Quality Uncertainty and Grain Merchandising Risk: Vomitoxin in Spring Wheat

by

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A mathematical programming model is used to demonstrate implications of a random quality factor, vomitoxin, for spatial flows and merchandising risk. The model is developed from a seller's perspective using crop quality and market data from 1993 and 1994, years of severe vomitoxin infestations in the spring wheat crop. Vomitoxin poses major risks for grain traders because of regulatory (FDA) limits, sampling difficulties, and imprecise measurement. If a shipment is rejected because of excess vomitoxin, it is commonly sold to an alternative customer (contract) at a reduced price. These implicit discounts influence precautionary efforts by sellers to ensure that contract specifications are satisfied.

The model is structured as a blending problem. There are 9 wheat supply regions (North Dakota crop districts), each with different quality attributes, and 7 contracts used by buyers for shipment to or through Minneapolis or the Pacific Northwest (PNW) with different prices and quality requirements. The objective is to maximize the value of wheat sales net of transportation costs. Inclusion of a random quality factor, vomitoxin, complicates the analysis. The distribution of vomitoxin (mean and variance) varies geographically, as well as between crop years. Traders can assemble grain from different regions and, through blending, influence the probability that shipments will receive the full price, avoiding discounts for excess vomitoxin. Relationships among these endogenous probabilities, market price spreads, and contract specifications are of central interest in model simulations.

Introduction

In many grain markets, price relationships and spatial flows are heavily influenced by quality factors. End-users of grain, both foreign and domestic, have diverse quality requirements. Supplies are heterogeneous, with qualities varying by producing region and through time, depending on conditions in individual crop years. This heterogeneity is a critical feature of grain handling and merchandising. Elevators segregate grain based on quality factors (such as protein or test weight) and enhance their marketing margins through blending and conditioning activities. Traders assemble grain from different producing regions, with different quality characteristics, to satisfy the needs of individual buyers and capture price premiums.

Among grain traders, the importance of quality risk is well-recognized. Interest was heightened by recent experiences in the spring wheat and barley markets. In 1993 and 1994, weather conditions led to severe quality problems for spring-planted grains. Vomitoxin, a toxic substance of mold origin (and subject to food safety regulations), was detected in high concentrations in some growing regions. Vomitoxin is an example of a quality characteristic that cannot easily be specified in contracts due to sampling and measurement error. Such

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characteristics increase risks for grain traders and complicate procurement strategies for domestic and international buyers.

Grain traders make sales on the basis of contract specifications for quality characteristics. When individual characteristics are subject to large sampling or measurement error, they are viewed as random from a trading perspective. This has implications for merchandising and procurement strategies. Grain sellers weigh the probability of not meeting contract specifications (and associated price risks) when assembling grain before shipment. If, after shipment and inspection at destination, the grain fails to meet the buyer's quality specifications, it may be discounted or (in the case of vomitoxin) forced into an alternative market at a lower price. The magnitude of this penalty will influence precautionary efforts by sellers, i.e., decisions about sourcing of grain, and levels of quality characteristics before shipment, to ensure that contract specifications are satisfied. Price effects (premiums or discounts) are transmitted to country origins as traders shift their procurement in response to perceived quality risks and changing price relationships in terminal markets.

Quality variability (uncertainty) creates numerous problems for end-users. Both the Office of Technology Assessment (U.S. Congress) and USDA studies (Mercier) on grain quality concluded that quality variability is a growing concern among importers. Because of the growing sophistication of buyers and competition in the international and domestic grain market, there is a trend toward greater specificity in contract terms. As contracts become more specific, buyers' procurement costs increase. In addition, procurement becomes more restricted geographically due to competitive pressures and reduced availability of specific qualities.

Importer procurement strategies, i.e., the combination of price and quality specificity, are critical factors in the spring wheat market. Some importers use more stringent contract specifications than domestic (U.S.) millers. The latter are accustomed to mixing and blending and can target specific producing regions for their wheat purchases. Contract specifications have considerable strategic importance, particularly in view of competition among buyers. As quality specifications become more restrictive, procurement becomes more difficult; higher prices must be bid to meet volume requirements.

These problems are not unique to wheat and vomitoxin. Similar problems exist with aflatoxin in corn and vomitoxin in barley. With growing awareness of food safety issues and increasing buyer sophistication, it is becoming increasingly important to integrate effects of quality variability into economic (and strategic) analyses of trade and procurement. As demonstrated in this report, the value of wheat in different geographical locations varies substantially with the level and variability of quality characteristics as well as with other parameters (e.g., price differentials and transportation costs) traditionally associated with spatial equilibrium.

The purpose of this report is to analyze effects of quality variability on the allocation of wheat among competing markets and contracts. The focus is on quality variability, trading risks, and competition among buyers offering different prices and contract terms. The primary quality characteristic of interest is vomitoxin, which had important effects on the upper great plains wheat and barley markets during 1993 and 1994. However, the analysis requires consideration of other quality characteristics relevant to wheat buyers. A math programming model was developed to incorporate the spatial dimensions of quality distributions, competing geographic market demands, and contract requirements and premiums/discounts for specific buyers. The model was used to evaluate the effect of quality variability and alternative buyer strategies on trade patterns and merchandising risk.

Background

Related Studies. Numerous studies have been devoted to grain quality issues, with several evolving strains of literature. Differentiation in the world grain (wheat) trade has been addressed by several authors, including Larue and Lapan; Veeman; Wilson and Gallagher; Wilson (1989, 1994); and Wilson and Preszler. Mercier analyzed the role of quality in wheat import decisions, based on results from a survey of international buyers. Johnson and Wilson (1995) developed an optimization model that simultaneously determined the importer's demand for quality attributes (in this case, cleaned wheat) and the exporter's supply of cleaned wheat.

Other studies have addressed issues related to the role of institutions affecting quality heterogeneity. These include the U.S. Congress Office of Technology Assessment and Hill. Researchers have begun to examine the economics of conditioning grain and the role of market and regulatory mechanisms in providing incentives. These include studies on wheat cleaning by Adam, Kenkel and Anderson; USDA studies (summarized by Lin and Leath; Mercier and Hyberg; and Hyberg et al.); and Wilson, Scherping, Johnson, and Cobia. Johnson and Wilson (1993) developed a blending model with integrated cleaning technology at the country elevator level.

A recurring theme has been the importance of quality variability. The OTA study found that grain buyers wanted more information on end-use performance and had major concerns about the lack of uniformity in quality. The USDA survey of buyers indicated that wheat from both Australia and Canada was superior to U.S. wheat in terms of quality variability and cleanliness. Concerns were raised about quality variability both within and between shipments. Much of the U.S. research has focused on quality levels, rather than on quality variability, even though both the level and variability are critical in commercial processing.[1] This problem was analyzed in the case of end-use performance variability by Wilson and Preszler. Their study uses a chance-constrained programming model to assess impacts of quality variability on wheat imports in the United Kingdom.

Quality Definitions. Wheat quality is conventionally described in terms of grade-determining and non-grade-determining factors. The former are easily measured and have

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[1]Variations in quality can interrupt production schedules, increase processing costs, require additional storage, and reduce end-product quality. In large part, *total quality management* is motivated by the objective of reducing quality variability.

standardized procedures for evaluation. Grade determining factors affect the grade number assigned to particular samples using the least-factor approach.

Non-grade determining quality factors are also important to end-users (but do not affect the grade). Of particular importance in the case of wheat are protein, dockage, falling numbers, vitreous kernels, and vomitoxin. Protein is a proxy for gluten strength, and dockage is a measure of the amount of "easily removable" non-wheat material in a sample.

Vitreous kernels (measured in %) relates to the hard, glossy appearance of wheat and usually varies with protein content. It is judged visually by comparing wheat samples with known standards under a constant light source. Sub-classes of Hard Red Spring (HRS) wheat are determined on the basis of vitreous kernels. Falling number is a test for potential sprout damage, or premature germination. It is a measure of alpha-amylase activity in flour that reduces the ability of flour to thicken. Technically, it is the number of seconds required for a plunger to fall a measured distance through a mixture. The higher the falling number value, the sounder the wheat.

Vomitoxin. Growing conditions during 1993 and 1994 gave rise to scab infestations in spring-planted grains. Vomitoxin, an undesirable characteristic associated with scab, became a major factor in the spring wheat and barley markets.[2] This section defines vomitoxin and explains its treatment in regulations. Impacts of vomitoxin on grain merchandising and procurement are also described.

Regulations and Grades: Vomitoxin is a non-carcinogenic fusarium mycotoxin also known as DON, an acronym for "deoxynivalenol" (NGFA, p. 1). Unlike some toxins, it generally "does not represent a threat to public health among the general population, ... [but] sometimes produces acute temporary nausea and vomiting in humans and animals" (Milling and Baking News, p. 11). Vomitoxin is a by-product of Fusarium graminearum or scab (Moore, p. 3).

Vomitoxin is measured indirectly in U.S. grade standards and is also regulated for safety reasons by the Food and Drug Administration (FDA). Although vomitoxin can be present in scabbed kernels, the presence of scab does not mean that vomitoxin is present. Nor does the scab kernel count give an accurate measure of the extent of vomitoxin. Vomitoxin is measured separately using one of two tests. The first, widely used by FGIS, is the Neogin (brand) Elisa test. This test measures vomitoxin in ranges and is not highly accurate. More advanced testing methods provide a precise and accurate measurement (and are the methods used in this study). The drawback is the higher expense of these procedures.

The FDA treats vomitoxin as an *advisory level*, meaning it is not subject to mandatory limits. However, the agency

[2] The technical and agronomic aspects of vomitoxin have been the subject of two major conferences. (Minnesota Wheat Research and Promotion Council, 1993 and 1994).

reserves the right to take regulatory action against persons who knowingly blend grain containing vomitoxin with clean grain if the resulting mixture is likely to result in an end-product that significantly exceeds the advisory level necessary to protect human and animal health (NGFA, p. 5).

The previous vomitoxin advisory level was established in 1982 and was set at 2 ppm for raw grains, 1 ppm for products, and 4 ppm for feed. These were changed in September 1993 as follows: the limit on raw grains was eliminated; product limits were retained at 1 ppm; and there was a change in advisory level for feed, with different limits for individual species.

Vomitoxin Statistics: The level and variability of vomitoxin among North Dakota Crop Reporting Districts (CRDs) are shown in Tables 1 and 2 for the 1993 and 1994 crops. Several of the regions had average vomitoxin levels above FDA advisory levels, particularly those in the eastern region (CRDs 3, 6, and 9). There was substantial variability both across and within CRDs. A comparison between years shows that vomitoxin was more extensive in 1993.

Data from crop quality surveys suggest that vomitoxin is positively correlated with damage, defects, and test weight. To control the level of vomitoxin, a buyer could use specifications for other, more easily measurable characteristics. For example, tighter specifications on damage (or defects) would be expected to have an impact on the level of vomitoxin in purchased grain.

The standard deviation of vomitoxin in the samples increases with mean levels. Where vomitoxin is more prevalent it is subject to greater uncertainty. Incidence of vomitoxin has been highly uneven. The average level of vomitoxin (weighed by production in 9 CRDs) was 2.84 ppm in 1993. Ignoring CRDs 3, 6, and 9, the weighted average was only 0.67.

Trading, Handling and Procurement: The existence of regulatory limits for vomitoxin forced a response by the trading and handling industry. The Minneapolis Grain Exchange, the principal futures contract for HRS wheat, requires deliveries to be "fit for human consumption," which was interpreted to mean in conformance with FDA regulations. Domestic food processors initially established contract limits at 2 ppm, which were subsequently replaced by limits for vomitoxin in the product.

Importers of HRS had varying responses; however, most instituted new contract specifications. Alternative measures of vomitoxin were used by importers shipping from the Pacific Northwest (PNW). Japan initially adopted a "scab-free" specification, defined as no scab-infected kernels using FGIS analysis. Presumably, scab free was considered equivalent to vomitoxin free. Vomitoxin was not easily testable until the FGIS tests were announced.

In this market environment, substantial price discounts emerged for vomitoxin-infected wheat. Even after the September 1993 FDA announcement, traders remained concerned about the potential reaction of customers to high levels of vomitoxin. Discounts were particularly severe at points of origination.[3] This was due partly to the lack of a quick test for vomitoxin. As an alternative practical approach, many buyers chose to purchase grain from locations with low reported levels of vomitoxin, i.e., western CRDs of North Dakota.

Discounts were largest in the immediate post-harvest period (1993 crop), but abated somewhat with the promulgation of new FDA regulations. Japan paid up to $10/mt (27c/b) for scab-free wheat (Oades). The highest discount for vomitoxin was 1$/bushel; this was reduced to 65c/b and eventually 40 to 50c/b (terminal discounts) for vomitoxin greater than 4 ppm (Milling and Baking News, Sept. 21, 1993). Discounts at country locations in North Dakota were 20c/b for vomitoxin greater than 2 ppm (Flaskerud).

Quality: Contract Specifications and Limits. Data were collected on the specifications required by principal HRS buyers. Two geographical markets were identified: Minneapolis and PNW. The Minneapolis market is comprised of four contractually different segments, which are representative of most east-bound shipments of wheat from North Dakota.[4] The milling contract (hereafter referred as *domestic milling*) is that generally used by millers located in and beyond Minneapolis. Domestic markets trade basis 14% protein, but individual transactions may deviate and are subject to premium/discount schedules. There are two contracts specified for *Terminal* wheat, distinguished only by levels of falling number and vomitoxin. These specifications are representative of HRS wheat exports from either Duluth/Superior or from the U.S. Gulf (which are priced basis Minneapolis).

There are several large buyers of HRS at the PNW, each with unique quality specifications. Although Japan specifies Grade No. 2, some of its factor limits call for higher quality. Most interesting are the limits on heat damage and the use of "scab-free," which implies zero tolerance for vomitoxin. Other countries specified vomitoxin at 2 ppm, consistent with previous FDA limits, or omitted a vomitoxin specification altogether. Sprout-damage in each of the contracts is specified at 0.5% (maximum). This is the predominant type of damage in the grade standards, and sprout damage was the precursor measurement to the Falling Number test.[5] Korea and Taiwan each explicitly specify No. 1, 14.5% protein and differ only in the value of vitreous kernels and falling number. Thailand and Philippines each require No. 2 grade specifications, with Thailand requiring 15% protein. Philippines specifications are somewhat loose and similar to those of other HRS buyers off the PNW. Similar information for these importers was collected for 1994 and used in one of the simulations.[6]

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[3] Pedrazza (Aug. 15, 1994).

[4] Minneapolis is the destination or transit point for about 50% of the HRS crop.

[5] There is no specific factor limit for sprout damage in the standards; it is simply a component of total damage.

[6] Contract requirements were identical with the following exceptions: Korea's falling number specification was reduced to 330; and, dockage was specified as 0.8 for Japan and Philippines, 0.7 for Taiwan, and 1.0 for Korea and Thailand. These contracts were on an all

Public Issues: A great deal of public attention was focused on problems associated with vomitoxin. During 1993, an estimated 90 million bushels were lost from North Dakota's HRS crop harvest. A similar problem, though not as severe, occurred in 1994 with estimated losses at 36 million bushels.

The U.S. General Accounting Office (GAO) initiated an investigation over pricing practices. The request was to determine "why producers in these states were forced to accept steep and inconsistent discounts in prices paid for their commodities..." (GAO). An interesting conclusion was that grain buyers offered higher discounts for vomitoxin-contaminated grain to compensate for this risk" (p. 4). The study also indicated that high reported vomitoxin levels (p. 3) may have been the result of biased sampling, as farmers and elevators chose to test grain they already suspected was contaminated.[7]

Model Specification

The analytical model has features in common with other blending problems.[8] Grain supplies are allocated to nine regions, each with different quality characteristics. The model includes seven customers (buyer contracts), each with different quality requirements. Grain can be assembled and blended from different origins to attain desired levels of particular characteristics. Prices in terminal markets are taken as fixed along with transport costs. The objective is to maximize (expected) sales revenue net of transportation costs, subject to grain availability and quality constraints.

Inclusion of a random quality factor, vomitoxin, complicates the analysis. More than other grain quality factors, vomitoxin is subject to sampling and measurement error. As a result, merchandisers can only expect to meet contract limits (e.g., no more than 2 ppm for domestic millers) in a probabalistic sense. If a shipment to a domestic or export customer is rejected because of excess vomitoxin, the wheat must be sold under an alternative contract with less stringent requirements at a reduced price. The price spread between "primary" and "secondary" contracts is equivalent to a discount for vomitoxin. The magnitudes of discounts (and probabilities of avoiding discounts) in different contracts are central features of the merchandising problem.

Other studies have incorporated "chance constraints" in blending models (Wilson and Preszler; St. Pierre and Harvey). In those studies, qualities of ingredients are random, but the "blend" must satisfy quality constraints with specified probability. The formulation of our model is somewhat different. Probabilities of satisfying vomitoxin constraints (i.e., maximum

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dockage-deductible basis, with Japan allowing 0.5 dockage before deduction.

[7]The testing measure was the Elisa test which only reports a range (Moore, personal communication).

[8]Applications in the case of grain include Schrueben; Wilson and Preszler; and Johnson and Wilson.

parts per million) are endogenous, embedded in the objective function, rather than entered as constraint constants.

Because the model is developed from a merchandising perspective, bid prices in terminal markets are taken as exogenous. This is unlike most formulations of spatial equilibrium problems, which treat demand quantities as fixed or (alternatively) specify demand functions for individual markets. Given the focus of our analysis (i.e., on grain quality attributes and buyer specifications) and limitations of available data, it was not possible to estimate demand schedules for the market segments (buyers) represented in our model. Fixed (bid) prices in terminal markets imply perfectly elastic demand, a reasonable assumption if the object is to model decisions by traders (grain buyers and sellers) in a competitive environment.

Formally, the objective is to maximize

$$Z = \sum_{i=1}^{7} [P_i - VDIS_i \cdot (1-PR_i)]NW_i - \sum_{j=1}^{9}\sum_{i=1}^{7} X_{ji} \cdot Tx_{ji} \tag{1}$$

where P_i is the price bid ($bu) by buyer i; $VDIS_i$ is a price discount[9] ($/bu) for vomitoxin; PR_i is the probability that contract limits for vomitoxin will be satisfied; NW_i is the net weight of wheat shipments (mil. bu) to buyer i; X_{ji} is a shipment of wheat (mil. bu) from producing region j to buyer i; and Tx_{ji} is the associated freight cost ($/bu). The bracketed term represents expected price for sales to buyer i.[10] Z is the expected net revenue from the sale of the crop.

Different contract limits and price discounts are specified for different buyers. In two cases, i.e., *Minneapolis feed* and one export contract, *PNW Other,* no vomitoxin limit is specified, and the vomitoxin discount is zero (Table 3). For sales to other buyers, expected revenue depends on the probability that the level of vomitoxin is less than a specified maximum. The larger is PR_i, the lower is the probability that vomitoxin will be excessive, causing a discount to be applied (i.e., to be sold on a different contract).

Grain origins, indexed by j, are identified with North Dakota crop-reporting districts. Within each CRD, vomitoxin is treated as a random variable with known mean and variance. These parameters vary by CRD; hence, the probabilities of satisfying contract limits are influenced by the "weights" of different CRDs in grain shipped to terminal buyers.

Various quality measurements are based on weight net of dockage. Let N_{ji} denote the net weight of a shipment from region j to buyer i, defined

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[9]The discount, $VDIS_i$ could represent the difference between P_i and the price in a secondary market, S_i. For example, if wheat is shipped to *Minneapolis Milling* but (at delivery) is found to have excess vomitoxin, it must be sold at the lower, *Terminal 6* ppm price.

[10] The expected price depends on PR_i and is therefore endogenous.

$$N_{ji} = X_{ji}(100 - DK_j)/100 \qquad (2)$$

where DK_j is the level of dockage (%) in region j wheat. Aggregating across producing regions, the total net weight of shipments to individual buyers is

$$NW_i = \sum_{j=1}^{9} N_{ji} \qquad (i=1,...,7) \qquad (3)$$

Let w_{ji} denote the weight of region j in shipments to buyer i:

$$w_{ji} = N_{ji}/NW_i \qquad (4)$$

The probability of satisfying an individual contract's vomitoxin constraint is based on the normal cdf:

$$PR_i = \int_{-\infty}^{\delta_i} \frac{1}{(2\pi)^{1/2}} e^{-(1/2)u^2} \, du \qquad (5)$$

where δ_i is given by

$$\delta_i = \frac{v_i - \sum_j \mu_j \cdot w_{ji}}{\sqrt{\sum_j w_{ji}^2 \cdot \sigma_j^2}} \; . \qquad (6)$$

The mean and variance of vomitoxin producing region j are denoted μ_j and σ_j^2 , respectively, and v_i is the maximum allowed level of vomitoxin (without price discount).

Quality characteristics other than vomitoxin are treated as nonrandom. (In practice, these are more easily measured and incorporated in contracts.) Levels of quality characteristics are assigned to each CRD. All buyers (except in the feed market) specify minimum levels of protein, test weight, vitreous kernels, and falling number. Maximum constraints apply to shrunken and broken kernels, foreign material, damage, and defects. Protein requirements vary across buyers.

$$\sum_j N_{ji} \cdot PRO_j \; / \; NW_i \geq KPRO_i \qquad (7)$$

where PRO_j is the protein level (%) in producing region j, and $KPRO_i$ is the minimum protein requirement (%) of buyer i. Constraints for other quality factors have the same general form.

Finally, supply constraints are imposed in each of the producing regions.

$$\sum_i X_{ji} \leq Q_j \qquad (j=1,...,9) \qquad (8)$$

where Q_j is the total quantity (mil. bu) available for shipping from region j.

Data Sources and Base-Case Parameters

This section describes data sources and explains how base-case parameters were derived. Most simulations use data from the 1993 crop year, which was characterized by a severe vomitoxin problem, particularly in eastern North Dakota. For comparison, additional simulations were conducted using market conditions and quality distributions from 1994.

Quantity and Quality Availability. Mean values of quality characteristics were derived from data collected as part of the annual wheat quality survey by the Department of Cereal Chemistry and Technology, North Dakota State University. (See Tables 1 and 2). Samples were taken from each of the CRDs, and each wheat quality characteristic was measured. Wheat quantities produced in each CRD were taken from North Dakota Agricultural Statistics Service (1994). These CRDs accounted for 54% of total HRS production in the United States in 1993.

Transportation Costs. All shipments were assumed to move by rail, which is the predominant mode to each of these market destinations. Rail rates for 26-car movements were used and were those in effect during the fall of 1993.

Prices and Discounts. Prices are not regularly reported or publicly disseminated for each of these markets and contracts. Thus, we constructed prices using a series of spreads for each of the grades/qualities used in our analysis. These were collected from several sources: interviews with traders, daily price reports from each of the Minneapolis Grain Exchange and Portland Grain Exchange, the USDA price reporting service at each market, and daily price sheets from a principal cash grain broker.

Price spreads were combined with Minneapolis futures prices at corresponding dates. For the 1993 crop year, the time period for these prices extended from August 1993 through April 1994. Prices for the 1994 crop year were from September to November 1994. A simple average was used in each case. As shown in Table 3, the discounts for vomitoxin were more severe in 1993 than 1994.

Quality Requirements. Table 4 shows the quality requirements for the contracts included in our analysis. We made two simplifying assumptions about PNW contracts. First, *PNW Other* was included to represent all other importers off the PNW coast. This contract was for No. 2, 14% protein, with no vomitoxin specification, and is the price generally reported by government price-reporting services. Second, the Japan specification for vomitoxin was set at 0.5 ppm (maximum). Technically, that contract called for "scab-free," which is a proxy for vomitoxin-free. Because we lacked relevant supply data on scab, we specified a vomitoxin constraint for Japan with limit of 0.5 ppm. Our treatment is somewhat more lenient than Japan's actual contract specification. However, given the presence of vomitoxin in all CRDs in 1993, a zero-vomitoxin specification would not have been feasible in model simulations.

Simulation Results

The analytical model was used to identify the optimal solution and to evaluate effects of alternative procurement strategies. Base-case results using data for 1993 are presented. We then examine the effect of both the mean level and standard deviation of vomitoxin on model results. For comparison, a simulation with data from 1994 (i.e., quality distributions and price spreads) is also presented. The remaining simulations focus on the effects of alternative procurement strategies by principal buyers. These entail adjustments in prices or changes in contract requirements.

Each simulation reveals the impacts on the value of North Dakota wheat as reflected in the objective function, which measures expected sales revenue net of transportation costs. Shadow prices were derived to reflect the value of wheat in each CRD. These should be interpreted as values to a trader at each origin, ignoring costs of assembly and blending (which are non-observable). Other variables of interest are the quantities shipped to individual markets, average levels of vomitoxin received, and probabilities of acceptance or rejection.

A measure of risk was developed to compare alternative contracts from a trader's perspective. Let EP_i denote the expected price for sales to buyer i. This is the bracketed term in (1), a function of the vomitoxin discount $VDIS_i$ and probability of satisfying contract limit PR_i. Equivalently, EP_i can be expressed

$$EP_i = PR_i \cdot P_i + (1-PR_i) \cdot S_i \tag{9}$$

where $(1-PR_i)$ is the probability of rejection and S_i is the price in a secondary contract (with a looser specification for vomitoxin).[11] The standard deviation is defined

$$\sigma_i = [PR_i(P_i - EP_i)^2 + (1-PR_i)(S_i - EP_i)^2]^{1/2} \tag{10}$$

and the coefficient of variation is

$$CV_i = \frac{\sigma_i}{EP_i} \tag{11}$$

Following Barry et al. (pp. 320-21), we use CV_i as a measure of risk, in this case, risk borne by the seller when shipping to buyer i. Risk increases with the vomitoxin discount and decreases with the probability of satisfying the contract limit.

[11] Recall that $VDIS_i$ is the difference between prices in "primary" and "secondary" markets. Thus,

$$EP_i = PR_i \cdot P_i + (1-PR_i) \cdot S_i = PR_i \cdot P_i + (1-PR_i) \cdot P_i - (1-PR_i) \cdot P_i + (1-PR_i) \cdot S_i$$
$$= P_i - (1-PR_i) \cdot (P_i - S_i) = P_i - (1-PR_i) \cdot VDIS_i$$

Base-Case Results. Tables 5 and 6 show selected base-case results, with comparisons to other scenarios. The objective function value, $1.216 billion, is interpreted as expected value of the state's HRS crop if optimally blended and shipped. Base-case flows are summarized in Figure 1. Flows are to the *Domestic Milling* market and to *PNW Korea* and *PNW Other*. There are no flows to Japan or the other Minneapolis markets.[12] The pattern of flows (by CRD) also differs drastically from what might be expected based on transportation costs. For example, *Domestic Milling* receives most of its wheat from the western CRDs, while some of the Korean contract is supplied by eastern CRDs. This is due to the combined effects of quality availability, quality requirements, price spreads, and discounts for vomitoxin in different contracts. Flows to *PNW Other* are due to a relatively high price and no vomitoxin specification.

For the 3 contracts receiving grain, the quality constraints for vitreous kernels, falling number, damage, and defects are not binding. Protein is binding for *Domestic Milling* and *PNW Korea*, while test weight is binding for *PNW Other*.

Expected levels of vomitoxin and probabilities of satisfying constraints are shown in Table 5. For *Domestic Milling* and *PNW Korea*, expected levels are well below contract limits (2 ppm). The vomitoxin level for *PNW Other* is relatively high, at 5.21 ppm; no vomitoxin limit is specified for that contract, which functions as the secondary contract for shipments to Korea and Japan.

Probabilities of satisfying vomitoxin constraints vary according to the buyer. These probabilities are determined by the model and should be interpreted as optimal from a seller's perspective, given relevant price relationships. In the case of *Domestic Milling*, the probability of satisfying the requirement (2 ppm) is .97. This indicates that it is optimal for traders to ship wheat to domestic millers with a 3 percent probability of rejection.

The standard deviation of vomitoxin in shipments under the domestic milling and Korean contracts are 18 and 51c/b, respectively. This indicates greater uncertainty about vomitoxin levels in shipments under the Korean contract. From a seller's perspective, the coefficient of variation (for expected returns) provides a more meaningful way to compare relative risks. As shown in Table 5, the CV_i for *Domestic Milling* is somewhat higher than that for Korea in the base case. This is largely due to the difference in vomitoxin discounts, 96 c/b for *Domestic Milling* versus 51 c/b for *PNW Korea*. Given the penalty for rejection, the *Domestic Milling* contract poses a greater risk. This induces greater precaution by traders (lower mean level of vomitoxin) in assembling grain for delivery to domestic millers.

Shadow prices were derived for each CRD and are shown in Table 6, column 2. These are interpreted as the value of an additional bushel in each CRD, given mean quality characteristics. These mirror the wide disparity in prices actually observed during 1993. The value of an additional bushel in regions with a high level of vomitoxin (e.g., CRD 3, 6, and

[12]For reference, exports of HRS off the PNW during 1993/94 were Japan 45 million bushels; Korea 12 million; and Total PNW 154 million.

9) is substantially lower than in contiguous regions, with discounts far above what would be expected based on transport costs. Regions with low levels of vomitoxin (and otherwise better quality) experience higher prices (e.g., CRD 2, 4 , 7 and 8).

Normal Crop Year Results. It is natural to ask what the results would look like in a more normal crop year. The term "more normal" is somewhat difficult to define. However, to provide perspective we ran model simulations with vomitoxin levels (and variances) reduced to zero in all CRDs. Base-case values were retained for other quality parameters. One of the peculiar features of the 1993 crop year was the abnormally wide price spreads between geographic markets and between buyers in the same market (i.e., Minneapolis or PNW). Accordingly, the model was run using price and basis levels more typical of these markets. Spreads and basis values were taken from the same time interval in 1992/93.[13]

Flows under this scenario are shown in Figure 2. Reductions in flows to *Domestic Milling* and *PNW Other* (relative to the base case) are offset by increases to *Minneapolis Terminal*, *PNW Korea* and *PNW Japan*. These would be more representative of a normal year. Korea is the premium market. Protein constraints are binding for the domestic milling, Korea, and Japan contracts. The overall poor quality of wheat, including high damage due to the unusually cold, wet growing conditions of 1993, constrains flows in all markets.

Shadow prices for individual CRDs are shown in Table 6, column 3. The premium in CRD2 reflects high quality and protein and the proximity to *PNW Korea*. The low value in CRD1 reflects a low average protein level, 13 percent. Low values in CRD3 and 6 are likely due to high damage.

The objective function value is $1.302 billion--$86 million higher than in the base case. This provides a rough indication of the impact of vomitoxin on total crop value in 1993 (as distinct from the value of estimated yield losses).

Simulation Results for 1994 Crop Year. For comparison, simulations were conducted with 1994 crop quality data and market prices. As shown in Table 2, vomitoxin remained a significant problem in the eastern producing regions, particularly CRD3 and CRD6. Western CRDs (1, 4, and 7) had virtually no vomitoxin in 1994.[14] Average protein

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[13]Contract prices were as follows: *Domestic Milling* 5.35; *Terminal* 5.25; *Minneapolis feed* 2.81; *PNW Korea* 6.29; *PNW Japan* 5.95; *PNW Other* 5.85.

[14]In the 1994 crop year, vomitoxin tests were not conducted in CRDs 1, 4 and 7 as part of the wheat quality survey. Vomitoxin tests in CRDs 2, 5 and 8 were based on composite samples; hence, sample variances for these CRDs were not available for 1994. For simulation purposes, we predicted the standard deviations for CRDs 2, 5 and 8 using a regression model with mean vomitoxin as the sole explanatory variable.

levels were higher in regions with high vomitoxin, a fact that helps to explain the flow patterns in model simulations, and shadow prices for individual CRDs.

Selected results are shown in Table 5. The objective function is $0.951 billion, lower than the base case due to substantially lower prices (Table 3). Flows are to *PNW Other* (157 million bu), *Domestic Milling* (70 million bu), and the Minneapolis *Feed* market (44 million bu). The expected vomitoxin level for *Domestic Milling* is higher than in the base case, and the probability of satisfying requirements is lower. In large part, that is due to the coincidence of high vomitoxin and high protein in CRDs 3, 6 and 9. Other CRDs did not have sufficient protein levels to satisfy contract specifications, which are binding for both *Domestic Milling* and *PNW Other*. This forced high-vomitoxin grain into the solution for these contracts. The risk measure for *Domestic Milling* is lower than in the base case because of a smaller implicit discount.

Effects of Means and Variability in Vomitoxin on Prices. Both the mean and variance of vomitoxin affect regional wheat prices as well as spatial flows. Higher mean values for vomitoxin affect blending opportunities, just as they do for other quality characteristics. Higher variances can increase the likelihood that wheat shipments will be rejected by buyers.

To evaluate the relative effects of changes in the mean and variance on wheat prices, simulations were conducted with different distributions for vomitoxin in one particular region. CRD5 was chosen for demonstration purposes; it is centrally located and not extreme in terms of its vomitoxin distribution. The mean level and variance of vomitoxin in this region was iterated within ranges observed in other regions. Results are summarized in terms of the impacts on shadow price for CRD5.

Mean Level: Lower mean levels of vomitoxin increase the value of wheat (Figure 3). There is a large reduction in the shadow price when vomitoxin increases from 0.3 to 1.2 ppm; thereafter, the impact on price diminishes. An increase in vomitoxin from 0.1 to 1.0 ppm decreases price by 13c/b, while an increase from 1.0 to 2.0 ppm decreases price by 4c/b.

Comparisons to the base case are made in Table 5. The effect on flows of reducing the mean vomitoxin level for CRD5 to zero is shown in the second row. The objective function increases to $1.233 billion. The added value reflects a larger flow to *PNW Korea* (19 mil. bu. more than in the base case). This affects *PNW Other*, which receives 19 mill. bu. less than in the base case and with more vomitoxin.

The trader's risk does not change for the Korea market. Twice the level of wheat is supplied; however, Korea receives the same expected level of vomitoxin with the same probability of satisfying contract requirements. Elimination of vomitoxin in CRD5 allowed more grain to be shipped to the highest priced market. CRD5 switches and fully supplies *Domestic Milling*, freeing up CRDs 2 and 7 to supply Korea. As a result, the trader's risk decreases in the *Domestic Milling* market.

Standard Deviation: The standard deviation also has a negative effect on the value of wheat in CRD5 (Figure 3). The effects of successive increases are fairly constant until the standard deviation exceeds 3.0; thereafter, the shadow price stabilizes. The logic is that, with increases in the higher standard deviation for vomitoxin, grain from CRD5 presents a larger risk to traders. In particular, there is a higher probability of rejection in higher-valued markets. Conversely, when the standard deviation for CRD5 is reduced to zero, the objective function value increases to $1.228 billion (Table 5). This implies that crop value would increase if there were no uncertainty about vomitoxin levels.

Changes in flows to individual markets are also interesting. With zero standard deviation for vomitoxin in CRD5, more grain is shipped to Korea, the higher priced market (Table 5). The probability of satisfying contract requirements and coefficient of variation for the Korea contract are about the same as in the base case; more grain is shipped with little change in risk measures. In the case of *Domestic Milling*, shipment volumes are reduced slightly relative to the base case, but the coefficient of variation is substantially lowered.

These results demonstrate that the value of wheat is affected by both the mean and variance of quality characteristics. Changes in either can affect the prospective risks and returns from shipping to different markets.

In both of these cases, the marginal value of wheat in CRD5 increased relative to the base case (Table 6). A zero mean for vomitoxin increases the CRD5 shadow price by $0.63, while zero uncertainty (standard deviation) increases it by $0.47. These values indicate the premiums that would have occurred if there had been no vomitoxin in CRD5 or if traders had perfect information about the true level of vomitoxin in purchased grain. The shadow prices for other regions are also affected by the level and standard deviation of vomitoxin in CRD5. This reflects changes in blending opportunities across producing regions and changes in aggregate grain flows. The effects are not uniform: shadow prices rise in some CRDs (e.g., 3 and 6) and fall in others (1, 4, 7, and 8) when vomitoxin in CRD5 is eliminated.

Strategic Impacts of Vomitoxin Discounts in Domestic Milling. There are two important strategic aspects to procurement. One is the buyer's bid price, including (explicit or implicit) discounts for undesirable characteristics. The other is the contract requirement, or specification. In the case of the domestic milling market, contract requirements for vomitoxin are somewhat constrained, due to the interpretation of FDA regulations. Thus, pricing decisions and discount values for vomitoxin are critical for this market segment. Changes in millers' bids and discounts affect the entire system. However, here we focus on three variables: the expected value of vomitoxin in shipments to millers, the probability of satisfying contract requirements, and aggregate flows.

Discounting for Vomitoxin: These effects were evaluated by changing the discount for excess vomitoxin in the *Domestic Milling* market.[15] As expected, the value of the

[15] For this set of simulations only, we vary the discount without changing any contract prices. In other words, VDIS becomes an explicit discount for *Domestic Milling,* no longer

objective function rises as the discount is reduced. With no milling discounts for vomitoxin (VDIS=0), the objective function reaches a value of $1.249 billion (Table 5).

The volume shipped to *Domestic Milling* is inversely related to the discount. At low discount levels, *Domestic Milling* attracts larger flows from regions with higher vomitoxin levels. As the milling discount increases, more is shipped to *PNW Other;* curiously, flows to Korea decline due to changing availabilities of high-quality wheat.

The expected level of vomitoxin received by *Domestic Milling* is inversely related to the vomitoxin discount (Figure 4). With zero discount, the mean level is 2.0 ppm, the constrained value. The mean value decreases rapidly until the discount reaches $1.00; thereafter, it changes little. These results show that discounts are a critical variable affecting competition between markets and contracts. With higher discounts, flows to the *Domestic Milling* market are reduced. However, the grain shipped is of higher quality, with a greater probability of satisfying requirements.

Domestic Vomitoxin Specifications: An alternative to changing the discount is to adjust the vomitoxin specification. To evaluate these effects, the vomitoxin specification for *Domestic Milling* was iterated between 1.5 and 2.5 ppm. (The base case specification was 2 ppm.) Quantities shipped to milling decline as the specification is tightened, and increase as the specification is relaxed. (Figure 5.)

By tightening the specification, *Domestic Milling* receives a lower expected level of vomitoxin. For the entire range of vomitoxin limits (1.5 to 2.5 ppm), the expected value of vomitoxin is always less than the specified maximum. In effect, the discount for excess vomitoxin causes traders to err on the side of caution, shipping lower mean levels of vomitoxin than allowed under the specification. At 1.5 ppm, the expected level of vomitoxin is 0.82, with a probability of satisfying the requirements of 98%, marginally higher than in the base case.

Analysis of Importer Strategies. In some cases, importers have more latitude than domestic buyers in their choice of specifications and pricing strategy. The base case includes drastically different prices and contract terms for different buyers. This reflects an important dimension of buyer competition: in a spatially and quality (contract) differentiated market, importers compete against each other and domestic buyers through price and contract specifications.

Analyses were conducted on these aspects of competition in the PNW export market. Simulations were conducted using Japan as an example (though equally interesting results could be shown with other importers). Japan receives no wheat in the base case, either because it offers too low a price or because its specification is too restrictive. The following simulations consider both possibilities. To simplify the analysis and to demonstrate more

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simply the price spread between *Domestic Milling* and *Terminal 6*.

clearly the competition between PNW and Minneapolis, we exclude *PNW Korea* from these simulations (by setting its price to zero).

Price Increase: To attract grain to *PNW Japan* without changes in specifications, the price must be raised to $6.04/b, 30 cents higher than assumed in the base case. Figure 6 shows the effects of successive price increases on quantities shipped to different buyers. Price increases allow *PNW Japan* to bid wheat away from *Domestic Milling*. Quantities received by *PNW Other* show a moderate increase, for reasons having to do with changes in availabilities and blending opportunities.

Figure 7 shows the mean level of vomitoxin shipped to *PNW Japan* and the probability of satisfying requirements for a range of contract prices. Vomitoxin levels increase with the contract price, and probabilities decrease moderately. A higher premium for *PNW Japan* over other contract alternatives induces larger total shipments and expanded sourcing from particular regions, with some reduction in average quality received. However, the mean vomitoxin level remains well below the specified maximum, 0.5 ppm.

Vomitoxin Specification: From a buyer's perspective, an alternative to changing the price is to change the contract specification. In the present context, that would mean relaxing the allowable maximum for vomitoxin shipped to *PNW Japan*. Figure 8 shows the effect of different contract limits on aggregate flows, assuming a fixed contract price for *PNW Japan* ($6/bu). As the allowable maximum increases from 0.5 to 0.9 ppm, *PNW Japan* is able to bid wheat away from *Domestic Milling* just as it did by raising prices. This reinforces the point that quality specifications affect spatial flows.

Figure 9 shows how relaxing Japan's vomitoxin specification affects qualities received. As the allowable maximum rises, so does the mean level of vomitoxin in shipments to *PNW Japan*. Probabilities of satisfying requirements also increase due to relaxation of the vomitoxin constraint.

Efficacy of Stringent Damage Specifications to Reduce Vomitoxin. One strategy pursued by grain buyers is to use contract specifications for easily measured quality factors as proxies for another, less easily measured characteristics. By tightening contract limits for the easily measured factor, the buyer can control (indirectly) expected levels of the other. Some buyers use damage specifications to control the expected value of vomitoxin, which is rarely measured at country elevators. This makes sense in view of the correlation between these two variables (r=0.79 in 1993).

To evaluate these effects, the base model was run with varying levels of damage allowed for *PNW Other*. (This contract does not specify vomitoxin.) Starting from the base-case limit of 4%, the allowable maximum was reduced incrementally to 2%. The expected value of vomitoxin decreases with tighter specifications on damage (Figure 10). This confirms that the expected vomitoxin level can be controlled through tighter specifications on other, more easily measured characteristics (damage in this case). This method of control is not perfect; with 2% damage allowed, expected vomitoxin for the contract is still relatively high at 3 ppm.

More interesting are the changes in aggregate flows (Figure 11). As *PNW Other* tightens its damage specification, larger flows are attracted to this contract, and volumes shipped to other premium markets (*PNW Korea* and *Domestic Milling*) are reduced. This is a counter-intuitive result, in sharp contrast to that described for Japan in the preceding section (where relaxation of the vomitoxin constraint induced larger sales volumes). The logic runs as follows. As its specification is tightened, *PNW Other* can no longer absorb the same volume of high-damage wheat. This forces some high-damage (and high-vomitoxin) wheat into other market segments. Such wheat can be sold in premium markets (i.e., *Domestic Milling* and *PNW Korea*) after appropriate blending, but average quality in those markets will decline. In fact, expected vomitoxin levels increase in shipments to premium markets as *PNW Other* tightens its damage specification. With fixed contract prices, this reduces the probability of satisfying requirements and hence the expected price received in premium markets. As a result, prices received in *PNW Other* become more attractive in relative terms, inducing larger sales.

In practice, changes in specifications by one buyer may lead to changes by other buyers. Thus, tightening of specifications by *PNW Other,* and the consequent redirection of high-damage grain to other market channels, could induce changes in bid prices or quality discounts by domestic millers. Such interactions are not captured in our model, although the results do suggest different possible forms of strategic response.

Summary and Discussion

Quality variability is a major concern of grain importers and domestic processors and, consequently, has implications for traders (merchandisers) and farmers. For spring-planted grains in North America, the importance of quality variability was heightened in 1993 and 1994. Untimely rains in those years increased the level and variability of vomitoxin. This is an undesirable characteristic subject to food safety concerns and regulations, and has been cited as a problem in both domestic and world market channels.

Characteristics like vomitoxin are not easily controllable through contracts, due to sampling difficulties (and expense) and measurement error. As a result, traders and end-users can be exposed to significant quality risks. These types of problems are found in wheat, barley, and corn (aflatoxin).

Confronted with severe quality problems, grain markets can respond in several ways. Large premiums and discounts can emerge, and normal spatial flows can be disrupted. In the case of vomitoxin in spring wheat, some importers responded by tightening their contract specifications or by offering premiums for shipments with reduced vomitoxin. Domestic processors, in competition with importers, responded similarly. In this trading environment, merchandisers confront several sources of risk. One is the risk of not being able to meet specifications and having to sell at a discount (i.e., in a secondary market). The other is the risk of paying too high a price for wheat based on false expectations. In 1993, farmers expressed concerns about large discounts for damaged or infected wheat delivered to country elevators.

We developed a mathematical programming model to analyze this problem. The model incorporates spatial dimensions of quality distributions, competing geographic market demands, and contract requirements and prices for specific buyers. One of the important features is that probabilities (i.e., of satisfying constraints for vomitoxin) are endogenous; implicitly, they reflect the price signals received by traders. The model was used to evaluate the effect of quality distributions and alternative buyer strategies on spatial flows and grain values in country locations.

Simulations were conducted using market data and grain quality distributions for 1993 (the base case) and 1994. For illustration, we varied the level and standard deviation of vomitoxin and simulated different procurement strategies (prices and contract specifications) by principal buyers of spring wheat. Following are some of the important results and implications:

- Flows in the base case (1993) are primarily to the *Domestic Milling* market and to the *PNW Other* and *PNW Korea* contracts. Flows to Japan are nil due to abnormally tight specifications on vomitoxin relative to supply and competing contracts. Shadow prices varied substantially across contiguous regions, reflecting differences in the level and variance of vomitoxin and other characteristics. An additional simulation was performed for the 1994 crop year; flows and shadow prices varied substantially from the base case.

- The model was used to evaluate the relative importance of the mean level and variances of vomitoxin on shadow prices of wheat in a particular producing region (CRD5). Results demonstrate that increases in either the mean level or variance would have a negative effect on shadow prices. Thus, traders are concerned with the mean value of an undesirable characteristic and with its variance.

- Buyers' procurement strategies are reflected in contract specifications and in the use of premiums and discounts for particular quality characteristics. In evaluating these alternatives, buyers have to be cognizant of the spatial dimension of competition and competition from other buyers. Specifying abnormally tight requirements, not matched by competing contracts, should reduce the geographical region in which a buyer is competitive. However, in the context of our model, with multiple quality factors and competing contracts, the effects of contract tightening are not always easy to anticipate. For example, by reducing the allowable limit for damage in one contract (*PNW Other)*, we induced larger sales under this contract at the expense of sales to other, premium buyers.

The results illustrate complex interactions among prices, contract specifications, and merchandising risks. These features of the marketing environment are critical to trading decisions and to an informed understanding of spatial flows and quality-related price spreads.

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Table 1. Wheat Supply and Quality Attributes by Region, 1993†

ND Crop Reporting District	Nonrandom factors									Vomitoxin	
	Q	PRO	TW	SB	DK	FM	DAM	VIT	FN	μ	σ
CRD 1	35.73	13.02	60.23	1.06	1.47	0.39	0.30	83.8	341.2	0.22	0.06
CRD 2	27.81	14.60	58.63	0.75	1.68	0.15	1.10	79.43	361.6	0.65	0.69
CRD 3	40.70	14.76	55.20	1.11	1.67	0.24	4.29	69.56	347.8	4.65	2.58
CRD 4	22.44	13.85	60.02	1.15	1.21	0.04	0.54	75.91	379.0	0.33	0.30
CRD 5	32.61	14.03	58.69	1.08	1.84	0.08	1.04	70.57	356.9	1.54	2.31
CRD 6	35.67	14.96	55.95	1.35	2.40	0.12	5.44	78.86	398.2	7.35	4.00
CRD 7	27.53	14.20	59.32	1.56	3.24	0.02	0.68	82.56	380.2	0.30	0.26
CRD 8	19.88	13.86	58.94	1.44	1.57	0.03	0.80	72.24	379.2	0.96	0.84
CRD 9	32.00	14.14	57.49	1.15	2.03	0.01	3.14	79.50	409.0	6.58	3.33

† Q: quantity (mil. bu); PRO: protein (%); TW: test weight (lbs/bu); SB: shrunken and broken kernels (%); DK: dockage (%); FM: foreign material (%); DAM: damage (%); VIT: vitreous kernels (%); FN: falling number; μ: mean parts per million; σ: standard deviation. Defects are the sum of SB, FM and DAM.

Table 2. Wheat Supply and Quality Attributes by Region, 1994

ND Crop Reporting District	Nonrandom factors 1994									Vomitoxin	
	Q	PRO	TW	SB	DK	FM	DAM	VIT	FN	μ	σ
CRD 1	27.7	13.1	61.24	1.23	1.43	0.29	0.20	81.9	394.0	0.01	0.01
CRD 2	27.5	13.8	60.16	1.38	1.63	0.23	0.63	84.1	375.5	1.20	1.31
CRD 3	51.0	14.3	57.75	1.39	1.15	0.23	4.67	78.1	348.3	10.94	10.35
CRD 4	21.4	13.4	61.32	2.03	2.99	0.46	0.07	92.3	382.8	0.01	0.01
CRD 5	34.3	13.6	59.32	1.58	3.55	0.50	1.49	78.0	397.0	2.30	2.51
CRD 6	37.1	14.6	56.69	1.90	3.75	0.17	5.82	70.2	391.4	7.29	5.82
CRD 7	26.1	13.6	61.37	2.29	1.76	0.10	0.12	95.3	378.6	0.01	0.01
CRD 8	19.9	13.3	60.97	1.39	3.58	0.09	0.26	86.3	388.7	0.20	0.21
CRD 9	33.8	14.2	60.19	0.76	2.82	0.24	0.40	88.5	401.6	1.10	1.23

Table 3. **Base-Case Prices and Vomitoxin Discounts**

Makret/Contract	-- 1993 -- Contract Price $/bu	-- 1993 -- Discount for Excess Vomitoxin $/bu	-- 1994 -- Contract Price $/bu	-- 1994 -- Discount for Excess Vomitoxin $/bu
Minneapolis				
Milling	5.36	.96 †	4.50	.25 †
Terminal, 2 ppm	5.05	.65 †	4.30	.05 †
Terminal, 6 ppm	4.4	1.59 ‡	4.25	1.20 ‡
Feed	2.81	n.a.	3.05	n.a.
PNW				
Korea	6.08	.51 *	5.00	.10 *
Japan	5.74	.17 *	4.90	0 *
Other	5.57	n.a.	4.90	n.a.

n.a. not applicable. † Alternative contract: Minneapolis terminal, 6 ppm.
‡ Alternative contract: Minneapolis feed. * Alternative contract: PNW Other.

Table 4. Buyer Quality Requirements

Contract	PRO % (Min)	TW lbs/bu (Min)	SB % (Max)	FM % (Max)	DAM % (Max)	DEF % (Max)	VIT % (Min)	FN (Min)	Vomitoxin ppm (Max)
Minneapolis									
Milling	14	58	3	.5	2	3	75	275	2
Terminal: 2 ppm	14	57	5	1	4	5	25	250	2
Terminal: 6 ppm	14	57	5	1	4	5	25	--	6
Feed	--	--	--	--	--	--	--	--	--
PNW									
Korea	14.5	58	3	.5	2	3	25	350	2
Japan	14	57	5	1	2	5	25	300	.5
Other	14	57	5	1	4	5	25	--	6

-- not specified.

Table 5. Selected Results from Model Simulations

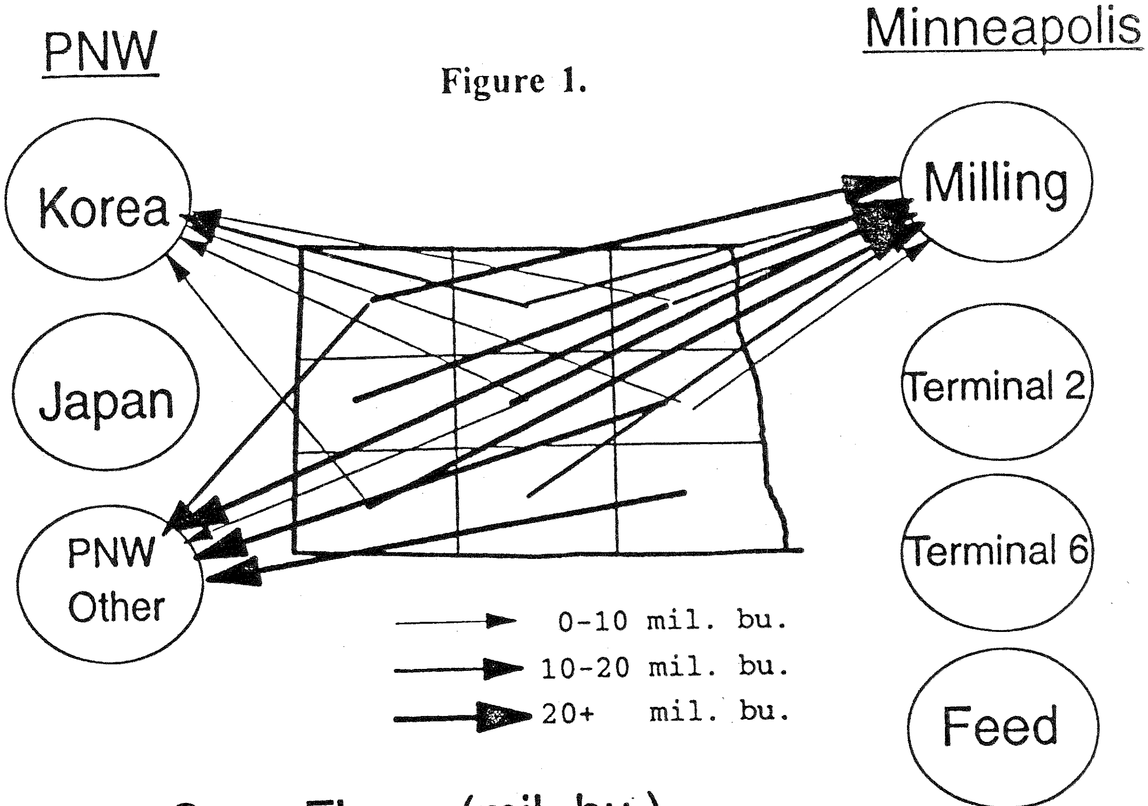
Simulation	Objective Function ($ mil)	Quantity (mil. bu.)			Expected value of vomitoxin received			Probability of satisfying contract requirements		Measure of Traders' Risk (C.V.)	
		Mill.	Korea	Other	Mill.	Korea	Other	Mill.	Korea	Mill.	Kor.
Base Case	1216	139	20	111	1.12	1.27	5.21	.97	.91	.033	.024
Normal Year *	1302	53	68	0	0	0	0	1	1	0	0
1994 *	952	71	0	157	1.55	n/a	n/a	.70	n/a	.026	n/a
CRD5 Vom. Mean=0	1233	139	39	91	1.22	1.26	5.40	.98	.92	.023	.023
CRD5 Vom.Variance=0	1228	132	34	103	1.35	1.26	5.22	.99	.92	.021	.023
Zero Vom. Discount for Domestic Milling	1249	151	48	69	2	1.28	5.66	.5	.93	.098	.022
Damage 2% Max for PNW Other*	1163	0	68	156	1.34	1.57	2.98	.93	.76	.047	.037

* Some flows are omitted from table. n/a not applicable.

Table 6. **Shadow Prices for Individual CRDs**

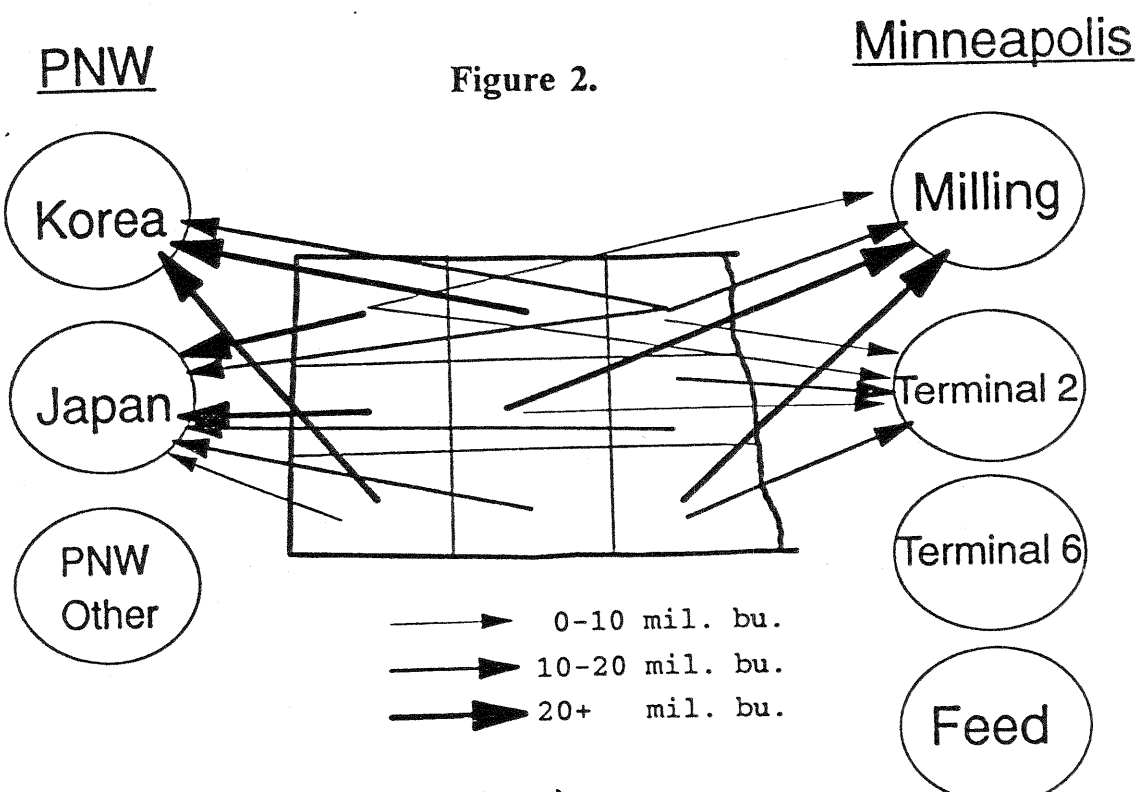
CRD	Base Case	Normal Year	1994	Zero Vom. Discount for Milling	CRD5 Vom. Mean=0	CRD5 Vom. Var.=0	Damage 2% Max for PNW Other
1	449	455	203	475	438	439	510
4	474	484	240	485	468	468	510
7	475	480	302	474	471	472	492
2	489	531	326	487	490	489	530
5	431	476	277	486	494	478	467
8	469	472	232	482	465	463	487
3	411	461	412	426	417	417	313
6	412	453	449	391	415	415	254
9	423	475	438	429	421	421	365

Figure 1.



Base Case Flows (mil. bu.)

Figure 2.



Normal Flows (mil. bu.)

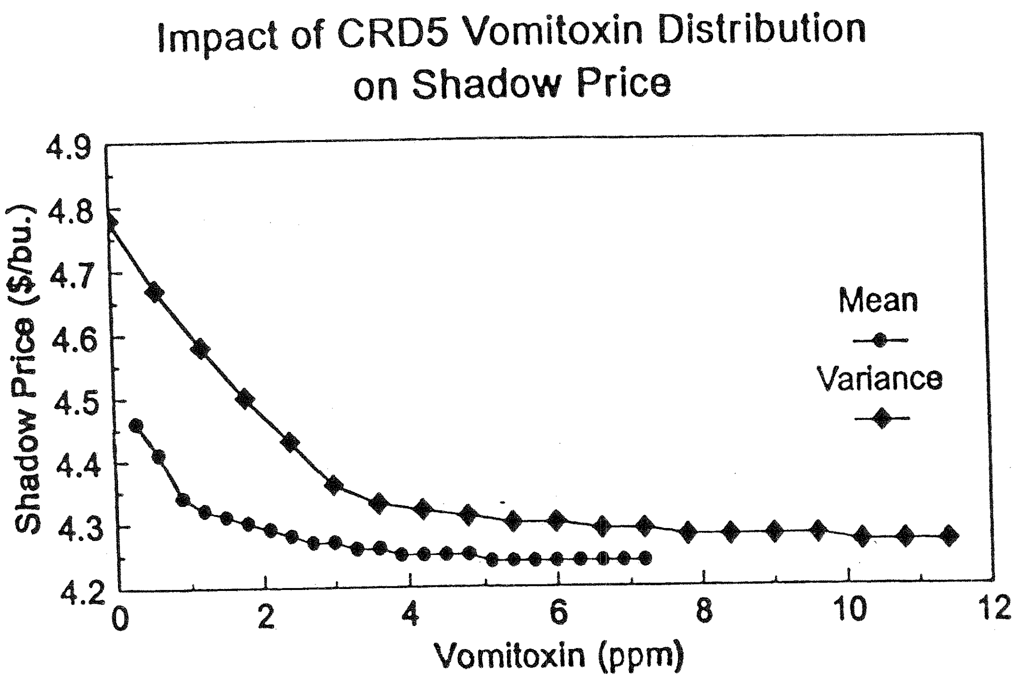

Impact of CRD5 Vomitoxin Distribution
on Shadow Price
Shadow Price ($/bu.)
4.9
4.8
4.7
4.6
4.5
4.4
4.3
4.2
0
2
4
6
8
10
12
Vomitoxin (ppm)
Mean
Variance

Figure 3.

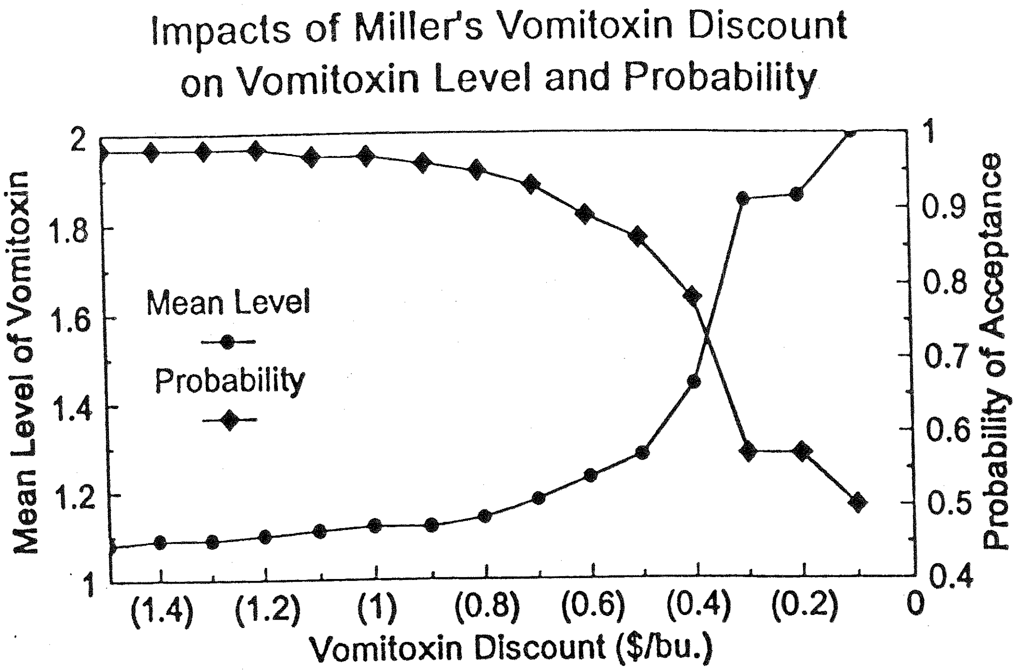


Figure 4.

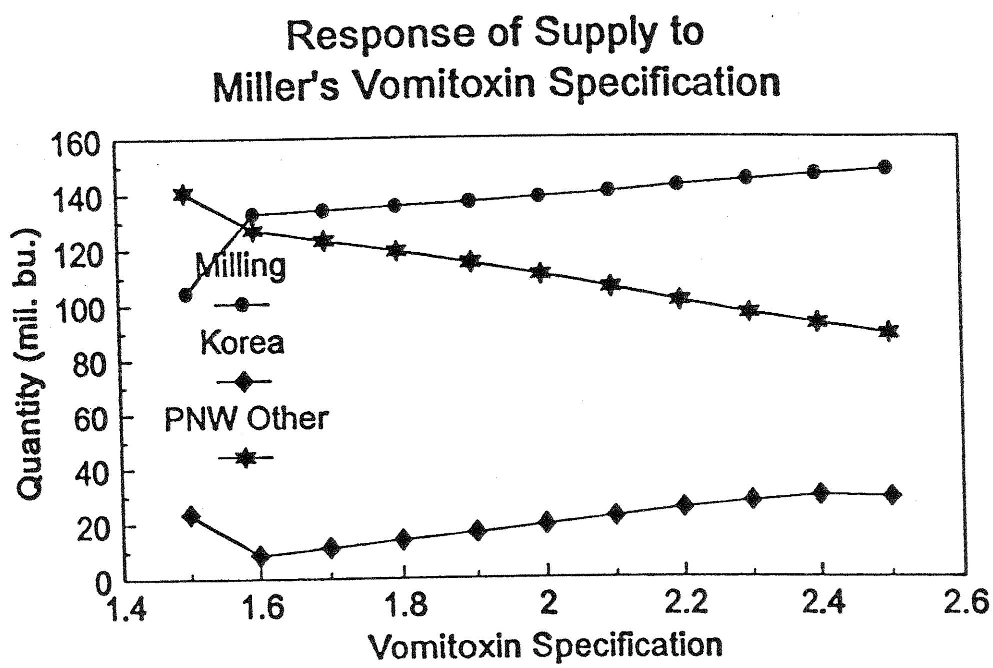


Figure 5.

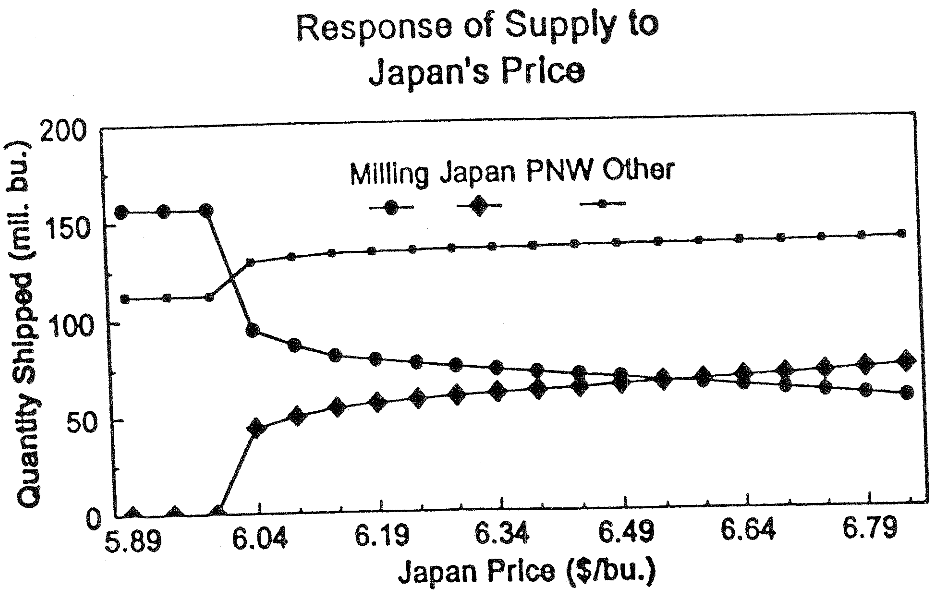


Figure 6.

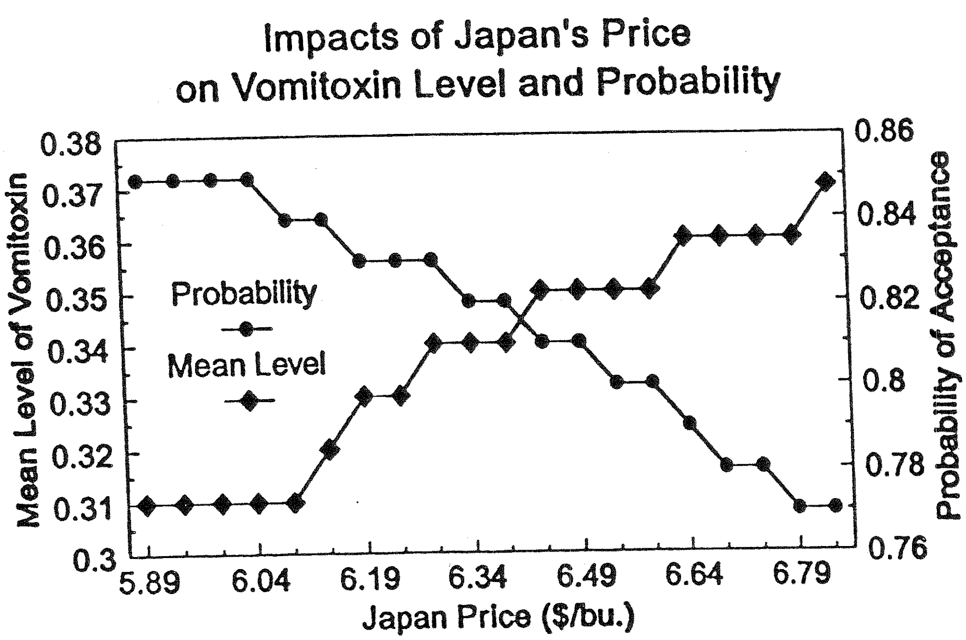


Figure 7.

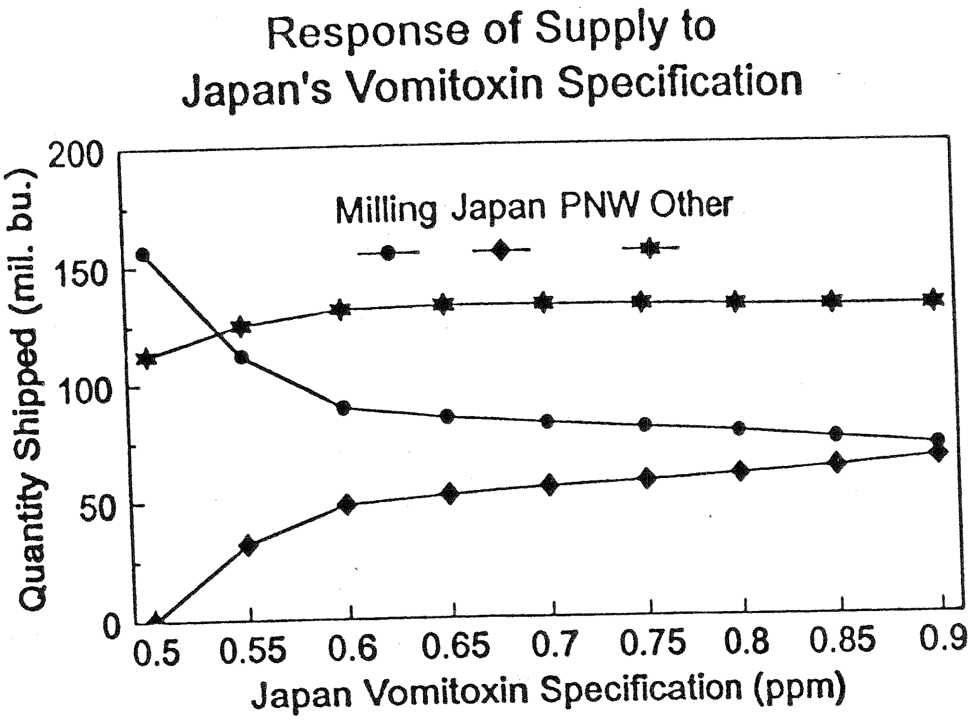


Figure 8.

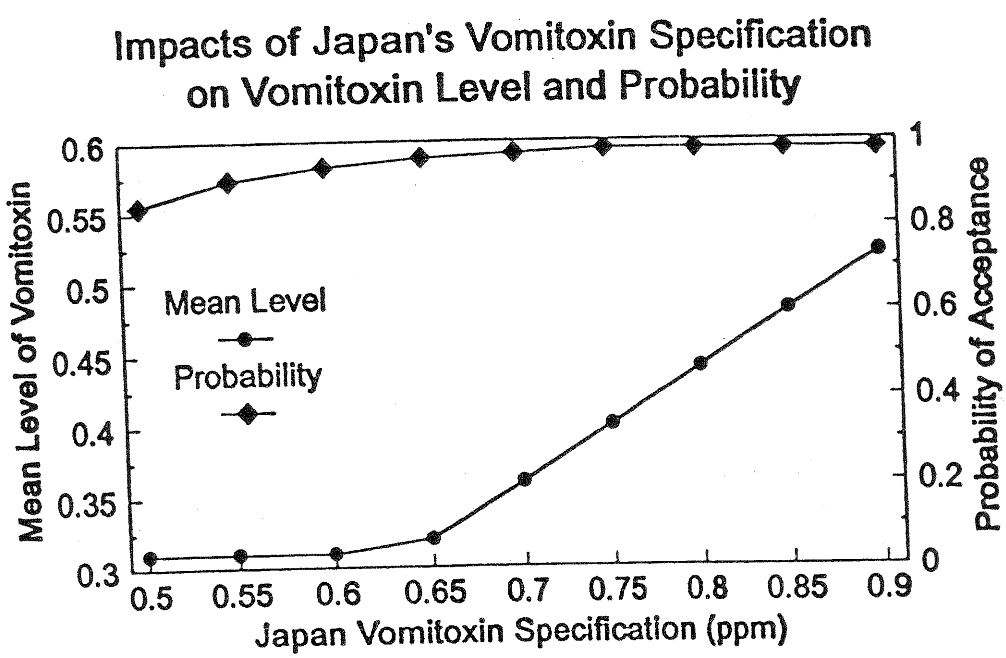


Figure 9.

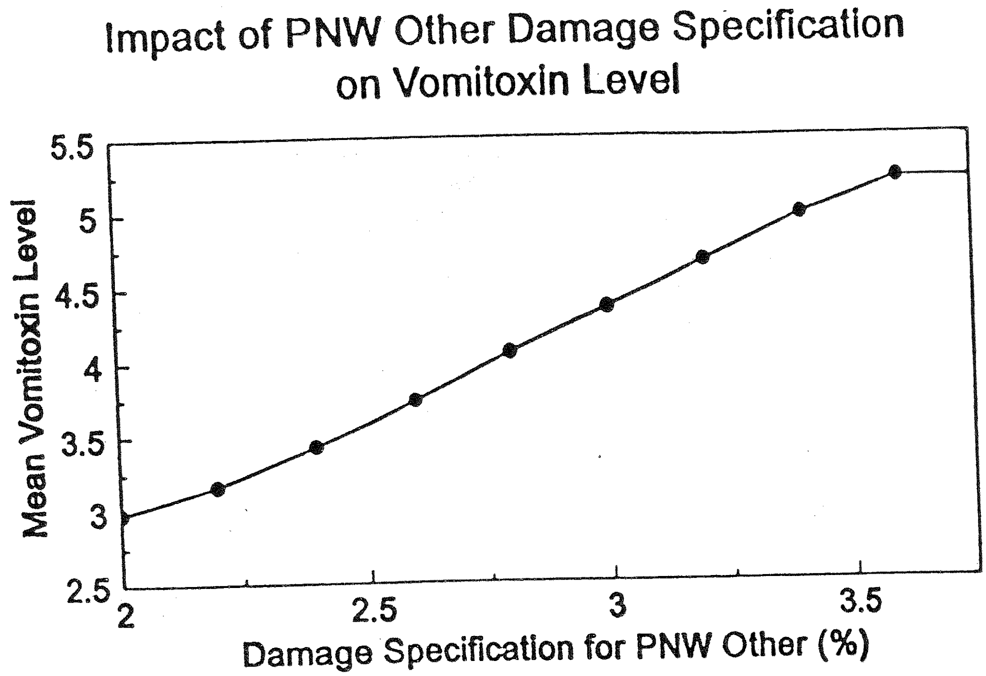


Figure 10.

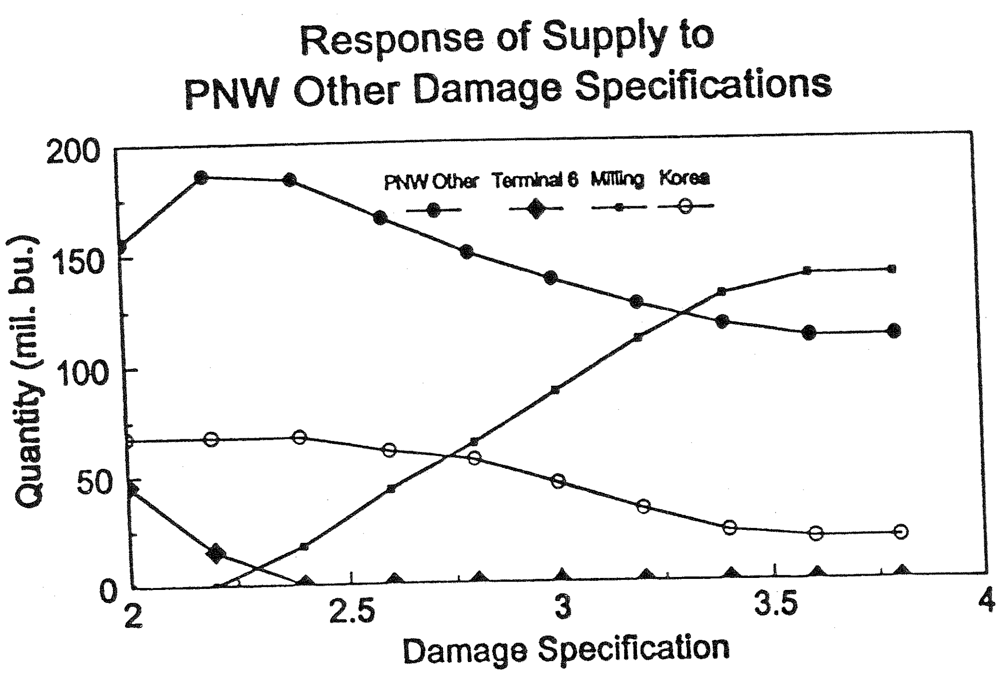


Figure 11.