Price Discrimination in the Context of Vertical Differentiation:
A Modeling Approach for Wheat Exports

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May 15, 2001

Selected Paper, AAEA Annual Meeting
Chicago, IL, August 5-8, 2001

Acknowledgements
This paper is based on my Ph.D. dissertation in progress at the University of California, Davis. I would like to thank Richard Sexton for his inputs as well as for useful discussions and comments. However, all errors are mine only.

1- Introduction

In microeconomics textbooks the wheat industry is often used as an example of an industry characterized by product homogeneity and perfect competition. This study challenges this view by investigating the presence of price discrimination in a differentiated wheat industry. It is, nevertheless, a surprise to many that there exists many types of wheat, each utilized for different end-uses. Different wheat "classes" are used in flour destined for the production of raised breads, flat breads, noodles, cookies and cakes, pasta, etc. Not only do wheat classes differentiate wheat, but within those classes, wheat is also differentiated by quality. As emphasized in the studies conducted by the Economic Research Service (ERS) of the U.S. Department of Agriculture (USDA) (Mercier, 1993) and Stephens and Rowan (1996), Canadian and Australian wheat are often considered by exporters to be of better quality than U.S. wheat.

With product differentiation, the potential exists for a large seller to exert market power through price discrimination. Interestingly, both Canada and Australia export wheat through a marketing board, which has been given the sole right to export. These two marketing boards are considered state-trading enterprises (STEs).[1] The CWB and AWB have faced challenges internationally and domestically given their status of STEs. Internationally, they are nowadays controversial institutions as they are believed to engage in unfair trade practices and distort worldwide trade. Under the next round of the WTO negotiation, the United States hopes to end the exclusive export rights and government financial backing of STEs (Miner, 2001).

In the past two decades, the benefits of having the Canadian Wheat Board (CWB) as the sole exporter of Canadian wheat and barley, have been questioned by some Canadian wheat and barley producers. The Australian Wheat Board (AWB), the sole exporter of Australian wheat, has faced similar pressure, but from particular grain exporting groups (Barraclough and Jones, 1993). The AWB is currently being investigated under the federal government National Competition Policy. Under this review, the AWB will have to demonstrate that the benefits of having a single-desk seller

[1] According to the U.S. General Accounting Office (GAO), "STEs are generally considered to be enterprises that are authorized to engage in trade and are owned, sanctioned, or otherwise supported by the government." (GAO, 1996)

of wheat are significant and important enough for the Australian economy to justify its continuation.

In the context of those challenges, prior research has sought to examine the benefits and costs of the CWB (Kraft, Furtan and Tyrchnewicz (KFT), 1996; Carter and Loyns, 1996) and of the AWB (Ryan, 1994; Booz, Allen and Hamilton, 1995; Piggott, 1992). Some of these studies have examined whether the CWB and AWB can market wheat at a premium over the price of comparable wheat from competitors due to their ability to price discriminate (KFT and Ryan). However, this work has not satisfactorily taken into account wheat differentiation among countries. Therefore, it is unclear whether measured price premia reflect solely the effects of price discrimination as opposed to differences in quality of the traded products.

In the current study, a conceptual model is developed to examine price discrimination when the products traded are differentiated by quality. The industrial organization and trade literature have primarily focused on consumer goods. However, the nature of intermediate goods, used as inputs in the production of consumer goods, is such that the current New Empirical Industrial Organization (NEIO) approaches and trade models are not readily applicable. This study modifies the model of quality differentiation developed by Mussa and Rosen (1978) to the realities of bread wheat import demand. The outline of an empirical model designed to test and isolate the bases of price discrimination under quality differentiation is also presented.

2- Canadian and U.S. Wheat Industries

This section examines the wheat marketing systems of the United States and Canada. Only these two exporting countries are described because they export the bulk of high-protein hard wheat, the type of wheat used in raised bread production. It is also the type of wheat for which Canada is recognized for its quality. Two important differences between the Canadian and U.S. wheat industries are their marketing and variety control systems.

Exports of U.S. wheat are dominated by the activities of a few multinational firms. In contrast, all Western Canadian wheat going for export or for domestic processing is marketed by a single firm, also called a single-desk seller, the CWB. The

CWB has the stated objective to sell wheat and barley at the best possible price (CWB, 2001). The CWB markets wheat and barley on behalf of farmers and returns to the farmers all the net proceeds from the sales, minus operating and administration costs, as a pooled price. Export sales revenue is pooled according to the wheat class and grade. Farmers are paid an initial price upon delivery to the country elevator, which is typically about 85 percent of the final pool price. The initial payments vary by class, grade, and protein level for some classes. At the end of the crop year, the pool accounts are closed and any surplus above the initial price and administration cost is distributed to producers in the form of a final payment.

The quality system in the U.S. and Canada both include a classification and a grading scheme. Classes segregate wheat based on color, kernel, hardness, and time of planting, whereas grades segregate wheat according to the defects present. Wheat belonging to each wheat class is also used for different purposes. For example, wheat in the Canada Western Red Spring (CWRS) and the U.S. Hard Red Spring (HRS) classes are used in the production of high-volume pan breads. Because of their good gluten strength they are also used in blends with weaker wheats in the production of hearth bread, noodles, flat breads, and steam breads.

Variety control in Canada is done by including varietal standards in official grade definitions for the top grades of wheat. For example, the Neepawa variety is the varietal standard for CWRS wheat. Only varieties that are determined to be of a quality equal to Neepawa or better can be marketed in the milling grades of CWRS (grade 1, 2, and 3). The foundation of this unique system is a visual quality identification method. Wheat can be segregated by classes because of the kernel visual distinguishability requirement of the variety registration system of the Canadian Grain Commission. For a new variety to be registered and placed on the market, it must not only be of equal quality to the existing standard in its class, or better, but also visually different from wheat in other classes. Non-registered and indistinguishable wheat varieties are not allowed to be grown in Western Canada.

In contrast to Canada, the U.S. varietal development and release system is unregulated. New varieties are developed and released by both public and private firms. According to Dahl and Wilson (1997), this difference in variety control policy has resulted in twice as many releases of new hard red spring varieties in the United States as in Canada. American wheat producers are free to choose among the wheat varieties available on the seed market. Because different varieties within each class have different end-use and agronomic quality, such as high yield, disease resistance, etc., producers may not always choose varieties with good end-use quality. The difference in the variety control system between Canada and the United States may partly explain why some importers consider Canadian wheat to be of better quality than U.S. wheat.

3- Wheat Quality

Quality and quantity of flour produced from a given quantity of wheat depend on the physical and intrinsic quality of the wheat kernels. Protein content is the single most important predictor of the end-use potential of wheat (Williams, 1997). For raised-bread baking, protein level directly influences loaf volume and crust and crumb texture. Up to about 13 percent protein is beneficial for raised breads, because higher protein will result in complications in mixing and fermentation (Williams, 1997). Wheat with more than 13 percent protein is normally used in blends with wheat of lower protein content. Protein quality, which varies by wheat varieties, is just as important as protein quantity. If two flours, coming from two different wheat varieties but with the same protein content, produce two different loaf volumes, everything else constant, their protein is said to be of different quality (Tweed, 1993).

Wheat quality also corresponds to the wheat characteristics that are valued by importers. Mercier (1993) reports the results of personal interviews with wheat users and importers from 18 countries. In that study, wheat quality is broadly defined as consisting of factors affecting end-use characteristics and the quality uniformity within and between shipments. Protein quantity was rated the most important quality characteristics in wheat purchasing decision, followed by gluten (protein) quality, moisture content, and nonmillable material. Moreover, “for a given class of wheat, the United States is perceived as being unable to provide the level of protein that buyers expect” (Mercier, 1993, p.19). Canada and Australia were recognized to export higher overall quality (physical and intrinsic) than the United States. Protein quality in HRS relative to CWRS wheat was determined to be a problem primarily for markets serviced through the Gulf of

Mexico and the Great Lakes. For other countries, the main concern with HRS wheat was the variability in protein quality within and between shipments.

Stephens and Rowan (1996) report that consistency of quality from shipment to shipment was deemed the most important factor on average for importers interviewed. Importers were asked to rank exporters on diverse quality factors. Canada was ranked the highest on: intrinsic quality, cleanliness, consistency of quality, technical support, long-term dependability of supply, and customer service policy. Canada was ranked last on price, which most likely indicates a higher price charged by the CWB.

Results from these surveys show that important wheat quality characteristics differ for different importing countries and importers. From the discussion above, consistency in quality and intrinsic quality, especially the level and consistency of protein quantity and quality, emerge as important characteristics for importers in general.

4- Review of the Literature

As an introduction to the conceptual model described in the next section, I review the wheat trade literature and models of trade in differentiated products.

4.1 Wheat Trade Literature

The literature on wheat trade has addressed both wheat differentiation among countries and noncompetitive behavior of exporting countries. However, these issues have not been considered jointly in models of the world wheat market and, more specifically, in the rationale behind price premia observed for certain sellers.

Several studies have provided empirical evidence regarding the impact of quality on wheat prices using hedonic pricing models (Veeman, 1987; Wilson, 1989; Larue, 1991; Espinosa and Goodwin, 1991; Uri and Hyberg, 1996; Stiegert and Blanc, 1997; Parcell and Stiegert, 1998). Veeman, Wilson and Larue find price premia for certain countries after controlling for measurable wheat characteristics. Veeman finds that Australia's wheat obtained the highest premium. However, both Wilson and Larue find that Canada achieves a premium over both the U.S. and Australian exports of high protein wheat.[2]

The interpretation of this premium has not been clarified. For example, Larue argues that the premium received by Canadian wheat can be attributed to a reputation for exports of a consistent quality. However, Ahmadi-Esfahani and Stanmore (1992) maintain that it is the elasticity of excess demand, faced by Canada, which is the final determinant of Canada's ability to achieve a premium. These conflicting views on whether price premia are due to quality differences or market power suggest the need for a study that accurately takes into account these two factors.

Ahmadi-Esfahani and Stanmore also point out that the hedonic model assumes implicitly that exporters are perfect competitors and thus "cannot handle strategic considerations reflecting an imperfectly competitive structure" (p.145). This point is especially relevant given that a number of studies have focused on the oligopolistic nature of the world wheat market. Early studies treated countries as players, and various models were proposed but, for the most part, not tested: United States-Canada duopoly (McCalla, 1966), United States-Canada-Australia triopoly (Alaouze, Watson and Sturgess, 1978), EC-Japan duopsony (Carter and Schmitz, 1979).[3] Because wheat from the United States and European Union is not exported through a single seller, it is unclear why these countries should be represented as monolithic entities in these models More recent studies have allowed for strategic interaction of the governments of these countries, in the formation of policy, and with powerful market intermediaries (e.g., Karp, 1982; Vanzetti and Kennedy, 1990; McNally, 1993).

The literature on marketing boards/STEs has in general paid too little attention to the specific characteristics of marketing boards and STEs. Early research investigating imperfect competition in wheat trade did not take into account the presence of market intermediaries. Countries were considered as agents with market power (McCalla, 1966; Alaouze, Watson and Sturgess (AWS), 1978; Carter and Schmitz, 1979). Moreover, the specific objective functions of STEs have not been given proper attention. STEs have

[2] Larue found that Canadian wheat achieved a premium of $26.40/tonne over U.S. wheat and $18.62/tonne over Australian wheat. Wilson found that the Canada-U.S. premium was $20/tonne and the Canada-Australia premium was $11/tonne. These premia represent between 10-15 percent of the price of CWRS wheat.

[3] More recently, Kolstad and Burris (1986) tested all three models using nonnested tests and 1972-73 data. Their results favored the U.S.-Canada duopoly of McCalla (1966).

various levels of government intervention and may pursue multiple and varied objectives, given the pressures that they face from different interest groups. Finally, it is important to consider the strategic interactions of STEs with private firms/multinationals. These three aspects of modeling trade in the presence of STEs – avoiding modeling countries as agents with market power, taking into account both the specific objectives of STEs, and modeling STEs strategic interactions with private firms – have been considered in the work of Thursby (1988), Thursby and Thursby (1990) and Krishna and Thursby (1992). However, their empirical applications are limited or non-existent.

4.2 Models of Trade in Differentiated Products

The previous section emphasized important issues in modeling the behavior of wheat exporters and their strategic interactions with competitors. This section examines issues related to the modeling of importers' demand for differentiated goods. In this study, a model of flour millers leading to a system of import demand equations (a demand for Canadian wheat and one for U.S. wheat) is developed for each importing country.

There are two types of product differentiation. Products are "horizontally" differentiated when they possess different characteristics, for example, a blue car versus a red car. Some consumers will prefer one car versus another, but all consumers do not agree on which car is preferred because they have different preferences for color. Products are "vertically" or quality differentiated when they differ by the level of a certain characteristics, where more of a given characteristic is better. For example, a car with more fuel efficiency is preferred to an identical car with less fuel efficiency. Under vertical differentiation, all consumers would choose the higher quality good if it was sold at the same price as the lower quality good.

Goods that are purely vertically differentiated are rare. Most goods contain a bundle of characteristics and are differentiated both horizontally and vertically. However, when interested in the quality aspect of a product, modeling is greatly simplified by considering quality as a summary index of the quantity of product characteristics. Using quality as a summary index of a product's characteristics is a reasonable assumption when consumers generally rank the differentiated products in the same order of quality. Assuming that wheat is vertically differentiated seems to be valid for bread wheat according to the surveys conducted by Mercier (1993) and Stephen and Rowan (1996), where many countries agree that Canadian wheat is of better quality than U.S. wheat. A conceptual model of vertical differentiation would therefore be appropriate.

Popular models used in trade of differentiated agricultural products are the Armington model and the Lancaster-Ladd (hedonic) model. The Armington model, where products are assumed to be differentiated by country of origin, is a popular approach for product differentiation in trade because it is parsimonious in the amount of information required for empirical analysis. It has been used in wheat trade in numerous instances (Johnson, Grennes, and Thursby, 1979; De Gorter and Meilke, 1987; Ahmadi-Esfahani, 1989; Alston et al., 1990; and Davis, 1995). Both the Armington and hedonic models assume a representative agent. However, Davis (1995) points out that, for both models, the only way a representative agent can generate a system of demand for the differentiated product is for products to be horizontally differentiated. Under vertical differentiation, the representative agent would prefer only the highest quality variety and this would not generate a demand system for each importer.

Vertical differentiation models have been developed primarily for consumer goods. The important difference in modeling consumer goods versus intermediate goods is the source of buyer heterogeneity leading to the purchase of the high- versus the low-quality good. For consumer goods, it is heterogeneity in consumers' willingness to pay for quality (income) (Gabszewicz and Thisse, 1979, 1980; Shaked and Sutton, 1982), or consumers' tastes for quality (Mussa and Rosen, 1978). For intermediate goods, it is the heterogeneity in firms' technology and their output's characteristics.

Vertical differentiation models have rarely been used or modified for intermediate goods. One exception is a model of differentiation in the sweetener industry (Cooper, Giraud-Héraud, and Réquillart, 1995). The model of vertical differentiation developed by Mussa and Rosen (1978) has the characteristics sought for the conceptual model of demand for this study. However, the model assumes that each consumer buys one unit of the differentiated good. Although it can be argued that many consumer goods are bought in discrete units, wheat is bought in bulk and this assumption cannot be justified. Moreover, the demands are derived from a utility maximization problem given that the good in question is consumed directly by the final consumers. The demand for wheat and its characteristics are in part derived from the consumers' demand for bread, but also from millers' objective to minimize processing costs or maximize profits. Wheat must be modeled as an intermediate input purchased in continuous quantities by flour millers. The model developed in the next section modifies the Mussa-Rosen model to the realities of the demand for high-protein wheat.

5- A Model of Trade with Wheat as a Vertically Differentiated Intermediate Good

Previous sections have shown that Canadian bread wheat is perceived by many importers to be of higher quality than comparable U.S. wheat, with protein quality, quantity, and consistency being repeatedly mentioned as important characteristics. Thus, Canadian and U.S. bread wheat can be modeled as vertically differentiated products. Few models of vertical differentiation exist for intermediate goods. In this section, the Mussa-Rosen model of vertical differentiation is modified to accommodate the realities of wheat trade when quality is an important demand feature. Section 4 also emphasized modeling correctly the objective function of STEs. Thus, the supply side of the model includes the specific objective function of the CWB and its strategic interactions with U.S. competitors. The model is used to develop a test of price discrimination.

5.1 Demand side

Assume that two countries each export a differentiated commodity to two markets. Assume further that the commodity – wheat – is differentiated by quality only. That is, country *H* (Canada) produces wheat of quality k_H and country *L* (United States) produces wheat of quality k_L. Country *H* wheat is of better quality than country *L* wheat, i.e., $k_H > k_L$. Wheat is therefore considered to be a vertically differentiated product. In other words, wheat *H* contains more of a certain characteristic than wheat *L*, all else equal. It is also assumed that all buyers value quality and would choose wheat *H* over wheat *L* if they were sold at the same price.

Suppose that wheat is imported in each market for processing into an end-product, e.g., flour. Moreover, it is assumed that importing country *m* produces wheat domestically of quality k_d^m, which is lower than the quality of both foreign wheats. Millers, in each country, differ according to their desired end-product qualities, k^m.

Markets 1 and 2 differ in domestic wheat quality and also in the general quality standard for the end-product. The quality of the end-product for the millers in market *m* ranges in the interval $k^m \in [s_m, K_m]$, where $K_m = s_m + 1$ and s_m can be viewed as a minimum quality standard in market *m*.

Assume that the minimum quality standard for the end-product in market 1 is greater than in market 2, i.e., $s_1 > s_2$. This could be the case if either (a) consumers in market 1 are more quality conscious or (b) flour is used for a different purpose in market 1 than in market 2. For example, different countries consume different types of bread; flat breads are consumed in the Middle-East, whereas hearth breads are consumed in Europe.

Finally, in both markets the maximum desired end-product quality is higher than the quality of the domestic wheat (in end-product quality equivalent terms), but lower than the quality of foreign wheat. That is, $k_H > k_L > K_m > k_d^m$. The end-product quality of a specific miller in country *m* may or may not be below the domestic wheat quality. If the end-product quality of miller *f* in market *m* is higher than the domestic wheat quality $(k^m > k_d^m)$, it must import wheat of quality k_H or k_L in order to blend in the production of the end-product. This situation applies well to high-protein hard wheat. Most importing countries produce wheat domestically that is not high enough in protein content to produce high protein flours used in the production of raised bread. Consequently, the domestic wheat must be blended with Canadian or U.S. hard wheat which has a higher protein content. This is particularly true of European markets, such as France and the United Kingdom. Japan, an important Canadian and U.S. customer, also blends both Canadian or U.S. high-protein hard wheat (CWRS and HRS, respectively) with domestic wheat and lower protein U.S. wheat (HRW).

Domestic and foreign wheat must be blended according to specific proportions depending on the quality of domestic wheat, the quality of foreign wheat and the desired end-quality. Moreover, the wheat input is combined with other inputs such as labor and capital to produce flour. Therefore, we can imagine a production function of the type:

$$y^m = \min\left\{\min\left[\frac{q_i}{a(k_i, k_d^m, k^m)}, q_d\right], \frac{h(S)}{b(k_i, k_d^m, k^m)}\right\}, \tag{1}$$

where y^m is the flour output of a typical firm in market m ($m=1, 2$), q_i is the quantity of imported wheat i ($i=H, L$), and q_d is the quantity of domestic wheat. The parameter $a(k_i, k_d^m, k^m)$ is the ratio of foreign wheat relative to domestic wheat, S is a vector of other inputs and $b(k_i, k_d^m, k^m)$ is the ratio of wheat input to other inputs. Other inputs S do not have to be used in fixed proportions with one another in $h(S)$.

Expression (1) says that output y^m of flour of quality k^m is produced with wheat and other inputs in a Leontief function, where the wheat input is a blend of foreign and domestic wheat that is determined by the fixed conversion parameter $a(\cdot)$. Given quality parameters k_i, k_d^m, and k^m, $a(k_i, k_d^m, k^m)$ units of foreign wheat must be combined with one unit of domestic wheat. Any other ratio of inputs used will result in flour with a quality other than the quality desired by the miller. Therefore, wheat of quality k_i must always be combined with wheat of quality k_d^m in a fixed ratio $a(k_i, k_d^m, k^m) : 1$ to produce flour of quality k^m. Recall from chapter 2 that millers target very specific end-product characteristics and exceeding the target quality is usually not desirable. For example, raised bread requires 13 percent protein wheat whereas cakes and cookies require 9 percent protein.

It is important to note that high- and low-quality imported wheat are considered to be perfect substitutes in this formulation. However, the higher quality wheat, k_H, is considered to be more "productive" in the production of the output. To obtain flour of quality k^m, the low-quality wheat is combined in a different ratio with domestic wheat, where the blending ratio changes with changes in the quality of domestic and imported wheat, as well as changes in the desired end-quality.

More specifically, as the quality of the imported wheat increases, less imported wheat is needed and the ratio of imported relative to domestic wheat decreases. Similarly, as the quality of domestic wheat increases, less imported wheat is required and the ratio of imported to domestic wheat used decreases. Finally, as the end-product quality increases, the quantity of foreign wheat must increase and the ratio of imported to domestic wheat increases. To incorporate these notions in a tractable way, assume that the parameter $a(\cdot)$ takes the following form:

$$a(k_i, k_d^m, k^m) = \frac{k^m}{k_i k_d^m} .$$

These assumptions mean that the output yield from one unit of the high-quality wheat (k_H) is higher than the yield from the low-quality wheat (k_L). For example, higher quality can take the form of a higher extraction rate of wheat endosperm from the wheat kernel. A higher extraction rate results in a higher flour yield. Higher quality could also be higher wheat gluten quality. Higher gluten quality may result in higher water absorption in bread dough, which in turn implies more bread units for a given quantity of wheat.

The ratio of other inputs relative to wheat inputs also depends on the quality of foreign and domestic wheat, as well as the end-product quality. As the quality of both foreign and domestic wheat increases, the ratio of other inputs relative to wheat input decreases. In other words, an increase in wheat quality increases the end-product yield for one unit of other inputs and therefore decreases processing cost. Moreover, as the end-product quality increases, the necessary quantity of other inputs is assumed to increase in a convex fashion. In other words, as the end-product quality increases, the use of processing inputs must increase at an increasing rate. For the sake of tractability, assume that the parameter $b(\cdot)$ takes the following form:

$$b\left(k_i, k_d^m, k^m\right) = \frac{\left(k^m\right)^2}{k_i k_d^m} = k^m a(\cdot)$$

This assumption means that use of high-quality foreign wheat results in lower processing costs than use of the low-quality wheat (k_L). Examples of wheat quality features resulting in lower processing costs are lower dockage or foreign material content, resulting in flour with lower mixing time, and consistency in quality across shipments, which avoids re-adjusting machine settings.

Assume that flour millers in market m each have a contract for y^{*m} quantity of flour to be delivered. Moreover, each miller produces a different end-product quality or, said differently, a different type of flour. Therefore, the flour miller must choose between the high- and low-quality wheat to import to minimize costs. The miller therefore faces the following problem:

$$\min_{q_H, q_L, q_d, S} p_H q_H + p_L q_L + p_d q_d + wS \quad s.t. \quad y^{*m} = \min\left\{ \min\left[\frac{q_i}{a(k_i, k_d^m, k^m)}, q_d \right], \frac{h(S)}{b(k_i, k_d^m, k^m)} \right\},$$

where i = *H, L* and w is a vector of other input prices. For notational simplicity, from now on I replace *a(·)* and *b(·)* by a_i and b_i, respectively.

To minimize cost, the flour miller must combine inputs such that

$$y^{*m} = \frac{q_i}{a_i} = q_d = \frac{h(S)}{b_i}. \tag{2}$$

Therefore, the cost from using wheat i for a typical miller in market m is given by:

$$C_i^m(p_i, p_d, w, k_i, k_d^m, k^m, y^{*m}) = p_i y^{*m} a_i + p_d y^{*m} + G^m(w, y^{*m} b_i), \; i=H,L.$$

$G^m(w, y^{*m} b_i)$ represents the non-farm product processing costs and is the result of minimizing costs with respect to the choice of the processing inputs, S. Assume that $G^m(w, y^* b_i) = g^m(w) y^{*m} b_i$, i.e., constant returns to scale. If we substitute the expressions for a_i and b_i, millers' cost from using imported wheat i becomes:

$$C_i^m(p_i, p_d, w, k_i, k_d^m, k^m, y^{*m}) = y^{*m}\left(p_i \frac{k^m}{k_i k_d^m} + p_d + g^m(w)\frac{(k^m)^2}{k_i k_d^m} \right), \; i=H,L. \tag{3}$$

The millers' costs in market m differ depending on k^m, the end-product quality. Some millers may purchase only domestic wheat. This is possible only for those millers whose desired quality of the end product is equal to or lower than the quality of the domestic wheat. The quality of the end-product will be higher than desired if domestic wheat is of higher quality than necessary.

Allowing for a firm to use only domestic wheat is similar to having an "outside good" in the standard model of vertically differentiated products. The outside good permits an income effect to occur. In the context of this study, allowing the millers to buy only domestic wheat guarantees that if the prices of both foreign wheat increase, the consumption of foreign wheat decreases and the consumption of domestic wheat increases.[4] When a firm uses only domestic wheat, millers' cost becomes:

[4] Alternatively, the outside good could be another class of wheat produced domestically or imported. One example is the Hard Red Winter wheat class produced by the United States and used by Japan in blends for bread-making purposes.

$$C_d^m(p_d, w, k_d^m, k^m, y^{*m}) = y^{*m}\left(p_d + g^m(w)\frac{(k^m)^2}{(k_d^m)^2}\right).$$

A flour miller in market *m* with end-product quality k^m will choose to use the type of wheat with the lowest cost. Thus, the cost function of a typical miller in market *m* can be expressed as:

$$C^m(p_H, p_L, p_d, w, k_H, k_L, k_d^m, k^m, y^{*m}) =$$
$$y^{*m}\left(p_d + \min\left[p_H \frac{k^m}{k_H k_d^m} + g^m(w)\frac{(k^m)^2}{k_H k_d^m}, p_L \frac{k^m}{k_L k_d^m} + g^m(w)\frac{(k^m)^2}{k_L k_d^m}, g^m(w)\frac{(k^m)^2}{(k_d^m)^2}\right]\right)$$

For example, a flour miller with end-product quality k^m will choose to import the high-quality wheat if the cost of using the high-quality wheat is lower than the cost of using the low-quality wheat, that is if:

$$p_H \frac{k^m}{k_H k_d^m} + g^m(w)\frac{(k^m)^2}{k_H k_d^m} < p_L \frac{k^m}{k_L k_d^m} + g^m(w)\frac{(k^m)^2}{k_L k_d^m}$$

which is equivalent to:

$$p_H - p_L \frac{k_H}{k_L} < k^m g^m(w)\left(\frac{k_H - k_L}{k_L}\right) \tag{4}$$

The above expression says that for a flour miller to import the high-quality wheat rather than the low-quality wheat, the decrease in processing cost must outweigh the increase in the quality-adjusted procurement cost. The cost minimization conditions for the choice between high- and low-quality wheat can be summarized as follows:

$$\begin{cases} q_H = y^{*m} \dfrac{k^m}{k_H k_d^m} \quad \textit{and} \quad q_L = 0 \qquad \textit{if} \quad C_H^m < C_L^m \\ q_H = 0 \quad \textit{and} \quad q_L = y^{*m} \dfrac{k^m}{k_L k_d^m} \qquad \textit{if} \quad C_H^m > C_L^m \end{cases}$$

The miller indifferent between buying the high- versus the low-quality wheat in each market is the miller for whom the cost of using the high-quality wheat is the same as the cost of using the low-quality wheat. Equivalently, it is the miller who produces the end-product of quality:

$$\bar{k}^m = \frac{(p_H k_L - p_L k_H)}{g^m(w)(k_H - k_L)}.$$ [5]

Similarly, the miller indifferent between buying the low-quality wheat versus not buying any foreign wheat and using only the domestic wheat, is the one for which the end-product quality makes the cost of the low-quality wheat equal to the cost of the domestic wheat. That is,

$$\underline{k}^m = \frac{p_L}{g^m(w)(k_L - k_d^m)}.$$

Assume that in each market there is a continuum of millers with different end-product qualities. More specifically, assume that millers in both markets are distributed uniformly with density 1 on $k^m \in [s_m, K_m]$ where $K_m = s_m + 1$. Figure 1 shows how millers in market m are divided into those who buy no foreign wheat, low-quality foreign wheat, and high-quality foreign wheat.

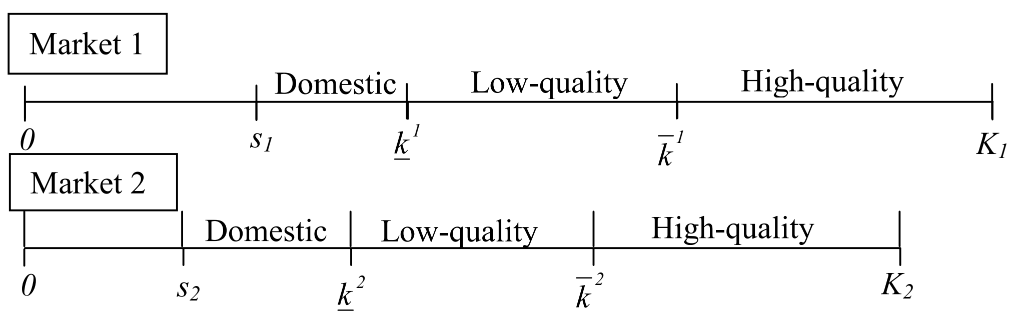

Figure 1. Division of millers in each market into the quality of wheat bought.

As implied by equation 2, the quantity of wheat imported by each miller is $q_i = y^{*m} a_i = y^{*m} \frac{k^m}{k_i k_d^m}$. In other words, the quantity imported per unit of output varies among millers depending on the quality of wheat imported and the quality of the end-product. The quantity imported by millers also varies across countries depending on the contracted quantity of output, the quality of the end-product and the quality of the

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[5] It is assumed that $\bar{k}^m < K_m$ so that a positive quantity of high-quality wheat is imported in each market. For non-zero imports of high-quality wheat, manipulations of equation 4.6 indicates that the minimum standard of end-product quality ($K_m = s_m + 1$) and the marginal processing cost ($g^m(w)$) must be high enough.

domestic wheat. These assumptions reflect well the market characteristics and pattern of imports of Japan, and the European markets. Japan is recognized for having very high-quality bread and flour products, but produces domestically a small quantity of wheat that is mostly used in the production of noodles. Consequently, Japan is a large importer of bread wheats from Canada and the United States. However, European markets such as France and the United Kingdom have a large production of soft wheat that must be supplemented with either Canadian or U.S. bread wheat in the production of bakery products.

The proportion of the millers choosing the high-quality product in markets 1 and 2 is:

$$\begin{aligned} s_H^1 &= K_1 - \frac{\left(p_H^1 k_L - p_L k_H\right)}{g^1(w)(k_H - k_L)} \\ s_H^2 &= K_2 - \frac{\left(p_H^2 k_L - p_L k_H\right)}{g^2(w)(k_H - k_L)} \end{aligned}.$$

The demand for the high-quality wheat is found by multiplying those shares by the average quantity of high-quality wheat used by each miller per unit of output times the total quantity of output produced. The average quantity is a simple linear average of the quantity of the miller indifferent between high- and low-quality wheat and the miller with an end-product quality equal to K_m. The average quantity per unit of output of high-quality wheat used by millers in market m can be expressed as

$$\frac{1}{2}\left(\frac{K_m}{k_H k_d^m} + \frac{\left(p_H^m k_L - p_L k_H\right)}{k_H k_d^m g(w)(k_H - k_L)}\right).$$

The demand for the high-quality good in both markets can therefore be expressed as:

$$D_H^1\left(p_H^1, p_L, w, K_1, k_H, k_L, k_d^1, Y^{*1}\right) = \frac{Y^1}{2k_H k_d^1}\left(\left(K_1\right)^2 - \left(\frac{\left(p_H^1 k_L - p_L k_H\right)}{g^1(w)(k_H - k_L)}\right)^2\right) \tag{5}$$

$$D_H^2\left(p_H^2, p_L, w, K_2, k_H, k_L, k_d^2, Y^{*2}\right) = \frac{Y^2}{2k_H k_d^2}\left(\left(K_2\right)^2 - \left(\frac{\left(p_H^2 k_L - p_L k_H\right)}{g^2(w)(k_H - k_L)}\right)^2\right) \tag{6}$$

where, Y^1 and Y^2 are the summation of the quantity of output produced by each miller in market 1 and 2 respectively. These expressions show that the quantity of high-quality wheat demanded can be expressed as a function of the prices of the high- and low-quality wheat, their qualities, the total quantity of the end-product, the quality of the domestic wheat in the importing market, the standard of quality of the market (K_m), and the price of the other inputs. These demands are consistent with the cost-minimizing behavior of flour millers. Moreover, they are appealing because they demonstrate how the qualities of the domestic and foreign wheat, as well as end-product quality, interact to determine the quantity demanded from each exporter.

The low-quality wheat demands can be found in a similar fashion and correspond to:

$$D_L^1\left(p_H^1, p_L, w, K_1, k_H, k_L, k_d^1, Y^1\right) = \frac{Y^1}{2k_L k_d^1}\left(\left(\frac{\left(p_H^1 k_L - p_L k_H\right)}{g^1(w)(k_H - k_L)}\right)^2 - \left(\frac{p_L}{g^1(w)(k_L - k_d^1)}\right)^2\right)$$

$$D_L^2\left(p_H^2, p_L, w, K_2, k_H, k_L, k_d^2, Y^2\right) = \frac{Y^2}{2k_L k_d^2}\left(\left(\frac{\left(p_H^2 k_L - p_L k_H\right)}{g^2(w)(k_H - k_L)}\right)^2 - \left(\frac{p_L}{g^2(w)(k_L - k_d^2)}\right)^2\right)$$ [6].

The low-quality wheat demand is also a function of the prices of the high- and low-quality wheats, their qualities, the total quantity of the end-product, the quality of the domestic wheat in the importing markets, the standard of quality of the market (K_m), and the price of the other inputs.

5.2 Supply Side

The wheat marketing systems of the two exporting countries differ. Wheat *H* is exported through a marketing board (the CWB). Given that the CWB has a stated objective, to sell wheat at the best possible price and return to farmers the net proceeds from sales, the objective function for this study is the maximization of producer surplus subject to a quantity constraint Q_H, which correspond to a given harvest of wheat. Producer surplus consists of sales revenues to the two markets minus marketing costs, where marketing costs corresponds to the costs of wheat transportation to export position in Canada, elevation, storage, etc. In contrast, wheat *L* is marketed by profit-maximizing firms.

[6] If the outside good was wheat of another class, say class *C* with quality k_C, and that wheat class was sold at p_C by perfect competitors, the demand for the low-quality good in market *m* would look like:

$$D_L^m\left(p_H^m, p_L, p_C, w, K_1, k_H, k_L, k_C, k_d^m, Y^m\right) = \frac{Y^m}{2k_L k_d^m}\left(\left(\frac{\left(p_H^m k_L - p_L k_H\right)}{g^m(w)(k_H - k_L)}\right)^2 - \left(\frac{p_L k_C - p_C k_L}{g^m(w)(k_L - k_C)}\right)^2\right)$$

Assume that the firms in country L engage in price competition among themselves. Each firm in country L sells a product that is non-differentiated from other firms in country L. Therefore, as long as there is more than one firm selling wheat of quality k_L, the price at which wheat L is exported to both markets is the price, p_L, corresponding to the intersection of the total demand wheat L with the supply. This equilibrium price can be found by equating the total demand with the fixed supply of low-quality wheat Q_L as follows:

$$D_L^1\left(p_H^1, p_L\right) + D_L^2\left(p_H^2, p_L\right) = Q_L, \tag{7}$$

and solving for p_L,

$$p_L = p_L\left(p_H^1, p_H^2, Q_L\right)$$

where $D_L^m(\cdot)$ is the demand of market m ($m=1,2$) for the low-quality wheat, and p_H^m is the price of the high-quality wheat in market m. Wheat is assumed to be produced once a year and there is no year-to-year storage.

We seek a Nash equilibrium in prices where the marketing board is also assumed to engage in price competition with the sellers of the low-quality wheat. Because the marketing board sells a product that is differentiated from that of its competitors, it can charge prices that are different from the competitors' prices and has the ability to price discriminate between the two markets. The CWB makes most sales f.o.b. at the port of export and in U.S. dollars, but importers' demands are based on the landed price in domestic currency, i.e., on a cost, insurance and freight rate (c.i.f.) basis.[7] Therefore, demand is affected by exchange rates and ocean freight rates. Moreover, importers member of the EU must pay an import duty when importing wheat from outside the EU and some countries received EEP subsidies from the U.S. government until 1995.[8] With those additions, the objective function of the CWB is to maximize producers' surplus by choosing f.o.b. prices to each market subject to a quantity constraint (Q_H) – the amount shipped cannot exceed the harvested quantity of wheat:

[7] Prices quoted cost-insurance-freight include all costs to ship wheat to the destination port, including ocean freight rates and insurance.

[8] The EEP bonuses are export subsidies that are allocated to specific countries chosen by the U.S. government. U.S. exporting firms agree on sales price and potential EEP bonuses with importers. U.S. firms then submit EEP bids to the Commodity Credit Corporation (CCC) of the USDA. The exporter with the lowest bid receives the subsidy. Therefore, importers do not directly receive the subsidy from the CCC, but receive it through U.S. exporting firms.

$$\max_{p_H^1, p_H^2} R = \left(p_H^1 - c_H^1\right) D_H^1 \left(p_H^{1\$} e^1, p_L^{1\$} e^1; \delta^1\right) + \left(p_H^2 - c_H^2\right) D_H^2 \left(p_H^{2\$} e^2, p_L^{2\$} e^2; \delta^2\right) +$$
$$+ \lambda \left(Q_H - D_H^1 \left(p_H^{1\$} e^1, p_L^{1\$} e^1; \delta^1\right) - D_H^2 \left(p_H^{2\$} e^2, p_L^{2\$} e^2; \delta^2\right)\right)$$

where:

$$D_H^1 \left(p_H^{1\$} e^1, p_L^{1\$} e^1; \delta^1\right) = \frac{Y^1}{2k_H k_d^1} \left(\left(K_1\right)^2 - \left(\frac{\left(p_H^{1\$} e^1 k_L - p_L^{1\$} e^1 k_H\right)}{g^1(w)(k_H - k_L)} \right)^2 \right) \tag{8}$$

$$D_H^2 \left(p_H^{2\$} e^2, p_L^{2\$} e^2; \delta^2\right) = \frac{Y^2}{2k_H k_d^2} \left(\left(K_2\right)^2 - \left(\frac{\left(p_H^{2\$} e^2 k_L - p_L^{2\$} e^2 k_H\right)}{g^2(w)(k_H - k_L)} \right)^2 \right) \tag{9}$$

c_H^m = cost of marketing wheat to market m, m = 1,2,

$$p_H^{m\$} = p_H^m + T^m + \frac{D^m}{e^m}, \tag{10}$$

$$p_L^{m\$} = p_L + T^m + \frac{D^m}{e^m} - EEP^m, \ m = 1,2, \tag{11}$$

T^m = Ocean freight rate to market m (in U.S. dollars),
e^m = Exchange rate for market m (domestic currency per U.S. dollar),
D^m = Duty in market m (in domestic currency),
EEP^m = EEP bonus offered to market m (in U.S. dollars),
δ^m = vector of other exogenous variables for market m, i.e. $Y^m, K_m, k_H, k_L, k_d^m, g^m(w)$.
λ = Lagrange multiplier.

Note that equations 8 and 9 correspond to equations 5 and 6 except that prices entering the demands are the landed prices in the destination's currency, $p_H^{m\$} e^m$ and $p_L^{m\$} e^m$, instead of the f.o.b. prices in the exporter's currency, p_H^m and p_L^m. The prices $p_H^{m\$}, p_L^{m\$}$ are the landed price in U.S. dollars. Separate data on freight rates for Canada and the U.S. are not available. Consequently, it is assumed that the ocean freight rates are the same from Canada and the United States to any given country. This assumption is reasonable because bread wheat is produced in adjacent areas in Canada and the United States and exported through ports located close to each other on the East Coast and the West Coast. The first-order conditions are:

$$\frac{\partial R}{\partial p_H^1} = 0 \Rightarrow p_H^1 = c_H^1 + \lambda - D_H^1 \left(p_H^{1\$} e^1, p_L^{1\$} e^1; \delta^1\right) \frac{\partial p_H^1}{\partial D_H^1(\cdot)} \tag{12}$$

$$\frac{\partial R}{\partial p_H^2} = 0 \Rightarrow p_H^2 = c_H^2 + \lambda - D_H^2 \left(p_H^{2\$} e^2, p_L^{2\$} e^2; \delta^2\right) \frac{\partial p_H^2}{\partial D_H^2(\cdot)} \tag{13}$$

$$\frac{\partial R}{\partial \lambda} = 0 \Rightarrow Q_H = D_H^1\left(p_H^{1\$}e^1, p_L^{1\$}e^1; \delta^1\right) + D_H^2\left(p_H^{2\$}e^2, p_L^{2\$}e^2; \delta^2\right).^{9} \quad (14)$$

Equations 12 and 13 are the supply relations.

In the model specified above, each country exports only one type of wheat. However, in the empirical applications I will be dealing with heterogeneous shipments of wheat for Canada and for the United States, i.e., shipments that differ by grade and protein content. In this case, equation 5 and 6 will be replaced by a system of demand equations and equation 11 and 12, by a system of supply relations. The typical NEIO approach to evaluate market power in differentiated products industries is to estimate jointly the demand system and supply relations. In doing so, estimates of own-price elasticities are obtained and therefore, estimates of the degree of market power through the Lerner Index: $L = \frac{P - MC}{P} = -\frac{1}{\eta}$, where η is the price elasticity of demand. For industries characterized by multiproduct firms, those elasticities have been estimated using the multi-stage budgeting approach (Hausman, Leonard and Zona, 1994) or the random coefficient discrete choice model approach (Berry, Levinsohn, and Pakes, 1995).

However, I must depart from these two approaches because they are not suitable for intermediate goods. The consumer goods examined in those studies (beer (Hausman, Leonard, and Zona, 1994), breakfast cereals (Nevo, 2000, 2001), soft-drinks (Cotterill, 1994), spaghetti sauce (Vickner and Davies, 1999), cars (Verboven, 1996), etc.) are goods for which all brands get sold in each market at each time period. These horizontally differentiated goods face a large market with consumers who differ in their tastes and preferences for each brand. These features result in an observation for each brand, at each time period and in each market. However, the markets for intermediate inputs such as agricultural products are very different. Often there are only a few buyers

[9] It is assumed that the quantity constraint is binding and that the quantity imported of high-quality wheat is positive in both markets. A binding quantity constraint indicates that all wheat available is marketed and not thrown away. By replacing the f.o.b. price in equation 4 by the landed price in domestic currency and by manipulating that equation, it can be observed that high-quality wheat is imported in any market for high enough values of the minimum quality standard, marginal processing cost (expressed in U.S. dollars), transportation cost, and the import duty (expressed in U.S. dollars). Small enough EEP bonus to a given country will also ensure that a positive quantity of high-quality wheat is purchased.

and a high degree of substitutability between different varieties of raw agricultural products. That is the case for wheat with most countries having only a few wheat buyers. In fact, many countries have central buying agencies, or state importers. Not only are different "brands" or classes and grades of wheat often almost perfect substitutes for one another, but wheat with different characteristics can also be combined to obtain wheat with the desired characteristics. These features of the wheat market are such that a given market does not import all "brands" or types of wheat available in each time period. Only a few types are necessary to achieve the desired end product. This is the case for wheat importers who generally buy CWRS wheat of only one grade and protein level in each month. It would be difficult to estimate a demand system with all grades and protein levels of CWRS and HRS wheat available, because in any given month nearly all observations would be zero.

An empirical model can be developed based on the reduced-form versions of the supply relations presented above and elements of the PTM approach.

5.3 Outline of an Empirical Test of Price Discrimination

Price discrimination takes place when different markups exist for sales to different consumers. In third-degree price discrimination, the firm can sort consumers on the basis of an observable characteristics such as age, geography, or time. This ability to charge different prices to different consumers allows a firm to exploit the different elasticities of different market segments, and increase its profits.

A common approach used to test for third-degree price discrimination in international trade is the Pricing-to-Market (PTM) approach (Krugman, 1987). The PTM approach has been used in numerous studies of both consumer goods and intermediate inputs, such as wheat (Pick and Park, 1991; Yumkella, Unnevehr, and Garcia, 1994; Patterson, Reca, and Abbott, 1996).[10] The popularity of this model is due to its simplicity and the small quantity of information required to implement it.

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[10] Another approach is to test whether the prices between any market pair is statistically different. Schmitz et al. (1997) and Brooks and Schmitz (1999) used this approach with CWB transactions data for feed barley. They found evidence of price discrimination between 1980-81 and 1994-95. One concern with this approach is that it does not take into account other factors, such as quality difference, which could explain the price difference.

The PTM model is based on the idea that an exporter with the ability to price discriminate can exploit changes in the equilibrium (and demand elasticities) caused by movements in exchange rates whereas a perfectly competitive firm cannot. In fact, not only exchange rates can be used as a tool to price discriminate. Other variables such as transportation costs and government policy instruments (taxes, import quotas, import duties, export subsidies, etc.) can also be used for price discrimination because they rotate or shift the demand curve perceived by the exporter. However, the PTM method has been used primarily to test for exchange rate induced price discrimination.

The basic PTM model (Knetter, 1989) consists of a fixed-effects model, where price at time t to destination i is expressed as a function of time, country effects, and exchange rate for destination i at time t. See Goldberg and Knetter (1997) for a review of the model.

It is important to note that most empirical applications use this approach to test for price discrimination using highly aggregated data and assuming homogeneous goods. However, significant country effects, which indicate different markups to different destinations, may in fact capture different qualities of product shipped to the destinations. Arnade and Pick (1999) attempt to alleviate this problem by controlling for the different quality imported in each market by using per capita income as a proxy variable, the rationale being that countries with higher per capita income will import higher quality wheat. They also depart in two significant ways from the classic PTM approach. First, they regress the price difference between two markets against per capita income, exchange rate, and the EEP subsidy. Second, this equation is estimated simultaneously with the corresponding demand equations for those two markets. Taking the difference in price or the log of the price ratio (Borenstein, 1989) facilitates estimation as it eliminates common variables to the two price equations. More importantly, as emphasized by Arnade and Pick (1999), it eliminates marginal cost when it can be assumed that the marginal cost to two destinations is the same.

The approach of Borenstein (1989) and Arnade and Pick (1999) can be used to develop a test of price discrimination in wheat exports. The key is to develop a model allowing to test for price discrimination while accounting for the presence of vertically differentiated goods. This can be achieved by obtaining reduced-form versions of equations 12 and 13 and taking their difference. The resulting expression consists of the difference in price between high-quality wheat sold to two markets. This reduced-form equation corresponds to:

$$p_H^{1*} - p_H^{2*} \approx \frac{1}{3}\left(c_H^1 - c_H^2\right) + \frac{2}{3}\left(\frac{k_H - k_L}{k_L}\right)\left(T^1 - T^2\right) + \frac{2}{3}\left(\frac{k_H - k_L}{k_L}\right)\left(\frac{D^1}{e^1} - \frac{D^2}{e^2}\right)$$
$$- \frac{2}{3}\frac{k_H}{k_L}\left(EEP^1 - EEP^2\right) + \left(\frac{k_H - k_L}{k_L}\right)\left(\frac{K_1 g^1(w)}{e^1} - \frac{K_2 g^2(w)}{e^2}\right) \tag{15}$$

Appendix I shows how to derive equation 15. This equation forms the basis of a test of price discrimination when a state-trader markets a higher-quality product relative to its competitors. If the state-trader can price discriminate, relative movements in ocean freight rates (T^m), duties (D^m), EEP subsidies (EEP^m), exchange rates (e^m), marginal processing cost ($g^m(w)$), and quality standard (K_m), will explain changes in the relative prices. However, if the state-trader does not have market power, the only factor that will affect the difference in f.o.b. price will be a difference in the cost of marketing wheat to these two destinations $\left(c_H^1 - c_H^2\right)$.

Interestingly, a measure of relative quality (k_H/k_L) or relative quality difference [$(k_H-k_L)/k_L$] between the high- and low-quality wheat multiplies each term in this equation. When $k_H=k_L$ equation 15 reduces to:

$$p_H^1 - p_H^2 = \frac{1}{3}\left(c_H^1 - c_H^2\right) - \frac{2}{3}\left(EEP^1 - EEP^2\right). \tag{16}$$

In this case, wheat from the United States and Canada are identical and the CWB cannot exploit changes in local processing costs, shipping costs or import duties because of competition from the low-quality sellers. Rather, the price difference between market 1 and market 2 is due only to differences in marketing costs to the CWB and differences in the EEP bonuses in the two markets. In other words, when $k_H=k_L$ and the CWB price discriminates, Canadian price differences adjust to EEP bonus differences. A price discriminating CWB can react strategically to a trade policy established by another country, such as the U.S. EEP subsidy, by allocating wheat to EEP- and non-EEP markets to maximize producer surplus. Thus, both wheat quality differences and U.S. government trade policy allow the CWB to price discriminate.

When $k_H > k_L$, wheat is heterogeneous. The greater the quality difference, the more the CWB can exploit cost differences (processing costs, shipping costs, and import duties) between the two importing markets, i.e., the more the CWB can price discriminate. Thus, expression 15 is appealing because it isolates the bases for price discrimination and demonstrates that the ability of the CWB to exploit cost differences in pricing depends on the extent of the differentiation between Canadian and U.S. wheat.

The empirical implementation of this model requires disaggregated prices for exports of CWRS wheat by grade, protein level and destination. The price difference for different pairs of market can be used as dependent variable. The empirical framework described in equation 15 must be expanded to take into account the presence of different grades (a product line) within both the high- and low-quality wheat exports. Both Canada and the United States export multiple grades and protein levels of bread wheat. When the price comparison between two destinations is for wheat of different qualities, variables accounting for the difference in grade and protein level can be added to equation 15.

Implementation of the model also requires the construction of proxies or index of quality for k_H and k_L. Because protein quantity and quality were emphasized in importers' survey as being some of the most important factors in bread making, a measure of protein quality (loaf volume) can be used to represent overall wheat quality.

As in Arnade and Pick (1999), the quality standard (K_m) in each market can be proxied with real GDP per capita in each country. The marginal processing cost of wheat can be approximated with labor cost ("manufacturing earnings") in each country, which can be found in the United Nations' Statistical Yearbook.

Finally, an index of the exchange rate for each market can be computed and the difference in this variable for two export markets can be added as an explanatory variable. This variable takes into account the separate effect of a change in the exchange rate difference on the price difference. Having the exchange rate as a separate explanatory variable also allows testing the PTM hypothesis. The implementation of this model is the subject of future research.

6- Conclusion

Previous studies of wheat trade have not satisfactorily combined the presence of imperfect competition, product differentiation, and the presence of state-trading enterprise competing against private firms. This study developed a conceptual and empirical model to examine price discrimination in the wheat industry when wheat can be described as a vertically differentiated intermediate good. The approaches used in the trade literature have primarily focused on consumer goods that are horizontally differentiated. Therefore, this study modified the model of vertical differentiation of Mussa and Rosen (1978) to the realities of wheat import demand. The outline of an empirical test of price discrimination for exports of Canadian bread wheat was presented. This model isolates the bases of price discrimination and demonstrates that the ability of the Canadian Wheat Board to exploit cost differences in pricing depends on the extent of the differentiation between Canadian and U.S. wheat.

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Appendix I

This appendix shows the derivations to equation 15. Take the first-order conditions specified in equations 12 to 14. Setting the first-order conditions to zero indicates that in equilibrium a quantity-constrained price discriminating monopolist equates marginal revenue with marginal shipping costs plus a "shadow value" reflecting a scarcity rent due to the fixed availability of the high-quality wheat. The value of the Lagrangian multiplier, λ*, at the optimum reflects the marginal increase in producer surplus from relaxing the quantity constraint by one unit. Therefore, rewriting equations 12 and 13 as

$$\lambda^* = p_H^{1*} + D_H^1(p_H^{1*}, p_L^*, \delta^1)\frac{\partial p_H^1}{\partial D_H^1(p_H^{1*}, p_L^*, \delta^1)} - c_H^1$$

$$\lambda^* = p_H^{2*} + D_H^2(p_H^{2*}, p_L^*, \delta^2)\frac{\partial p_H^2}{\partial D_H^2(p_H^{2*}, p_L^*, \delta^2)} - c_H^2$$

where:

p_H^{1*} = equilibrium price for high-quality wheat sold to market 1,

p_H^{2*} = equilibrium price for high-quality wheat sold to market 2,

p_L^* = equilibrium price for low-quality wheat,

give equivalent expressions in equilibrium for marginal producer surplus from sales in market *m*.

To examine the predictions of this model as they pertain to price discrimination, equilibrium values for the prices and the Lagrangian multiplier must be found. Equations 12, 13, 14, and 7 form a system of four equations and four unknowns. The equilibrium values for the Lagrangian multiplier and the price of the low-quality wheat are expressed as a function of all exogenous variables, i.e.,

$$\lambda^* = \lambda(Q_H, Q_L, c_H^1, c_H^2, k_H, k_L, k_d^1, k_d^2, e^1, e^2, K_1, K_2, g^1(w), g^2(w), T^1, T^2, D^1, D^2, EEP^1, EEP^2) \quad \text{(A.1)}$$

$$p_L^* = p_L(Q_H, Q_L, c_H^1, c_H^2, k_H, k_L, k_d^1, k_d^2, e^1, e^2, K_1, K_2, g^1(w), g^2(w), T^1, T^2, D^1, D^2, EEP^1, EEP^2) \quad \text{(A.2)}$$

The demand equations in (8) and (9), the equilibrium value of the Lagrangian multiplier, and the equilibrium value of the low-quality price can be substituted in the supply equations of the state-trader for each market (equations 12 and 13) to obtain:

$$p_H^{1*} = c_H^1 + \lambda * - \left[\frac{\left[K_1 g^1(w)(k_H - k_L)\right]^2 - \left(p_H^{\$1*} e^1 k_L - p_L^{\$1*} e^1 k_H\right)^2}{\left[K_1 g^1(w)(k_H - k_L)\right]^2 - 2e^1 k_L \left(p_H^{\$1*} e^1 k_L - p_L^{\$1*} e^1 k_H\right)} \right]$$

$$p_H^{2*} = c_H^2 + \lambda * - \left[\frac{\left[K_2 g^2(w)(k_H - k_L)\right]^2 - \left(p_H^{\$2*} e^2 k_L - p_L^{\$2*} e^2 k_H\right)^2}{\left[K_2 g^2(w)(k_H - k_L)\right]^2 - 2e^2 k_L \left(p_H^{\$2*} e^2 k_L - p_L^{\$2*} e^2 k_H\right)} \right]$$

where:

$$p_H^{\$m*} = p_H^{m*} + T^m + \frac{D^m}{e^m},$$

$$p_L^{\$m*} = p_L^* + T^m + \frac{D^m}{e^m} - EEP^m, \; m=1,2.$$

The f.o.b. price for high-quality wheat can be isolated from each equation using the quadratic formula $p_H^{m*} = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$:

$$p_H^{m*} = \frac{1}{3}\left(c_H^m + \lambda^*\right) + \frac{2}{3}\left(\frac{k_H - k_L}{k_L}\right)\left(T^m + \frac{D^m}{e^m}\right) + \frac{2}{3}\frac{k_H}{k_L}\left(p_L^* - EEP^m\right)$$
$$\pm \frac{1}{3}\sqrt{\left[EEP^m \frac{k_H}{k_L} - \left(\frac{k_H - k_L}{k_L}\right)\left(T^m + \frac{D^m}{e^m}\right) - p_L^* \frac{k_H}{k_L} + c_H^m + \lambda^*\right]^2 + 3\left(\frac{K_m g^m(w)}{e^m}\right)^2 \left(\frac{k_H - k_L}{k_L}\right)^2}$$

(A.3)

In this case, the term under the square root is positive because as the minimum quality standard (K_m) increases the f.o.b. price should increase. Equation A.3 is the first step towards an expression that can be estimated empirically. Following Borenstein (1989) and Arnade and Pick (1999), I wish to estimate a regression with price difference as a dependent variable. However, the term under the square root in the resulting expression is difficult to interpret. Note however that this term disappears when the difference in wheat quality is small, i.e., when $k_H \to k_L$. To see that, let $Z = \sqrt{x^2 + y^2}$, where,

$$x = EEP^m \frac{k_H}{k_L} - \left(\frac{k_H - k_L}{k_L}\right)\left(T^m + \frac{D^m}{e^m}\right) - p_L^* \frac{k_H}{k_L} + c_H^m + \lambda^*,$$

$$y = \sqrt{3}\left(\frac{K_m g(w)}{e^m}\right)\left(\frac{k_H - k_L}{k_L}\right)$$

The limit of Z when k_H approaches k_L is:

$$\lim_{k_H \to k_L} Z = EEP^m - p_L^* + c_H^m + \lambda^* . \tag{A.4}$$

An expression for the low-quality price is found in what follows. When wheat is a nearly homogeneous product (i.e., when $k_H \to k_L$), the landed price in both markets converge, otherwise the exporter with the lowest price will serve the whole market. Said differently, when wheat is a homogeneous product, $p_H^{m\$*} = p_L^{m\$*}$. Note that this equality is contingent on the assumptions that both exporters sell to both markets and that the quantity demanded in each market is smaller or equal to the harvest quantity in either of the export markets. Otherwise, if exporter *i* sells wheat at a lower price than exporter *j,* but cannot fully serve the market at that price, then some sales will be conducted by exporter *j* at the higher export price. The equality of the landed prices implies that the high-quality wheat f.o.b. price is equal to the f.o.b. price of the low-quality wheat minus the EEP bonus, i.e., $p_H^{m*} = p_L^* - EEP^m$, where $p_H^{m*} \approx \frac{2}{3}\left(c_H^m + \lambda^*\right) + \frac{1}{3}\left(p_L^* - EEP^m\right)$ when $k_H \to k_L$. Therefore, $\frac{2}{3}\left(c_H^m + \lambda^*\right) + \frac{1}{3}\left(p_L^* - EEP^m\right) = p_L^* - EEP^m$, and

$$p_L^* = c_H^m + \lambda^* + EEP^m . \tag{A.5}$$

Replacing A.5 into A.4, it follows that $\lim_{k_H \to k_L} Z = 0$. Therefore, when $k_H \to k_L$, the f.o.b. price for high-quality wheat can be approximated by:

$$p_H^{m*} \approx \frac{1}{3}\left(c_H^m + \lambda^*\right) + \frac{2}{3}\left(\frac{k_H - k_L}{k_L}\right)\left(T^m + \frac{D^m}{e^m}\right) + \frac{2}{3}\frac{k_H}{k_L}\left(p_L^* - EEP^m\right), \tag{A.6}$$

and the price difference between market 1 and 2 corresponds to:

$$\begin{aligned} p_H^{1*} - p_H^{2*} \approx {} & \frac{1}{3}\left(c_H^1 - c_H^2\right) + \frac{2}{3}\left(\frac{k_H - k_L}{k_L}\right)\left(T^1 - T^2\right) + \frac{2}{3}\left(\frac{k_H - k_L}{k_L}\right)\left(\frac{D^1}{e^1} - \frac{D^2}{e^2}\right) \\ & - \frac{2}{3}\frac{k_H}{k_L}\left(EEP^1 - EEP^2\right) \end{aligned} . \tag{A.7}$$

Thus, equation A.6 is an approximation to equation A.3 when it can be argued that the difference in quality is both small and matters in wheat pricing. This argument can be made for bread wheat trade. Bread wheat from Canada, the United States and Australia are all considered to be of high quality, but there are quality differences among wheat from those exporters that matter to certain importers.

If the difference in quality is relatively large, the price difference equation in (A.6) is mis-specified. However, all the terms in the radical in (A.3) appear in the same form outside the radical, except for $\left(\frac{k_H - k_L}{k_L}\right)\left(\frac{K_m g^m(w)}{e^m}\right)$. An alternative price difference equation could simply add this term to equation A.6 and obtain the following price difference equation:

$$\begin{aligned} p_H^{1*} - p_H^{2*} \approx & \frac{1}{3}\left(c_H^1 - c_H^2\right) + \frac{2}{3}\left(\frac{k_H - k_L}{k_L}\right)\left(T^1 - T^2\right) + \frac{2}{3}\left(\frac{k_H - k_L}{k_L}\right)\left(\frac{D^1}{e^1} - \frac{D^2}{e^2}\right) \\ & - \frac{2}{3}\frac{k_H}{k_L}\left(EEP^1 - EEP^2\right) + \left(\frac{k_H - k_L}{k_L}\right)\left(\frac{K_1 g^1(w)}{e^1} - \frac{K_2 g^2(w)}{e^2}\right) \end{aligned} \tag{A.8}$$

Equation A.8 corresponds to equation 15 in the text. Notice that the scarcity rent and the low-quality wheat price in equilibrium are the same across both markets, so the variables determining λ^* and p_L^*, cancel in forming the difference in the price of high-quality wheat between markets 1 and 2. However, in the subsequent estimation, I will be dealing with heterogeneous shipments of wheat for Canada and for the United States, i.e., wheat shipments that differ by grade and protein content. In these cases, scarcity rents and the price of low-quality wheat will not be identical across shipments. Stated alternatively in a more generalized model, Canada faces multiple volume constraints – one constraint for each grade and protein level of CWRS wheat – and in general, the scarcity rent is not equal for CWRS wheat of different grade and protein level in a given month. A reasonable proxy for the scarcity rent for wheat of each grade and protein level is the remaining supply of the grade and protein level in question.

Due to the lack of disaggregated data on HRS wheat prices, the low-quality wheat price variable may not be included in a more generalized model where the United States and Canada produce multiple wheat grades and protein levels.