the binomial distribution to determine the optimal testing strategy (application, intensity, and tolerance). It is specified as follows: BINOMDIST (number_s, trials, probability_s, cumulative), where number_s is the number of successes (lot size * tolerance), trials is the lot size, probability_s is the underlying lot concentration, and cumulative is TRUE. Lot size is 1000, tolerance ranges from .04 to 5%, and lot concentration is defined as $\frac{NGM_{AP}}{NGM_{Total}}$ at the designated grain-marketing point. The model identifies the probability of rejecting a lot at each location depending upon incoming GM lot concentration in the non-GM flow and the simulated tolerance at each location. The probability of rejecting a lot is defined as $P_{REJECT} = 1 - P_{ACCEPT}$, and potential grain rejection equals $NGM_{AP} * P_{REJECT}$. Calculation $NGM_{AP} * P_{REJECT}$ defines defective units in the hypergeometric distribution, which subsequently determines the amount of grain rejected and diverted within the non-GM flow. Figure 4.3 illustrates computed operating characteristic (OC) curves using the normal approximation to the binomial. The probability curves depict the probability of acceptance given GM lot concentration and tolerance.

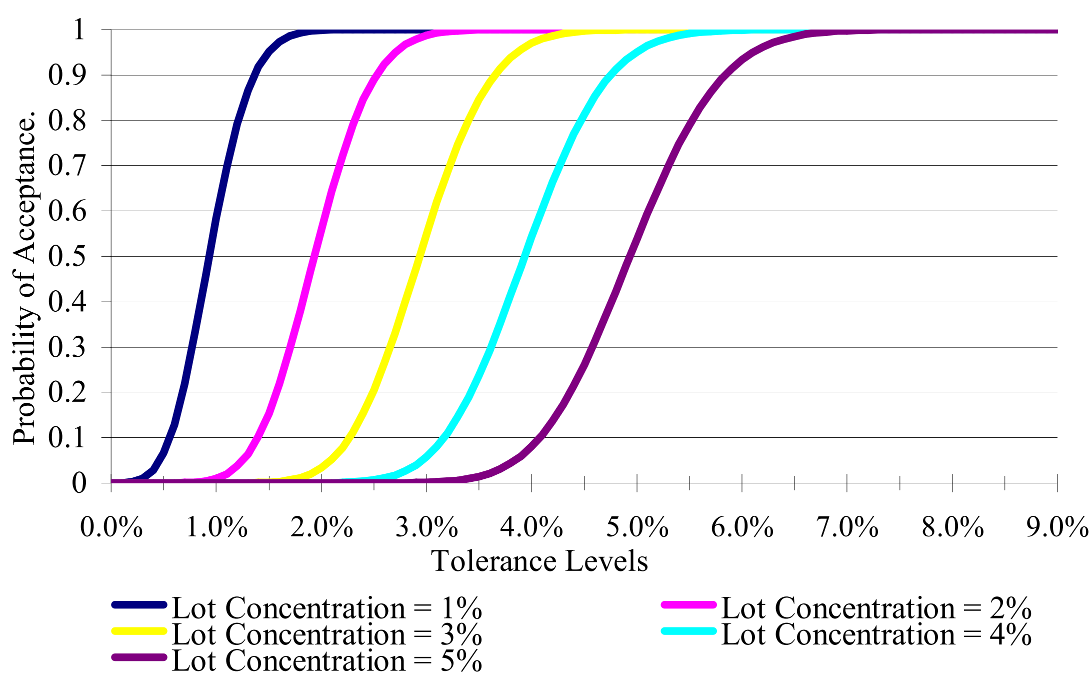

Figure 4.3. Operating Characteristic Curves.

Test Accuracy

Test kit manufacturers and testing service organizations provide strip and PCR test accuracies. The model determines test accuracy through the optimal selection of a test tolerance, which defines the corresponding test accuracy. Tolerance and its corresponding test accuracy are presented in Table 4.4.

Table 4.4. Base Case Test Tolerance/Accuracy

Test Tolerance (%)	Accuracy (%)	Cost ($)
Strip Tests		
0.04	95	28.0
0.05	95	21.0
0.075	95	14.0
0.10	95	10.5
0.25	95	10.5
0.50	99	3.5
0.75	99	3.5
1.00	99	3.5
2.00	99	3.5
3.00	99	3.5
4.00	99	3.5
5.00	99	3.5
PCR Tests		
0.04	99	275
0.05	99	275
0.075	99	275
0.10	99	262
0.25	99	250
0.50	99	250
0.75	99	250
1.00	99	250
2.00	99	250
3.00	99	250
4.00	99	250
5.00	99	250

Source: Midwest Seed Services, Inc. (PCR) and Strategic Diagnostics, Inc. (Strip).

Quality Loss Distribution

Quality loss is the loss imparted to society when deviating from the designated target value of zero. The penalty, A_o, for exceeding the upper GM tolerance limit is uniformly distributed with a range of 40-90 c/bu. in the export market and 2-20 c/bu. in the domestic market. Additional penalties at intermediate points may be incurred due to re-elevation charges or grain transfers among non-integrated firms. The aforementioned penalty range identifies a best/worse case scenario through two cost components, discounted grain and logistical costs. Discounts for GM in non-GM corn are historically 10% of the value, which is approximately 40 c/bu. in the case of wheat. In addition, rejection may entail re-shipping grain to an alternative market, which is 50 c/bu. in many geographic locations internationally. Ultimately, contract specifications govern the testing protocols and penalties sustained by the buyer and seller. Origin versus destination testing and external shipping bins provide flexibility to the shipper for re-routing of GM lots, and minimizes out-of contract costs.

Transportation Modes

Transportation modes were designated for grain marketing locations and include truck, rail, and barge hold for country elevator receiving, country elevator loading/export elevator receiving, and export elevator loading/importer receiving, respectively. Sampling is conducted on the respective mode at each location and determines testing cost based on application and intensity. Transportation parameters are presented in Table 4.5.

Optimal Testing Parameters

The optimal testing strategy simultaneously chooses test application, intensity, and tolerance for intermediate points (country elevator and export elevator) subject to defined

Table 4.5. Transportation Modes

Location	Mode	Unit Size (Bushels)
Country Elevator		
Receiving	Truck	800
Loading	Rail	3,300
Export Elevator		
Receiving	Rail	3,300
Loading	Barge Hold	33,000
Importer Elevator		
Receiving	Barge Hold	33,000

Source: Wilson and Dahl, "Costs."

importer and domestic end-user tolerances. Tests may be applied at country elevator receiving, country elevator loading, export elevator receiving, and export elevator loading; however, they are required at the importer (base case) and domestic end-user. Test intensity is 1:1 at the importer and domestic end-user, but may vary from 1:1 to 1:5 at intermediate points. Test tolerance for PCR and strip testing can be applied from .04 to 5% at intermediate points (Table 4.4) but is predefined at the importer and domestic end-user from 0.5 to 5% with a base case of 1%.

Utility Parameters

The risk parameter, λ, affects the positiveness of the utility function; ϕ and η affect the absolute risk aversion coefficient. The risk parameters λ, ϕ, and η, were assumed to be 2, .01, and .5, respectively, for the base case.

Data

Data Sources

Several sources of data were used in this research. Data Sources are listed in Table 4.6.

Data Behavior

Stochastic and strategic variables are identified and included in the model. Stochastic variables included in the base case are randomness in adventitious commingling risk, sampling, and binomial specification at grain-marketing points. In addition, uncertainty is included for variety declaration at country elevator receiving/loading and export loading locations. Furthermore, quality loss randomness is included for importer and domestic end-user locations.

Table 4.6. Data Sources

Model Component	*Data Source*
Utility Specification	Saha
Risk Premium	Serrao and Coelho
Adventitious Commingling Risk, Handling	Hurburgh et al.; Casada, Ingles, and Maghirang
Adventitious Commingling Risk, Variety	EPA
Variety Declaration	Wilson and Dahl, "Costs."
Sampling Parameters	Winston
Binomial Specification	USDA, Sampling
Test Cost/Accuracy	Strategic Diagnostics, Inc.; Midwest Seed Services, Inc.
Quality Loss	Taguchi
Transportation Modes	Wilson and Dahl, "Costs."

Strategic variables include the utility specification of λ, ϕ, and η, risk premium, testing cost and accuracy, and unit size for transportation mode. In addition, the testing strategy for importers and domestic end-users is included.

Simulation/Optimization Procedures

Risk Optimizer^{TM} utilizes Latin Hypercube simulation and genetic algorithm-based optimization techniques to optimize models containing uncertainty. Probability distribution functions representing uncertainty are employed to define risk for model components and entered into specific spreadsheet cells in lieu of a formula or number (Palisade 3-4).

Weighted disutility is defined as the target cell to be minimized via adjusting test application, test intensity, and test tolerance cells subject to constraints at the country elevator receiving/loading and export elevator receiving/loading locations. Model constraints are specified for test application, test intensity, and test tolerance. Test application specifies whether a test is applied (Yes=1 and No=0); test intensity specifies the frequency the test is applied (1:1, 1:2, 1:3, 1:4, or 1:5); and test tolerance specifies the tolerance the test is applied (.04 to 5%). Subsequently, *Risk Optimizer™* runs a full simulation for each potential trial solution generated by the genetic algorithm-based optimizer. Each iteration of a trial solution's simulation samples probability distribution functions to generate a new value for the target cell. One thousand iterations are performed successively until distributions are adequately filled and simulated results are plausible (Palisade 114-115). The mutation rate is set at 0.2; the crossover rate is 0.5; and only default operators are employed.

The mean distribution calculates the mean of the simulated distribution. It is used in the model to report additional system costs and location proportions of GM and non-GM grain for various testing and tolerance strategies (Palisade 205).

Planned Simulations/Sensitivities

Sensitivities are conducted for critical and interesting random variables to illustrate their effect on the optimal solution(s). Sensitivities include varying importer tolerances, variety declaration, varying risk parameter η, modifying A_o and/or penalties, altering adventitious commingling risk, changing GM adoption rate, and delivering to domestic end-users. Results are presented and contrasted with base case values with respect to testing strategy, additional system cost, location proportion, etc.

Summary

The parameters and distributions in this chapter form the base case scenario for the empirical model. Extraneous assumptions are made where necessary for calculation simplicity. A dual-marketing system of GM and non-GM grain is examined and illustrated. The mathematical model details utility, risk premium, testing cost, and quality loss calculations for the determination of an optimal testing strategy. Additionally, detailed descriptions of grain flow protocols and procedures for each grain marketing location are examined. Finally, model elements and distributions for stochastic and strategy variables are defined; data sources are presented; and planned sensitivities are foreshadowed.

CHAPTER 5
RESULTS AND SENSITIVITIES

Introduction

This chapter includes the results from the base case model and a presentation of the impacts that various stochastic, strategic, and parametric variables have on the optimal testing strategy and accompanying additional system costs. Section two defines the base case. In section three, Sensitivities on Stochastic Variables, including variety risks, penalty differentials, and re-elevation discounts, are conducted. In section four, Sensitivities on Strategic Variables, including importer tolerance specifications and variety declaration are performed. In section five, Sensitivities on Parametric Variables, including risk aversion and GM adoption are examined. In section six, the effect of a domestic versus import system is explored. Each section provides a detailed description; reports the optimal testing strategy, risks, and costs; illustrates relevant graphic depictions; and compares and contrasts simulation outputs with the base case. A summary of the results is presented in section seven.

Base Case Definition and Results

The base case is defined to reflect the most likely system and protocols for a dual-marketing system. The base case assumptions are as follows:

Export shipment is to importers;

GM adoption of 20% by farmers (based on market distributions of GM aversion);

No variety declaration of GM content at country elevator;

Variety risk is 3 * unidentified GM percentage at the country elevator;

Testing application is allowed at any or all of the following locations: country elevator (CE) receiving/loading and export elevator (EE) receiving/loading;

Tests applied at CE and EE locations utilize strip-test technology;

Tests applied at the importer utilize PCR test technology;

Testing intensity is allowed to vary from 1 to 5 at the CE and EE;

Testing intensity is every unit at the importer;

Testing tolerance is allowed to vary from .04 to 5% at the CE and EE;

1% importer tolerance specification;

$\lambda = 2$, $\phi = 0.01$, and $\eta = 0.5$;

The penalty for exceeding the upper tolerance limit is 40-90 c/bu.

The results presented in Table 5.1 identify the optimal testing strategy, accompanying costs, and risks that maximize utility (minimize disutility) of a dual-marketing system versus a non-GM system. The optimal strategy is to test every other truckload at the country elevator when receiving at a 4% tolerance, test every railcar at the country elevator when loading at a 0.5% tolerance, and test every barge lot at the export elevator when loading at a 0.5% tolerance. This strategy results in average rejection of non-GM bushels delivered to the importer (i.e., seller risk) of 2.83% and 0.000154% of lots containing adventitious presence of GM within the importer flow after testing (i.e., buyer risk). The cumulative distribution of the probability of rejection at the importer is shown in Figure 5.1. The distribution of the probability of rejection identifies discrete levels of rejection at .015, .0275, and .04. Correspondingly, there is a 10, 70, and 90% probability of being less than 1.5, 2.75, and 4%, respectively.

The proportion of flows in the non-GM channel declines from 80% at the farm level to 48% at the importer due to sampling, testing, and diversion of non-GM lots containing adventitious presence of GM. The cumulative distribution of the proportion of flows at the

Table 5.1. Base Case Results

	Base Case
Utility	1.0145
Optimal Strategy	
Test (1=yes, 0=no)-Intensity-Tolerance	
Country Elevator Receiving	1-2-4%
Country Elevator Loading	1-1-0.5%
Export Elevator Receiving	0-NA-NA
Export Elevator Loading	1-1-0.5%
Probabilities	
GM in Importer Flows	.000154%
Rejection at Importer	2.83%
Costs (c/bu.)	
Testing/All bushels	0.68
Quality Loss/All bushels	4.47
Testing/Non-GM bushels	1.42
Quality Loss/Non-GM bushels	9.36
Certainty Equivalent (Premium)	2.42
Total/All bushels	7.57
Total/Non-GM bushels	15.83
Location Percentage of Non-GM flow	
Adoption Rate	80.0%
Farmer in Bin	80.0%
Country Elevator Received	77.7%
Country Elevator Loaded	50.6%
Export Elevator Received	51.6%
Export Elevator Loaded	48.9%
Importer Received	48.0%

importer is illustrated in Figure 5.2. The distribution of the proportion of flows indicates a 5% probability of being less than 46.3% and a 95% probability of being less than 49.7%.

The utility of the base case is 1.0145, equating a certainty equivalent of 2.42 c/bu. The certainty equivalent represents the premium required by the handler/shipper to be indifferent between the non-GM/GM system with its accompanying test strategy (application, intensity, and tolerance) and a non-GM system. Alternatively, the premium reflects the perceived value of the additional risk incurred in a dual-marketing system

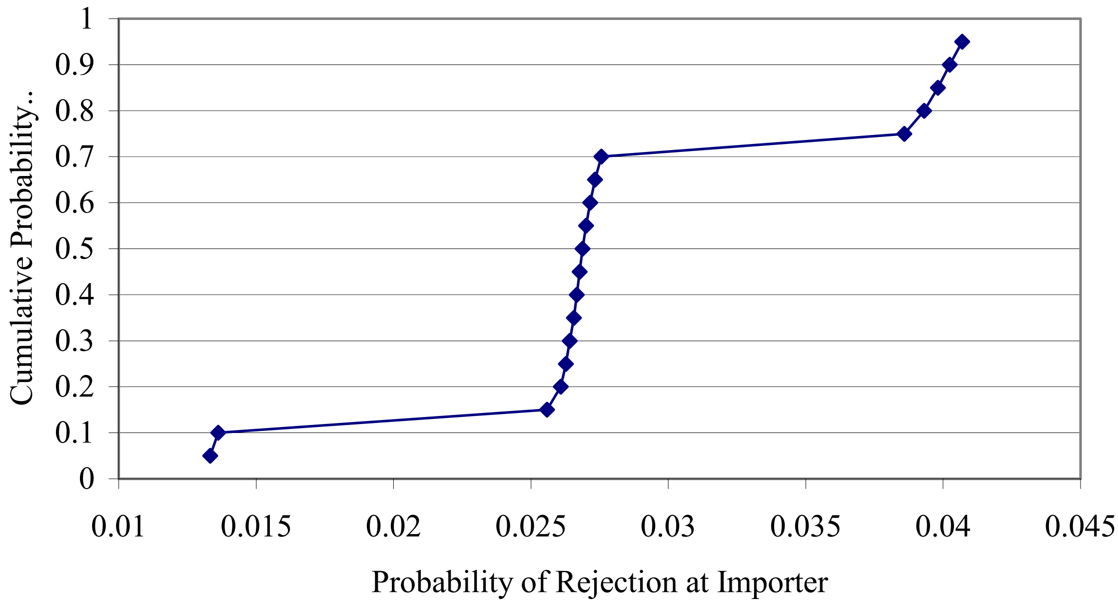

Figure 5.1. Base Case: Distribution of the Probability of Rejection at the Importer.

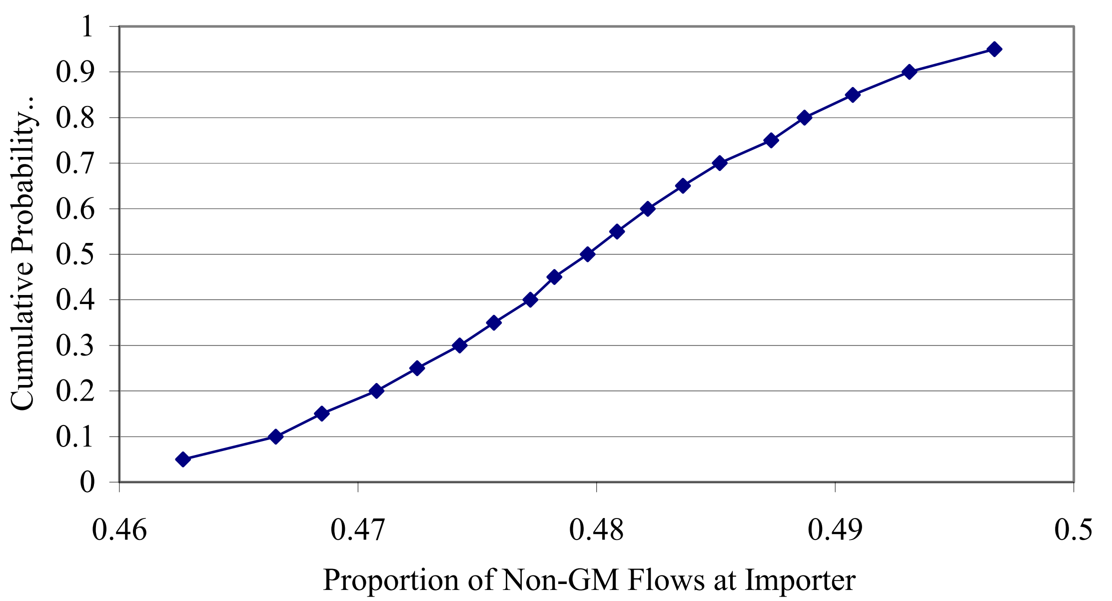

Figure 5.2. Base Case: Distribution of the Proportion of Non-GM Flows at the Importer.

through handling GM grain and marketing non-GM grain.

Testing and quality loss at the importer are 5.15 c/bu. for all bushels. Components of cost are as follows: testing every other truck with a 4% tolerance at country elevator receiving, .219 c/bu.; testing every railcar with a 0.5% tolerance at country elevator loading, .082 c/bu.; testing every barge hold with a 0.5% tolerance at export elevator loading, .006 c/bu.; testing every barge hold at the importer, .38 c/bu.; and quality loss at the importer of 4.47 c/bu. If attributed solely to non-GM bushels, the cost escalates to 10.78 c/bu. for testing and quality loss. In conjunction with the risk premium, total costs are 7.57 c/bu. evaluated for all bushels and 15.83 c/bu. evaluated for non-GM bushels. The abovementioned costs are inclusive of testing and quality loss within a dual-marketing system and do not account for additional segregation, monitoring, etc. Figure 5.3 illustrates the cumulative distribution of additional system costs for non-GM bushels. The distribution of additional system costs indicates a 5% probability of total costs being less than 3.98 c/bu. and a 95% probability of being less than 39.35 c/bu.

Sensitivities Overview

Discrete choices specify integer values for test application, intensity, and tolerance; thus, continuous values are not considered. In addition, disutility is based on weighted additional system costs, which dissimilarly value positive and negative deviations from the mean for different cost components. Cost components are valued differently when the optimal testing strategy changes. As a result, the costs and risks within sensitivities should be viewed with caution.

Sensitivities on Stochastic Variables

Stochastic variables are used to demonstrate risks inherent in the dual marketing

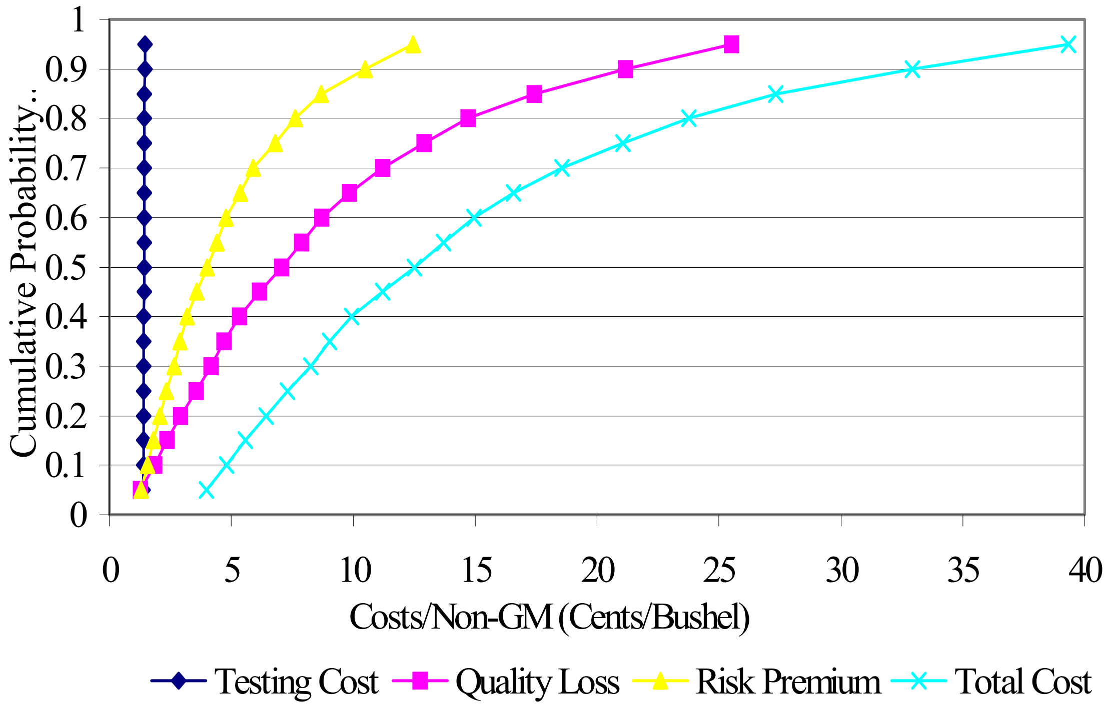

Figure 5.3. Base Case: Distributions of Additional System Costs.

system. The primary uncertainty is adventitious presence of GM within the non-GM flow and its potential impact on additional system costs arising from adventitious commingling risks, penalty differentials, and re-elevation discounts. Each catalyst for uncertainty is examined in the successive sections.

Variety Risk

Adventitious commingling risk includes handling and shipping, and variety risks at various grain marketing locations from the farmer to the end-user. Hurburgh et al. and Casada, Ingles, and Maghirang collectively quantify handling and shipping risk while the EPA quantifies variety risk. In the base case, handling, shipping, and variety risks utilized distributions provided in Table 4.2. However, the extent of variety risk depends upon critical factors such as local percentages of GM and non-GM grain, size of storage facilities, number of grain elevations, etc. To this end, variety risk is varied to determine impacts upon testing strategy, risks, and costs. Two cases are developed, one with lower variety risk (2 * Unidentified GM) and a second with higher variety risk (3.5 * Unidentified GM). Unidentified GM is the proportion of GM grain flows that are not diverted when received and stored at the country elevator; thus, non-GM flows are commingled with GM lot concentrations approximating 100%, thereby amplifying contamination. The results presented in Table 5.2 quantify the impacts of variety risk.

The lower variety risk model tests less intensively than the other cases, testing every unit at country elevator loading at a 5% tolerance and every unit at export elevator loading at a 0.75% tolerance. The higher variety risk model tests at the same intensity as the base case; however, testing tolerances are tighter at country elevator receiving and export elevator loading, and looser at country elevator loading with an overall lower testing cost.

The probability of rejection at the importer is the highest for the lower variety risk model, 3.08% versus 2.83% in the base case and 3.03% in the higher variety risk model. The degree of seller risk varies according to testing strategy; the less intensive (lower cost) strategy results in higher rejection risk at the importer when importer specifications are unchanged. GM percentage in importer flows is negligible.

Quality loss increased while testing costs declined for non-GM bushels in both lower and higher variety risk models. Disutility for each of the models increased as variety risks were inflated, resulting in an increase of the required risk premium at which decision makers would be indifferent between a non-GM/GM and a non-GM system. In addition,

Table 5.2. Base Case Results and Sensitivity to Variety Risk

Variety Risk	2*	Base Case 3*	3.5*
Utility	1.0144	1.0145	1.0147
Optimal Strategy			
Test (1=yes, 0=no)-Intensity-Tolerance			
Country Elevator Receiving	0-NA-NA	1-2-4%	1-2-3%
Country Elevator Loading	1-1-5%	1-1-0.5%	1-1-5%
Export Elevator Receiving	0-NA-NA	0-NA-NA	0-NA-NA
Export Elevator Loading	1-1-0.75%	1-1-0.5%	1-1-0.75%
Probabilities			
GM in Importer Flows	.000293%	.000154%	.000152%
Rejection at Importer	3.08%	2.83%	3.03%
Costs (c/bu.)			
Testing/All bushels	0.46	0.68	0.66
Quality Loss/All bushels	5.24	4.47	4.93
Testing/Non-GM bushels	1.04	1.42	1.47
Quality Loss/Non-GM bushels	12.01	9.36	10.98
Certainty Equivalent (Premium)	2.42	2.42	2.46
Total/All bushels	8.12	7.57	8.06
Total/Non-GM bushels	18.61	15.83	17.92
Location Percentage of Non-GM flow			
Adoption Rate	80.0%	80.0%	80.0%
Farmer in Bin	80.0%	80.0%	80.0%
Country Elevator Received	100.0%	77.7%	77.7%
Country Elevator Loaded	46.6%	50.6%	47.7%
Export Elevator Received	47.6%	51.6%	48.8%
Export Elevator Loaded	44.6%	48.9%	46.0%
Importer Received	43.8%	48.0%	45.1%

the percentage of non-GM flows at the importer declined 8.75 and 6.04% from the base case for lower variety risk and higher variety risk, respectively. The combinatorial nature of the abovementioned factors, discrete choices, and utility theory results in higher non-GM costs for both lower variety risk and higher variety risk models as illustrated in Figure 5.4.

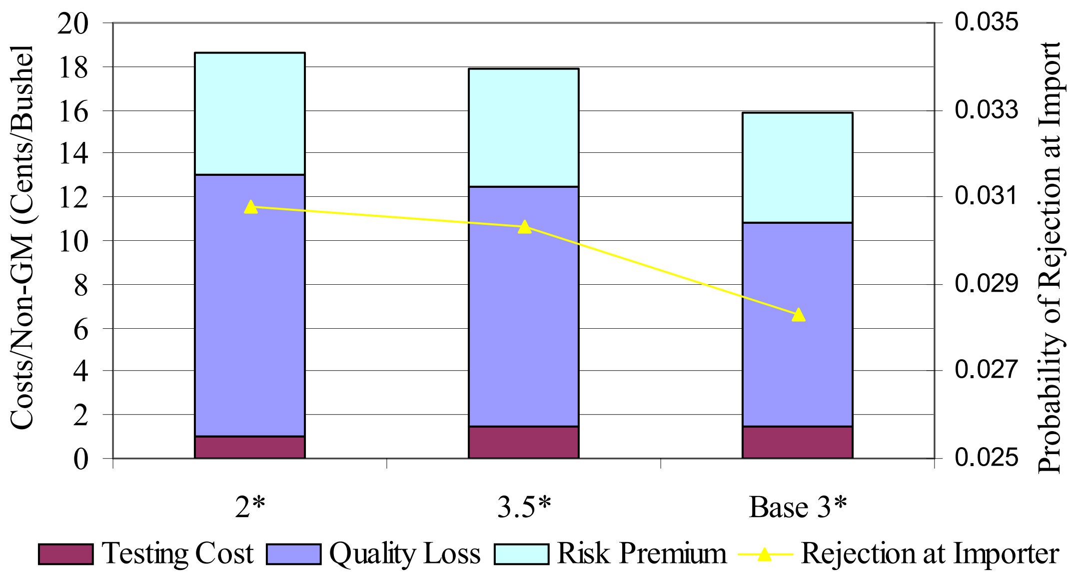

Figure 5.4. Effects of Variety Risk on Testing Cost, Quality Loss, Risk Premium, and Probability of Rejection at Importer.

Penalty Differentials (Discounts)

The base case assumed a discount (i.e., A_0) of 40-90 c/bu. at the importer when the upper tolerance limit was exceeded. However, discounts are governed via contract specifications of individual buyers and through cumulative interaction of all buyers and sellers in a competitive equilibrium. To illustrate, discounts are varied at the importer to reflect higher and lower values placed on non-conforming shipments. Two cases are developed, one with lower discounts (0-10 c/bu.) and a second with higher discounts (100-150 c/bu. The results for discounts applied at the importer are presented in Table 5.3.

Lower penalties resulted in a less intensive optimal testing strategy with respect to the base case. Testing is performed on every unit at country elevator loading at a 5% tolerance and every unit at export elevator loading at a 0.5% tolerance. The less intensive testing strategy exposes the seller to additional risk of rejection at the importer, which

Table 5.3. Sensitivities to Importer Penalty Differentials

Penalty	0-10 c/bu.	Base Case 40-90 c/bu.	100-150 c/bu.
Utility	1.0054	1.0145	1.0191
Optimal Strategy			
Test (1=yes, 0=no)-Intensity-Tolerance			
Country Elevator Receiving	0-NA-NA	1-2-4%	1-1-2%
Country Elevator Loading	1-1-5%	1-1-0.5%	0-NA-NA
Export Elevator Receiving	0-NA-NA	0-NA-NA	0-NA-NA
Export Elevator Loading	1-1-0.5%	1-1-0.5%	1-1-0.75%
Probabilities			
GM in Importer Flows	.000233%	.000154%	.0000702%
Rejection at Importer	4.57%	2.83%	1.78%
Costs (c/bu.)			
Testing/All bushels	0.34	0.68	1.01
Quality Loss/All bushels	0.82	4.47	4.76
Testing/Non-GM bushels	1.18	1.42	1.38
Quality Loss/Non-GM bushels	2.82	9.36	6.53
Certainty Equivalent (Premium)	0.33	2.42	4.18
Total/All bushels	1.49	7.57	9.95
Total/Non-GM bushels	5.15	15.83	13.65
Location Percentage of Non-GM flow			
Adoption Rate	80.0%	80.0%	80.0%
Farmer in Bin	80.0%	80.0%	80.0%
Country Elevator Received	100.0%	77.7%	77.7%
Country Elevator Loaded	31.5%	50.6%	77.7%
Export Elevator Received	32.8%	51.6%	78.2%
Export Elevator Loaded	29.7%	48.9%	74.3%
Importer Received	29.0%	48.0%	73.2%

increases from 2.83% in the base case to 4.57% with lower discounts. In contrast, imposing higher penalties resulted in testing at fewer points compared to the base case, but at greater intensities or tolerances. Testing is conducted on every unit at country elevator receiving at a 2% tolerance and every unit at export elevator loading at a 0.75% tolerance, effectively reducing seller risk to 1.78% at the importer (Figure 5.5). GM percentage in importer flows is negligible.

Additional system costs increase for all bushels as higher penalties are imposed. Concurrent with testing intensity, testing cost increases 100% from the low penalty case to the base case and 48.5% from the base case to the high penalty case. Similarly, quality loss increases 445% from the low penalty case to the base case and 7% from the base case to the high penalty case. Disutility for each of the cases increased as the penalty, A_o, increased and is reflected in the risk premium required for compensating handlers/shippers participating in a dual-marketing system. With a penalty differential of 0-10 c/bu., the risk premium is .33 c/bu., but increases 633% to 2.42 c/bu for the base case and another 72.7% to 4.18 c/bu. for the high penalty case.

Interestingly, the percentage of non-GM flows at the importer increases as higher penalties are prescribed with 29.04% non-GM grain delivered in the low penalty case, 47.98% non-GM grain delivered in the base case, and 73.24% non-GM grain delivered in the high penalty case. As a result, additional system costs for non-GM bushels are lower for the high penalty case versus the base case (Figure 5.5).

Re-Elevation and Re-Elevation/Diverted GM Discounts

Cases are examined where discounts are applied at intermediate points for re-elevation and/or lots are identified as GM and diverted. In the first case, a re-elevation penalty of (0-10 c/bu.) is employed at country and export elevator loading to reflect the estimated cost of redirecting grain destined for shipment back to the facility. Penalties are not assigned at country elevator receiving and export elevator receiving because all grain is equally segregated at the point of origin.

A second case is developed that incorporates re-elevation discounts plus an

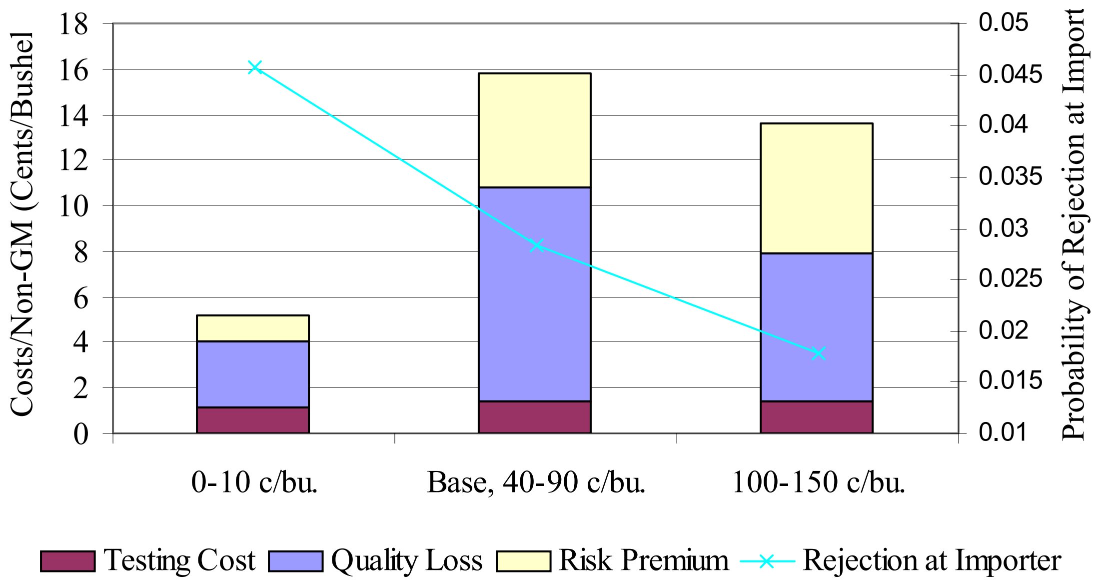

Figure 5.5. Effects of Penalty Differentials on Rejection Rates and Costs per Non-GM Bushel.

assigned implicit cost for diverted GM grain along the marketing chain. A penalty of 5 c/bu. is allocated to all GM lots that are diverted at country elevator loading, and export elevator receiving and loading. Discounts for GM versus non-GM grain may prevail, thus the penalty effectively accounts for potential losses in marketing GM grain once ownership is taken. Table 5.4 presents re-elevation and re-elevation/GM discount cases with respect to the base case.

Re-elevation and re-elevation/diverted GM cases tested more intensively at country elevator receiving versus the base case but avoided testing when loading at the country elevator. Testing was conducted on every unit at country elevator receiving at a 4% tolerance for the re-elevation case and 0.75% tolerance for the re-elevation/diverted case, and on every unit at export elevator receiving at a 0.75% tolerance.

Testing cost for all bushels increased for both cases while the probability of

Table 5.4. Sensitivities to Re-Elevation and Re-Elevation/GM Discounts

Penalty	Base Case 0 c/bu.	Re-Elevation 0-10 c/bu.	Re-Elevation 0-10 c/bu., Diverted GM 5 c/bu.
Utility	1.0145	1.0156	1.016
Optimal Strategy			
Test (1=yes, 0=no)-Intensity-Tolerance			
Country Elevator Receiving	1-2-4%	1-1-4%	1-1-1%
Country Elevator Loading	1-1-0.5%	0-NA-NA	0-NA-NA
Export Elevator Receiving	0-NA-NA	0-NA-NA	0-NA-NA
Export Elevator Loading	1-1-0.5%	1-1-0.75%	1-1-0.75%
Probabilities			
GM in Importer Flows	.000154%	.0000702%	.0000702%
Rejection at Importer	2.83%	1.78%	1.78%
Costs (c/bu.)			
Testing/All bushels	0.68	1.01	1.21
Quality Loss/All bushels	4.47	2.67	2.67
Testing/Non-GM bushels	1.42	1.38	1.65
Quality Loss/Non-GM bushels	9.36	3.66	3.66
Certainty Equivalent (Premium)	2.42	2.67	2.81
Total/All bushels	7.57	6.35	6.68
Total/Non-GM bushels	15.83	8.69	9.15
Location Percentage of Non-GM flow			
Adoption Rate	80.0%	80.0%	80.0%
Farmer in Bin	80.0%	80.0%	80.0%
Country Elevator Received	77.7%	77.7%	77.7%
Country Elevator Loaded	50.6%	77.7%	77.7%
Export Elevator Received	51.6%	78.2%	78.2%
Export Elevator Loaded	48.9%	74.3%	74.3%
Importer Received	48.0%	73.2%	73.2%

rejection at the importer decreased from 2.83% in the base case to 1.78% for re-elevation and re-elevation/diverted GM cases. Quality loss decreased in both cases when compared to the base case for all bushels, suggesting a tradeoff between testing cost and quality loss. GM in importer flows is negligible. Disutility increased as discounts escalated, hence the risk premium also increased to account for additional risks to the handler/shipper for re-elevation and/or diverted GM grain charges. Total cost for non-GM bushels decreased for both re-elevation and re-elevation/diverted GM cases, reflecting a disproportionate decrease in quality loss versus increases in testing costs and risk premium. Compounding this effect are markedly higher non-GM deliveries at the importer of 73.2% versus 48% in the base case. Figure 5.6 presents non-GM costs and the probability of rejection at the importer.

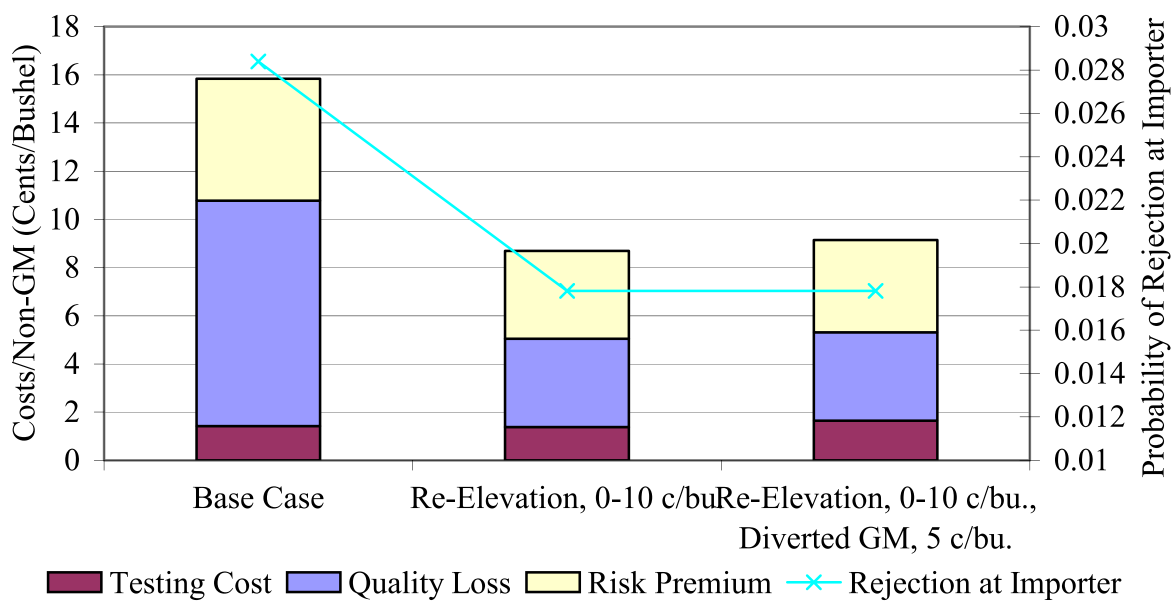

Figure 5.6. Effects of Re-Elevation and Re-Elevation/GM Diversion Costs on Costs/Non-GM and Probability of Rejection at Importer.

Sensitivities on Strategic Variables

Sensitivities on strategic variables are performed to determine changes in optimal testing strategies, risks, and costs when importers and handlers/shippers alter their strategic decisions. Strategic variables that are performed include import tolerance specifications and variety declaration contract mechanisms elicited by the handler/shipper.

Import Tolerance Specifications

In the base case, importers specified an upper tolerance limit of 1% GM lot concentration. Depending upon regulatory mandates, labeling requirements, end-user quality specifications, and commercial firm preferences, the tolerance designated at the importer may be tighter or looser. To illustrate, import tolerances are loosened and tightened to quantify additional system costs arising from each respective strategy. To simulate the impact, 5 cases are developed with tolerances of 0.5, 2, 3, 4, and 5%. The range is inclusive of current industry practices; the EU has set a level of 0.9% for all food and feed containing GM commodities; other countries, such as Japan, Taiwan, Thailand, Hong Kong, etc., require a 5% tolerance while numerous countries mandate tolerances between 0.5% and 5% (Table 2.4). The results are presented in Table 5.5.

The optimal testing strategy becomes progressively less intensive as import tolerances are loosened from 0.5 to 5%. Testing is similar to the base case for a 0.5% import tolerance with the exception of test tolerances. Testing is conducted on every unit at country elevator receiving at a 1% tolerance, every fifth unit at country elevator loading at a 5% tolerance, and every unit at export elevator loading at a 0.5% tolerance. In contrast, the optimal testing strategies for import tolerances tighter than the base case preclude testing at country elevator receiving. The lack of test application at country elevator receiving exacerbates adventitious presence of GM within the non-GM flow, primarily through adventitious commingling of high GM lot concentrations with non-GM lots (Table 4.2). As a result, the percentage of non-GM flows at the importer significantly declines for the 2, 3, 4, and 5% import tolerance cases.

Relative to the base case, the probability of rejection at the importer decreases for

Table 5.5. Sensitivities to Importer Tolerance Specification

Tolerance	0.5%	Base Case 1%	2%	3%	4%	5%
Utility	1.0253	1.0145	1.0086	1.0060	1.0052	1.0044
Optimal Strategy						
Test (1=yes, 0=no)-Intensity-Tolerance						
Country Elevator Receiving	1-1-1%	1-2-4%	0-NA-NA	0-NA-NA	0-NA-NA	0-NA-NA
Country Elevator Loading	1-5-5%	1-1-0.5%	1-1-1%	1-1-2%	1-2-0.5%	1-2-1%
Export Elevator Receiving	0-NA-NA	0-NA-NA	0-NA-NA	0-NA-NA	0-NA-NA	0-NA-NA
Export Elevator Loading	1-1-0.5%	1-1-0.5%	1-1-2%	1-1-2%	1-1-4%	1-1-1%
Probabilities						
GM in Importer Flows	.000108%	.000154%	.000364%	.000152%	.000564%	.000341%
Rejection at Importer	1.93%	2.83%	4.35%	3.84%	6.07%	5.43%
Costs (c/bu.)						
Testing/All bushels	1.03	0.68	0.34	0.34	0.21	0.21
Quality Loss/All bushels	9.64	4.47	2.64	1.17	1.47	0.94
Testing/Non-GM bushels	1.41	1.42	1.18	1.17	1.12	1.11
Quality Loss/Non-GM bushels	13.26	9.36	9.12	4.05	7.75	4.94
Certainty Equivalent (Premium)	7.66	2.42	0.84	0.43	0.31	0.22
Total/All bushels	18.33	7.57	3.83	1.95	1.99	1.37
Total/Non-GM bushels	25.19	15.83	13.20	6.71	10.51	7.17
Location Percentage of Non-GM flow						
Adoption Rate	80.0%	80.0%	80.0%	80.0%	80.0%	80.0%
Farmer in Bin	80.0%	80.0%	80.0%	80.0%	80.0%	80.0%
Country Elevator Received	77.7%	77.7%	100.0%	100.0%	100.0%	100.0%
Country Elevator Loaded	77.8%	50.6%	31.4%	31.4%	31.4%	31.4%
Export Elevator Received	78.2%	51.6%	32.8%	32.8%	32.8%	32.8%
Export Elevator Loaded	74.2%	48.9%	29.7%	29.7%	19.5%	19.5%
Importer Received	73.0%	48.0%	29.1%	29.3%	19.1%	19.2%

the 0.5% case and increases for the 2, 3, 4, and 5% cases. GM percentage in importer flows is negligible. The tradeoff between the probability of rejection and testing cost for all bushels is illustrated in Figure 5.7.

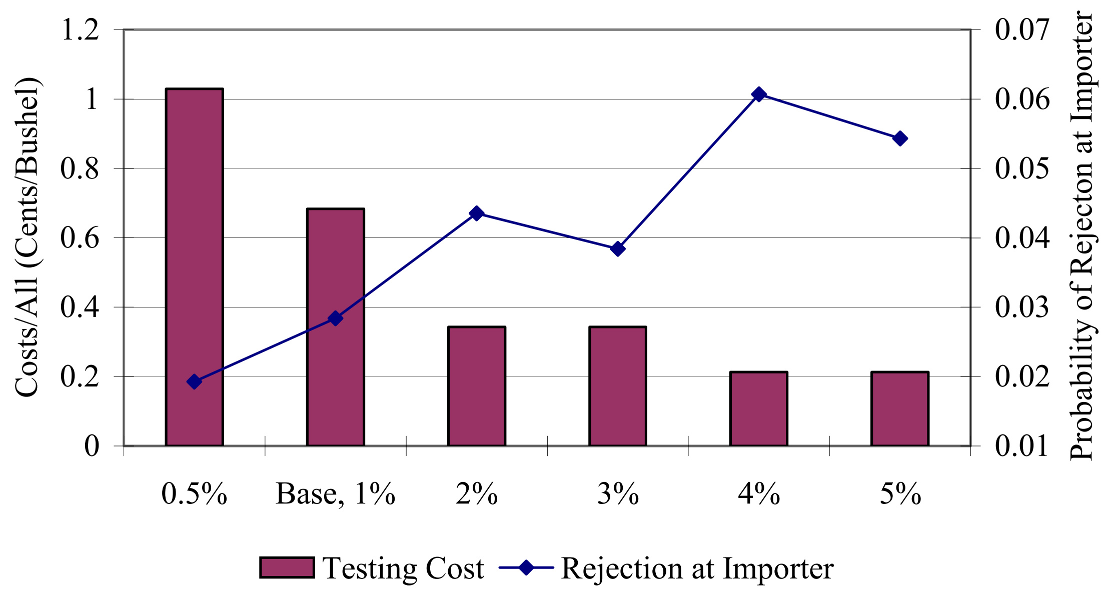

Figure 5.7. Effect of Testing Cost on Rejection at Importer for Import Tolerances.

Disutility from additional system costs significantly decreases as tolerances are loosened. Hence, the risk premium required to compensate handlers/shippers is 7.66 c/bu. for a 0.5% import tolerance; but progressively declines to 2.42, 0.84, 0.43, 0.31, and 0.22 c/bu. for a 1, 2, 3, 4, and 5% import tolerance specification, respectively.

Relative to the base case, non-GM testing costs increase for the 0.5% import tolerance case and decrease for 2, 3, 4, and 5% import tolerance cases illustrative of reduced non-conformance risk as tolerances are loosened. Quality loss for non-GM bushels decreases 41.67% from the 0.5% import tolerance case to the base case, 2.63% from the base case to 2% import tolerance case, and 125% from the 2% import tolerance case to 3% import tolerance case. Quality loss increases 91.36% from the 3% import tolerance case to the 4% import tolerance and then decreases 56.88% from the 4% import tolerance case to the 5% import tolerance case. Increased quality loss at the 4% import tolerance can be attributed to the optimal testing strategy, which utilizes discrete choice and utility theory. Figure 5.8 illustrates the cumulative distribution of quality loss for various import tolerances.

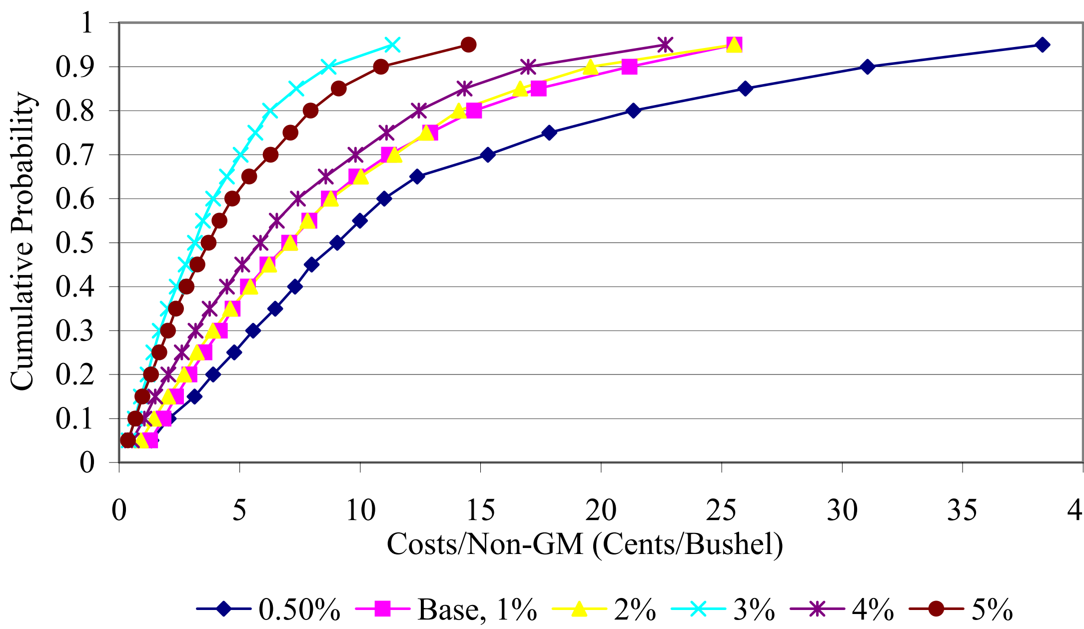

Figure 5.8. Distribution of Quality Loss.

Total cost for all bushels decreases as tolerance is loosened except at a 4% import tolerance, where cost increases slightly due to a different strategy being employed that trades off a decrease in testing cost for an increase in quality loss. Figure 5.9 shows disutility and additional system costs for all bushels. Figure 5.10 graphically depicts additional system costs for non-GM bushels and the percentage of non-GM flows at the importer.

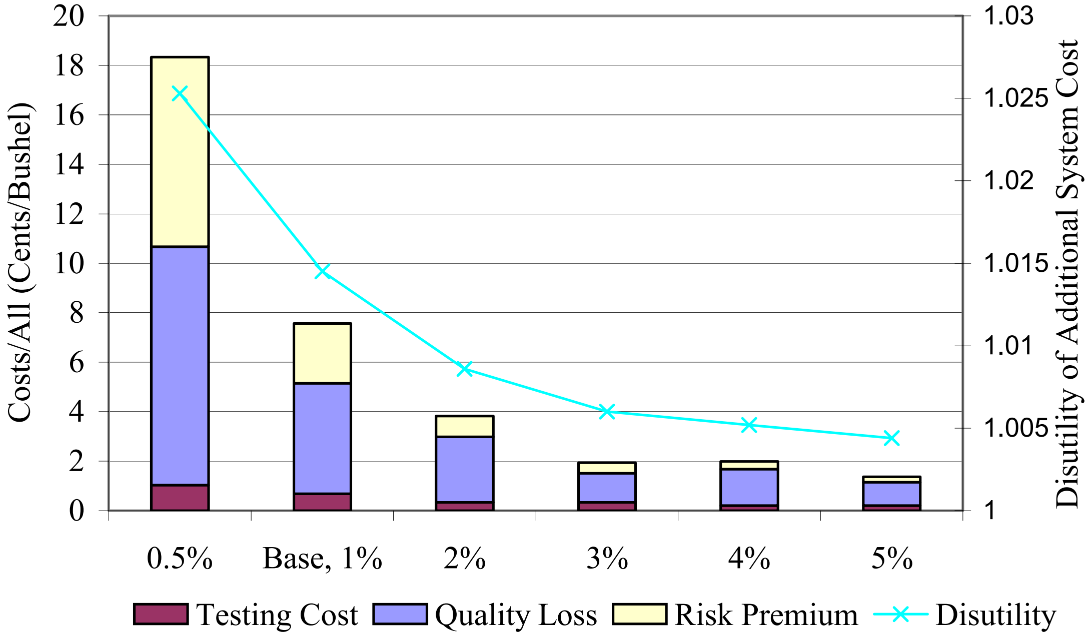

Figure 5.9. Effects of Importer Tolerances on Disutility and Costs for All Bushels.

Variety Declaration

The base case scenario lacks sufficient mechanisms to elicit information from growers regarding the GM content of their grains. As a result, non-GM and GM grain is commingled upon receipt at the country elevator depending on the extent of testing, which may potentially impact adventitious presence of GM within the non-GM flow. A system of contracts whereby growers sign affidavits to declare varieties of either non-GM or GM would facilitate segregation at the point of first receipt. To simulate the system's effectiveness, three models utilizing triangular distributions are developed with variety declaration that assumes minimum, most likely, and maximum values for farmer variety declaration at the point of origination. The first model assumes variety declaration has a minimum of 40%, most likely of 50%, and maximum of 60%. The second model increases variety declaration to 65, 75, and 85% for minimum, most likely, and maximum values,

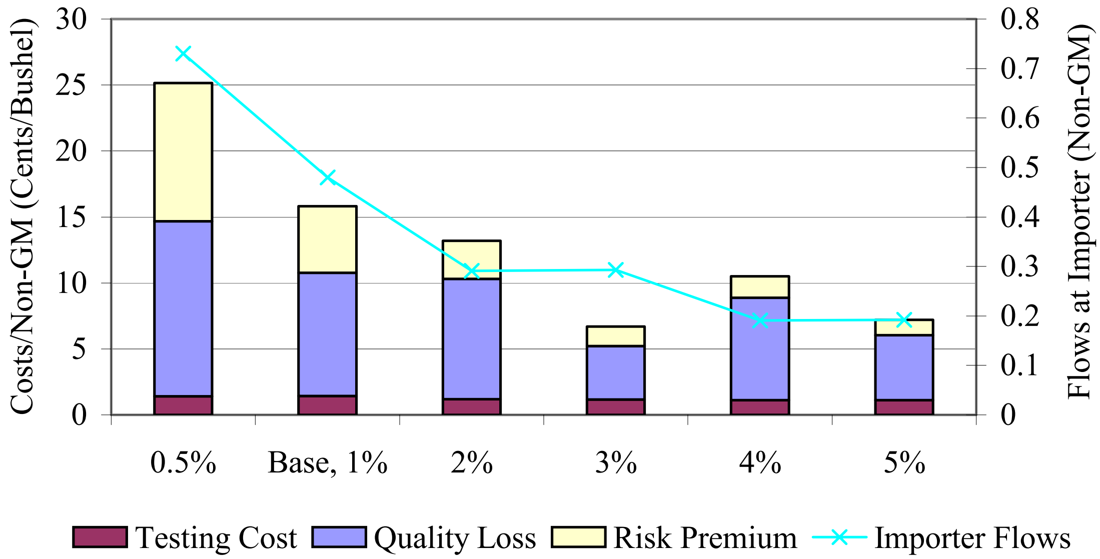

Figure 5.10. Effects of Importer Tolerances on Costs and Importer Flows for Non-GM Bushels.

respectively. The third model further increases variety declaration to 80, 95, and 100% for the minimum, most likely, and maximum, respectively. The results are presented in Table 5.6.

With variety declaration, the optimal testing strategy becomes progressively less intensive as the rate of farmer variety declaration increases. The less intensive strategy evolves due to less uncertainty surrounding variety identification and segregation. The low variety declaration model tested every other unit at country elevator receiving and loading at a 3 and 5% tolerance, respectively, and every unit at export elevator loading at a 4% tolerance. Conversely, the moderate variety declaration model avoided testing at country elevator receiving, but tested every other unit at country elevator loading at a 1% tolerance and every unit at export elevator loading at a 4% tolerance. Similarly, the high variety declaration model relaxed testing to every fifth unit at country elevator loading at a 3%

Table 5.6. Sensitivities to Variety Declaration

Variety Declaration	Base Case	40-50-60%	65-75-85%	80-95-100%
Utility	1.0145	1.0144	1.0141	1.0139
Optimal Strategy				
Test (1=yes, 0=no)-Intensity-Tolerance				
Country Elevator Receiving	1-2-4%	1-2-3%	0-NA-NA	0-NA-NA
Country Elevator Loading	1-1-0.5%	1-2-5%	1-2-1%	1-5-3%
Export Elevator Receiving	0-NA-NA	0-NA-NA	0-NA-NA	0-NA-NA
Export Elevator Loading	1-1-0.5%	1-1-4%	1-1-4%	1-1-1%
Probabilities				
GM in Importer Flows	0.000154%	0.000120%	0.000139%	0.000092%
Rejection at Importer	2.83%	2.53%	2.60%	2.15%
Costs (c/bu.)				
Testing/All bushels	0.68	0.67	0.47	0.51
Quality Loss/All bushels	4.47	3.75	3.92	3.06
Testing/Non-GM bushels	1.42	1.24	0.88	0.82
Quality Loss/Non-GM bushels	9.36	7.01	7.50	4.97
Certainty Equivalent (Premium)	2.42	2.34	2.26	2.19
Total/All bushels	7.57	6.75	6.64	5.77
Total/Non-GM bushels	15.83	12.59	12.70	9.33
Location Percentage of Non-GM flow				
Adoption Rate	80.0%	80.0%	80.0%	80.0%
Farmer in Bin	80.0%	80.0%	80.0%	80.0%
Country Elevator Received	77.7%	77.7%	85.0%	81.7%
Country Elevator Loaded	50.6%	62.7%	63.4%	72.1%
Export Elevator Received	51.6%	63.4%	64.2%	72.7%
Export Elevator Loaded	48.9%	54.9%	53.7%	63.6%
Importer Received	48.0%	54.0%	52.8%	62.6%

tolerance and every unit at export elevator loading at a 1% tolerance.

The rejection at the importer decreased for all variety declaration cases relative to the base case. GM percentage in importer flows is negligible.

The percentage of non-GM flows at the importer increases for variety models reflecting less diversion at the country elevator. Total costs for non-GM bushels decrease from 15.83 c/bu. in the base case to 12.59 c/bu. for the low variety declaration model, increases to 12.7 c/bu. for the moderate variety declaration model, and decreases to 9.33 c/bu. for the high variety declaration model. However, when measured across all bushels, cost is inversely proportional to the level of variety declaration. The risk premium similarly decreases with higher levels of variety declaration due to a continued decrease in disutility. Since current grain margins have evolved to approximately 2.5 c/bu., the development of a contract mechanism for variety declaration is essential. Additional system costs for non-GM bushels and the probability of rejection at the importer are shown in Figure 5.11.

Sensitivities on Parametric Variables

Sensitivities on parametric variables are performed to determine changes in optimal testing strategies, risks, and costs when farmers and handlers/shippers alter their parametric decisions. Parametric variables include risk aversion, η, and GM adoption rate.

Risk Aversion (η)

The risk parameter, η, will inevitably vary among handlers/shippers depending upon their aversion to risk. Correspondingly, sensitivities are conducted for the base case with more and less risk aversion to illustrate the tradeoff between testing cost and quality loss. Two cases, $\eta = .9$ (more risk averse) and $\eta = .1$ (less risk averse), are developed, and the optimal testing strategy, risks, and costs are contrasted with the base case ($\eta = .5$). The results are presented in Table 5.7.

The optimal testing strategies intensified from the less risk averse case to the more risk averse case, indicating a preference shift for testing cost versus quality loss and rejection at the importer. Testing for the less risk averse case is conducted on every unit at country and export elevator loading locations at a 0.5 and .75% tolerance, respectively.

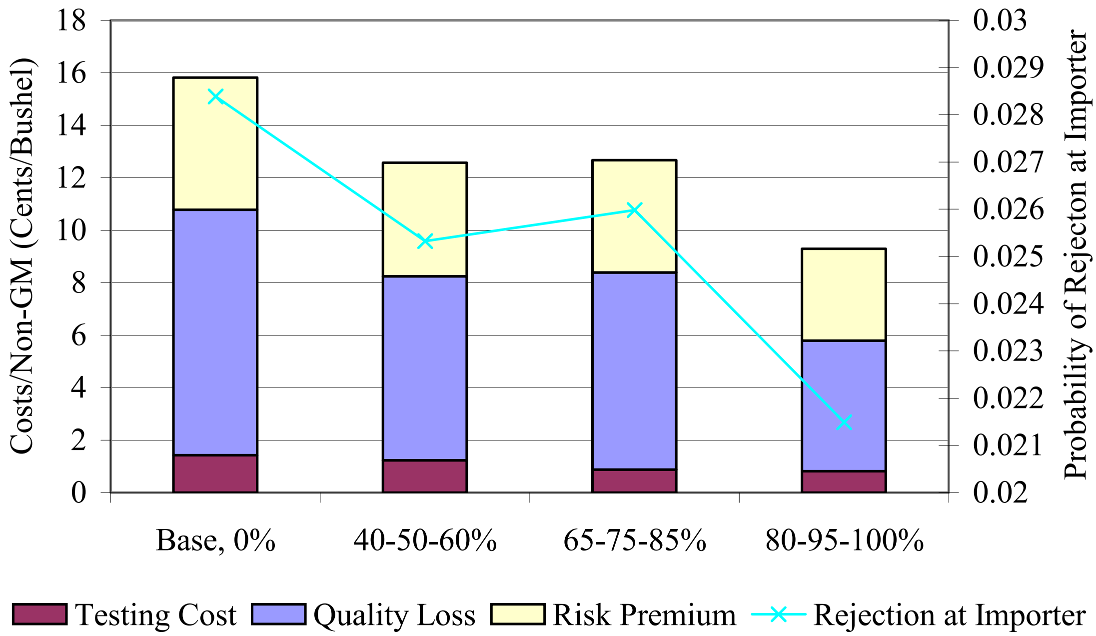

Figure 5.11. Effects of Variety Declaration on Costs/Non-GM and Importer Rejection.

The more risk averse case tests every unit at country elevator receiving at a 0.5% tolerance, every fifth unit at country elevator loading at a 5% tolerance, and every unit at export elevator loading at a 0.75% tolerance.

The rejection rate at the importer is the highest for the less averse case, 4.55% versus 2.83% in the base case and 1.76% in the more risk averse case. In addition, the percentage of non-GM flows is the lowest for the less risk averse case, 29% in contrast to 48% for the base case and 73.2% for the more risk averse case. The large diversion of non-GM flows occur primarily at country elevator loading for the less risk averse case since testing is not conducted at country elevator receiving.

Disutility for each of the cases increased as the risk parameter, η, was increased, indicating an increased propensity to avoid quality loss uncertainty. With $\eta = .9$, the risk

Table 5.7. Sensitivities to Risk Aversion (η)

Risk Aversion	0.4	Base Case, 0.5	0.9
Utility	1.0112	1.0145	1.0281
Optimal Strategy			
Test (1=yes, 0=no)-Intensity-Tolerance			
Country Elevator Receiving	0-NA-NA	1-2-4%	1-1-0.5%
Country Elevator Loading	1-1-0.5%	1-1-0.5%	1-5-5%
Export Elevator Receiving	0-NA-NA	0-NA-NA	0-NA-NA
Export Elevator Loading	1-1-0.75%	1-1-0.5%	1-1-0.75%
Probabilities			
GM in Importer Flow	0.000367%	0.000154%	0.000137%
Rejection at Importer	4.55%	2.83%	1.76%
Costs (c/bu.)			
Testing/All bushels	0.34	0.68	1.03
Quality Loss/All bushels	10.57	4.47	2.39
Testing/Non-GM bushels	1.18	1.42	1.41
Quality Loss/Non-GM bushels	36.50	9.36	3.29
Certainty Equivalent (Premium)	1.63	2.42	3.28
Total/All bushels	12.54	7.57	6.7
Total/Non-GM bushels	43.30	15.83	9.19
Location Percentage of Non-GM flow			
Adoption Rate	80.0%	80.0%	80.0%
Farmer in Bin	80.0%	80.0%	80.0%
Country Elevator Received	100.0%	77.7%	77.7%
Country Elevator Loaded	31.4%	50.6%	77.7%
Export Elevator Received	32.8%	51.6%	78.2%
Export Elevator Loaded	29.7%	48.9%	74.2%
Importer Received	29.0%	48.0%	73.2%

premium is 3.28 c/bu. but declines to 1.63 c/bu. when $\eta = .4$. More risk averse handlers/shippers discount additional testing cost and quality loss more than less averse shippers and, consequently, require a higher premium to participate in a dual-marketing system.

Total system costs decrease across non-GM/all bushels as risk aversion increases.

Testing cost for non-GM/all bushels increases while quality loss decreases from the less risk averse case to the more risk averse. The less risk averse handler/shipper is willing to incur high quality loss with uncertainty to avoid testing cost with certainty; conversely, the more risk averse handler/shipper prefers to test more intensively and reduce quality loss. The preference of the handler/shipper largely determines the optimal testing strategy and resulting tradeoffs between testing cost and quality loss, thus risk aversion, η, is a critical parameter in the analysis. Figure 5.12 illustrates the proponents of additional system costs for non-GM bushels and the probability of rejection at the importer.

GM Adoption

In the base case, a 20% GM adoption rate is assumed approximating that of GM corn. However, the level of GM adoption by farmers is uncertain and depends upon factors such as import restrictions, agronomic benefits, existence of a viable testing and segregation strategy, variety declaration, etc. To illustrate, prospective cases are developed for no variety declaration and variety declaration that increase or decrease the level of GM adoption. For no variety declaration, the low adoption case assumes 10% GM adoption while the high adoption case assumes 25% GM adoption. A 30% GM adoption case was simulated, but prohibitive costs indicated that, if GM adoption rates evolve to greater than 25%, variety declaration becomes essential. For variety declaration, 4 cases, 25, 50, 60, and 70% GM adoption, are examined. Additionally, a 75% GM adoption case was simulated, but prohibitive costs indicated that, if GM adoption is greater than 70%, an alternative system of testing and segregation must be adopted. The results for the no variety declaration cases are presented in Table 5.8.

The low adoption case averts testing at country elevator receiving and tests at a

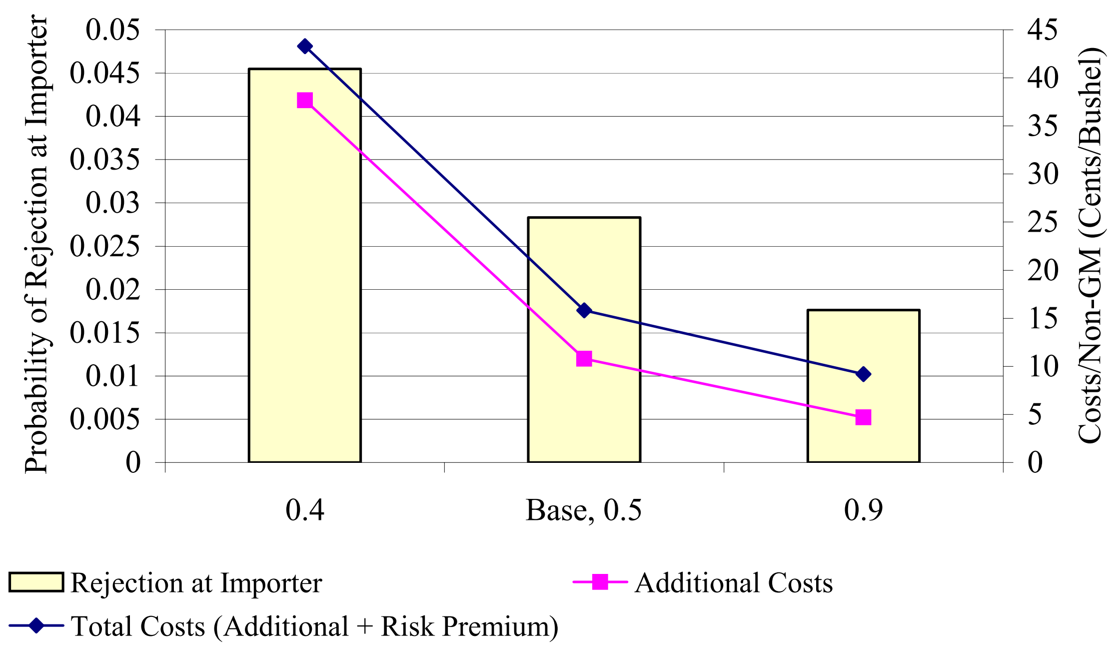

Figure 5.12. Effects of Risk Aversion Parameter η on Importer Rejection, and Additional/Total Costs per Non-GM Bushel.

looser tolerance at country and export elevator loading compared to the base case. Alternately, the high adoption case tests the same as the base case at country elevator receiving and loading, and export elevator loading. At 30% GM adoption with no variety declaration, the defined system of testing and segregation becomes cost prohibitive irrespective of the testing strategy.

The probability of rejection at the importer is directly proportional to the level of GM adoption, thus rejection risk is 2.34% for the low adoption case, 2.83% for the base case, and 3.48% for the high adoption case. GM in importer flows is negligible.

Total costs attributed to non-GM bushels decrease to 10.71 c/bu. for the low adoption case and 15.83 c/bu. for the base case, and increases to 24.36 c/bu. for the high adoption case compared to the base case. Testing cost increases from 0.98 c/bu. in the low

Table 5.8. Sensitivities of No Variety Declaration to GM Adoption

GM Adoption	10%	Base Case, 20%	25%
Utility	1.0140	1.0145	1.0150
Optimal Strategy			
Test (1=yes, 0=no)-Intensity-Tolerance			
Country Elevator Receiving	0-NA-NA	1-2-4%	1-2-4%
Country Elevator Loading	1-1-5%	1-1-0.5%	1-1-0.5%
Export Elevator Receiving	0-NA-NA	0-NA-NA	0-NA-NA
Export Elevator Loading	1-1-1%	1-1-0.5%	1-1-0.5%
Probabilities			
GM in Importer Flow	0.000119%	0.000154%	0.000215%
Rejection at Importer	2.34%	2.83%	3.48%
Costs (c/bu.)			
Testing/All bushels	0.56	0.68	0.61
Quality Loss/All bushels	3.37	4.47	6.28
Testing/Non-GM bushels	0.98	1.42	1.56
Quality Loss/Non-GM bushels	5.86	9.36	16.12
Certainty Equivalent (Premium)	2.23	2.42	2.60
Total/All bushels	6.16	7.57	9.49
Total/Non-GM bushels	10.71	15.83	24.36
Location Percentage of Non-GM flow			
Adoption Rate	90.0%	80.0%	75.0%
Farmer in Bin	90.0%	80.0%	75.0%
Country Elevator Received	100.0%	77.7%	72.9%
Country Elevator Loaded	60.9%	50.6%	41.5%
Export Elevator Received	61.7%	51.6%	42.7%
Export Elevator Loaded	58.7%	48.9%	29.9%
Importer Received	57.8%	48.0%	39.1%

adoption case compared to the base case. Testing cost increases from 0.98 c/bu. in the low adoption case to 1.42 c/bu. in the base case and 1.56 c/bu. in the high adoption case. Similarly, quality loss escalates from 5.86 c/bu. in the low adoption case to 16.12 c/bu. in the high adoption case. The increase in both testing cost and quality loss stems from additional GM in the system commingling adventitiously with a larger proportion of non-

GM flows.

Firms segregating both non-GM/GM flows experience increased GM adventitious commingling risk from higher adoption without variety declaration. Consequently, disutility increases from the low adoption case to the high adoption case, necessitating a larger required risk premium for handlers/shippers.

The percentage of flows at the importer decreased as adoption rates increased, reflecting lower initial percentages of non-GM grain. The low adoption case delivered 57.8% of non-GM flows to the importer versus 48% for the base case and 39.1% for the high adoption case. Figure 5.13 illustrates costs for non-GM bushels and the probability of rejection at the importer. The results for GM adoption in the variety declaration cases are presented in Table 5.9.

The optimal testing strategies became less intensive for GM adoption rates higher than the base case. The 25% case precluded testing at country elevator receiving, and tested at the country and export elevator. The base case and 50% case performed testing at country elevator receiving and loading, and export elevator loading while the 60 and 70% cases tested at country elevator receiving and export elevator loading.

Relative to the base case of 2.83%, rejection at the importer decreased to 2.30% for the 25% case; and progressively increased to 2.97, 3.69, and 4.87% for the 50, 60, and 70% cases, respectively. GM percentage in importer flows is negligible.

Total cost for non-GM bushels decreased for the 25% case due to a decrease in testing costs, quality loss, and risk premium; and an increase in the percentage of non-GM flows at the importer relative to the base case. Conversely, total cost increased for the 50, 60, and 70% cases relative to the base case. The increase in total cost originated from an

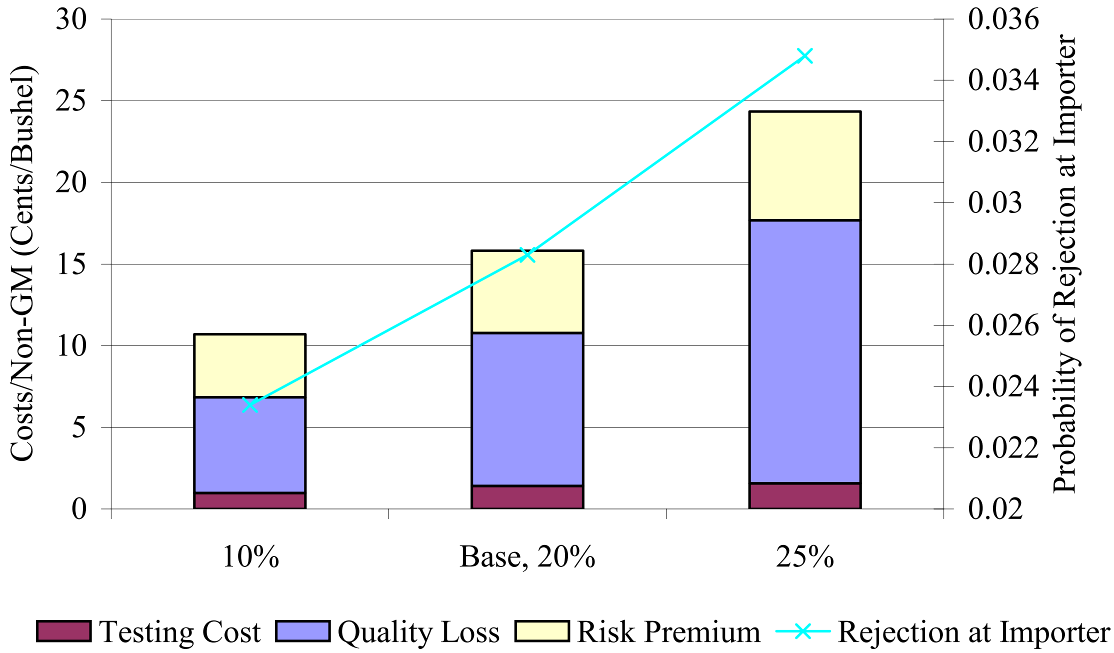

Figure 5.13. Effects of GM Adoption on Non-GM Costs and Importer Rejection with No Variety Declaration.

increase in quality loss and risk premium, and a decrease in the percentage of non-GM flows at the importer. Total cost surges at progressively higher GM adoption rates and eventually becomes cost prohibitive at 75% GM adoption, suggesting an upper bound to the defined system of testing and segregation. Figure 5.14 shows total cost for non-GM bushels and the probability of rejection at the importer.

Domestic System

The base case examines the impacts on optimal testing strategies, risks, and costs of a dual-marketing system with delivery to importers. Alternatively, if the end-user is domestically located, it entails less handling, transportation, and subsequent adventitious commingling risk. Models with no variety declaration and variety declaration using a triangular distribution, 80-95-100%, are developed to examine the effects of delivery to a

Table 5.9. Sensitivities of Variety Declaration to GM Adoption

GM Adoption	Base Case, 20%	25%	50%	60%	70%
Utility	1.0145	1.0139	1.0145	1.0151	1.0162
Optimal Strategy Test (1=yes, 0=no)-Intensity-Tolerance					
Country Elevator Receiving	1-2-4%	0-NA-NA	1-1-1%	1-1-2%	1-1-3%
Country Elevator Loading	1-1-0.5%	1-2-5%	1-5-5%	0-NA-NA	0-NA-NA
Export Elevator Receiving	0-NA-NA	0-NA-NA	0-NA-NA	0-NA-NA	0-NA-NA
Export Elevator Loading	1-1-0.5%	1-1-2%	1-1-0.75%	1-1-0.75%	1-1-0.75%
Probabilities					
GM in Importer Flows	0.000154%	0.000144%	0.00022%	0.000384%	0.000286%
Rejection at Importer	2.83%	2.30%	2.97%	3.69%	4.87%
Costs (c/bu.)					
Testing/All bushels	0.68	0.51	0.61	0.49	0.38
Quality Loss/All bushels	4.47	3.32	4.75	7.12	12.03
Testing/Non-GM bushels	1.42	0.86	1.34	1.35	1.40
Quality Loss/Non-GM bushels	9.36	5.73	10.47	19.67	44.71
Certainty Equivalent (Premium)	2.42	2.20	2.38	2.66	3.14
Total/All bushels	7.57	6.03	7.73	10.26	15.55
Total/Non-GM bushels	15.83	10.37	17.06	28.36	57.79
Location Percentage of Non-GM flow					
Adoption Rate	80.0%	75.0%	50.0%	40.0%	30.0%
Farmer in Bin	80.0%	75.0%	50.0%	40.0%	30.0%
Country Elevator Received	77.7%	77.1%	48.6%	38.9%	29.1%
Country Elevator Loaded	50.6%	66.3%	48.6%	38.9%	29.1%
Export Elevator Received	51.6%	67.0%	49.6%	40.1%	30.6%
Export Elevator Loaded	48.9%	59.9%	46.3%	37.0%	27.6%
Importer Received	48.0%	58.9%	47.2%	36.2%	27.0%

domestic market.

The optimal strategy determines test application, intensity, and tolerance for country elevator receiving and country elevator loading using a strip test. Domestic user receiving requires testing on every unit using a PCR test. The penalty for non-conformance

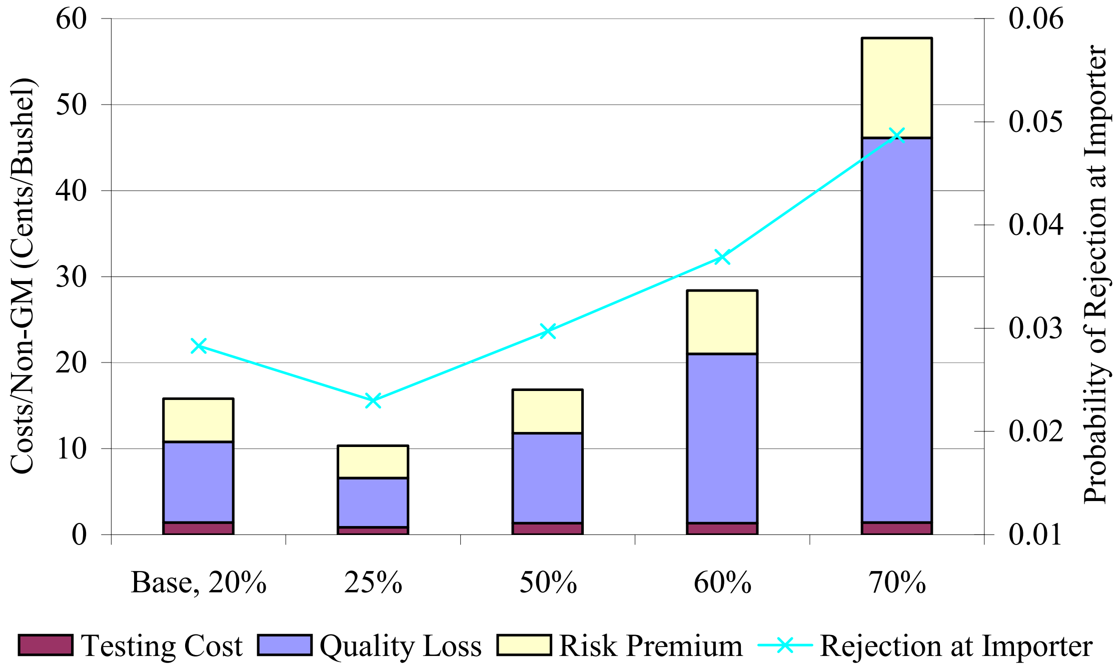

Figure 5.14. Effects of GM Adoption on Costs and Importer Rejection for Non-GM Bushels with Variety Declaration.

at the domestic end-user is 2-20 c/bu., reflecting discounts and/or re-routing of grain. Other parameters are as previously defined for the base case. The results are presented in Table 5.10.

The domestic case under no variety declaration tested less intensively than the base case, testing every fourth unit at country elevator receiving at a 0.75% tolerance and every fifth unit at country elevator loading at a 0.75% tolerance. The variety declaration case tested even less intensively than the no variety declaration case, testing every fourth unit at country elevator loading at a 0.5% tolerance. The probability of rejection at the domestic user increased to 3.59% for the no variety declaration case but decreased to 1.98% for the variety declaration case. Additional system costs across non-GM bushels decreased 4.81 and 13.29 c/bu. relative to the base case for no variety and variety declaration cases,

Table 5.10. Domestic System

	Base Case	Domestic, No Variety Declaration	Domestic, Variety Declaration
Utility	1.0145	1.0120	1.0079
Optimal Strategy			
Test (1=yes, 0=no)-Intensity-Tolerance			
Country Elevator Receiving	1-2-4%	1-4-0.75%	0-NA-NA
Country Elevator Loading	1-1-0.5%	1-5-0.75%	1-4-0.5%
Export Elevator Receiving	0-NA-NA	NA	NA
Export Elevator Loading	1-1-0.5%	NA	NA
Probabilities			
GM in Importer Flow	0.000154%	NA	NA
Rejection at Importer	2.83%	NA	NA
GM in Domestic User Flow	NA	0.0127%	0.0895%
Rejection at Domestic User	NA	3.59%	1.98%
Costs (c/bu.)			
Testing/All bushels	0.68	0.36	0.16
Quality Loss/All bushels	4.47	3.33	0.90
Testing/Non-GM bushels	1.42	0.72	0.23
Quality Loss/Non-GM bushels	9.36	6.70	1.26
Certainty Equivalent (Premium)	2.42	1.79	0.75
Total/All bushels	7.57	5.48	1.81
Total/Non-GM bushels	15.83	11.02	2.54
Location Percentage of Non-GM flow			
Adoption Rate	80.0%	80.0%	80.0%
Farmer in Bin	80.0%	80.0%	80.0%
Country Elevator Received	77.7%	77.7%	81.7%
Country Elevator Loaded	50.6%	50.6%	72.2%
Export Elevator Received	51.6%	NA	NA
Export Elevator Loaded	48.9%	NA	NA
Importer Received	48.0%	NA	NA
Domestic User Received	NA	49.8%	71.3%

respectively.

The increase in the probability of rejection at the domestic user under no variety declaration is attributable to adventitious commingling at country elevator loading and the inability of the system to divert all GM flows from the non-GM flow prior to domestic user inspection. Conversely, the decrease in additional system cost results from lesser penalties for non-conformance and reduced adventitious commingling from handling and shipping. The percentage of non-GM flows is 49.8% for the no variety declaration case and 71.3% for the variety declaration case. GM percentage in domestic flows after rejection is negligible for both cases.

Total costs substantially decrease across all and non-GM bushels in the domestic case, reflecting lower testing costs, quality losses, and required risk premium. Testing cost across non-GM bushels decreased from 1.42 c/bu. in the base case to 0.72 and 0.23 c/bu. for the no variety and variety declaration cases, respectively. In addition, quality loss across non-GM bushels decreased from 9.36 c/bu. in the base case to 6.70 c/bu. for the no variety declaration case and 1.26 c/bu. for the variety declaration case. Furthermore, disutility decreased, equating a risk premium of 1.79 c/bu. and 0.75 c/bu. for the no variety and variety declaration cases, respectively. The results indicate that additional system costs are less for both cases, although the probability of rejection is higher for the no variety declaration case due to lower penalties for non-conformance. The incentive for establishing contract mechanisms is illustrated via an 8.48 c/bu. differential between the no variety and variety declaration cases. Figure 5.15 illustrates the probability of rejection at the importer and total costs across non-GM bushels.

Summary

A dual-marketing system encompassing non-GM and GM flows is simulated to quantify optimal testing strategies, risks, and costs. The optimal testing strategy simultaneously determines test application, intensity, and tolerance that minimize

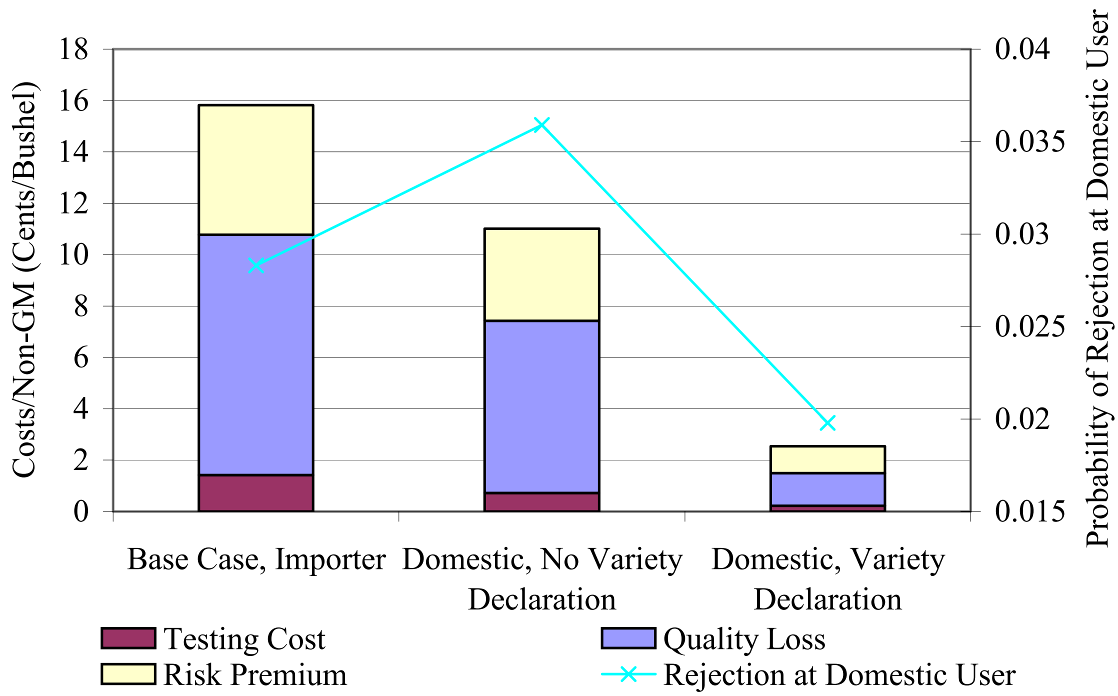

Figure 5.15. Effects of a Domestic versus Import System on Costs/Non-GM and Rejection at Importer.

additional system cost. Additional system costs include testing cost, quality loss, and risk premium. Testing cost and quality vary antagonistically across optimal testing strategies. Risk premium is based on handler/shipper disutility from additional system costs. The base case results identify the cost of testing and segregation for a typical system and protocols evolving in a dual-marketing system. Total cost across all and non-GM bushels is 7.57 and 15.83 c/bu., respectively. At the importer, the percentage of non-GM flows is 47.1%, and the probability of rejection is 6.01%.

Sensitivities of stochastic, strategic, and parametric variables affect the optimal testing strategy; rejection risk; percentage non-GM at the end-user; and testing, quality loss, and risk premium costs. Table 5.11 lists the sensitivities performed and their effects relative to the base case on total costs across non-GM bushels, rejection risks, and percentage of non-GM flows at the end-user.

The table reports small, moderate, and large deviations from the base case for all sensitivities. Total cost across all bushels is based on total non-GM and GM flows in the system. Alternatively, total cost across non-GM bushels relies on the percentage of non-GM flows delivered to the end-user. Thus, the relative magnitude of base case increases and decreases in total cost across non-GM bushels depends on the proportion of non-GM flows at the end-user. Rejection risk defines the probability of rejection at the end-user.

Table 5.11. Conclusion on Sensitivities

Sensitivity	*Total Cost/All*	*Total Cost/Non-GM*	*Non-GM Flows*	*Rejection Risk*
Stochastic				
Variety Risk, 2*	Small Increase	Moderate Increase	Moderate Decrease	Small Increase
Variety Risk, 3.5*	Small Increase	Moderate Increase	Moderate Decrease	Small Increase
Penalty Differential, 0-10 c/bu.	Moderate Decrease	Large Decrease	Large Decrease	Large Increase
Penalty Differential, 100-150 c/bu.	Moderate Increase	Moderate Decrease	Large Increase	Large Decrease
Re-Elevation Discount	Moderate Decrease	Moderate Decrease	Large Increase	Large Decrease
Re-Elevation/Diverted GM Discount	Small Decrease	Moderate Decrease	Large Decrease	Large Decrease
Strategic				
Importer Tolerance, 0.5%	Large Increase	Moderate Increase	Large Increase	Moderate Decrease
Importer Tolerance, 2%	Moderate Decrease	Moderate Decrease	Large Decrease	Large Increase
Importer Tolerance, 3%	Moderate Decrease	Moderate Decrease	Large Decrease	Large Increase
Importer Tolerance, 4%	Moderate Decrease	Moderate Decrease	Large Decrease	Large Increase
Importer Tolerance, 5%	Moderate Decrease	Moderate Decrease	Large Decrease	Large Increase
Variety Declaration, 40-50-60%	Small Decrease	Moderate Decrease	Moderate Increase	Small Decrease
Variety Declaration, 65-75-85%	Small Decrease	Moderate Decrease	Moderate Increase	Small Decrease
Variety Declaration, 80-95-100%	Moderate Decrease	Moderate Decrease	Large Increase	Moderate Decrease
Parametric				
Risk Aversion, $\eta = 0.4$	Moderate Increase	Large Increase	Large Decrease	Large Increase
Risk Aversion, $\eta = 0.9$	Small Decrease	Moderate Decrease	Large Increase	Large Decrease
GM Adoption				
10% Variety Declaration	Moderate Decrease	Moderate Decrease	Moderate Increase	Small Decrease
25% Variety Declaration	Moderate Increase	Moderate Increase	Moderate Decrease	Moderate Increase
30% Variety Declaration	Cost Prohibitive	Cost Prohibitive	Cost Prohibitive	Cost Prohibitive
25% No Variety Declaration	Moderate Decrease	Moderate Decrease	Large Increase	Moderate Decrease
50% No Variety Declaration	Small Increase	Moderate Increase	Small Decrease	Small Increase
60% No Variety Declaration	Moderate Increase	Large Increase	Large Decrease	Moderate Increase
70% No Variety Declaration	Moderate Increase	Large Increase	Large Decrease	Large Increase
75% No Variety Declaration	Cost Prohibitive	Cost Prohibitive	Cost Prohibitive	Cost Prohibitive
Other				
Domestic	Large Increase	Large Increase	Small Decrease	Large Increase

	Total Cost/All	*Total Cost/Non-GM*	*Non-GM Flows*	*Rejection Risk*
Small	0-1 c/bu.	0-1 c/bu.	0-2.5%	0-0.5%
Moderate	1-10 c/bu.	1-10 c/bu.	2.5-10%	0.5-1%
Large	> 10 c/bu.	> 10 c/bu.	> 10%	> 1%

CHAPTER 6
CONCLUSIONS

Review of Problem

The continued adoption of GM commodities is occurring, prompting systems of segregation and testing to facilitate segregation of GM and non-GM flows. Currently, 75% of U.S. soybean production is herbicide tolerant; 34% of U.S. corn production is genetically modified; and commercialization of GM wheat is in initial stages. Import restrictions and consumer differentiation among genetically modified organisms provide the impetus for existence of a dual marketing system.

Segregation

Segregation of like varieties with particular attributes exists to avoid commingling and value-added losses. The introduction of transgenic varieties has necessitated additional testing and segregation to avert contamination at production, loading, unloading, storage, and transportation phases of grain movement. Segregation costs included in the research were testing costs and risk premiums required to compensate handlers/shippers for the risk of non-conformance at the end-user. Infrastructure modifications, storage utilization, and additional costs of segregation are not considered.

End-User Specifications

Importers and domestic end-users designate tolerances for genetically modified grain. Tolerances are governed through regulatory guidelines and commercial firm preferences. Typically, non-conforming grain shipments incur a discount or are rejected when tolerance exceeds end-user specifications. Quality loss was included in the research to assess both the extrinsic and intrinsic value of non-GM lots containing adventitious presence of GM at the end-user.

Review of Objectives

The main objective of this research was to evaluate the optimal testing strategy encompassing test application, intensity, and tolerance for a dual-marketing system consisting of non-GM and GM flows. Specific objectives included assessing 1) total costs to the system, 2) testing cost, 3) quality loss at the importer, 4) risk premium required to induce market participation, 5) probability of lots being rejected at the importer, 6) distribution of flows at the importer, and 7) unidentified GM remaining in importer flows. A final objective was to determine which variables most significantly affect optimal testing strategies, and their accompanying risks and costs. Sensitivities of these variables were included in the model and discussed throughout the results.

Review of Procedures

Model Description

A stochastic optimization model was constructed utilizing an objective function that maximizes portfolio utility (minimizes portfolio disutility) of additional system costs for a grain marketing channel handling two states of nature (non-GM and GM). The model determined the optimal testing application, intensity, and tolerance to employ at country elevator receiving, country elevator loading, export elevator receiving, and export elevator loading subject to a specified tolerance at the end-user. Tests can be applied at any point in the marketing channel with varying discrete intensities (1:1 to 1:5) and tolerances (.04 to 5%). PCR tests were required on every lot at the end-user while strip tests were applied based on testing strategy at country and export elevators concurrent with industry practices. The percentage of non-GM and GM flows was tracked throughout the system and used in calculating portfolio disutility.

Elements of Uncertainty

There are several important areas of uncertainty in the stochastic optimization model. The level of variety declaration is not known with certainty. Variety, handling, and shipping adventitious commingling assume a triangular distribution representing minimum, most likely, and maximum values. A binomial distribution is used to determine the probability of accepting various GM lot concentrations with specified tolerances. The hypergeometric distribution determines rejected and diverted lots at each grain marketing point. Importer and re-elevation penalties (A_o) utilize a uniform distribution. In addition, uncertainty in testing accuracy may result in Type I errors. Uncertainty is captured in the model via *Risk Optimizer*^{TM}, a tool that evaluates probability distributions for model components.

Review of Results

The optimal testing strategy simultaneously determined test application, intensity, and tolerance that minimized additional system costs for a portfolio of segregations. The model identified system costs through total costs across all bushels and non-GM bushels. Total cost is comprised of testing cost, quality loss, and risk premium components. In addition, GM in importer flows and the probability of rejection at the importer were measured to identify buyer and seller risk, respectively. The base case defined total costs and risks for the most likely system and protocols evolving in a dual-marketing system. Various sensitivities were performed to determine how stochastic, strategic, parametric, and other variables affected optimal testing strategies, risks, and costs. Stochastic sensitivities included variety risks, penalty differentials, and re-elevation/diverted GM discounts. Strategic sensitivities included import tolerance specifications and variety declaration. Parametric sensitivities included risk aversion and GM adoption. A final sensitivity evaluated the effect of a domestic versus import system.

Stochastic Sensitivities

The main benefit to performing sensitivities on stochastic variables was to assess changes in optimal testing strategies, risks, and costs from random probability distributions. Sensitivities of stochastic variables are examined in succeeding sections, and variations are compared with base case results.

Variety Risk

Costs and risks increased as variety risks deviated from the base case. Higher variety risk from adventitious commingling of GM and non-GM grain (3.5 * unidentified GM flows) increased total costs through increases in testing cost, quality loss, and risk premium. Probability of rejection at importer also increased while the percentage of non-GM flows decreased. Similarly, lower variety risk (2 * unidentified GM flows) increased total costs, albeit with decreases in testing and risk premium components. The low variety risk case exhibited increases in quality loss and, thus, total cost due to no testing at country elevator receiving. Correspondingly, the probability of rejection at the importer increased, and importer non-GM flows decreased.

Penalty Differentials (Discounts)

Penalties varied from 0-10 c/bu. for the low penalty case to 100-150 c/bu. for the high penalty case at the importer. Total cost for all bushels trended upwards as penalties were increased. The most pronounced effect occurred in the risk premium, which increased from 0.33 cu/bu. for the low penalty case to 4.18 c/bu. in the high penalty case, reflecting a higher cost risk for non-conforming lots. Testing cost and quality loss exhibited similar increases. However, when costs were attributed to non-GM bushels, total cost declined for the high penalty case compared to the base case. The percentage of non-GM flows at the importer was 29% for the low penalty case, 48% for the base case, and 73.2% for the high penalty case. The probability of rejection at the importer decreased as penalties increased, providing evidence of the tradeoff between testing cost and seller risk.

Re-Elevation and Re-Elevation/Diverted GM Discounts

Re-elevation and re-elevation/diverted GM discount cases were incorporated to reflect re-elevation costs at country and export elevator loading, and discounts for diverting GM lots at country elevator loading and export elevator receiving and loading. For the re-elevation case, total cost decreased due to increased testing at country elevator receiving. The re-elevation/diverted GM discount case tested more intensively than the re-elevation case, increasing total costs relative to the re-elevation case but decreasing total cost compared to the base case. Both cases decreased the probability of rejection at the importer from 2.83% in the base case to 1.78% and increased non-GM flows at the importer to 73.2%. Handlers/shippers required progressively larger risk premiums as re-elevation and re-elevation/diverted GM discounts were added, providing evidence that re-elevation and marketability of grain are critical factors.

Strategic Sensitivities

Strategic decisions by importers and commercial firms have implications for optimal testing strategies, risks, and costs in a system. The following sections examine sensitivities on strategic variables and compare variations with base case results.

Import Tolerance Specifications

Importers designate tolerances based on government mandates and their preferences. Firms may specify tighter tolerances than necessary based on consumer preferences and value-added market potential for differentiating products. Importer tolerances of 0.5, 2, 3, 4, and 5% were examined relative to the base case tolerance of 1%.

In general, total costs decreased as tolerances were loosened with the exception of the 4% tolerance, which increased slightly due to a different testing strategy. Testing costs increased for the 0.5% case and then decreased for tolerances looser than the base case. Quality loss decreased as tolerances were loosened with the exception of the 4% tolerance, which increased slightly. As expected, the risk premium required for handlers/shippers significantly decreased with a looser tolerance specification. This finding reveals that loosely specified tolerances for GM commodities could be attained with little additional risk imparted to the handler/shipper. Ironically, the percentage of non-GM flows at the importer decreased as tolerance was loosened. This anomaly occurred due to large diversions at country elevator loading from variety risk since testing was not conducted at country elevator receiving for the 2, 3, 4, and 5% cases. The probability of rejection at the importer generally decreased when tolerance was tightened and increased when tolerance was loosened; however, it decreased from the 2% case to the 3% case and again from the 4% case to the 5% case. Similar testing strategies and a correspondingly looser tolerance within each range from 2 to 3% and 4 to 5% caused the irregularity.

Variety Declaration

Contract mechanisms were adopted to elicit information from farmers regarding the GM content of their grains. The level of farmer variety declaration assumed a triangular distribution representing minimum, most likely, and maximum values. Three models were developed, 40-50-60%, 65-75-85%, and 80-95-100% cases, to indicate the probability that farmers will tell the truth. Higher levels of variety declaration decreased total costs across all bushels. Total costs across non-GM bushels also decreased except for the moderate case where they slightly increased due to the percentage of non-GM flows at the importer. The total cost spread between the base case and the high variety declaration case was 6.5 c/bu. across non-GM bushels. It can be viewed as the value of implementing contract mechanisms for variety declaration. Testing cost and quality loss generally declined for higher levels of variety declaration, indicating that less intensive testing strategies sufficiently reduced adventitious presence of GM. The risk premium also declined slightly from 2.42 c/bu. in the base case to 2.34, 2.26, and 2.19 c/bu. for the low, moderate, and high variety declaration cases, respectively. At the importer, non-GM flows generally increased for higher levels of variety declaration, and the probability of rejection generally decreased although the moderate case experienced a slight increase and decrease in probability of rejection and non-GM flows, respectively.

Parametric Sensitivities

Sensitivities on parametric variables assess impacts to optimal testing strategies, risks, and costs from system changes including risk aversion of handlers/shippers and the rate of GM adoption. The successive sections examine these changes and compare variations with the base case.

Risk Aversion (η)

The risk parameter, η, was varied from 0.5 in the base case to 0.4 and 0.9 to represent less risk averse and more risk averse handlers/shippers, respectively. The optimal testing strategy intensified as risk aversion increased, indicating that more risk averse firms prefer testing to quality loss. Correspondingly, testing costs progressively increased, and quality loss steadily decreased for higher levels of η. The risk premium required to compensate handlers/shippers decreased from 2.42 c/bu. in the base case to 1.63 c/bu. for the less risk averse case and increased to 3.28 c/bu. for the more risk averse case. The probability of rejection at the importer increased for the less risk averse case and decreased for the more risk averse case. Total costs across all bushels and non-GM bushels declined for higher levels of η. Across non-GM bushels, the less risk averse case had a total cost of 43.3 c/bu. compared to 15.83 c/bu. for the base case and 9.19 c/bu. for the more risk averse case. The large disparities resulted from quality loss and were further exacerbated by the percentage of non-GM flows at the importer, which significantly increased for higher levels of risk aversion.

GM Adoption

Varying levels of GM adoption could proliferate in the case of GM wheat, depending upon import restrictions, agronomic benefits, and consumer preferences. GM adoption rates were varied for no variety declaration and variety declaration scenarios to identify system implications.

No Variety Declaration

Three cases, 10, 25, and 30% GM adoption, were examined; however, only the 10 and 25% cases provided feasible results. The 10% case employed a less intensive testing strategy that resulted in lower testing costs, quality loss, and total costs across all bushels and non-GM bushels. In addition, the percentage of non-GM flows increased from 48% in the base case to 57.8%. The 25% case tested the same as the base case and resulted in higher testing cost, quality loss, and total cost when measured across non-GM bushels, partially due to 39.1% of flows being non-GM at the importer. The risk premium and probability of rejection at the importer both increased for higher GM adoption rates, indicating that it becomes more challenging to remove the adventitious presence of GM grain in a no variety declaration. The 30% case was unable to achieve segregation of non-GM and GM flows at a cost less than the underlying value of the commodity. This finding reveals that GM adoption rates greater than 25% necessitate a system of variety declaration with contract mechanisms.

Variety Declaration

The rate of GM adoption was varied to 25, 50, 60, 70, and 75% to simulate impacts on the system. The 75% case was implausible, indicating that a GM adoption rate greater than 70% would necessitate an alternate system of testing, segregation, and/or identity preservation to maintain segregation of GM and non-GM flows. As the rate of GM adoption increased, testing became less intensive, and quality loss generally increased with the exception of the 25% case. Total costs across all and non-GM bushels generally increased as the GM adoption rate increased except for the 25% case where total cost declined. The risk premium initially decreased for the 25 and 50% cases, and then increased for the 60 and 70% cases because disutility was lower for 25 and 50% and higher for 60 and 70% compared to the base case. The probability of rejection at the importer initially decreased for the 25% case and then progressively increased for the 50, 60, and 70% cases. Conversely, the percentage of non-GM flows at the importer increased for the 25% case and then progressively decreased for the 50, 60, and 70% cases. The use of discrete choice and utility theory resulted in lower importer rejection, risk premium, and total costs for the 25% case and lower risk premium for the 50% case.

Other Sensitivities

Domestic System

The domestic model evaluates delivery to a domestic end-user (e.g., processor, miller, etc.) who designates a GM tolerance. The optimal strategy tested as intensively as possible, but failed to reduce total costs and the probability of rejection. Total costs were inflated to cost prohibitive levels of 240.21 c/bu. using the defined system of testing and segregation. All cost components, including testing cost, quality loss, and risk premium, increased substantially. Testing cost represented the smallest change since testing was not conducted at the export elevator as in the base case. Quality loss jumped from 9.36 c/bu. in the base case to 162.51 c/bu. in the domestic case while risk premium increased to 34.2 c/bu. versus 2.42 c/bu. in the base case. The probability of rejection for the domestic case soared to 6.01% versus 2.83% in the base case. The percentage change in non-GM flows at the end-user was negligible. The results demonstrated that variety declaration should be implemented to reduce adventitious commingling of GM commodities.

Implication of Results

Development and commercialization of genetically modified crops continue to challenge the current functions and operations of the grain marketing system. With the anticipated commercialization of GM wheat, these issues remain increasingly important. The research defines several relationships among optimal testing strategies, risks, costs, and different variables impacting the dual-marketing system. The impact of stochastic, strategic, parametric, and other variables on the optimal testing strategies, risks, and costs is shown and evaluated. Implications for public and private sectors are presented in the following sections.

Public Implications

There are several implications for the public sector. First, a system of testing and segregation can efficiently provide end-users differentiated grain shipments to meet consumer requirements at a low cost. While nil tolerances are unattainable, GM content can reasonably be assured for current import specifications of 0.5% or above. Second, grain uniformity and quality deviations existing in the marketplace are minimized due to quality loss applied at the end-user. Sellers view deviations from zero percent GM contamination as an implicit cost; thus, more rigorous testing ensues, thereby reducing GM content in non-GM shipments. Third, consumer differentiation among value-added products necessitates a system of testing and segregation to properly allocate non-GM and GM flows.

Private Implications

In addition to public implications, several additional private sector implications exist. First, a system of testing and segregation drastically reduces cost when compared to an identity-preservation alternative. Identity preservation entails increased monitoring and documentation through the production, storage, transportation, and handling phases. Second, with rapid advancements in testing technology, costs and risks will progressively decrease. Third, risk premiums evolve to compensate grain handlers for added risks of a dual-marketing system versus a non-GM system. Fourth, adventitious presence resulting from variety risks will encourage grain handlers to adopt a system of contract mechanisms. Fifth, additional penalties (A_o) encourage handlers/shippers to test more intensively to avoid quality losses. Sixth, import tolerance defines testing strategy, and accompanying costs and risks. Seventh, more and less risk averse grain handlers tradeoff definite testing costs for indefinite quality loss. Eighth, the rate of GM adoption has a significant bearing on the viability of the defined system of testing and segregation. With no variety declaration, GM adoption of greater than 25% necessitates variety declaration mechanisms. With variety declaration, GM adoption of greater than 70% provides cost prohibitive results and thus necessitates an alternate form of testing, segregation, and/or identity preservation. Ninth, delivery to a domestic user requires a system of variety declaration.

Limitations of Study

A major limitation of this research is the uncertainty surrounding genetically modified wheat. GM corn and soybean data are used throughout the study to provide estimates. The rate of GM adoption is uncertain. Probability distributions for adventitious commingling, variety declaration and penalty differentials are estimated. The calculation of rejected and diverted lots assumes a hypergeometric distribution where sampling is assumed to be representative of a lot. Testing accuracy and the probability of Type I errors are uncertain. The probability of accepting a GM lot with a specified tolerance relies on a binomial distribution. The probability of rejecting a GM lot and GM contaminated grain may be understated by the binomial distribution when exceedingly tight tolerances close to zero (e.g., .04%) are applied at grain marketing points. The variance for quality loss relies on assignment of an average tolerance to lots exhibiting fractionally higher and lower tolerances.

The system that is modeled assumes a vertically integrated system, which is prototypical of the industry. However, a non-integrated system would encompass differing accountabilities, quality loss calculations, and contract mechanisms.

Other limitations include the evaluation of an average lot concentration based on the amount of adventitious presence in the flow versus lot concentration of individual lots. Grain flows throughout the system assume bin configurations that limit additional contamination of GM and non-GM grain during handling and shipping.

Need for Further Research

The determination of GM lot concentration based on individual transportation units arriving at country elevator, export elevator, and import locations would greatly improve estimates for sampling, testing, and rejection using the binomial distribution. In addition, the variance of quality loss at the end-user would be more accurate.

Further research on adventitious commingling rates for handling, shipping, and variety risks would greatly impact the analysis. Determining bin flow based on configuration and utilization would augment the tracking of individual lots and the estimation of commingling rates.

A study incorporating farmer deliveries, contract affidavits, and the resulting level of accountability would be contributive to this research. As a result, specific benefits of imposing contract mechanisms could be quantified.

Risk parameter ϕ should be varied to determine effects on the risk premium. In addition, η should be varied with differing levels of ϕ to quantify effects on optimal testing strategies, risks, and costs.

Further research should be conducted on the probability of rejecting a lot and contaminated GM grain based on exceedingly tight tolerances at grain marketing points (e.g., .04%). The probability may be understated by the binomial distribution.

Summary

This thesis has explored optimal testing strategies, costs, and risks of a dual-marketing system. The research is an area of increasing importance due to regulatory mandates, consumer differentiation, and commercial preferences towards genetically modified grain. Numerous issues are covered, and results are drawn based on additional system costs and risks in a dual-marketing system.

REFERENCES

Agdia, Inc. Agdia Testing Services. n.d. Accessed 4 Nov. 2002 < http://www.agdia.com>.

American Bakers Association. American Bakers Association Biotechnology Position Statement. n.d. Accessed 28 Nov. 2001 <http://www.americanbakers.org/pubs/biotech_paper_2001_for_web.pdf >.

Apel, Andrew. Home page. n.d. Accessed 25 Feb. 2002 <http://www.biotech-info.net/risk_assessment_challenge.html>.

Archer Daniels Midland. 2000. "2000 ADM Identity Preserved STS Soybeans Treated with Synchrony Herbicide." Sample Contract Between ADM and an Elevator. Unpublished document.

Askin, Tom. 1988. "The Cost of Grade Segregating to Primary Elevators." Canadian Grain Commission, Winnipeg, Canada.

Australian Bureau of Agricultural and Resource Economics (ABARE). 2001. "Genetically Modified Grains: Market Implications for Australian Grain Growers." ABARE, Canberra.

Bender, Karen, Lowell Hill, Benjamin Wenzel, and Robert Hornbaker. 1999. "Alternative Market Channels for Specialty Corn and Soybeans," Department of Agricultural Economics, University of Illinois at Urbana-Champaign, AE-4726, Feb. 1999.

Biotechnology Australia. 2000. "Australian Public Unsatisfied with Media Coverage of Genetically Modified Issues." Press Release. Updated 10 Aug. 2000. Accessed 11 Aug. 2002 <http://www.plant.uoguelph.ca/safefood/archives/agnet-archives.htm>.

Buckwell, Allan, Graham Brookes, and Dylan Bradley. 1998. "Economics of Identity Preservation for Genetically Modified Crops." CEAS 1745/GJB. Wye, U.K.: CEAS Consultants (Wye) Ltd.

Bullock, David S., Marion Desquibet, and Elisavet Nitsi. "The Economics of Non-GMO Segregation and Identity Preservation." American Agricultural Economics Association Annual Meeting. Tampa, Florida. 30 July - 2 Aug. 2000.

Canadian Wheat Board. CWB Biotechnology Position Statement. n.d. Accessed 28 Nov. 2001 <http://www.cwb.ca/publicat/biostate/index.shtml>.

Casada, Mark, M. Elena Ingles, and Ronaldo Maghirang. "Report of Preliminary Findings from a Study of Value-Added and Identity Preserved Grain Handling in Commercial Elevators." Working Paper, 2001.

Central-Hanse Analytical Laboratory, LLC. 1999. “Price List.” Belle Chasse, LA, June 1999.

“The Concept of Substantial Equivalence in Safety Assessment of Foods Derived from Genetically Modified Organisms,” Review of Marianna Schauzu. AgBiotechNet 2 (2000): 1-4.

Cotterill, Ken. “Seeds of Doubt.” The Traffic World Jan. 17, 2000: 19-20.

Dahl, Bruce L., and William W. Wilson. “The Logistical Costs of Marketing Identity Preserved Wheat.” Agribusiness and Applied Economics Report No. 495, Department of Agribusiness and Applied Economics, North Dakota State University, Fargo, 2002.

D’Errico, John R., and Nicholas A. Zaino, Jr. “Statistical Tolerancing Using a Modification of Taguchi’s Method.” Technometrics 30.4 (1988): 397-405.

DuPont Specialty Grains. 2000a. OSCAR Visitor’s Site. n.d. Accessed 20 Sept. 2002 <http://oscar.itsoptimum.com>.

DuPont Specialty Grains. 2000b. Purchase Agreement for 2000 ADM Identity Preserved STS Soybeans Treated with Synchrony Herbicide. Sample Contract. n.d. Accessed 12 Sept. 2002 <http://170.54.59.100/SampleContract.asp?ID=OSCR00000129>.

DuPont Specialty Grains. 2000c. 2000 PTI Identity Preserved Non-GMO Soybean Program, Protein Technologies, Inc.; Bloomington, IL Area Grower Agreement: Non-GMO Soybeans. Sample Contract. n.d. Accessed 12 Sept. 2002 <http://170.54.59.100/SampleContract.asp?ID=OSCR00000211>.

Dye, Dan. 2000. “Building the Identity Preservation System of the Future.” Speech presented at the 2000 Institute of Food Technologies. <http://www.cargill.com/today/speeches>. Updated 10 June 2002. Accessed 25 Sept. 2002.

Elliott, Ian. 2002. “After Months of Delays, EU Ministers Agree to Tighten GMO Labeling Rules.” Feedstuffs [Minnetonka]: 1, 4.

EnviroLogix, Inc. Products: GMO Monitoring Kits. Updated 20 Apr. 2002. Accessed 4 Nov. 2002 <http://www.envirologix.com/artman/publish/article_13.shtml>.

Environmental Protection Agency. EPA Preliminary Evaluation of Information Contained in the October 25, 2000 Submission from Aventis Cropscience. n.d. Accessed 9 Apr. 2003 <http://www.epa.gov/oscpmont/sap/2000/november/prelim_eval_sub102500.pdf>.

European Union. European Commission. Comments from the European Commission Services to the Codex Secretariat. 14 pp. Updated 14 Apr. 2001. Accessed 16 Sept. 2002 <http://europa.eu.int/comm/food/fs/ifsi/eupositions/ccgp/ccgp01_en.html>.

Evans, David H. "Statistical Tolerancing: The State of the Art: Part I-Background." Journal of Quality Technology 6.4 (1974): 188-195.

Evans, David H. "Statistical Tolerancing: The State of the Art: Part II-Methods for Estimating Moments." Journal of Quality Technology 7.1 (1975): 1-12.

Gadallah, M.H., and H.A. Elmaraghy. "A New Algorithm for Discrete Tolerance Optimization." Proceedings of the Fourth International Conference on Computer Integrated Manufacturing and Automation Technology. Troy, NY, 10-12 Oct. 1994. 292-297.

Gersema, Emily. "Testing for Roundup Ready." AGWEEK 29 Oct. 2001: 29.

Gosnell, D. 2001. "Non-GM Wheat Segregation Strategies: Comparing the Costs." Diss. University of Saskatchewan, Saskatoon.

Greenlees, W.J., and S.C. Shouse. "Estimating Grain Contamination from a Combine." American Society American Engineers Mid-Central Conference. Paper No. MC00-103, Iowa State University Extension, 2000. St. Joseph, MI. 28-29 Apr. 2000.

Hanna, Mark, and Wally Greenlees. "Planter Tips when Changing Seed Varieties." Integrated Crop Management, Iowa State University, Department of Entomology, Ames. 2000. n.d. Accessed 15 Sept. 2002 <http://www.ipm.iastate.edu/ipm/icm/2000/3-20-2000/cleanout/html>.

Hermann T.J., M. Boland, and A. Heishman. "Economic Feasibility of Wheat Segregation at Country Elevators." Kansas State University, Manhattan, KS. 1999. n.d. Accessed 15 Sept. 2002 <http://www.css.orst.edu/nawg/1999/herman.html>.

Hoban, Thomas J. Trends in Consumer Attitudes about Agricultural Biotechnology. North Carolina State University, Raleigh. n.d. Accessed 25 Aug. 2002 <http://www.agbioforum.org/vol11no1/hoban.html>.

Hobbs, Jill E., William A. Kerr, and Peter W.B. Phillips. "Identity Preservation and International Trade: Signaling Quality Across National Boundaries." Canadian Journal of Agricultural Economics 49 (2001): 567-579.

Hurburgh, Charles R. Jr., et al. "The Capability of Elevators to Segregate Grain by Intrinsic Quality." American Society Agricultural Engineers Summer Meeting. Paper No. 946050, Iowa State University, Ames. June 1994. 1-15.

Inadequate safety assessment of GE foods. Physicians and Scientists for Responsible Application of Science and Technology. Updated 8 Sept. 2001. Accessed 3 Sept. 2002 <http://www.psrast.org/subeqow.htm>.

Irianto, Dradjad. "Inspection and Correction Policies in Setting Economic Product Tolerance." International Journal of Production Economics 46-47 (1996): 587-593.

Jeang, Angus. "Tolerance Design: Choosing Optimal Tolerance Specification in the Design of Machined Parts." Quality And Reliability Engineering International 10 (1994): 27-35.

Jeang, Angus. "Optimal Tolerance Design for Product Life Cycle." International Journal of Production Resources 34 (1996): 2187-2209.

Jenkyn, Thomas R. "Investigation of the Shape of Flow Channels in a Funnel Flow Bin." American Society of Agricultural Engineers Summer Meeting. Paper No. 94-4031. St. Joseph, MI. 19-22 June 1994. 1-21.

Jirik, Patrick J. 1994. "Identity Preserved Grain Marketing." Diss. Saint Mary's College, Winona, MN.

Kalaitzandonakes, Nicholas, Richard Maltsbarger, and James Barnes. "Global Identity Preservation Costs in Agricultural Supply Chains." Canadian Journal of Agricultural Economics 49 (2001): 605-615.

Kim, Sunn Ho, and Kenneth Knott. "A Pseudo-Boolean Approach to Determining Least Cost Tolerances." International Journal of Production Resources 26.1 (1988): 157-167.

Konsor, Greg. "fyi." E-mail to Bill Wilson. 19 Dec. 2001.

Krejci, David. "Feasibility and Cost of Marketing Identity-Preserved Crops: Challenge to Changing the Infrastructure." USDA Agricultural Outlook Forum 2002. Arlington, VA. 21-22 Feb. 2002.

Krishnaswami, Mukund, and R.W. Mayne. "Optimizing Tolerance Allocation Based on Manufacturing Cost and Quality Loss." Advances in Design Automation 69.1 (1994): 211-217.

Krueger, Angela, et al. "Risk Management Strategies for Grain Elevators Handling Identity-Preserved Grains." IAMA World Food and Agribusiness Congress. West Lafayette, IN. June 2000.

Kuntz, G. 2001. "Transgenic Wheat: Potential Price Impacts for Canada's Wheat Export Market." Diss. University of Saskatchewan, Saskatoon.

Larson, Paul D. "The Integration of Inventory and Quality Decisions in Logistics: An Analytical Approach." Journal of Business Logistics 10.2 (1989): 106-123.

Lin, William. "Segregation of Non-biotech Corn and Soybeans: Who Bears the Cost?" Sixth International Consortium of Agricultural Biotechnology Research (ICABR). Ravello, Italy. 11-14 July 2002.

Lence, S., and D. Hayes. 2001. "Response to an Asymmetric Demand for Attributes: An Application to the Market for Genetically Modified Crops." Working Paper, Iowa State University, Ames.

Maltsbarger, R., and N. Kalaitzandonakes. "Hidden Costs in the IP supply chain." Feedstuffs 72.36 (2000): 1-2.

Mansour, Mark, and Jennifer B. Bennett. "Regulation of Biotech Foods: Obstacles and Opportunities." Council For Biotechnology Information. n.d. Accessed 4 Sept. 2002 <http://www.whybiotech.com/en/news/con518.asp?MID=17>.

McPhee, Terry L., and Anita Bourget. 1995. "Cost of Grain and Grade Segregation at Terminal Elevators in Canada." Canadian Grain Commission, Winnipeg, Canada.

Mendenhall, William, and Terry Sincich. 1996. "A Second Course in Statistics." 5th ed. Prentice-Hall, Inc., Upper Saddle River, NJ.

Midwest Seed Services, Inc. GMO-Free Testing Services. n.d. Accessed 16 Sept. 2002 <http://mwseed.com>.

Miranowski, John A. et al. 1999. "Economic Perspectives on GMO Market Segregation." Working Paper, Iowa State University, Ames.

Moss, Charles, Troy Schmitz, and Andy Schmitz. "The Economics of GMO Market Segmentation." International Agricultural Trade Research Consortium. Tucson, AZ. 14-16 Dec. 2001.

Nagarwala, Moiz Y., P. Simin Pulat, and Shivakumar Raman. "A Slope-Based Method for Least Cost Tolerance Allocation." Concurrent Engineering 3.4 (1995): 319-328.

National Grain and Feed Association. 2001. Agricultural Biotechnology Policy of the National Grain and Feed Association. n.d. Accessed 4 Nov. 2001 <http://www.cwb.ca/pulicat/biostate/index.shtml>.

Nelson, Gerald C. et al. "The Economics and Politics of Genetically Modified Organisms in Agriculture: Implications for WTO 2000." Bulletin 809, Research Consumer and Environmental Science Department, Univ. of Illinois at Urbana-Champaign, 1999.

Neogen Corporation. Neogen's CP4 (Roundup Ready) Test Strip. n.d. Accessed 4 Nov. 2002<http://www.neogen.com/gmo.htm>.

North American Grain Millers Association. 2001. Statement on Biotechnology. n.d. Accessed 6 Nov. 2001 <http://www.namillers.org>.

Palisade. 1998. "Risk Optimizer: Optimization with Simulation for Microsoft Excel." Newfield, NY, Palisade Corporation.

Phillips, Peter W.B., and G.E. Isaac. "GMO Labeling: Threat or Opportunity." AgBioForum 3.1 (1998) n.d. Accessed 4 Sept. 2002 <http://www.agbioforum.org/vol11no1/phillips.html>.

Phillips, Peter W.B., and Heather McNeill. "A Survey of National Labeling Policies for GM Foods." AgBioForum 3.4 (2000). n.d. Accessed 4 Sept. 2002 <http://www.agbioforum.org/v3n4/v3n4a07-phillipsmcneill.htm>.

Porter, Leslie J., and Paul Rayner. "Quality Costing for Total Quality Management." International Journal of Production Economics. 27 (1992): 69-81.

Porteus, Evan L. "Optimal Lot Sizing, Process Quality Improvement and Setup Cost Reduction." Operations Research 34.1 (1986): 137-144.

Quality Systems for Identity Preservation, Producer's Natural Processing Inc. n.d. Accessed 7 Nov. 2001 <http://www.pnpi.com/IP.htm>.

Ross, Phillip J. 1996. "Taguchi Techniques for Quality Engineering." McGraw-Hill, New York, NY.

Roy, Ranjit. "Primer on the Taguchi Method." Van Nostrand Reinhold, New York, NY, 1990.

"Safety and Regulations." Council for Biotechnology Information. n.d. Accessed 27 Aug. 2002 <http://www.whybiotech.com/en/safety/con116.asp>.

Saha, Atanu. "Expo-Power Utility: A 'Flexible' Form for Absolute and Relative Risk Aversion." American Journal of Agricultural Economics 75 (1993): 905-913.

Serrao, Amilcar, and Luis Coelho. "The Role of Area-Yield Crop Insurance in Farmers' Adjustment against Risk in a Dryland Region of Portugal." American Agricultural Association Annual Meeting. Evora, Portugal. 2000. 1-13.

Shlecht, Shannon M. "Logistical Strategies for Differentiated Wheat Classifications." Master's Thesis. North Dakota State University, Fargo, 2001.

Smyth, Stuart, and Peter W.B. Phillips. “Identity-Preserving Production and Marketing Systems in the Global Agri-Food Market: Implications for Canada.” Working Paper, University of Saskatchewan, Saskatoon, Aug. 2001.

Soderberg, Rikard. “Tolerance Allocation Considering Customer and Manufacturer Objectives.” Advances in Design Automation 65.2 (1993): 149-157.

Sonka, Steven, R. Christopher Schroeder, and Carrie Cunningham. 2000. “Transportation, Handling, and Logistical Implications of Bioengineered Grains and Oilseeds: A Prospective Analysis.” USDA-AMS, Washington, DC.

Sparks Company. 2000. “The IP Future: Identity Preservation in North American Agriculture.” Sparks Company. Memphis, TN.

Stave, James W., and Donald Durandetta. “GM Crop Testing Grows Amid Controversy.” Today’s Chemist at Work 9.6 (June 2000). n.d. Accessed 7 Nov. 2001 <http://pubs.acs.org/hotartcl/tcaw/00/jun/stave.html>.

Strategic Diagnostics, Inc. Trait4 RUR Lateral Flow Test User Guide. n.d. Accessed 13 Mar. 2003 <http://www.sdix.com/PDF/Products/7000014.Users%20Guide%20TraitCheck%20RUR%20Bulk%20Soybean%20100T%205min.doc>.

South Dakota State University Cooperative Extension Service. “10 Steps in Cleaning a Combine.” Videocassette tape. 2000. n.d. Accessed 15 Sept. 2002 <http://www.amsoy.org/video/clean-combine.htm>.

“Substantial Equivalence in Food Safety Assessment.” Council for Biotechnology Information. 3 pp. Updated 11 Mar. 2001. n.d. Accessed 4 Sept. 2001 <http://www.whybiotech.com/index.asp?id=1244>.

Taguchi, Genichi. 1986. “Introduction to Quality Engineering: Designing Quality into Products and Processes.” Tokyo, Japan, Asian Productivity Association.

Tickner, Joel, and Carolyn Raffensperger. “The Precautionary Principle in Action: A Handbook.” Science and Environmental Health Network. 1st ed. n.d. Accessed 16 Sept. 2002 <http://www.sehn.org/rtfdocs/handbook-rtf.rtf>.

United States Department of Agriculture. Economic Research Service. Biotechnology: U.S. Grain Handlers Look Ahead. (Apr. 2000): 29-34.

United States Department of Agriculture. Economic Research Service. Implications of Testing and Segregating Non-biotech Crops for Grain Grades and Standards. Agriculture Information Bulletin No. 762 (Mar. 2001): 23-27.

United States Department of Agriculture. Federal Grain Inspection Service. Grains Inspected and/or Weighed for Export by Region and Country of Destination. Calendar Year 1999 to 2003. 31 Dec. 1999. Unpublished datasheet.

United States Department of Agriculture. Foreign Agricultural Service. Dec. 2000. Oilseeds: World Markets and Trade. GPO, Washington, DC.

United States Department of Agriculture. Foreign Agricultural Service. May 2000. Grains: World Markets and Trade. GPO, Washington, DC.

United States Department of Agriculture. Foreign Agricultural Service. United States Trade Exports Calendar Year 2001. n.d. Accessed 25 Sept. 2002 <http://www.fas.usda.gov/ustrade/ustexbico.asp?QI=>.

United States Department of Agriculture. Grain Inspection Packers, and Stockyards Administration. Process Verification: An Alternative to Traditional Inspection Services. n.d. Accessed 1 Nov. 2002 <http://www.usda.gov/gipsa/programsfgis/inspwgh/processver/processv.pdf>.

United States Department of Agriculture. Grain Inspection, Packers and Stockyards Administration. Notice to the Federal Register, Facilitating the Marketing of U.S. Agricultural Products with New Testing and Process Verification Services. 67.151 (2002): 50853-50854.

United States Department of Agriculture. Grain Inspection, Packers and Stockyards Administration. Test Kit Performance Verification. Updated 3 Apr. 2002. Accessed 2 Nov. 2002 <http.www.usda.gov/gipsa/tech-servsup/metheqp/testkit.htm>.

United States Department of Agriculture. Grain Inspection, Packers and Stockyards Administration. Proficiency Program. n.d. Accessed 2 Nov. 2002 <http://www.usda.gov/gipsa/biotech/proficiency-program.htm>.

United States Department of Agriculture. National Agricultural Statistics Service. Agricultural Statistics Data Base. n.d. Accessed 25 Sept. 2002 <http://www.nass.usda.gov:81/ipedb/>.

United States Department of Agriculture. Sampling for the Detection of Biotech Grains. Updated 5 Oct. 2000. Accessed 7 Nov. 2001 <http://www.unitedstatesdepartmentofagriculture.gov/gipsa/biotech/sample2.htm>.

United States Department of Agriculture. Value Enhanced Grain Survey. Illinois Market News, NASS, 8 Feb. 2000.

United States Department of Agriculture. Value Enhanced Grain Survey. Illinois Market News, NASS, 6 Feb. 2001.

United States Wheat Associates. Biotechnology Position Statement. n.d. Accessed 28 Nov. 2001 <http://uswheat.org>.

Wei, Chiu-Chi. "Tolerance Design with Concurrent Optimization of Quality Loss and Process Capability." International Journal of Industrial Engineering 5.2 (1998): 169-174.

Wilcke, Bill. Identity Preservation of Grain Crops. University of Minnesota Extension Service, Updated 6 Sept. 1999. Accessed 7 Nov. 2001 <http://www.bae.umn.edu/extens/postharvest/ip.html>.

Wilson, William W., and Bruce L. Dahl. "Costs and Risks of Testing and Segregating GM Wheat." Agribusiness and Applied Economics Report No. 501, Department of Agribusiness and Applied Economics, North Dakota State University, Fargo, 2002.

Wilson, William W., and Bruce L. Dahl. "Evaluation of Changes in Grade Specifications for Dockage in Wheat." Agribusiness and Applied Economics Report No. 458, Department of Agribusiness and Applied Economics, North Dakota State University, Fargo, 2001.

Wilson, William W., Bruce L. Dahl, and William Nganje. "Testing and Tolerance Strategies for Commercialization of Genetically Modified Grains." National Research Institute Proposal. North Dakota State University, Fargo, 2002.

Winston, Wayne L. 2001. Simulation Modeling Using @Risk. Duxbury, Pacific Grove, CA.

Wu, Chin-Chung, Zhuoning Chen, and Geo-Ry Tang. "Component Tolerance Design for Minimum Quality Loss and Manufacturing Cost." Computers in Industry 35 (1998): 223-232.

Wu, Z., W.H. Elmaraghy, and H.A. Elmaraghy. "Evaluation of Cost-Tolerance Algorithms for Design Tolerance Analysis and Synthesis." Manufacturing Review 1.3 (1988): 168-179.

Wylie, Stormy. "Existing I.P. System not set up to Handle GMOs, Grain Industry Executive says." World Grain. (October 2001): 44-46.

Zhang, H.C., and M.E. Huq. "Tolerancing Techniques: The State-of-the-Art." International Journal of Production Resources 30.9 (1992): 2111-2135.