Agricultural Economics Report No. 284 February 1992

MEASURING THE IMPACT OF DOCKAGE ON FOREIGN DEMAND FOR U.S. WHEAT

D. Demcey Johnson and William W. Wilson

Department of Agricultural Economics
Agricultural Experiment Station
North Dakota State University
Fargo, ND 58105

ACKNOWLEGEMENTS

This research was financed by the Federal Grain Inspection Service (FGIS) through Cooperative Agreement # 58-3AEK-0-800094, entitled "Economics of Alternative Regulations on Wheat Cleaning in Hard Red Spring, Durum, and White Wheat," between the Economic Research Service (ERS) of the USDA, and the North Dakota Agricultural Experiment Station. We are grateful to Roger Johnson, Seung Yang, and Won Koo for constructive comments, and to Charlene Lucken for editorial suggestions. Remaining errors and omissions are the responsibility of the authors.

ABSTRACT

This paper presents a methodology for assessing the impact of dockage on foreign demand for U.S. wheat and for evaluating the costs and benefits of cleaning prior to export. Two optimization models are developed--the first from the perspective of a foreign importer, and the second from the perspective of a U.S. export firm. The two models are linked in the manner of a Stackelberg game, permitting an interpretation of dockage as an instrument of U.S. commercial strategy. Simulations indicate that the "optimal" level of dockage in U.S. exports varies across importing countries.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

HIGHLIGHTS

Commercial treatment of wheat dockage differs drastically across exporting countries. In Canada and Australia, regulations ensure that only minimal levels of dockage are contained in exports and these are uniform across importing countries. In the United States, dockage is not a factor in the grading system. The level of dockage contained in particular shipments is subject to negotiation between buyers and sellers. Dockage differs from other quality attributes in that it can be controlled (removed) at several points in the marketing system, including the point of processing (i.e., the foreign mill), and the by-product of the cleaning process can be sold.

The purpose of this paper is to develop a methodology that can be used to identify and assess impacts of critical variables on the demand for cleaner wheat exported from the United States. Results can be used to determine the "optimal" level of dockage for particular importers, and to identify trade-offs (from an importer's perspective) between price discounts (premiums) and dockage levels. Simulations are conducted with parameter values representative of two importing countries.

Two optimization models are specified and solved to determine the optimal level of dockage contained in U.S. exports to particular importing countries. The first model represents a cost-minimization problem of an importer. The importer can buy wheat from the US and/or a competitor country. Levels of dockage and other quality attributes differ by country of origin. An important feature of this model is that it allows cleaning to take place prior to milling within the importing country. Results from this model can be used to define the value of (demand for) wheat with low dockage and can used to evaluate impacts of clean wheat on increased export sales.

The other model represents a vertically integrated U.S. export firm whose objective is to maximize the net revenue from an export sale. This involves choosing the level of dockage in wheat offered for export, as well as the most efficient location to clean in the U.S. marketing system. Embedded in the objective function are additional revenue from the sale of sceenings and domestic freight costs. The model evaluates the export firm's strategic choice: What combination of price and dockage level should be offered, given the importer's behavior and quality requirements?

The two models are linked to one another in the manner of a Stackelberg game. The U.S. firm acts as leader, choosing the price at which it will sell wheat and a dockage level for export; the importer acts as a follower, taking the U.S. price and dockage level as given. The leader anticipates the optimal response of the follower and makes strategic choices accordingly.

Solutions to the model were derived using parameters from two importing countries, Thailand and Turkey. Key differences exist in their respective costs of cleaning, import tariffs (which are applied to the gross weight of wheat), and domestic value of screenings. Important results include:

- *Different optimal solutions exist depending on the characteristics of the importing country. The optimal solution (from the perspective of the U.S.) for Thailand would be to match the competitor's price and clean more intensively. For Turkey, it is preferable for the U.S. to offer wheat at a discount relative to the competitor, and to avoid cleaning. Given the quality requirements of the importer and the relative costs and prices in this case, selling the wheat at a discount is more profitable than cleaning prior to export.*

- *The optimal location to clean wheat within the U.S. market system, at least in the case of wheat grown in North Dakota, is at the country elevator. This is due to the combined impacts of transport costs and differentials in screening values and cleaning costs.*

- *The tradeoff between price and incoming dockage is steeper for Thailand than for Turkey. This reflects the excess of tariffs and ocean freight over the domestic value of screening in Thailand, and suggests that millers in Thailand would be willing to pay a higher price premium for clean wheat.*

- *The impact of reducing the dockage level contained in U.S. wheat on market shares is reflected in an importer's demand for cleaner wheat. This is affected by quantifiable factors, such as the price and level of dockage contained in purchases from competitor countries, the level of unmillable material required before milling, ocean shipping costs and tariffs, the cost of removing dockage, and screenings values in the importing country.*

An important feature of this analysis is that cleaning wheat in the U.S. must be competitive with cleaning in the importing countries. Since relevant costs and incentives vary through time and (more importantly) across countries, it is difficult to generalize about the likely effects of lower dockage levels on U.S. export market shares.

MEASURING THE IMPACT OF DOCKAGE ON FOREIGN DEMAND FOR U.S. WHEAT

D. Demcey Johnson and William W. Wilson[1]

I. Introduction

No formal regulations govern dockage levels contained in U.S. wheat exports. Dockage is one of many contract terms that are subject to negotiation between individual buyers and sellers. This market orientation distinguishes the United States from other exporting countries (i.e., Canada and Australia), where regulations ensure that wheat is intensively cleaned before export and all buyers of a particular grade receive the same quality (level of dockage).

Allegations are frequently made that high levels of dockage place U.S. wheat at a competitive disadvantage in world markets. However, dockage is one of many quality attributes--and not necessarily the most important--differentiating U.S. wheat from that of competing exporters.[2] Demand for U.S. wheat is affected by quality-related price differentials and the specific end-use requirements of importers. These make it difficult to generalize about the likely effects of lower dockage levels (under proposed new regulations) on the level of U.S. wheat exports.

Dockage differs from other quality attributes in that it can be controlled (removed) at several points in the marketing system--including *after* export. Indeed, wheat is typically cleaned in importing countries before milling. The value of high levels of incoming dockage to an importer is influenced by domestic costs of cleaning, costs of transportation and tariffs, and the domestic value of wheat screenings. These factors vary substantially across importing countries as well as through time. While the value of clean wheat may be high to some importers (because of the high costs of domestic cleaning or low price of screenings), the value to other importers may be substantially less.

The heterogeneity of wheat importers provides impetus for the analytical framework used in this study. Rather than attempting a highly aggregative analysis--which for reasons outlined below would be of doubtful value--our approach involves assessing the impact of dockage for individual importers within the context of a formal optimization model.

Specifically, we formulate a cost-minimization problem in which an importer can buy wheat from the United States and/or from competitor countries. Levels of dockage and other quality attributes differ by country of origin; the importer can purchase wheat from either or both sources but must clean to a specified level before milling. Other

---

[1]The authors are Assistant Professor and Professor, respectively, in the Department of Agricultural Economics, North Dakota State University, Fargo.

[2]A comprehensive analysis of quality characteristics in international trade was conducted by the Office of Technology Assessment (U.S. Congress). Wilson, and Wilson and Preszler, specifically address quality competition in wheat.

quality constraints, reflecting end-use requirements, also must be satisfied. The model highlights the significance of quality and price differences for import purchase decisions and can be used to identify possible "trade-offs" between price and dockage. Further, it provides an analytical basis for intercountry comparisons.

In addition to the importer's optimization model, we develop a second optimization model from the perspective of a vertically integrated U.S. export firm. The firm seeks to maximize net revenue from an export sale by choosing (among other things) the level of dockage in wheat offered for export. The firm assembles wheat at an interior location and incurs costs of domestic transportation to an export facility. Cleaning activities can occur at either or both locations; these are endogenously determined based on relative costs, the value of screenings at different U.S. locations, and transportation savings. Quantities exported are derived from the importer's cost minimization problem. The two models are solved jointly to determine the optimal level of dockage contained in export shipments. This allows dockage to be viewed as an instrument of U.S. commercial strategy.

Broadly, our models seek to answer the following questions: 1) How do dockage levels affect demand for U.S. wheat, and how does this vary across countries?; 2) What is the "optimal" level of dockage before export?; and 3) Where in the U.S. marketing system is it optimal to clean wheat? Although the study does not offer categorical answers for all these questions, it does provide an integrated framework for an analysis of decisions by importers and U.S. merchandisers and demonstrate the impact of critical parameters on the "value" of cleaner wheat.

The report is organized as follows: The next section provides background for the analysis. The importer's optimization problem is described in the third section and the exporter's problem in the fourth section. The fifth section provides an overview of model linkages and solution methods. Results of some preliminary simulations are presented and discussed in the sixth section. The report concludes with a summary and discussion of results.

II. Problem Setting and Analytical Background

In the context of grain quality discussions, it is crucial to recognize that foreign buyers are heterogeneous. That is evident from the diverse specifications for protein, damage, and other quality attributes in U.S. export contracts (see Appendix 1). This variation is due to differences in final demand (i.e., desired product characteristics in individual markets) and also reflects different levels of technological and commercial sophistication across countries.

Specifications for dockage in export contracts are not uniform. Wheat is often purchased on a "clean basis," that is, with weight of dockage deducted. Some buyers (e.g., the Philippines) deduct dockage above a specified level. Other buyers (e.g., Taiwan) purchase wheat on a clean basis, but also apply penalties for dockage in excess of levels specified in the sales contract. Still other countries make no specification at all for dockage, implying that gross weight (including dockage) is used for settlement.

The variety of contract specifications suggests that importers value dockage differently, just as they do other quality attributes. In countries where screenings are highly valued as animal feed, high levels of dockage are more tolerable. By purchasing wheat on a clean basis, an importer can acquire screenings at the cost of ocean freight plus domestic cleaning. On the other hand, some countries (e.g., New Zealand, Taiwan) impute large costs to dockage because of environmental safeguards (i.e., avoidance of seed contamination or dust from cleaning operations) and problems of disposal.

The effect of dockage on import demand is difficult to evaluate statistically. Available data series--especially for international wheat prices--are too aggregative to be practically useful in analyzing the impact of quality attributes. Moreover, an econometric analysis would have to confront two problems: First, U.S. dockage levels are not strictly exogenous; they reflect the incentives embedded in export contracts and the importer's own reckoning of cleaning costs and benefits. Second, average dockage levels in U.S. exports have varied little historically, and the United States has had limited experience exporting wheat with dockage comparable to Canada or Australia. Hence there would be little statistical basis for projecting the impact of any new regulations intended to reduce dockage in U.S. exports.

An alternative approach is to formulate and solve an importer's optimization problem, using country-specific parameters and constraints. Optimization models explicitly consider the details--including quality and price differentials, end-use requirements, and incentives for domestic cleaning--that influence purchase decisions in particular markets.

The model outlined in the next section is conceptually similar to the Input Characteristics Model (ICM) of Wilson and Preszler. They frame an optimization problem for a U.K. flour mill that seeks to minimize costs of importing and processing wheat, while satisfying various constraints relating to flour quality. The ICM is designed to explain input demand (in this case, demand for wheat from different sources) and to identify the implicit values associated with a number of input characteristics. A hedonic analysis of wheat demand is developed from an explicit optimization problem, along lines originally suggested by Ladd and Martin.

The logic of the ICM is straightforward. Wheat is priced differently and has different end-use characteristics, according to the origin, grade, and contract specifications. Buyers of wheat (millers) have specific quality requirements, depending on their product mix. These can be satisfied by purchasing wheat from one or more sources; cost minimization and quality constraints may dictate blending several types of wheat. Wilson and Preszler formulate the ICM (in its simplest version) as a linear programming problem. The model developed here includes a number of nonlinear constraints, necessitated by the introduction of dockage and cleaning activities; however, it shares other essential features with the earlier model.

The costs and incentives for cleaning by importers are a focal point for the analysis in Section III, which seeks to quantify the impact of dockage on demand. As explained later, these microeconomic aspects of import demand are also relevant to the analysis of "optimal" cleaning within U.S. marketing channels.

III. The Importer's Optimization Model

Following is an outline of the importer model. For convenience, we use notation identical to that of the computer program used in model simulations. Copies of the program are available from the authors upon request.

The importer solves a cost minimization problem. Wheat can be purchased from two sources (the United States and Canada), which have different prices and quality attributes, including dockage, which the importer takes as given. The importer is constrained to purchase some minimum tonnage from either source. Blending is assumed to be costless. The importer must ensure that some standard of "cleanliness" is met before milling, either through domestic cleaning (in the importing country) or purchasing wheat with lower dockage. In addition, blended wheat must satisfy quality constraints for protein, test weight and moisture. (Additional quality constraints could be added in a more complete formulation of the model.)

Wheat is purchased on a clean basis, but the importer also incurs the ocean freight cost, which is calculated on gross weight, including dockage.[3] Import tariffs are likewise based on gross weight. The relationship between these costs (ocean freight and tariffs) and the domestic price of screenings in the importing country is a significant feature of the problem, as will become evident.

The function to be minimized is:

$$\text{cost} = \sum_{i} [P(i) \cdot QN(i) + (OFR(i) + TF) \cdot Q(i)] + TCC - PS \cdot TS$$

acquisition cost	+	transportation and tariffs	+	cleaning costs	-	sale of screenings

where P(i) is the price of wheat imports from country i; QN(i) is the quantity of imports in metric tons (MT) net of dockage; Q(i) is the gross quantity (MT) inclusive of dockage; OFR(i) is the applicable ocean freight rate; TF is the tariff rate on wheat imports; TCC is the total cost of cleaning; PS is the price of screenings ($/MT) in the importing country; and TS is the quantity of screenings generated by cleaning operations. The importer pays for wheat purchase, transportation, tariffs and cleaning costs, but earns revenue from the sale of wheat screenings. If the importer imputes a negative value to screenings (i.e., $PS<0$), because of environmental or disposal problems, the last term can be interpreted as an additional cost of cleaning.

Cleaning costs and quantities of screenings are determined endogenously based on the amount of grain cleaned and the intensity of cleaning operations. Because of the possibility of blending, these are not trivial choices: rather than cleaning all grain equally,

[3]This corresponds to an f.o.b. sales contract, which is common in world grain trade. If the importer bought on a c.i.f. basis (with shipment costs paid by the exporter), the seller would have an additional incentive to reduce dockage levels prior to shipment.

the importer has the option of cleaning some grain more intensively and blending to meet a final dockage constraint.

Let X(i,j) denote the quantity imported from country i and allocated to activity j. The index j represents a binary choice: grain from a given source can be cleaned or blended directly without cleaning. Formally, the model uses two set definitions:

$$i \in I = \{ US, CAN \};\ j \in J = \{ C, NC \}$$

where C (*clean*) and NC (do *not clean*) are alternatives before blending:

$$\sum_j X(i,j) = Q(i) \qquad \text{for all } i$$

Besides deciding how much grain to clean, the importer chooses how intensively to clean. Let DK(i) denote the initial dockage level in wheat from country i, and let EDK(i) denote the desired ending dockage level after cleaning operations. The latter is a choice variable.

Cleaning costs depend on the throughput rates of cleaning equipment (Scherping et al.). The rated capacity of cleaning equipment, in metric tons per hour, represents maximum throughput under ideal conditions. Actual throughput rates depend on the levels of initial and ending dockage; throughput rates are inversely related to initial dockage and directly related to ending dockage. To capture these relationships and to allow for possible nonlinearities, the following equation is specified:

$$PRC(i) = a_0 + a_1\, DK(i) + a_2\, DK(i)^2 + a_3\, EDK(i)$$

where PRC(i) is the proportion of rated capacity and a_0 through a_3 are estimated coefficients. Cleaning costs are given by:

$$CC(i) = CPH \cdot \left[\frac{X(i,'C')}{PRC(i) \cdot RCAP} \right] + [X(i,'C') \cdot HCC]$$

$$TCC = \sum_i CC(i)$$

where CC(i) is the cost associated with cleaning X(i,'C'); RCAP is rated capacity of cleaning equipment; CPH is the cost per hour of operating cleaning equipment; and HCC represents an additional handling cost per ton.

In addition to the costs of operating equipment, cleaning involves the loss of some wheat.[4] The model allows for this material loss in the specification for screenings:

[4]The model does not distinguish "millable" from "nonmillable" wheat. In practice, much of the wheat lost in cleaning is composed of shrunken and broken kernels, which may be classified as "nonmillable" for some purposes. Because wheat prices apply to weight net of dockage--rather than to weight net of all nonmillable material--costs can be identified with "wheat loss" even if the wheat removed is not suitable for milling.

$$S(i) = X(i,'C') \cdot \left[\frac{DK(i) - EDK(i)}{100}\right] \cdot LF$$

$$TS = \sum_i S(i)$$

where S(i) denotes tons of screenings from cleaning wheat from country i; and LF is a known coefficient (loss factor), greater than or equal to one. If the loss factor is 1.5, then screenings are 50 greater (by weight) than the amount of dockage removed. This is of great potential importance when the importer evaluates cleaning costs.

Several additional variables are created to facilitate specification of quality constraints. Define Y(i,j) as the gross weight of grain after cleaning operations:

$$Y(i,j) = \begin{cases} X(i,'C') - S(i) & \text{if grain is cleaned} \\ X(i,'NC') & \text{otherwise} \end{cases}$$

and define YN(i,j) as weight net of dockage:

$$YN(i,j) = \begin{cases} Y(i,'C') \cdot \left[\frac{100 - EDK(i)}{100}\right] & \text{if grain is cleaned} \\ Y(i,'NC') \cdot \left[\frac{100 - DK(i)}{100}\right] & \text{otherwise} \end{cases}$$

Quality constraints apply to dockage, test weight, moisture and protein. Subsequent to cleaning and blending operations, dockage cannot exceed some level:

$$\sum_i \left[\frac{[\,EDK(i) \cdot Y(i,'C') + DK(i) \cdot Y(i,'NC')\,]}{\sum_i \sum_j Y(i,j)}\right] \leq \text{Max Dockage}$$

Other quality constraints are specified as follows:

$$\sum_i \sum_j \left[\frac{TW(i) \cdot YN(i,j)}{\sum_i \sum_j YN(i,j)}\right] \geq \text{Min Test Weight}$$

$$\sum_i \sum_j \left[\frac{MST(i) \cdot YN(i,j)}{\sum_i \sum_j YN(i,j)}\right] \leq \text{Max Moisture}$$

where TW(i) and MST(i) denote the test weight and moisture levels, respectively, in wheat imported from country i. The protein constraint is specified on a constant (12 percent) moisture basis:

$$\sum_i \sum_j \left[\frac{PRO(i) \cdot YNM(i,j)}{\sum_i \sum_j YNM(i,j)}\right] \geq \text{Min Protein}$$

where PRO(i) denotes the protein level from country i and YNM(i,j) denotes the moisture-adjusted net weight:

$$YNM(i,j) = YN(i,j) \cdot \left[\frac{100 - MST(i)}{88}\right]$$

Finally, the importer is constrained to hold some minimum quantity of wheat, net of dockage, after cleaning operations:

$$\sum_i \sum_j YN(i,j) \geq \text{Min Quantity}$$

Other characteristics and constraints could be introduced (e.g., for other quality parameters) with little additional modification. However, the model is sufficiently detailed in its present form to suggest the complexity of import decisions and to indicate the microeconomic aspects of "demand" for low dockage.

IV. The Exporter's Optimization Problem

In this section we develop a model from the perspective of a vertically integrated U.S. export firm. Although framed for a single firm, the model offers some insight into the performance of a vertically integrated industry composed of many firms. The firm's objective is to maximize returns from an export sale to a given country, net of domestic transportation and cleaning costs. The behavior of the importer, and prices and quality attributes offered by foreign competitors, are taken as given by the U.S. firm. The model addresses a strategic choice: What combination of price and dockage level should be offered, given the importer's behavior and quality requirements?

Because the net returns from an export sale also depend on cleaning costs, a subsidiary issue concerns the domestic allocation of cleaning activity. For simplicity, the model assumes that grain assembly and processing activities occur at two distinct locations: at country elevators (e.g., in North Dakota) and at an export facility (e.g., Portland). Country elevators purchase wheat at a fixed price for uniform quality. An initial dockage level is specified (e.g., 0.9 percent). Cleaning can occur at either location, but different costs and benefits apply. The cost of domestic freight (paid on the basis of gross weight) provides an incentive to clean at country elevators; however, this can be offset, in principle, by locational differences in the value of screenings or costs of cleaning.

Formally, the export firm seeks to maximize (subject to various constraints):

$$\text{Profit} = PX \cdot QN - PA \cdot VN - T \cdot GW - \sum_{p=1}^{2} [TCC(p) - RSS(p)]$$

sale revenue	-	acquisition cost	-	domestic freight	-	net costs of cleaning

where PX is the export price; QN is the quantity exported (MT) net of dockage; PA is the domestic acquisition price; VN is the quantity country elevators purchase, net of dockage; T is the cost of domestic transportation ($/MT); GW is the gross weight shipped to the export terminal; TCC(p) is the total cost of cleaning at location p; and RSS(p) signifies revenue from the sale of screenings.

The firm chooses the export price PX, the dockage level before export, and allocation of domestic cleaning activity. The quantity exported (QN) is endogenous and is derived from the importer's cost-minimization problem, described in the previous section. Conceptually, the export firm acts as the leader in a Stackelberg game, taking as given that the importer responds "optimally" to any combination of U.S. price and dockage. The linkage between the exporter model and the importer model is explained in Section V.

The firm's cleaning decisions are complex. At both domestic locations, the firm chooses how much grain to clean and how intensively to clean. Blending cleaned and uncleaned grain is possible and may be preferable (depending on throughput rates and operating costs) to cleaning all grain uniformly. Moreover, the model allows for some segmentation of domestic shipments, so that quantities with different levels of dockage can be shipped to the export facility before final cleaning and blending.

Let V(j,m) denote the quantity of wheat (gross MT) designated for a particular activity at the country location. The indexes are identified with cleaning and blending alternatives; i.e., they are drawn from the sets:

$$j \in J = \{ C, NC \}; \quad m \in M = \{ B, NB \}$$

where C indicates *clean*; NC, *do not clean*; B, *blend*; and NB *do not blend.* Thus, V('C','NB') represents a quantity of wheat that is cleaned at the country location but not blended with other grain. The quantities V(j,m) are related to wheat purchases as follows:

$$VN = \sum_{j} \sum_{m} V(j,m) \cdot \left[\frac{100 - BD}{100} \right]$$

where VN is the quantity of wheat purchased, net of dockage, and BD is the initial dockage level (%) at country elevators.

Specifications of cleaning costs are similar to those used in the importer model. Let ED1(m) denote the desired level of dockage after stage-1 cleaning operations. Operating efficiency of cleaning equipment is related to beginning and ending dockage levels:

$$PRC1(m) = b_0 + b_1 . BD + b_2 . ED1(m)$$

where PRC1 is the proportion of rated capacity for stage-1 cleaning operations and b_0 through b_2 are estimated coefficients. Total cleaning costs for stage-1 are defined:

$$CC1(m) = CPH1 \cdot \left[\frac{V(m,'C')}{(PRC1(i) \cdot RCAP1)} \right] + [V(m,'C') \cdot FCC1]$$

$$TCC1 = \sum_m CC1(m)$$

where CC1(m) is the cost associated with cleaning V(m,'C'); RCAP1, the rated capacity of cleaning equipment (MT/hour); CPH1, the cost per hour of operating the equipment; and HCC1, the additional handling cost per ton. Screenings are given by:

$$S1(m) = V(m,'C') \cdot \left[\frac{(BD - ED1(m))}{100} \right] . LF1$$

$$TS1 = \sum_m S1(m)$$

where LF1 is a parameter indicating wheat loss, as explained in Section III. Screenings are sold locally, generating revenues to partially offset the costs of cleaning:

$$RSS(1) = \sum_m S1(m) \cdot PS1$$

where PS1 is the prevailing price of screenings at the country location.

Shipments of wheat to the export terminal are divided into three categories, depending on previous cleaning or blending activities. Let W(k) denote a quantity shipped to the export terminal. The index k indicates whether cleaning and/or blending occurred before shipment:

$$k \in K = \{ NCNB, BLEND, CNB \}$$

The quantities W(k) are given by:

$$W('NCNB') = V('NC','NB')$$

$$W('CNB') = V('C','NB') - S1('NB')$$

$$W('BLEND') = V('NC','B') + V('C','B') - S1('B')$$

Total gross weight, used in the calculation of domestic transportation costs, is defined:

$$GW = \sum_k W(k)$$

Associated with each shipment category is a dockage level, denoted BD2(k). These are dockage levels received at the export terminal before stage-2 cleaning operations:

$$BD2('NCNB') = BD$$

$$BD2('CNB') = ED1('NB')$$

$$BD2('BLEND') = BD \cdot \left[\frac{V('B','NC')}{W('BLEND')}\right] + ED1('B') \cdot \left[\frac{V('B','C') - S1('B')}{W('BLEND')}\right]$$

Thus, dockage levels in the initial blend are a weighted average of original dockage BD and ending dockage ED1.

Upon receipt at the export terminal, the firm can undertake additional cleaning or divert grain directly into a final blend. In terms of functional specifications, the stage-2 cleaning operations are identical to those outlined for stage-1 and need not be repeated. For each shipment category k, the firm chooses how much to clean and how intensively to clean. Let Z(j,k) denote the relevant quantities, and let ED2(k) denote the desired ending dockage for stage-2 cleaning operations. The following constraints apply:

$$\sum_j Z(j,k) = W(k)$$

$$ED2(k) \leq BD2(k) \qquad \text{for all } k$$

Define total gross weight (after stage-2 cleaning):

$$Q = \sum_k [Z('C',k) - S2(k) + Z('NC',k)]$$

where S2(k) denotes screenings. This is the gross quantity exported, for which the importer incurs ocean freight charges. Define total net weight:

$$QN = \sum_k \left(Z('NC',k) \cdot \left[\frac{100 - BD2(k)}{100}\right] + Z('C',k) \cdot \left[\frac{100 - ED2(k)}{100}\right] \right)$$

is the export quantity net of dockage. The final dockage level (in percentage terms) is given by:

$$FD = 100 \cdot \left[\frac{Q - QN}{Q}\right]$$

The firm chooses the final dockage level (along with other variables) to maximize net revenue from the export sale, conditional on the importer's behavior. The next section outlines the relationship between the exporter and importer models.

V. Model Linkages and Solution Methods

Conceptually, the two models are linked to one another in the manner of a Stackelberg game. The U.S. firm acts as a Stackelberg "leader," choosing the price at which it will sell wheat and a dockage level for export; these may be interpreted as strategic variables. The importer acts as a "follower," taking the U.S. price and dockage level as given. The leader anticipates the follower's optimal response and makes strategic choices accordingly.

The importer's behavior is characterized as *solution* to a constrained optimization problem. The importer's constraints and substitution possibilities can cause discontinuities in the demand for U.S. wheat. For that reason it is not straightforward to combine the models analytically, e.g., by inserting an import demand function into the exporter's maximization problem.

It is nevertheless possible to identify an overall solution through a grid-search procedure. (Figure 1). This involves some minor reformulation of the exporter's problem. The two strategic variables of interest, the U.S. export price and dockage level, are treated as exogenous and are varied by increments. For each combination of U.S. price and dockage the importer model is solved, yielding a U.S. export quantity, which is entered as a constraint in the exporter model. With price and ending dockage also treated as exogenous, the exporter seeks to minimize the cost of satisfying the contract. The overall solution is found experimentally by varying the export price and dockage level and identifying the combination that yields highest net revenue for the export firm.

Both models have smooth, nonlinear constraints. Because of the curvature of the constraints, the "feasible region" is not convex for either optimization problem. This means that, unlike standard LP models, there is no mathematical assurance that a "local" optimum (identified by GAMS software) is actually "global." One way to deal with this problem is to supply the nonlinear algorithm with different initial values for the choice variables; if the solution is invariant with respect to initial values, there is reason to believe a global optimum has actually been identified. That is the approach we have taken in developing and checking the models. Following a suggestion in the GAMS User's Manual (p. 157), we also scale selected variables to avoid losses of precision.

VI. Simulation Results

Results of some preliminary simulations are summarized in this section. For illustrative purposes, the importer model is solved with two sets of parameters, representing two different countries. Informal interviews with two foreign flour millers (from Thailand and Turkey, respectively) provided screening values, transportation costs, tariffs, and costs of cleaning. Other parameters for the importer model reflect *ad hoc* assumptions, as noted below. The simulations are indicative of the results that could be obtained with more complete information; however, they should not be viewed as fully developed "case studies."

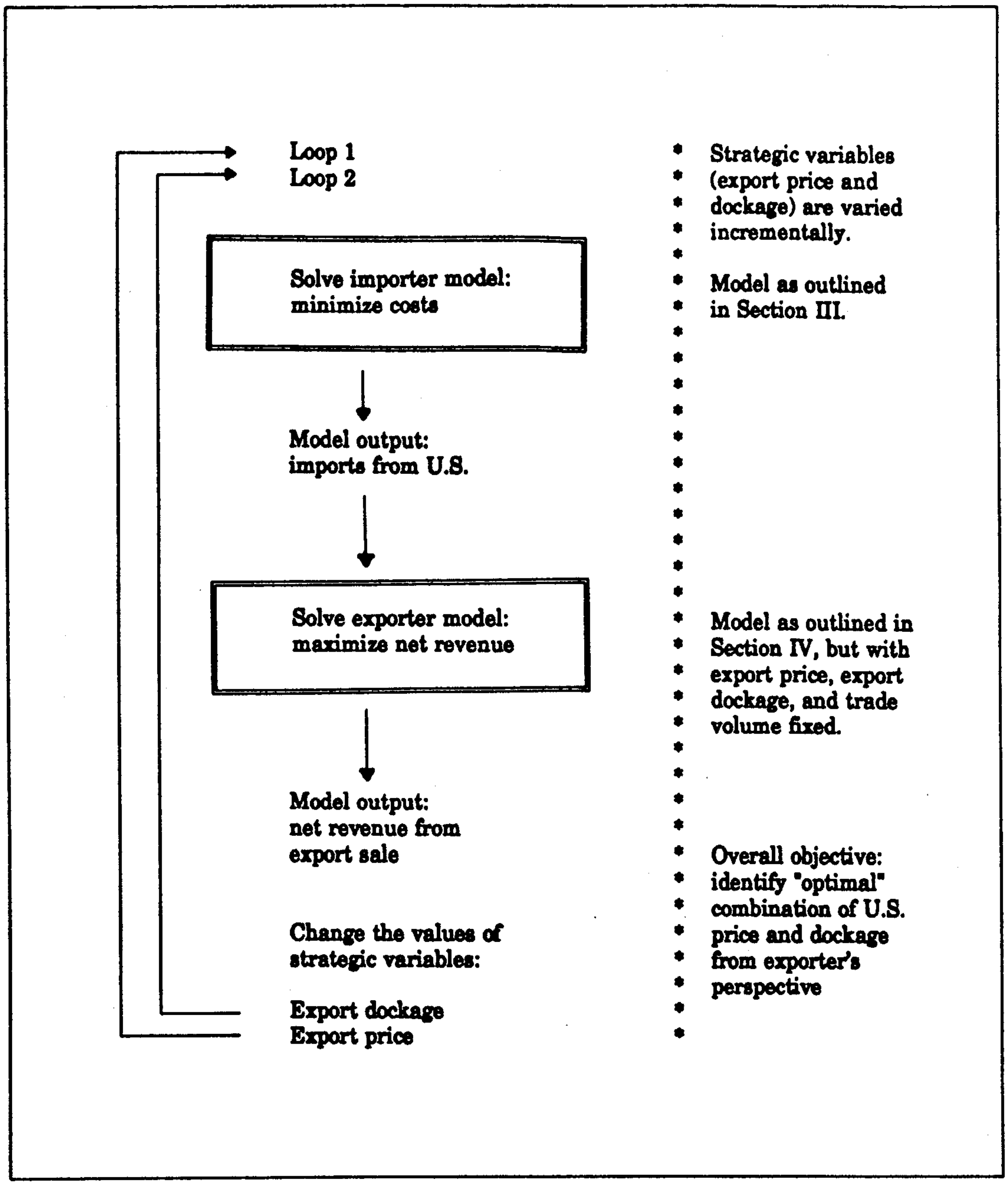

Figure 1:
Solving the Exporter's Problem via Grid Search

For ease of comparison, we assume that importers from both countries have the same quality requirements. After cleaning and blending operations, the imported wheat must satisfy the constraints in Table 1.

Table 1:
Importer's Constraints

Minimum net tonnage:	100 thousand
Minimum protein:	13.5 percent
Maximum dockage before milling:	0.05 percent
Minimum test weight:	59.0 lbs / bu
Maximum moisture:	13.5 percent

Wheat quality attributes and prices are displayed in Table 2 for each exporter.

Table 2:
Quality Attributes and Import Costs

	Canada	U.S.
Protein	14.46	14.52
Dockage	.24	*
Test weight	60.90	60.47
Moisture	12.48	11.96
Price ($/MT)		
f.o.b. export port	125.00	*

(* to be determined)

Note that the quality attributes of U.S. and Canadian wheat are similar. (These numbers are based on actual cargo data for shipments received in Taiwan in 1989-90.) Under these circumstances, the importer's requirements for protein, test weight and moisture can be satisfied by either source, i.e., there are no constraints that require blending U.S. and Canadian wheat. This highlights the importance of price and dockage as determinants of import decisions.

Cleaning costs and other model parameters are specified differently for the two importers (Table 3). Based on interviews with a Turkish flour miller, we imputed a large handling cost to cleaning operations. Apart from wheat loss, the Turkish cleaning costs do not depend on the extent of dockage removal or on the operating efficiency of cleaning equipment (i.e., CPH = 0). In volume terms, wheat loss is equivalent to 50 percent of the dockage removed. The amounts of wheat "not cleaned" are constrained to zero; all imported wheat is cleaned before milling. No import duties apply to Turkish imports, and the domestic price of screenings is marginally higher than the cost of ocean freight.

In the case of Thailand, our interviews did not yield detailed information about cleaning costs; for simplicity, we assume that Thai cleaning costs are identical to those for U.S. country elevators (Table 3). The amounts purchased but not cleaned are unconstrained; hence, the Thai importer might satisfy the ending dockage constraint by blending cleaned and uncleaned grain. A large duty applies to gross wheat imports; costs of the Thai import tariff and ocean freight far exceed the domestic value of screenings.

Table 3:
Cleaning Costs, Ocean Freight, and Tariffs

	Thailand	Turkey
Handling cost ($/MT) HCC	.20	2.5
Cost per hour ($) CPH	24	0
Rated Capacity (MT/hour) RCAP	27.3	27.3
Wheat loss factor	1.5	1.5
Price of screenings ($/MT) PS	40	28
Ocean freight ($/MT)		
from United States	29	25
from Canada	29	25
Import duty ($/MT)	40	0

The exporter model requires the specification of cleaning costs and screening values at two locations and costs of domestic transportation. We assume that the firm uses high-volume, rotary-screen cleaning equipment at its export facility. The operating efficiency of this equipment (proportion of rated capacity) depends on beginning and ending dockage levels:

$$PRC2 = .521 - .148\ BDK2 + .013\ BDK2^2 + .283\ EDK2$$

These coefficients were developed econometrically, based on information from a U.S. manufacturer of rotary-screen cleaning equipment. Country elevators use disk-cylinder cleaning equipment with a lower-rated capacity. The efficiency of this equipment (likewise based on estimates from manufacturers) is given by:

```
PRC1 = .745 - .102 BD + .388 EDK1
```

The initial dockage level before cleaning at the country elevator is 0.9 percent. Cleaning cost parameters and the value of screenings at the two U.S. locations are outlined in Table 4.

Table 4:
Cleaning Costs for U.S. Export Firm

	Country Elevator	Export Elevator
Handling cost ($/MT) HCC	.20	.20
Cost per hour ($/hour) CPH	24	145
Rated capacity (MT/hour) RCAP	27.3	600
Wheat loss factor LF	1.5	2
Price of screenings ($/MT) PS	30	15

The loss of salable wheat is substantially higher at the export facility, which diminishes the cost advantage associated with high-volume cleaning equipment. The value of screenings is also lower at the export facility. U.S. country elevators purchase wheat at $82 per MT, and the cost of domestic transportation (e.g., from North Dakota to Portland) is $36.7 per MT. Potential savings in transportation costs reinforce incentives to clean at country elevators.

Results of the grid search for each of the two importing countries are summarized in Table 5. For Thailand, the optimal solution (from the perspective of the U.S. export firm) is to match the Canadian price ($125/MT) and clean more intensively, i.e., to 0.2 percent dockage. For Turkey, results indicate the U.S. firm should accept a price discount (relative to Canada) and avoid extra costs of cleaning.

Figures 2 and 3 provide a three-dimensional view of these results. In each graph, net revenue for the exporter is measured along the vertical axis with U.S. export price and dockage measured along the other axes. The viewer is positioned in the positive orthant; hence, dockage levels are *decreasing* to the right. In both markets, dramatic shifts in net revenue are associated with changes in the U.S. export price or dockage level. When price or dockage are "too high," U.S. wheat is displaced from the import market and revenue falls to zero.

Table 5:
Summary of Simulation Results

	Thailand	Turkey
Optimal Strategic Variables		
U.S. export price ($/MT)	125.0	124.5
U.S. dockage (%)	0.2	0.9
Objective Function Values		
Importer's total cost ($'000)	19,526.3	15,254.2
Exporter's net revenue ($'000)	499.8	548.9

In each figure, the flat northeast section is identified with market saturation. At low levels of price and dockage, the U.S. firm captures the entire import market. These "saturation" surfaces have a pronounced downward tilt away from the viewer, indicating costs to the U.S. firm of offering terms that unnecessarily favor the importer.

In Figure 2 (Thailand) the saturation surface is roughly triangular. Bordering it is an "intermediate" surface where net revenues are distinctly lower but positive. Although not obvious from the graph, this intermediate surface reflects blending activities; at the indicated combinations of U.S. price and dockage, the importer minimizes costs by blending Canadian and U.S. wheat and cleaning only the latter.

By assumption, the Turkish importer (Figure 3) cleans all imported grain regardless of dockage level. Because possibilities for blending are circumscribed, the case of Turkey has no "intermediate" solutions; either the U.S. firm saturates the market or it exports nothing. Of course, this also reflects the absence of other quality differences (other than dockage) between U.S. and Canadian wheat. If other quality differences or constraints were introduced, market shares would be altered.

In general, the solution to the exporter's problem involves cleaning at country elevators, rather than at the export terminal, because of screenings-price differentials and savings on domestic freight costs. This "prediction" of the model is also consistent with empirical observation. (See Scherping et al. regarding the allocation of cleaning activities within the U.S. marketing system.)

For pricing decisions, the exporter model is more problematic. In particular, it overstates the price-setting ability of a single firm. That would be more obvious if, contrary to earlier assumptions, the U.S. export firm had a significant quality advantage over its foreign competition. If wheat from other sources could not meet an importer's quality requirements, then (given the importer's constraints) the U.S. firm could command an unlimited price premium. Failure to take into account inter-firm competition within the United States limits this modeling framework. (Some related issues are raised in the concluding section.)

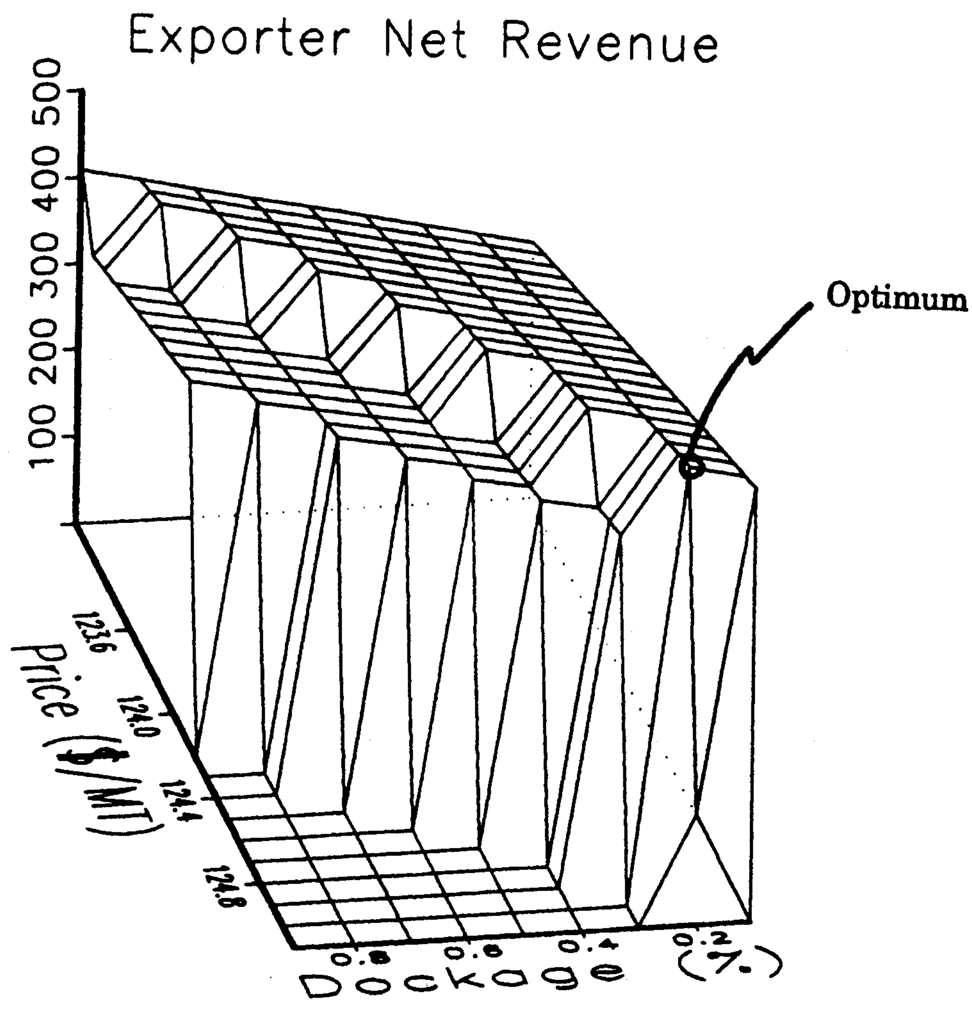

Figure 2.
Results of Grid Search, Exporting to Thailand

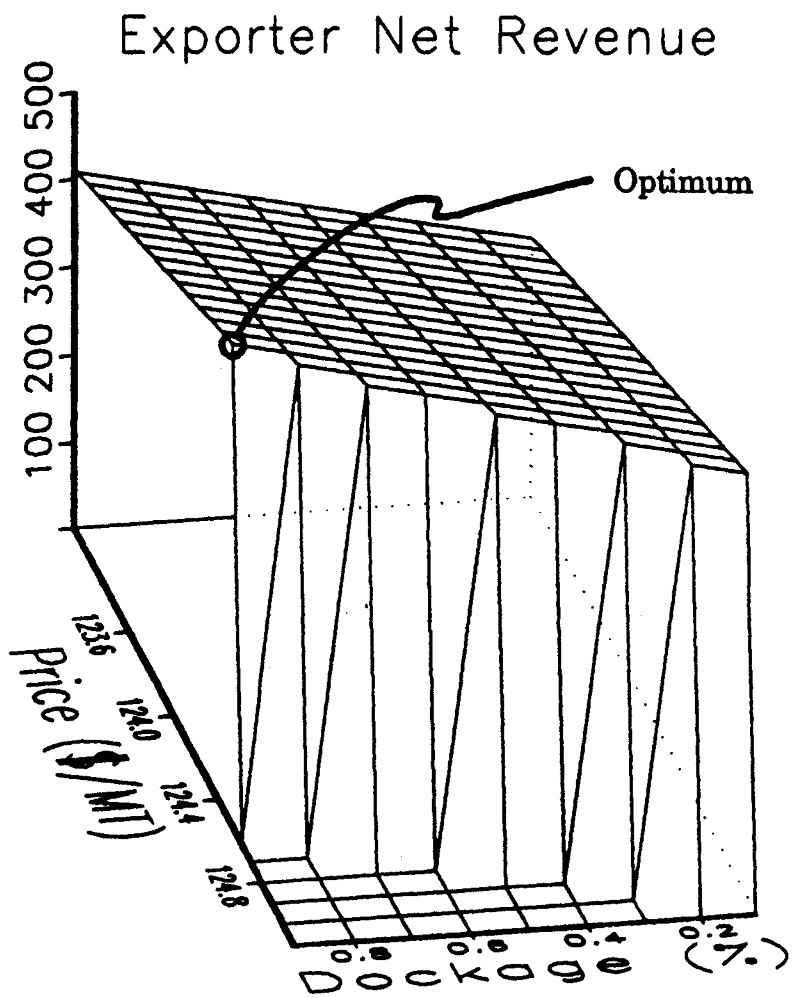

Figure 3.
Results of Grid Search, Exporting to Turkey

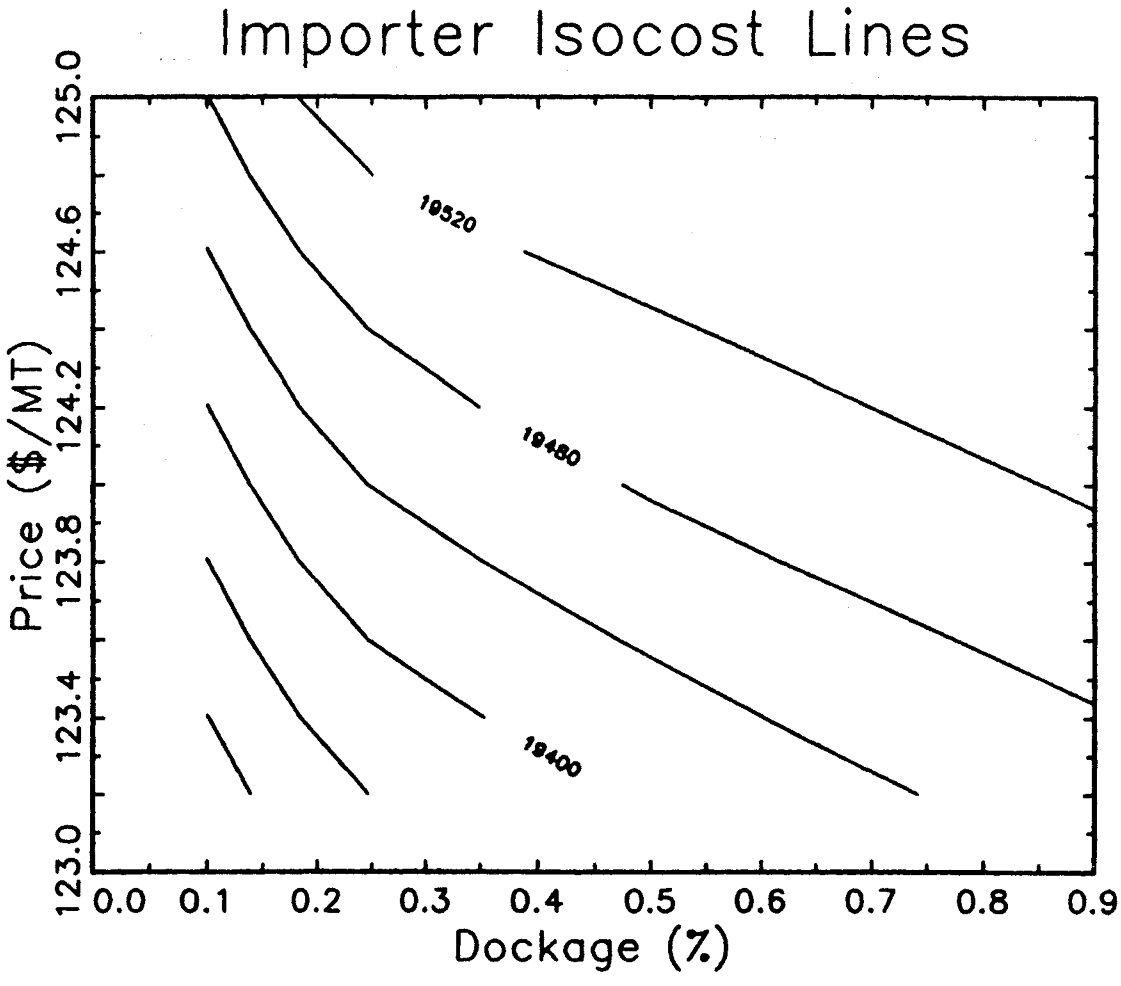

Figure 4.
Trade-off Between U.S. Price and Dockage, Thailand

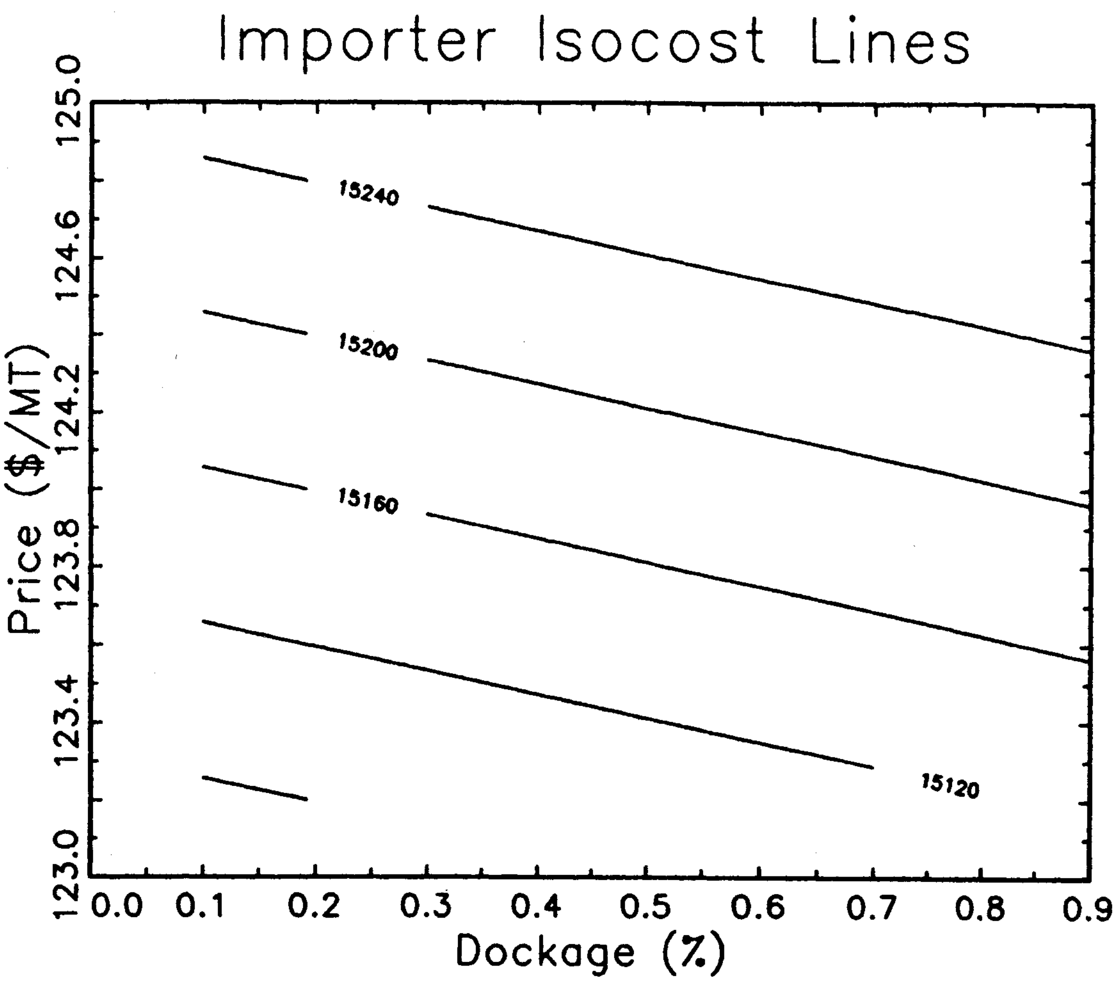

Figure 5.
Trade-off Between U.S. Price and Dockage, Turkey

Nonetheless, experimentation with U.S. export prices does provide some useful information. For example, the trade-off, from an importer's perspective, between price and incoming dockage can be quantified. Importer isocost lines, displayed in Figures 4 and 5, are based on the same simulations used to generate Figures 2 and 3, i.e., by varying the U.S. export price and dockage level and repetitively solving the importer model. Each line is a locus of points (U.S. export price and dockage level) representing equivalent value to the importer. Movements to the "northeast" are associated with higher costs to the importer, including cleaning costs. The curvature of the lines depends on cleaning-cost parameters and on the levels of dockage supplied by competing exporters.

Note that the isocost lines are "steeper" for Thailand (Figure 4) than for Turkey (Figure 5), indicating a higher implicit value for clean wheat. This reflects the excess tariffs and ocean freight over the domestic value of screenings in Thailand. Moreover, cleaning costs (exclusive of wheat loss) in Thailand are sensitive to the level of incoming dockage, while those in Turkey are not.[5]

VII. Conclusion and Discussion

The level of dockage is one of many quality attributes that affect the competitiveness of U.S. wheat in international trade. Although other countries regulate the level of dockage in their wheat exports, the United States does not. Dockage is a non-grade determining factor in the U.S. system, meaning that the level of dockage in U.S. export shipments is a negotiable term of trade. The upshot is that, in many importing countries, the level of dockage received from the U.S. exceeds that from other exporters. This paper develops a methodology that can be used to identify and assess the impacts of critical variables on the demand for cleaner wheat exported from the United States.

Dockage differs from other quality attributes because it can be removed at different locations in the marketing system, and the by-product of the cleaning process can be sold. An importer's demand for cleaner wheat is affected by quantifiable factors, such as the price and level of dockage contained in purchases from competitor countries, the level of unmillable material required before milling, the cost of removing dockage, the value of screenings in the importing country, and ocean shipping costs and tariffs. For analysis, we formulate a model of import decisions based on cost minimization with quality constraints, possibilities for blending, and cleaning activities. The results help to identify the possible trade-offs between price discounts (premiums) and dockage levels from the importer's perspective.

An exporting firm faces numerous decisions. Terms of trade (i.e., price and dockage) are offered with a view toward the likely response of a foreign buyer. The export firm also decides how (and where) to clean grain most efficiently. We analyze these

---

[5]See Table 3. For Thailand, by assumption, costs depend on throughput rates for the cleaning equipment. Throughput rates are affected by levels of incoming dockage. For Turkey, cleaning costs are fixed on a per-metric ton basis, irrespective of dockage levels.

decisions in the context of a formal optimization model in which a U.S. firm seeks to maximize revenue from an export sale, net of cleaning and transportation costs. The two optimization problems are solved jointly in the manner of a Stackelberg game, with the U.S. firm taking the importer's demand behavior as given. The results help to determine the optimal level of dockage and price in particular import markets and to evaluate the impacts of alternative price-dockage combinations on import market shares and export revenue.

The results are useful in demonstrating the impacts of critical variables on the demand for cleaner wheat exported from the United States. The value of cleaner wheat from the United States (from the buyer's perspective) is positively related to cleaning costs in the importing country, ocean shipping costs and tariffs, and the importer's requirement for "cleanliness" before milling. Demand for cleaner wheat is negatively related to the value of screenings in the importing country.

In each importing country, a trade-off exists between price and cleaner wheat. To the extent that these factors vary across importing countries, the impact of providing cleaner wheat (in terms of U.S. export sales) will vary. For this paper, data were collected for two specific countries, Turkey and Thailand. For Thailand, simulation results indicate that the optimal U.S. strategy is to provide cleaner wheat rather than price discounts. This reflects the combined influence of cleaning costs and screening values, and a relatively high import tariff applied to the gross weight of imports. For Turkey, cleaning costs are insensitive to the level of incoming dockage and import tariffs do not apply. Hence, the optimal policy for the United States would be to provide a price discount (relative to Canada) and ship wheat that has been cleaned less intensively.

This analytical framework has a number of important limitations. First, the results are highly specific to particular countries. A number of factors are identified that affect the demand for cleaner wheat, including screening values, costs of cleaning, and requirements prior to milling. These vary substantially across countries. Hence, as a tool for "aggregative" analysis (e.g., examining the global impact of proposed dockage regulations), the framework would require highly specific information from a large number of individual markets.

Second, the importer model is based on an objective of cost minimization *including* cleaning costs before milling. This is acceptable for countries where the importer and the end-user are identical. However, in numerous countries (such as the former USSR and China) the importing agency is not an end-user, or end-users have limited influence on the specification of quality limits. In these countries, the appropriate objective may be to minimize gross import cost (i.e., excluding cleaning and sale of screenings). Such countries would likely respond more to international price differentials than to relative values of dockage and other quality parameters.

Third, the analysis was conducted on the assumption that competitors would not respond to a change in the quality of U.S. exports. It is possible (indeed, likely) that competing exporters would respond to a threatened loss of market share by lowering prices. In that event, the prospective gains from exporting cleaner U.S. wheat would be substantially reduced.

REFERENCES

Brooke, A., D. Kendrick and A. Meeraus. GAMS: A User's Guide. San Francisco: Scientific Press, 1988.

Ladd, G. and M. Martin. "Prices and Demands for Input Characteristics." American Journal of Agricultural Economics. 58(1976):21-30.

Scherping, D., D. Cobia, D. Johnson, and W. Wilson. February 1992. "Wheat Cleaning Costs and Grain Merchandising." Agricultural Economics Report No. 282, Department of Agricultural Economics, North Dakota State University, Fargo.

U.S. Congress Office of Technology Assessment. Grain Quality in International Trade: A Comparison of Major U.S. Competitors. F-402. Washington, D.C.: Office of Technology Assessment, 1989.

Wilson, W. "Differentiation and Implicit Prices in Export Wheat Markets." Western Journal of Agricultural Economics. 14(1989):67-77.

Wilson, W. and T. Preszler. "Quality and Price Competition in the International Wheat Market: A Case Study of the U.K. Wheat Import Market." American Journal of Agricultural Economics. (Forthcoming, August 1992).

Appendix:
Contract Specifications of Selected Buyers of Dark Northern Spring Wheat

KOREA

#1 OR #2 O/B BS/DNS (BUYERS OPTION)
MIN 14.0%, 14.3%, OR 14.5% PROTEIN (BUYERS OPTION)
CLEAN BASIS (DOCKAGE ALL DEDUCTIBLE)
MAXIMUM 13.50% MOISTURE
MAXIMUM 0.5% SPROUT DAMAGE (CUSUM BASIS)
MINIMUM 350 FALLING NUMBERS, AVERAGE OF SUBLOTS

TAIWAN

#1-DNS 14.50% PROTEIN
CLEAN BASIS-DOCKAGE ALL DEDUCTIBLE PLUS AN ADDITIONAL PENALTY: 1 FOR 1 ADDITIONAL PENALTY FOR .4% DOCKAGE OR LESS, 2 FOR 1 ADDITIONAL PENALTY IF DOCKAGE EXCEEDS .4%, ALL BASED OFF CONTRACT PRICE.
MAXIMUM 0.5% SPROUT DAMAGE (CUSUM)
MAXIMUM 13.50% MOISTURE
DOTY LABS IN KANSAS CITY AS FINAL SETTLE, GRADE AND PROTEIN

PHILIPPINES

#2 0/B NS/DNS
MINIMUM 14.0% PROTEIN
0.5% DOCKAGE NON-DEDUCTIBLE
MAXIMUM 13.80% PROTEIN PER SUBLOT
MINIMUM 65% DHV PER SUBLOT

JAPANESE FOOD AGENCY

#2-0/B NS/DNS-MIN 14% PROTEIN
0.5% DOCKAGE NON-DEDUCTIBLE
MAX. 1.0% DOCKAGE (CUSUM)
MAX. 0.5% SPROUT DAMAGE (CUSUM)
MIN. 300 F/N-COMPOSITE BASIS
MAX. 13.50% MOISTURE
MAX. 0.0% HEAT DAMAGE AVERAGE
0% TOLERANCE TREATED KERNALS ON A SUBLOT BASIS

(Source: U.S. Wheat Associates)