10-2020

The Role of Quality Characteristics in Pricing Hard Red Winter Wheat

Shane J. Roberts
University of Nebraska-Lincoln, shane.roberts@huskers.unl.edu

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By

Shane Roberts

A THESIS

Presented to the Faculty of

The Graduate College at the University of Nebraska

In Partial Fulfillment of Requirements

For the Degree of Master of Science

Major: Agricultural Economics

Under the Supervision of Professors Kate Brooks and Lia Nogueira

Lincoln, Nebraska

October, 2020

THE ROLE OF QUALITY CHARACTERISTICS IN PRICING HARD RED WINTER WHEAT

Shane Roberts, MS

University of Nebraska, 2020

Advisors: Kate Brooks, Lia Nogueira

In this thesis, we empirically examine the role of conventional and end-use wheat quality characteristics on the pricing of hard red winter wheat (HRWW). We use detailed quality characteristic data as well as location matched price data for 50% and 100% harvest completion weeks and utilize a hedonic price analysis framework. We find evidence that end-use characteristics, specifically milling and baking quality characteristics, have a statistically and economically significant effect on the price of HRWW. This evidence suggests that, while HRWW producers are not directly paid premiums or discounts for end-use quality, they are paid indirectly through basis. Comparing results between harvest completion periods, there is evidence suggesting the importance of new market quality information as harvest progresses. Our findings indicate that there are other characteristics to consider when grading wheat, to better convey end-use quality to both producers and buyers. These results suggest that breeders enhancing end-use characteristics in new wheat cultivars may improve producer profitability.

Authors Acknowledgments

I would first like to acknowledge the tremendous amount of help and support given to me by my two advisors, Dr. Kate Brooks and Dr. Lia Nogueira, as well as Dr. Cory Walters. Without the three of them, this thesis would be nowhere near the level of quality it is now, and I would be nowhere near the person I am now. Together, they made this one of the best experiences of my life, and I will be forever grateful.

Kate, your incredible combination of attention to detail and consciousness of the big picture proved unbelievably valuable. Your ability to get me to refocus on the big picture after getting bogged down was extremely helpful.

Lia, your attention to detail provided incredible dividends to this thesis, and changed the way I write altogether. I promise I will never use the words, 'relation' and 'relationship' incorrectly ever again.

Cory, your ability to ask difficult, thought-provoking questions and your insistence for providing justification and proper motivation has changed the way I think about and analyze problems.

I would like to acknowledge my classmate, Iyore Eronmwon. Without her friendship and help, this would have been a much longer two years.

I would also like to acknowledge my family, Rob, Cindy, Jake, Cody, Strider and Marley. Without their support through my undergraduate and graduate careers, I would not be where I am today.

Finally, I would like to acknowledge the limitless love and support of my fiancée, Kacie. Without her in my life, I would never have been able to do any of this.

Contents

1. Introduction

According to the United States Standards for Grain (USDA-FGIS 2014) there are eight classes of wheat that are specified based on color, kernel hardness and planting season. These eight classes of wheat are then divided into five U.S. numerical grades and a U.S. sample grade based on test weight and total defects which reflect the physical conditions of a sample (USDA-FGIS 2014). There are several other non-grade characteristics of wheat that are tested for and may affect wheat's milling and baking quality including dockage, moisture, protein, falling number, and color. Moisture, for instance, is a measure of storability of both wheat and flour and can be an important indicator of profitability in milling as low moisture levels require added water prior to milling (Wheat Marketing Center 2008). These grade and non-grade wheat characteristics, or conventional characteristics, are used as indicators of the suitability of the wheat for milling and baking and are therefore factors in determining the value of wheat.

When a wheat farmer delivers their grain to an elevator, they receive a settlement sheet listing the U.S. standard grade factors, test weight and total defects, and one non-grade factor, moisture content with their associated premiums and discounts. Elevators may also report and assign premiums and discounts to two other non-grade factors, protein and falling number. As a result, farmers perceive the prices they receive for their wheat are based on these conventional wheat characteristics found on their settlement sheet. However, millers, as well as bakers, utilize additional quality characteristics to inform their purchasing decisions. These additional characteristics, from here on referred to as end-use characteristics, include tests of the wheat quality for milling and baking applications conducted using wheat sampled from elevators across the United States by millers as well as other wheat testing laboratories. For example, a mixograph tests for the water absorption and mixing time needed to reach a consistent dough (Wheat Marketing Center 2008). These two characteristics are deemed to be important by milling industry experts and are shown to be significant in determining domestic wheat prices in previous literature (e.g. Espinosa and Goodwin 1991; for more on the selected conventional and end-use characteristics for this study see section 6). These end-use quality characteristics are provided in reports, such as the U.S. Wheat Associates 2019 Crop Quality Report (U.S. Wheat Associates 2019), for free after harvest completion, typically around October. These end-use quality characteristics better describe the quality of the wheat to millers prior to purchasing and are then used in determining the price millers offer to elevators. As a result, producers may in fact be paid for quality, but indirectly through the local basis, rather than through direct premiums and discounts.

In this study, we seek to empirically understand the role of quality characteristics in pricing of hard red winter wheat (HRWW). HRWW is the largest class of wheat grown in the United States, with approximately 833 million bushels produced in 2019, representing about 43% of total U.S. wheat production (USDA-NASS 2019a). Conventional and end-use quality characteristic data sampled from the entire HRWW growing region as well as location matched price data are used to empirically estimate implicit price premiums or discounts for HRWW quality characteristics. These implicit prices are used to determine the role that quality characteristics have in pricing HRWW. Our results help analyze the efficiency of the current pricing/grading system for U.S. HRWW. Further, understanding the relation between the different quality characteristics and price is important for production, wheat breeding, marketing and risk management decisions for all stakeholders involved in the HRWW market.

2. Background

The eight classes of wheat grown in the United States are: HRWW, hard red spring (HRS), soft red winter, soft white, hard white, durum, unclassed and mixed (USDA-FGIS 2014).[1] HRWW and HRS wheat are both good for pan and hearth style breads as well as for blending, the softer wheat is better for more delicate baked goods such as cakes and cookies. Hard white wheat is also utilized in pan type breads as well as tortillas while durum wheat is almost exclusively used for pasta production as well as some Middle Eastern style breads (U.S. Wheat Associates 2019).

In 2019, over 45 million acres of wheat were planted, with just under 22 million of those being HRWW, or approximately 48% of total acres. In the same year, approximately 12.7 million acres of HRS wheat were planted, or approximately 28% (USDA-NASS 2019a). Total wheat production in 2019 was about 1.9 billion bushels, with a value of approximately $8.9 billion. The largest two classes, HRWW and HRS made up 43% and 27% of total production in terms of bushels, respectively (USDA-NASS 2019a). For the years 2012 to 2019, the share of HRWW in total production averaged approximately 41%.

Figure 1 and Figure 2 show the HRWW production regions by zip code and the average basis price between 2012 and 2019 across regions at 50% harvest completions and 100% harvest completion, respectively. The HRWW production regions span from upper Texas and continue north into the central and northern Great Plains. Comparing the

[1] Unclassed refers to grain that is not classifiable or is neither red nor white while mixed class is any mixture containing less than 90% of one type of wheat.

two Figures demonstrates the temporal differences in basis between the two harvest periods, with basis tending to be lower on average in the 100% harvest period compared to the 50% period. Additionally, there are distinct spatial differences in basis across the production region as well as between adjacent zip codes. These differences in basis, especially between adjacent zip codes, may stem from differences in quality.

The wheat export market is also a very important part of the U.S. wheat industry. In the 2019/20 marketing year (June to May), of the 1.9 billion bushels of wheat (all classes) produced, over 900 million bushels were exported or just about half of all production (USDA FAS 2020).[2] The top 3 destinations of U.S. wheat in the same year were: Mexico, the Philippines and Japan, equating to approximately 18% of total production (USDA ERS 2019). During the 2019/20 marketing year, of the 900 billion total wheat bushels exported, HRWW made up over 350 million of those or approximately 35%. During the same year, HRS was the second largest at approximately 24% of total wheat exports. From the 2012/13 to 2019/20 marketing years, HRWW averaged approximately 37% of the total wheat export share while HRS averaged approximately 27% (USDA-FAS 2020).

3. Literature Review

There are several studies that analyze different parts of the wheat industry: a producer's choice of wheat variety (for example: Dahl, Wilson and Wilson 1999; Barkley and Porter 1996; Barkley, Peterson and Shroyer 2010); the effect of dockage and wheat cleanliness (i.e. lack of defects) in domestic and export markets (for example: Johnson and Wilson

[2] These data are reported in terms of metric tons. To convert to bushels, a conversion rate of 1 metric ton to 36.7437 bushels is utilized. This conversion rate assumes a 60 lb/bu test weight and is obtained from the U.S. Grains Council, available at: https://grains.org/markets-tools-data/tools/converting-grain-units/ .

1992; 1993; 1995); the role of producer and elevator decision making frameworks on quality premiums (for example: Adam and Hong 2001); and how market structure affects prices in the world wheat market(for example: McCalla 1966; Alaouze, Watson and Sturgess 1978; Dong, Marsh and Stiegert 2006).

To model the role of quality characteristics in pricing of HRWW we need to understand the quality preferences of the wheat milling companies. There are two different methods of analyzing the preferences of wheat milling companies for wheat quality characteristics: stated preference and revealed preference. The main tool used in stated preference studies is the choice experiment. Lee, Lerohl and Unterschultz (2000) perform a choice experiment to test for the preferences of U.S. buyers of Canadian durum wheat. They examine the preferences for three characteristics: protein, test weight, amylase (i.e. falling number) as well as country of origin, either United States or Canada. The authors find that buyers prefer higher test weight and protein, and U.S. durum over Canadian durum. Gallardo et al. (2009) conduct a choice experiment to analyze the preferences of Mexican millers for U.S. HRWW quality and consistency. The authors use both conventional and end-use characteristics as well as the variances of those characteristics to analyze quality consistency. The characteristics used are test weight, protein content, falling number, farinograph stability, dough extensibility/resistance (P/L) ratio and kernel diameter. They find that, overall, Mexican millers do show preferences for several end-use characteristics such as farinograph stability, a dough mixing stability test. However, they also find that, contrary to expectations, Mexican millers do not prefer less variability.

The other method for eliciting preferences in the literature is through revealed preference. These studies generally use a hedonic price model, in part based on Lancaster (1966), with multiple applications in both the consumer and agricultural fields.[3] Rosen (1974) further expands upon Lancaster (1966) and examines the consumer side of hedonic analysis, studying the market for consumer goods and consumer goods' characteristics. Stemming from the work of Lancaster and Rosen, there is another type of hedonic model which analyzes input characteristics used in the production of a good. First applied to agricultural commodity markets by Ladd and Martin (1976), this model, known as the Input Characteristics Model (ICM), specifically analyzes inputs used in the production of a good or commodity. Analyzing the corn market, Ladd and Martin (1976) equate the price of an input to the sum of the value of the input's characteristics to the buyer. The ICM is based on Neoclassical Firm Theory and assumes a perfectly competitive market structure.

Several papers use the ICM to analyze various agricultural markets, such as wine (e.g. Golan and Shalit 1993), rice (e.g Brorsen, Grant and Rister 1984), malting barley (e.g. Wilson 1984), and tuna (e.g. McConnell and Strand 2000). The ICM has also been used to analyze the role of quality characteristics in the international wheat market. Wilson (1989) uses the ICM to analyze the effect that wheat differentiation has on price in the international market for U.S. HRS and HRWW. Ahmadi-Esfahani and Stanmore (1994) and Uri et al. (1994) use the ICM to analyze the role that conventional wheat characteristics have on export prices of Australian and U.S. wheat, respectively.

[3] For a detailed summary of the various hedonic models see Ladd (1978).

Stiegert and Blanc (1997) continue the focus on the international wheat market but include several end-use characteristics into their model. The authors use the ICM to analyze the effect that non-contracted end-use characteristics have on contracted characteristics as well as prices for Japanese wheat imports. The authors use conventional and end-use characteristic data on wheat from Australia, Canada and the United States to test for protein premiums while interacting certain end-use characteristics related to protein. The authors include several end-use characteristics, such as ash content, color, farinograph stability, flour absorption and extensogram resistance/extensogram extension and the ratio of those numbers also known as the proportional number. The last three characteristics, farinograph stability, flour absorption and proportional number, are interacted with protein because they not only partly depend on protein but also describe the quality of the protein.

Focusing on the link between quality characteristics and HRWW in the United States, Espinosa and Goodwin (1991) apply the ICM to domestic HRWW production in Kansas. The authors utilize Kansas average annual prices and conventional and end-use quality data aggregated at the crop reporting district level. They estimate implicit prices for both conventional as well as end-use characteristics to test the efficiency of the U.S. wheat grading system. The authors first estimate the implicit prices for the standard grading characteristics. They estimate an approximately five cent per bushel premium for an additional percentage point of protein or about $1.83 per metric ton premium. All of the conventional characteristics are statistically significant except for test weight. When both sets of characteristics are included, conventional and end-use, the implicit price estimates for the individual end-use characteristics are not statistically significant, indicating that, individually, the characteristics do not have a significant effect on price. However, the F-test for joint significance of the end-use characteristics is statistically significant, suggesting that the end-use characteristics do have some effect on price when included in the regression. The authors' results indicate that end-use characteristics jointly influence price when controlling for conventional characteristics, meaning that end-use characteristics do contain some quality information that conventional characteristics do not. We expand upon the analysis in Espinosa and Goodwin (1991), utilizing conventional and end-use characteristic data at the zip code level for the entire HRWW growing region as well as zip code level prices during harvest time rather than average annual prices.

Lambert and Wilson (2003) analyze wheat variety valuation with imperfect output quality measurement, or the lack of observable premiums and discounts for end-use quality characteristics. Currently, varieties are bred and released to enhance agronomic traits (i.e. disease or drought resistance) or price/return enhancing traits (i.e. protein, test weight, yield). However, millers and other intermediate processors value other end-use characteristics but as previously discussed, these characteristics are not reported to producers and are not given direct price premiums or discounts. The authors analyze several varieties of HRS and find that the lack of observable end-use characteristic premiums and discounts leads to inefficient choice of wheat variety. The inefficiency arises from wheat varieties that focus on enhancing characteristics that do not satisfy end-user demand.

Dahl, Wilson and Johnson (2004) examine HRS variety tradeoffs between grower and end-user. Development and adoption of new wheat varieties is characterized by tradeoffs between growers, who favor varieties that improve agronomic or price increasing traits, and end-users like milling companies who favor improved end-use characteristics. The authors find that grower valuation increased with increases in protein and yield while end-user valuation increased with increases in end-use characteristics, which are not given observable premiums or discounts. The authors consider these findings to show some of the limitations of the current grading system, as well as the current systems ineffectiveness of conveying end-use quality.

4. Milling Industry and Theoretical Assumptions

The domestic wheat milling industry is characterized by a high degree of market concentration, with approximately 80% of the market controlled by six companies in 2015. These six companies are: Ardent Mills, Archer Daniels Midland (ADM), GrainCraft, Bay States Milling, General Mills and Miller Milling Company (Rabobank 2017). Market concentration in the U.S. milling industry is a recent phenomenon, where during the 1970's 70% of the market share was owned by family owned or local elevator owned mills. The other 30% of the market share was owned by large food processing and manufacturing companies such as General Mills as well as larger milling operations like ADM and Cargill (Kim et al. 2001). However, by 1992 the market share of the four largest firms was around 70% (Kim et al. 2001). In the 23 years between the 1992 Kim et al. (2001) estimate and the Rabobank estimate, Cargill and Conagra merged their milling interests and formed Ardent Mills, to become the leader with approximately 31% of the market share in 2015 (Rabobank 2017). This increasing concentration has led to changes in market structure, from perfect competition to monopolistic competition and now to oligopolistic competition (Kim et al. 2001). This type of market structure, with a small number of large firms, leads to market power, which allows firms to add a margin to marginal cost, otherwise known as a price-cost margin (Cowling and Waterson 1976). This price-cost margin is a key component of an oligopolistic market structure. One of the contributions of this study to the literature on wheat quality valuation is that we incorporate the price-cost margin to our theoretical model.

The wheat milling industry can be set up as a repeated oligopolistic competition game (Kim et al. 2001), with a normal form representation as follows. The players are the six firms that control 80% of the market: Ardent, ADM, Graincraft, Bay State, Miller Milling and General Mills (Rabobank 2017). Despite the high concentration, these firms are assumed to sell a homogenous product and have similar costs. Based on the websites of these six firms (Archer Daniels Midland 2019; Ardent Mills 2019; Bay State Milling 2019; General Mills 2019; Graincraft 2019; Miller Milling Company 2019), there are two main products available: flour and pre-made mixes. Flour is simple milled wheat, though there are different types for different uses, such as high protein bread flour or lower protein cake flour. Comparing the same type of flours from different companies reveals that the actual listed characteristics of the flour, such as protein, ash content and color are very similar, sometimes being differentiated by a company specific name alone. The pre-made mixes utilize both flour as well as additional non-flour ingredients to make a mix that just needs one or two additional ingredients such as water or eggs to be ready to bake.

We assume that all milling firms will face the same futures price for wheat, with the only difference in costs coming from the local, elevator level basis, as well as transportation cost. From personal communication with country and terminal elevators

(Personal communication, July-August 2019) the milling firms set the basis and subsequently, the cash price at the elevator level, based on the local quality as well as transportation costs. The importance of transportation costs as well as the regional differences in quality (conventional and end-use) of the wheat leads us to differentiate the input costs as well as the input quantity by grain location (i.e. the region where the wheat is produced). The regional differences in quality may be represented by regional differences in basis. Figures 1 and 2 show average, zip code level basis for the HRWW production region for two different harvest completion times from 2012 to 2019. We observe distinct regional differences in basis in Figures 1 and 2.

Also included in the costs is the markup that is added to the marginal cost by the milling firm, which comes from the oligopolistic market structure. This markup is similar to what Karp and Perloff (1993) include in their analysis of the international coffee export market. All other fixed costs are assumed to be the same for milling firms, however. These assumptions allow us to have the same profit function for all milling firms.

5. Theoretical Model

Following Ladd and Martin (1976), we extend the ICM to the domestic milling industry, allowing for a markup as well as transportation costs. Let X_h be the amount of characteristic h used in the production of flour, where the production function, F, is a function of X_h. We assume that the production of flour depends on the average amount of characteristic h used in production. For example, h could be protein and thus, production of flour depends on the average amount of protein used for production (i.e. production of an all-purpose flour needing 11.5% protein would need an average of 11.5% of the characteristic protein). Let v_j be the quantity of wheat from the *j*th location, and $x_{h,j}$, be the amount of characteristic *h* from wheat from the *j*th location, where $h \in (e, c)$. Here, *e* represents end-use characteristics and *c* conventional characteristics. The average amount of characteristic *h*, X_h, is a function of both the quantity of wheat from the *j*th location, v_j, and the amount of characteristic *h* from wheat from the *j*th location, $x_{h,j}$:

$$\boldsymbol{X_h = X_h(x_{e,j}, x_{c,j}, v_j)} \tag{1}$$

The production function for flour, *F*, thus depends indirectly on v_j (the input quantity of wheat from the *j*th location), and $x_{h,j}$ (the average amount of characteristic *h* from wheat from the *j*th location). The profit function $\boldsymbol{\pi}$ of the typical milling firm is then:

$$\boldsymbol{\pi = PF\big(X_h(x_{e,j}, x_{c,j}, v_j)\big) - \textstyle\sum_j^n r_j\big(x_{e,j}, x_{c,j}, t_j, k_j\big)v_j - C} \tag{2}$$

Let *P* be the output price (price of flour), r_j be the input cost of wheat from the *j*th location, t_j be the transportation cost of wheat from the *j*th location, k_j is the markup that milling firms add to the marginal cost of the wheat, differentiated by the location of the wheat, and *C* represents all other costs. This markup allows us to expand the ICM to incorporate the oligopolistic nature of the current U.S. milling industry.

Deriving the first order conditions with respect to input quantity, v_j, we get:

$$\boldsymbol{\frac{\partial \pi}{\partial v_j} = P\left(\frac{\partial F(\,X_h)}{\partial X_h}\right)\left(\frac{\partial X_h}{\partial v_j}\right) - r_j - t_j - k_j = 0} \tag{3}$$

We then rearrange equation (3) to get r_j on the left-hand side, yielding the hedonic equation (4) with a few new additions specific to our model:

$$\boldsymbol{r_j = -k_j - t_j + P\left(\frac{\partial F(\,x_h)}{\partial x_h}\right)\left(\frac{\partial x_h}{\partial v_h}\right)} \tag{4}$$

We assume *P*, the output price, to be exogenous. This assumption is based on personal communication with milling industry experts (D. Green, personal communication, November 30, 2018) who have emphasized the presence and importance of contracts and specifically how those contracts are formed. The next-in-line buyers, the bakers, have a specific budget for the product that they want and this budget is what is used in setting up the contracts and the milling companies find the wheat that suits the bakers' needs at this contract price. For the milling firms to be able to maximize profit, given that P is fixed, they can increase their markup, k_j, by changing the input cost or the transportation cost. From personal communication with industry experts (D. Green, personal communication, November 30, 2018) firms focus on the wheat regions closest to the mill to reduce transportation cost and then move further and further away to obtain the specific wheat characteristics that they are looking for.

Following the standard ICM from Ladd and Martin (1976) the term $\left(\frac{\partial F(X_h)}{\partial X_h}\right)$ in equation (4), is the marginal physical product of one unit of characteristic h in the production of flour. Multiplying this term by the output price, P, yields $P\left(\frac{\partial F(X_h)}{\partial X_h}\right)$, which is the value of the marginal product of characteristic h. The next term in equation (4), $\left(\frac{\partial X_h}{\partial v_j}\right)$, is the marginal amount of characteristic h from wheat from the jth location used in the production of flour. Our model differs from that of Ladd and Martin, with the two terms, $-k_j$ and $-t_j$. The standard ICM is based on a perfectly competitive market structure and does not include any form of transportation cost. We contribute to the literature by expanding the ICM to capture the oligopolistic nature of the milling industry and the importance of transportation costs. Adding these two terms makes our model a better representation of what is currently observed in the U.S. domestic milling industry.

6. Data

This section examines the origins of our various data, as well as the specific variables utilized in our empirical model. First, the origin of the wheat quality characteristic data is discussed, followed by an examination of the specific characteristics used and their definitions. Next, the price data origins are discussed as well as the methods used to formulate the price variable. Finally the transportation cost data origins are discussed along with the formulation of the transportation cost term utilized in the empirical model. Summary statistics for the selected variables are presented in Table 1.

6.1 Wheat Quality Characteristics

The HRWW quality characteristic data used in this analysis are provided by Plains Grains Inc. (PGI), a nonprofit wheat marketing organization that samples elevators across the HRWW growing region, for the years 2012 to 2019. The samples collected are utilized to test for almost 80 different characteristics detailing the quality of the wheat in milling and baking applications, additionally conventional quality (test weight, defects, moisture and protein) are tested and reported. These conventional characteristics, along with several other similar characteristics such as thousand kernel weight and falling number, are reported at the elevator level, with multiple individual samples taken at the same elevator.

The end-use quality tests require more grain than the conventional characteristic tests, therefore, these samples are aggregated into what PGI refers to as grainsheds. A grainshed is a geographic region which acts similarly to its namesake, watershed, in that the grain in the region all flows to a single terminal elevator. Each grainshed contains a collection of elevators and their corresponding individual samples. To test for the end-use quality characteristics, a grainshed's individual samples are aggregated to form composite samples, which aggregate the elevator level individual samples together into three different groups (known as protein splits), based on protein content. The three composite samples are defined as: low protein (below 11.5%), medium protein (between 11.5% and 12.5%) and high protein (greater than 12.5%). Since the end-use characteristic tests require more grain than the conventional characteristic tests, each protein split needs to have a minimum of 22% of the individual samples in a grainshed to be tested for end-use quality, otherwise it is not included in the testing.[4] For our analysis, we use the end-use characteristic data at the grainshed level matched to the elevator level conventional characteristic data based on their grainshed and protein level.

6.1a Characteristic Descriptions

In previous literature, three studies utilized end-use characteristics in their analysis of the determinants of wheat price. To our knowledge, Espinosa and Goodwin (1991) are the first to include any end-use characteristics in a study of this kind. They include the four conventional characteristics: protein, test weight, moisture and total defects as a baseline. They also include a set of end-use characteristics: milling rating, falling number, theoretical flour yield, wet gluten content, water absorption, mixing time, dough stability and valorimeter measures. However, no rationale for why these characteristics are chosen is given.

In Stiegert and Blanc's (1997) analysis on the effect of non-contracted end-use characteristics on Japanese wheat price, they utilize only protein for conventional

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[4] The percent of grain in a protein split is calculated by taking the number of individual samples in the protein split divided by the total number of samples in the grainshed. If that protein split contains at least 22% of the total number of samples, then that protein split is tested for end-use quality.

characteristics as it is the most important contracted characteristic for Japanese importers/millers. They also use multiple end-use characteristics including flour color, farinograph absorption and stability, extensograph extensibility and resistance and the P/L ratio. These characteristics, excluding color, are used because they are typically thought to be proxied by protein content. In their choice experiment of Mexican millers using U.S. HRWW, Gallardo et al. (2009) consulted previous literature as well as milling experts to determine which characteristics to include in their survey. They included test weight, protein content, falling number, farinograph stability, P/L ratio, and kernel diameter.

The specific wheat quality characteristics used in our analysis come from personal communication with industry experts to find out which of the close to 80 quality characteristics are most important in informing millers' and other grain buyers' purchasing decisions (M. Hodges and B. Seabourn, personal communication, November 8, 2019). The conventional and end-use characteristics are defined from *WHEAT AND FLOUR TESTING METHOD: A Guide to Understanding Wheat and Flour Quality* (Wheat Marketing Center 2008). The next sections describe the five conventional wheat characteristics and the ten end-use characteristics used in this study. The end-use characteristics used in this analysis are categorized into tests describing milling quality and baking quality, which reflect the physical, chemical and functional properties of the wheat and flour.

6.1b Conventional Characteristics

The conventional characteristics used in the analysis are: protein, test weight, moisture, falling number and total defects. These conventional characteristics are tested for by the

FGIS, reported to producers and are often given premiums and discounts. These conventional characteristics as well as expected relation with price are discussed in the following paragraphs.

Protein is represented as a percent of the total weight at a specific moisture basis and indicates the amount of gluten proteins present in the wheat. Protein is an indicator for several end-use quality metrics, including mixing time and water absorption, as well as crumb texture, and is often considered an important determinant of baking quality. The minimum protein threshold considered to be of good quality is 11% and we expect protein to have a positive effect on price.

Test weight is defined as the weight of the grain needed to fill one Winchester bushel (a volumetric measure) and is an indicator of milling quality and flour yield. The minimum quality threshold is 60 pounds per bushel, and we expect a positive relation between test weight and price.

Moisture content is expressed as a percentage by weight and is used in other tests as well as being an indicator of wheat and flour storage stability as well as flour yield. The ideal moisture content is 14.5% or lower and we expect a negative relation between moisture and price.

Falling number is a measure of sprouting damage and enzyme activity present in the wheat. Measured in seconds, lower values indicate sprout damage, which is detrimental to baking quality. The minimum quality threshold for falling number is 300 seconds and we expect a positive relation between falling number and price.

Total defects is expressed as a percent by weight and is the sum of three factors: shrunken and broken kernels, damaged kernels and foreign material, and reflects the overall quality and cleanliness of the wheat. While total defects is included in the FGIS grading standards, we did not include this characteristic in our analysis. The milling process contains multiple rounds of sorting, cleaning and filtering, leading to the removal of any defects present in the wheat, therefore, millers likely do not account for this characteristic when making purchasing decisions.

6.1c Milling Characteristics

Milling characteristics describe the quality of the wheat in milling applications. These characteristics represent physical properties of the wheat that affect how much flour a miller can produce from a given amount of wheat, how much energy is needed to mill the wheat, or how consistent in terms of size the wheat kernels are. These characteristics are not tested by the FGIS and consequently are not reported to the producer or given premiums and discounts. The milling characteristics are described in detail and the expected relations with price are discussed in the following paragraphs.

Thousand kernel weight measures the weight in grams of 1,000 kernels counted by a mechanical counter and is a complement to test weight. The thousand kernel weight is a good indicator of flour yield, with an ideal value of at least 30 grams, therefore we expect a positive effect on price.

Percent large, percent medium and percent small kernels give the percentages of kernels considered large, medium and small by their weight. Due to the colinear relation between these three characteristics, the percent medium and the percent small characteristics are dropped from the analysis. There is no defined ideal threshold for the percent of large kernels, however a higher percentage is better and indicates better milling yield. From this relation between percent of large kernels and milling quality, we expect a positive relation between percent large kernels and price.

The Single Kernel Characterization System (SKCS) is a device that tests 300 kernels for characteristics such as weight, diameter and hardness, and reports the average and standard deviation. The average of the weight, diameter and hardness characteristics are good indicators of both milling yield and milling quality; while the standard deviations of these characteristics are good indicators of the consistency of the wheat, where consistency has an effect on the roller mill gap settings. We utilize the SKCS characteristics for standard deviation of weight in grams, standard deviation of diameter in millimeters and the average and standard deviation of hardness on a -20 to 120 scale (where higher values mean harder wheat).

The ideal value for the SKCS weight standard deviation is less than or equal to 8 milligrams so we expect a negative relation between the characteristic and price. The ideal value for the SKCS diameter standard deviation is less than or equal to 0.4 millimeters so we expect a negative relation between the characteristic and price. The SKCS average hardness ideal values are between 60-80, with higher values being less desirable for the average value, while the ideal value for the SKCS hardness standard deviation is less than 17. From the undesirability of harder wheats, a negative relation is expected between SKCS average hardness, while the millers' preference for more consistency leads to the expectation of a negative relation between SKCS hardness standard deviation and price.

6.1d Baking Characteristics

Baking characteristics describe the quality of the wheat in baking applications. These characteristics represent chemical properties of the wheat that affect all aspects of the baking process, including dough mixing times, volumes of baked loaves and the quality of the internal loaf structure. These characteristics are not tested by the FGIS and consequently are not reported to producer or given premiums and discounts. The baking characteristics are described in detail and the expected relations with price are discussed in the following paragraphs.

The alveograph is a machine that tests for gluten strength and quality, specifically extensibility and resistance, using dough made from a flour sample. The dough is formed into a disc and then inflated into a bubble until it breaks. The alveograph results include three values: the P value, the L value and the W value. Focusing on the P and L values: the P value indicates how much force is required to inflate and break the dough (resistance), the L value indicates how large the dough bubble got, or how far it stretched before breaking (extensibility). The ratio of these two values, the P/L value, is the characteristic we use in this analysis and gives a good indication of the overall baking quality of the flour, and the suitability for different end-uses (i.e. pan/hearth breads or cakes/pastries). The ideal value for the P/L ratio is around 1 with a range between 0.5 and 2.5. The ideal value of one indicates a preference for a balance between strength and elasticity, and consequently, the expected sign is ambiguous. To account for this behavior, both the level and square of P/L ratio are included.

The mixograph is a machine that tests the gluten properties of a flour by testing the resistance of a dough to mixing. The mixograph tests three key baking characteristics:

mixing time, water absorption and mixing tolerance, which together provide an indication of the strength and quality of the gluten, as well as the functional and chemical quality of the wheat.

Mixing time, measured in minutes, indicates the time it takes for a dough sample to reach optimum consistency, measured against a control. Lower dough mixing times lead to lower costs for the baker and so are desirable. The ideal value for mixing time is less than or equal to three minutes, so we expect a negative relation between mixing time and price.

Water absorption, measured as a percent, indicates the amount of water needed to reach optimum dough consistency, measured against a control. Water is the cheapest ingredient in the baking process and thus, the more water used in the process leads to a cheaper cost for the baker. The ideal water absorption is greater than or equal to 62%, so we expect a positive relation between water absorption and price.

Mixing tolerance, measured on a 0 to 6 scale, describes the tolerance of the dough to over-mixing, where 0 indicates low tolerance and 6 indicates high tolerance. The more tolerant a dough is to overmixing the less risk is present to the baker, so wheat with a higher tolerance is desirable. The minimum threshold for quality in terms of mixing tolerance is a score of at least 3. Due to the discrete nature of the characteristic, as well as the aggregate nature of the data leading to non-whole numbers, we categorized this characteristic into 3 groups: low, medium, and high. Where low is coded as 1 if the mixing tolerance is below 2.5 and 0 otherwise, medium is coded as 1 if the mixing tolerance is between 2.5 and 3.5 and 0 otherwise and high is coded as 1 if the mixing tolerance is greater than 3.5 and 0 otherwise. The low categorical variable is dropped and serves as the baseline condition and we expect a positive effect on price for the medium and high categories when compared to the low category.

Loaf volume measures the volume of a baked pan loaf, in terms of cubic centimeters, from a given flour sample, indicating the functionality of the wheat in a baking application. The ideal value for loaf volume is at least 850 cubic centimeters and we expect a positive relation between loaf volume and price. Due to the relatively large scale of this characteristic, it is divided by 100 to obtain results in 100's of cubic centimeters.

Crumb grain, measured on a 0 to 6 scale, is a subjective measure of the quality of the interior, or crumb, of the baked pan loaf, where zero indicates low quality and six high quality. The minimum threshold for a quality crumb grain is a measure of three. Similar to the mixing tolerance characteristic, the discrete nature of the variable and the aggregated nature of the data led us to categorize the crumb grain characteristic into three groups, low, medium, and high. Where, similar to mixing tolerance, low is coded as 1 between 0 and 2.5, medium between 2.5 and 3.5 and high between 3.5 and 6. We expect a positive effect on price for the medium and high categories when compared to the low category.

6.2 Wheat Price

The HRWW price data are obtained from DTN, an agricultural data delivery and analysis company.[5] The HRWW price data contains daily per bushel futures and basis prices at the elevator level across the HRWW growing region from 2012 to 2019. These prices are converted to a dollars per bushel cash price by adding the futures and basis prices

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[5] DTN's website is available at: https://www.dtnpf.com/agriculture/web/ag/home.

together. Summary statistics for these price data as well as the other selected variables are presented in Table 1.

We utilize harvest time prices to capture any wheat quality related to implicit premiums or discounts associated with the new crop. HRWW harvest starts in the Southern Great Plains, in Northern Texas and Oklahoma in early June, moving north as the summer progresses. Harvest is usually completed by the middle of August with Montana and the upper Great Plains being the last to harvest. Personal communication with HRWW industry experts has suggested that there may be several different time frames where grain buyers may start purchasing (M. Hodges and B. Seabourn, personal communication, November 8, 2019). The first time frame is when Kansas, the largest HRWW producer, has finished harvesting (corresponding to approximately 50% of the harvest complete, typically around the end of June to the beginning of July). The second time frame is when the harvest is nearly 100% completed, around the middle of August. Harvest progress data come from the USDA's Crop Progress Reports, detailing the national progress and condition of multiple crops in the United States (USDA-NASS multiple years). The Crop Progress Report estimates the wheat harvest progress by week. Our price data are daily, therefore we use a one week average of prices for each of the two scenarios (50% and 100% harvest completion). Each year in the data has its own unique harvest weeks depending on the harvest progress in that year.

6.3 Transportation Cost

Transportation cost is a major factor in the domestic HRWW industry. Production is spread across Southern, Central and Northern Great Plains and the Pacific Northwest while millers tend to locate closer to retail markets due to more expensive flour shipping costs compared to grain shipping costs (Kim et al. 2001). Due to the variable spatial nature of the industry, transportation cost plays an important role in both HRWW price as well as millers' purchasing decisions, where millers prefer to buy closer to them if their desired quality is present and will move out from there (D. Green, personal communication, November 30, 2018).

The majority of wheat in the United States is shipped using railroads, with barge and truck making up the rest (Denicoff, Prater and Bahizi 2014). In the United States, railroad prices consist of three components: the base tariff, secondary auction prices and fuel surcharges (USDA-AMS 2020). Tariffs are the base rail rate per car set by the rail company, while the secondary market acts as an auction where purchasers of rail contracts can sell their contracts at a higher or lower price depending on the supply and demand of rail services as well as service quality at the time. These secondary auction prices take the form of premiums or discounts added to the base tariff rate and are often zero, only occurring during times of high demand or low supply. Finally, the fuel surcharge acts as a premium added to the per rail car tariff rate during times of higher fuel prices (USDA-AMS 2020).[6] Our transportation cost data are obtained from the USDA Agricultural Marketing Service's weekly Grain Transportation Report (USDA-AMS 2020).

The USDA-AMS transportation cost data are in the form of a per mile cost for a carload of wheat. The per mile railcar cost is extrapolated to a total cost for shipping a carload of wheat to the port, either the Gulf of Mexico or the Pacific Northwest. Then this total cost for a carload is divided by the bushel capacity of the typical railcar to obtain a

[6] For more on wheat and transportation costs see Bekkerman and Taylor (2018) and Bushnell, Hughes and Smith (2020).

per bushel cost for shipping wheat to a port area.[7] We use the ports due to the importance of exports in the HRWW market, as well as the unavailability of a data set of milling company plant locations. To obtain the distance value to create the total shipping cost, we use the straight-line distance from the center of the grainshed to the port area that PGI records as the export destination for each grainshed.[8] The port cities chosen for the distance calculations are Portland, Oregon for the Pacific Northwest and Houston, Texas for the Gulf of Mexico. These cities come from a USDA-AMS report on agricultural export profiles of top U.S. export locations (USDA-AMS 2013). Summary statistics for the prices, transportation cost, conventional and end-use characteristics are presented in Table 1.

6.4 Aggregated Data

To form our final data set we aggregate the data at the zip code level and at the elevator level. We compile a zip code level data set with 1,390 observations. Due to elevator nomenclature inconsistencies between the price and characteristic data, we are only able to successfully match a relatively small selection of elevator level characteristic and price data leading to a data set of 970 observations. We estimate our model using both of these data sets.

7. Empirical Model and Econometric Procedures

The price paid for HRWW is assumed to be a linear summation of the implicit values of the conventional and end-use quality characteristics (Ladd and Martin 1976; and Espinosa and Goodwin 1991). Under this assumption, equation (4) can be written as:

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[7] The typical rail car has a carrying capacity of approximately 222,000 lbs (USDA-AMS 2020), which is then divided by an assumed 60 lb/bu test weight to obtain a capacity of approximately 3,700 bushels.

[8] We utilize straight line distance due to the unavailability of a rail distance data set.

$$Price_{j,t} = \beta_0 + \alpha_j + \sum_{h=1}^{5} \beta_h Conv_{h,j,t} + \sum_{h=6}^{8} \beta_h Milling_{h,j,t} + \sum_{h=9}^{14} \beta_h Baking_{h,j,t} + \sum_{t=2012}^{2019} \theta_t Year_t + \rho Transportation_{j,t} + \varepsilon_{j,t} \quad (5)$$

Where $Price_{j,t}$ represents the price paid for wheat from the location j in year t, β_0 represents the constant term; α_j represents the time-invariant fixed effects parameter for location j. The fixed effects parameter is included to account for any unobservable heterogeneity between cross sectional units. $Conv_{h,j,t}$ represents the conventional characteristics while the end-use characteristics are split into two groups: $Milling_{h,j,t}$ which represents characteristics describing milling quality, and $Baking_{h,j,t}$, which represents characteristics describing the baking quality. Estimated parameters represent the implicit prices for characteristic h. Graphical analysis of our data demonstrates extreme year to year variation in our dependent variable independent of quality and to account for this temporal variation, $Year_t$, represents the year effects. $Transportation_{j,t}$ represents the transportation cost from location j in year t.

7.1 Econometric Procedures

White's heteroskedasticity test (White 1980) indicated the presence of heteroskedasticity (test statistic: 735.73, p<0.001, while Wooldridge's autocorrelation test (Wooldridge 2002) indicated the presence of serial correlation (test statistic: 126.18, p<0.001). To account for these econometric issues, we use a cluster robust standard error estimator, clustered by fixed effect variable, which is represented by $\varepsilon_{j,t}$. We estimate equation (5) using two different dependent variable specifications, 50 and 100% harvest completion prices, as well as recognition of a markup in the price to allow for imperfect competition.[9]

Additionally, issues of multicollinearity are present among some of the milling characteristics. Specifically, three characteristics are highly correlated, the Single Kernel Characterization System (SKCS) average weight, SKCS average diameter and thousand kernel weight.[10] The two SKCS characteristics are dropped and the thousand kernel weight is chosen to remain due to indication from milling experts that thousand kernel weight is an important characteristic for international millers and grain buyers (M. Hodges and B. Seabourn, personal communication, November 8, 2019). We utilize the grainshed level fixed effect term in the fifth and sixth specification to account for any unobservable heterogeneity at the grainshed level, stemming from the aggregation level of the end-use characteristics.

7.2 Specifications

Using equation (5), we estimate six specifications. We estimate the specifications using two different data sets, a zip code level data set and an elevator level data set, three different fixed effects and prices at 50% harvest completion and 100% harvest completion. The specifications are as follows:

1. Zip code level fixed effect with 50% harvest completion prices

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[9] Due to our price data originating from elevators rather than representing what millers truly paid for the wheat, we are unable to disentangle the markup from the price. However, to our knowledge, we are the first to recognize the imperfectly competitive market structure of the milling industry in the literature on hedonic analyses of wheat characteristics.

[10] Correlation coefficients among the three characteristics are greater than 0.87 for each, and the variance inflation factors are 222.40, 243.73 and 12.74 for thousand kernel weight, SKCS average weight and SKCS average diameter, respectively.

2. Zip code level fixed effect with 100% harvest completion prices
3. Elevator level fixed effects with 50% harvest completion prices
4. Elevator level fixed effects with 100% harvest completion prices
5. Zip code level data set with grainshed fixed effects with 50% harvest completion prices
6. Zip code level data set with grainshed fixed effects with 100% harvest completion prices.

Table 2 presents results from specifications 1 and 2, Table 3 presents results from specifications 3 and 4, and Table 4 presents results from specifications 5 and 6. Additionally, we calculate marginal effects by multiplying the estimated coefficients by the standard deviation of the exogenous variable to provide a better interpretation of the economic significance of our results. These marginal effects by standard deviation allow for a more intuitive economic interpretation for characteristics where a one unit increase is not a realistic marginal change.[11]

8. Results

In this section we present and discuss the results of the six different specifications following equation (5). The year effects for all specifications are omitted from the results for brevity, but included in Appendix I. The F-test results are also included in Appendix I, and indicate that the year effects are jointly significant at the 1% level in each of the six specifications.

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[11] If the characteristic follows a normal distribution, this marginal increase represents approximately a 34% increase.

8.1 Zip Code Level

Table 2 presents estimated coefficients and marginal effects given a one standard deviation increase from specification 1 (50% harvest completion prices, first two columns), and specification 2 (100% harvest completion prices, last two columns) using zip code level fixed effects. For specification 1, only test weight is significant of the conventional characteristics, with a coefficient of 0.025, indicating an approximately \$0.03 premium per bushel for an additional pound per bushel.[12]

Of the milling characteristics, the percent large kernels, the SKCS weight, SKCS diameter and SKCS hardness standard deviations, and the SKCS average hardness are significant. However, the percent large kernels and SKCS weight and SKCS hardness standard deviation coefficients have signs opposite to our expectations. The percent large kernels has a coefficient of -0.004, indicating an approximately less than \$0.01 discount per bushel for an additional percentage point of large kernels. SKCS weight standard deviation has a coefficient of 0.075, indicating an approximately \$0.08 premium per bushel for a one milligram increase in the weight standard deviation. SKCS diameter standard deviation has a coefficient of -2.162, which while relatively high, is based on an unrealistic one unit increase.[13] The estimated marginal effect with a one standard deviation increase is -0.086, indicating an approximately \$0.09 discount per bushel for an increase of one standard deviation (approximately 0.04 mm). The result for SKCS diameter standard deviation suggests millers prefer wheat with more consistency in terms of diameter, which aligns with our expectations. Wheat that is more consistent is

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[12] Coefficients will be referred to as significant if they are statistically significant at the 10% level.
[13] A one unit increase in the SKCS diameter standard deviation would be equivalent to an approximately 300% increase at the margin.

beneficial to millers because the more consistent the wheat, the fewer adjustments needed for the mill gap settings.

SKCS average hardness has a coefficient of -0.010, indicating an approximately $0.01 discount per bushel for an additional unit of the hardness scale. The marginal effect given one standard deviation for SKCS average hardness is -0.094, indicating an approximately $0.09 discount per bushel for a one standard deviation increase (or an approximate increase of 9.04 units) in the hardness scale. The results for SKCS average hardness align with our expectation that millers prefer softer wheat, due to the higher energy requirements to mill harder wheat leading to higher costs. SKCS hardness standard deviation has a coefficient of 0.012, indicating an approximately $0.01 premium per bushel for a one hardness scale unit increase in the hardness standard deviation The SKCS diameter standard deviation, SKCS average hardness and SKCS hardness standard deviation are measured in units in which a one unit increase is not a realistic change. Therefore the marginal effect given one standard deviation will be reported and discussed in place of the coefficient estimate, to allow for more intuitive economic interpretation.

In terms of the baking characteristics, the P/L ratio, water absorption, mixing time and medium and high crumb grain are all significant and of the expected sign, while loaf volume is significant but not of the expected sign.The P/L ratio level has a coefficient of -0.238 and is not significant while the quadratic term has a coefficient of 0.164 and is significant. However, the marginal effect of the P/L ratio level and quadratic terms is not significant.

Water absorption has a coefficient of 0.061, indicating a premium of approximately $0.06 per bushel for an additional percent of water absorption. The water absorption result aligns with expectations, as water is the cheapest ingredient in the baking process and, thus, the more water that is absorbed by the flour the less flour is needed to reach the intended dough weight. Mixing time has a coefficient of -0.091, indicating an approximately $0.09 discount per bushel for an additional minute of mixing time. The result for mixing time also aligns with expectations, as more energy expended in mixing a dough leads to higher cost. The coefficient on loaf volume is -0.050, indicating an approximately $0.05 discount per bushel for an additional 100 cubic centimeters of loaf volume.[14] Medium crumb grain has a coefficient of 0.067, indicating an approximately $0.07 premium per bushel for wheat with a crumb grain between 2.5 and 3.4 when compared to wheat in the 0 to 2.4 range. High crumb grain has a coefficient of 0.134, indicating an approximately $0.13 premium per bushel for wheat with crumb grains in the 3.5 to 6 range when compared to wheat in the 0 to 2.4 range. The crumb grain result aligns with expectations in that wheat with a higher subjective crumb quality should be preferred to lower quality.

Finally, the 50% harvest completion transportation cost coefficient is both significant and of the expected sign, indicating that transportation cost does have a negative effect on price. The estimated coefficient for the 50% harvest completion transportation cost is -0.511, indicating an approximately $0.51 discount per bushel for a one dollar per bushel increase in the transportation cost. The coefficient estimate provides evidence that locations further away from a port may see larger discounts due to higher transportation costs. However, it is important to note that the cash price we utilize is what the elevator offers to the producer, whereas the transportation cost is born primarily by

[14] An increase of 100 cubic centimeters is approximately an 11% increase at the mean value of loaf volume.

the miller. And while there is evidence that millers set the basis at the elevator level, it is unlikely that the full amount of the transportation cost discount is passed on to producers. The transportation cost result does align with observations in the wheat industry, as well as expert testimony and our own expectations that transportation cost is an important component of price.

A potential explanation as to why some of the characteristics are not of the expected sign is that end-use characteristics are used jointly to indicate quality, rather than independently. Or in other words, millers utilize all of the characteristics together to indicate end-use quality while our specifications report coefficients assuming *ceteris paribus*.[15] These unexpected results are observed in the all of the following specifications as well. This evidence of joint utilization of the end-use characteristics in determining quality follows the results of Espinosa and Goodwin (1991), where the authors found that many of the end-use characteristics were not individually significant but were jointly significant. F-test results determining joint significance of the milling and baking characteristics used in this analysis are presented in Appendix II.

For the specification with zip code level fixed effects and 100% harvest completion price results (specification 2), there are several notable differences when compared to the 50% harvest completion price results (specification 1). First, the coefficients which are significant for the 50% harvest completion regression are also significant for the 100% harvest completion regression, except for loaf volume, SKCS hardness standard deviation, the P/L ratio level and quadratic terms, and the 100% harvest transportation cost. Falling number and protein content are not significant in the

[15] For example, a miller might overlook a negative result from a milling or baking test in an elevator's wheat due to a different, positive result from a more desirable milling or baking test.

50% harvest completion regression (specification 1) but are significant in the 100% harvest completion regression (specification 2). While the coefficient on falling number does not have the expected sign, the crumb grain coefficient and protein coefficients have the expected sign. The unexpected sign on falling number is similar to what is observed in the previous specification. Additionally, the magnitudes for the coefficients in the 100% harvest completion regression are comparable, if slightly larger, than the estimates for the 50% harvest completion specification (specification 1). For protein content, the coefficient is 0.044, indicating an approximately $0.04 premium per bushel for an additional percentage point of protein. This estimate is similar to the $0.05 premium found by the authors in Espinosa and Goodwin (1991), and aligns with expectations that millers prefer wheat with higher protein. Falling number has a coefficient of -0.061, indicating an approximately $0.06 discount per bushel for an additional minute on the falling number test.

The coefficient for percent large kernels is -0.007, indicating an approximately $0.01 discount per bushel for an additional percentage point of large kernels. SKCS weight standard deviation has a coefficient of 0.051, indicating an approximately $0.05 premium per bushel for an additional milligram in the weight standard deviation. The marginal effect given one standard deviation for SKCS diameter standard deviation is -0.080, indicating an approximately $0.08 discount per bushel for a one standard deviation increase (approximately 0.04 mm). The marginal effect given one standard deviation for SKCS average hardness is -0.112, indicating an approximately $0.11 discount per bushel for a one standard deviation increase (approximately 9.4 units of the hardness scale). The result for SKCS diameter standard deviation and SKCS average hardness follows the result from the 50% harvest completion regression, indicating that millers prefer softer wheat with a more consistent kernel diameter.

For the baking characteristics, water absorption, mixing time and the medium crumb grain coefficients are significant, while the P/L ratio marginal effect is significant. The estimated marginal effect for P/L ratio is 0.235, indicating an approximately $0.24 premium for an additional unit in the P/L ratio at the margin. Additionally, the positive sign for the P/L ratio level and negative sign for the quadratic term indicate a convex relation with price. This P/L ratio result indicates that wheat with higher P/L ratios receive higher prices, but that the effect is diminishing. The estimated coefficient for water absorption is 0.065, indicating an approximately $0.07 premium per bushel for an additional one percent of water absorption. The water absorption result provides further evidence that millers prefer wheat with higher water absorption rates.

The estimated coefficient for mixing time is -0.125, indicating an approximately $0.13 discount per bushel for an additional minute of mixing time. The coefficient for mixing time provides further evidence that millers prefer wheat with lower mixing times. The medium crumb grain coefficient is 0.078, indicating an approximately $0.08 premium per bushel for wheat with a crumb grain score of 2.5 to 3.4, when compared to wheat with crumb grain of 0 to 2.4. While the high crumb grain coefficient is 0.102, indicating an approximately $0.10 premium per bushel for wheat with a crumb grain score in the 3.5 to 6 range when compared to wheat in the 0 to 2.4 range. The crumb grain results further indicates millers’ preferences for wheat with higher crumb grain quality.

The differences between the 50% and 100% harvest completion specifications, specifically the protein content, indicate that there is a temporal effect in terms of pricing wheat. Additionally, several of the milling and baking characteristics are significant and of the expected sign for both the 50% and 100% harvest completion specifications, indicating the effect of these end-use characteristics on HRWW price.

8.2 Elevator Level

Table 3 presents estimated coefficients and marginal effects given a one standard deviation increase, for the elevator level fixed effects specificiation 3 (50% harvest completion prices, first two columns), and specification 4 (100% harvest completion prices, last two columns). For specification 3, the results are similar to the zip code level results, with a few exceptions. Of the conventional characteristics, only test weight is significant, with a coefficient comparable to the estimate in the zip code level 50% harvest completion specification.

For the milling characteristics, percent large kernels, SKCS weight standard deviation and SKCS average hardness are significant; whereas in the zip code level 50% harvest completion results, SKCS diameter and SKCS hardness standard deviation are also significant. However, only the SKCS average hardness is of the expected sign. The coefficient for percent large kernels is -0.003, which indicates a less than $0.01 discount per bushel for an additional percent point of large kernels. SKCS weight standard deviation has a coefficient of 0.036, indicating an approximately $0.04 premium for a one milligram increase in the weight standard deviation. The marginal effect given one standard deviation for SKCS average hardness is -0.067, indicating an approximately $0.07 discount per bushel for a one standard deviation increase (approximate increase of

9.4 units in the hardness scale). This result further indicates the undesirability of harder wheat.

Of the baking characteristics, water absorption, mixing time, and medium and high crumb grain are all significant and of the expected sign. Loaf volume is the only baking characteristic with an unexpected sign which may stem from millers purchasing wheat with lower loaf volumes due to other, more desirable qualities, as mentioned above. The baking characteristic coefficients are of comparable magnitudes to the zip code level specifications.

Finally, the 50% harvest completion transportation cost coefficient is -1.129, it is significant and of the expected sign. This transportation cost result indicates an approximately $1.13 discount per bushel for a one dollar per bushel increase in transportation cost and further indicates the importance of this cost as a component of HRWW price.

In the elevator level, 100% harvest completion specification (specification 4), test weight, moisture and protein are significant for the conventional characteristics, with only moisture not having the expected sign. As mentioned earlier, this unexpected sign may be due to millers purchasing wheat with higher moisture which also contain other, more desirable qualities. We see comparable premiums and discounts to what is estimated in the zip code level, 100% harvest completion specification (specification 2) with an approximately $0.03 premium per bushel for an additional pound per bushel of test weight, an approximately $0.05 premium per bushel for additional percentage point of protein and an approximately $0.02 premium per bushel for an additional percentage point of moisture.

We also see a change for the milling characteristics from the zip code level, 100% harvest completion specification (specification 2), with only percent large kernels and SKCS average hardness being significant. For these milling characteristics, the percent large kernels characteristic does not have the expected sign. As observed in previous specifications, this unexpected sign may be explained by millers purchasing wheat with smaller kernels but which also contains other, more desirable milling and baking qualities. The coefficients for percent large kernels and SKCS average hardness are comparable to the estimate presented in specification 2. The coefficient for percent large kernels is -0.008, indicating an approximately $0.01 discount per bushel for an additional percentage point of large kernels. The marginal effect given one standard deviation for SKCS average hardness is -0.096 hardness scale units, indicating an approximately $0.10 discount per bushel for a one standard deviation increase in the hardness scale.

Of the baking characteristics, only water absorption, mixing time, and medium and high crumb grain are significant and of the expected sign. The baking characteristics all have coefficients comparable to the estimates presented in the zip code level, 100% harvest completion (specification 2), suggesting that these particular baking characteristics are important in informing millers' purchasing decisions.

The 100% harvest completion transportation cost coefficient is also significant and of the expected sign. The coefficient estimate is -0.884, indicating an approximately $0.88 discount per bushel for a one dollar per bushel increase in the cost to ship to a port area. The elevator level, 100% harvest completion transportation cost marginal effect given one standard deviation is approximately $0.24 lower than the elevator level 50% harvest completion transportation cost. This difference could stem from differences in rail demand between the two harvest periods. The bulk of HRWW production occurs in the southern and central plains, and those regions complete harvest nearer to the 50% harvest time frame than the 100% harvest time. Therefore demand for grain transportation may be lower during the 100% harvest completion time frame due to these regional differences, which may lead to lower transportation costs during the later harvest period.

When comparing the two elevator level specifications (specifications 3 and 4), we observe similar temporal differences between the two harvest completion specifications as in the zip code level specifications (specifications 1 and 2). These differences between harvest completion specifications provide more evidence that time has an effect on the price of wheat. Additionally, several of the milling and baking characteirstics are consistently significant between harvest completion levels, further indicating the effect these end-use characteristics have on HRWW price.

8.3 Grainshed Level

Table 4 presents estimated coefficients and marginal effects given a one standard deviation increase, using the zip code level data set with grainshed level fixed effects for specification 5 (50% harvest completion prices, first two columns), and specification 6 (100% harvest completion prices, last two columns). When comparing specification 5 in Table 4 to the zip code level, 50% harvest completion specification in Table 2 (specification 1), the results are similar. Of the conventional characteristics, test weight is not significant in specification 5 but it is significant in specification 1. However, the results for the milling and baking characteristics in the grainshed specification are similar to the zip code specification. For the milling characteristics, the percent large kernels, SKCS weight standard deviation, SKCS diameter standard deviation, SKCS average hardness and SKCS hardness standard deviation are significant, however, only the SKCS diameter standard deviation and SKCS average hardness are of the expected sign. The unexpected signs for those milling characteristics, as observed in previous specifications, may stem from millers purchasing wheat with less desirable milling qualities but which possesses other, more desirable milling qualities.

Of the baking characteristics, water absorption and mixing time coefficients are significant, while the transportation cost coefficient is also significant. The coefficient estimates for both the milling and the baking characteristics are of comparable magnitudes to the previous specifications.

For the 100% harvest completion regression (specification 6), protein content and moisture are significant, similar to the previous specifications, with comparable coefficient estimates. However, as observed before, the moisture coefficient is not of the expected sign. For the milling characteristics, the coefficients on percent large kernels, SKCS weight standard deviation, SKCS diameter standard deviation, SKCS average hardness and SKCS hardness standard deviation are significant, with only the coefficients on SKCS diameter standard deviation and SKCS average hardness having the expected sign.

For the baking characteristics, coefficients on water absorption and mixing time remained significant, and had similar magnitudes and signs to specification five as well as the other specifications. The 100% harvest completion transportation cost coefficient is also significant, but the coefficient estimates for 50% and 100% harvest completion transportation cost are unreliable due to the inclusion of the grainshed level fixed effects. Harvest transportation cost is calculated using the distance from the center of each grainshed to a port area, leading to multicollinearity between the fixed effects terms at the grainshed level and the transportation cost terms.[16]

8.4 Results Summary

Tables 2, 3 and 4 present estimated results at different aggregation levels and with different cross-sectional units. For all three, there are temporal differences shown between the 50% and 100% harvest completion regressions, with the protein coefficient being significant at the 100% harvest completion level but not the 50% harvest level in all three of the aggregation levels. Additionally, coefficients on several of the milling and baking characteristics are consistently significant between all three aggregation levels. For all three aggregation levels, coefficients on SKCS diameter standard deviation and SKCS average hardness are consistently significant and of the expected sign for the milling characteristics and coefficients on water absorption and mixing time are consistently significant and of the expected sign for the baking characteristics.

The three sets of characteristics, conventional milling and baking, are also tested for joint significance in each of the specifications, the results of which are included in Appendix II. For all six specifications, both sets of end-use characteristics, milling and baking are jointly significant. Additionally, for the zip code specifications (specifications 1 and 2) and elevator specifications (specifications 3 and 4), the conventional characteristics are not jointly significant at the 50% harvest price level (specifications 1 and 3) but are jointly significant at the 100% harvest level (specifications 2 and 4).

[16] VIF greater than 100 for both 50% and 100% harvest transportation costs.

9. Concluding Remarks

This thesis examined the effect of end-use quality characteristics on the price for HRWW. Our analysis followed the Espinosa and Goodwin (1991) application of the ICM (Ladd and Martin 1976) to the Kansas HRWW market, with several additions. We expanded the study area to include the entire HRWW growing region, included transportation cost, recognized the oligopolistic nature of the milling industry, and varied the HRWW price by harvest completion time. We utilized a comprehensive data set of four conventional characteristics and ten end-use characteristics determined to be important by milling industry experts (M. Hodges and B. Seabourn, personal communication, November 8, 2019). And we used six different specifications, two with zip code level fixed effects (50% and 100% harvest completion prices), two with elevator level fixed effects (50% and 100% harvest completion prices) and two with grainshed level fixed effects (50% and 100% harvest completion prices) to analyze the results at different aggregation levels and cross-sectional effects.

We find evidence that end-use characteristics do have an effect on the local price of HRWW. This evidence is robust to aggregation level as well as harvest completion period. This evidence also suggests that wheat producers are indirectly paid for end-use quality through local basis adjustments, rather than through direct premiums and discounts. Given this information, wheat breeders enhancing end-use characteristic traits may improve wheat producer outcomes (consistent with findings in Lambert and Wilson 2003; Dahl, Wilson and Johnson 2004). We also find evidence of a temporal effect in the price of HRWW, suggesting that the market quality information that is available to millers and other buyers at a given time has a role in the importance of the various quality characteristics. Additionally, F-tests testing for joint significance of the milling and baking characteristics are significant for each specification, suggesting that though only some of the characteristics are individually significant, as a group they have an effect on price. This evidence of joint significance of the end-use characteristics follows the results of Espinosa and Goodwin (1991).

Some of the limitations of this study are that while we recognize the imperfectly competitive market structure of the milling industry, we are unable to disentangle the markup from the HRWW price. A method of including that structure into the model would better reflect the conditions of the current domestic milling industry. Also, obtaining more robust transportation cost data that measures transportation cost to various milling/processing plants rather than ports, could be beneficial to further examine the importance of transportation cost to milling firms. Finally, more disaggregated end-use characteristic data could potentially provide a clearer view of how these characteristics affect price.

While this analysis provides evidence that end-use characteristics are an important component of HRWW price, advocating for the inclusion of these characteristics into FGIS standards is beyond the scope of this thesis. A full cost-benefit analysis on including these end-use characteristics would need to be conducted to fully propose their inclusion into the FGIS grading standards. Additionally, given the results we found indicating the importance of end-use characteristics, examining HRWW variety choice and valuation could be beneficial to increasing producer profitability. With the importance of exports in the HRWW market, analyzing the role of quality characteristics using export prices could further uncover the effect that these end-use characteristics have on the HRWW industry. If a method of including the milling industry market structure and a comprehensive rail cost data set are created and utilized, then this examination of the effect of quality characteristics on HRWW price would better reflect the nature and conditions currently observed in the U.S. milling industry. However, our results and our contributions to the analysis conducted in Espinosa and Goodwin (1991) represent a step forward for the literature, provide evidence that producers are indirectly being paid for end-use quality and provide a solid foundation for future research into the role of quality characteristics in pricing wheat.

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Figures

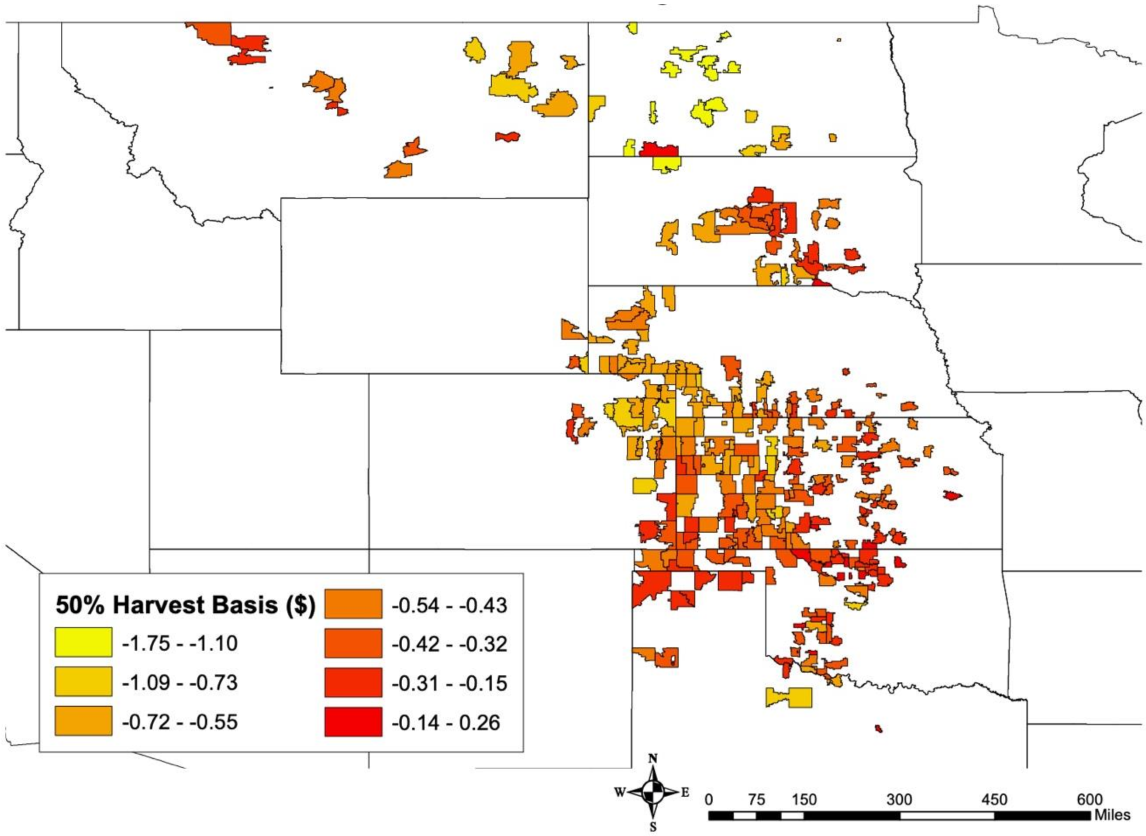

Figure 1: 50% harvest completion average basis by zipcode, 2012 to 2019 (Source: DTN, ESRI)

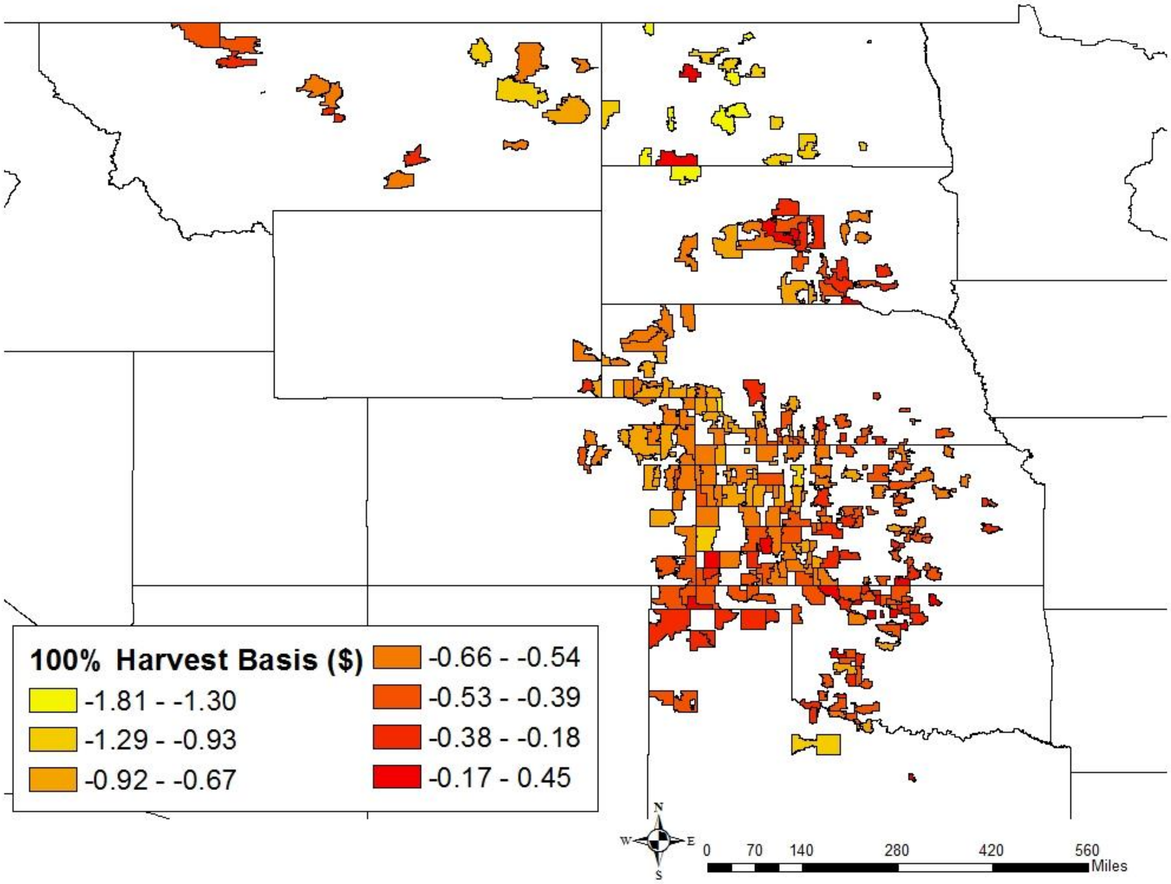

Figure 2: 100% harvest completion average basis by zip code, 2012 to 2019 (Source: DTN, ESRI)

Tables

Table 1: Summary Statistics of Variables

	N	Mean	SD	Min	Max
50% Harvest Price ($/bu)	1,390	4.620	1.466	1.725	7.924
100% Harvest Price ($/bu)	1,390	4.506	1.859	1.200	8.305
50% Harvest Transportation Cost ($/bu)	1,389	0.927	0.265	0.288	1.777
100% Harvest Transportation Cost ($/bu)	1,389	0.937	0.268	0.293	1.794
Conventional Characteristics					
Test Weight (lb/bu)	1,388	60.40	1.692	52.10	64.80
Moisture (%)	1,390	11.44	1.194	1.230	15.80
Protein (%)	1,390	12.14	1.339	7.700	17.20
Falling Number (min)	1,387	6.547	0.610	3.025	8.708
Total Defects (%)	1,384	1.492	0.821	0.200	8.400
Milling Characteristics					
Thousand Kernel Weight (g)	1,389	29.94	3.015	20.78	46.41
Large Kernels (%)	1,390	61.19	14.92	0.350	88.90
SKCS Weight Standard Deviation (mg)	1,364	8.687	1.259	5.109	13.45
SKCS Diameter Standard Deviation (mm)	1,364	0.342	0.040	0.204	0.489
SKCS Hardness (-20-120)	1,389	62.54	9.375	29.59	90.36
SKCS Hardness Standard Deviation (-20-120)	1,364	17.46	1.822	12.11	31.25
Baking Characteristics					
P/L Ratio	1,313	0.931	0.293	0.430	2.320
Water Absorption (%)	1,314	62.30	1.903	57	68.20
Mixing Time (min)	1,314	3.645	0.636	2.380	6.130
Mixing Tolerance (0-6)	1,314	2.646	0.813	1	5
Loaf Volume (100’s cc)	1,314	8.463	0.619	6.60	10.25
Crumb Grain (0-6)	1,314	3.341	0.798	1	5

Table 2: Regression results and marginal effects given one standard deviation for the zip code level fixed effects specifications

	Specification 1		Specification 2	
	50% Harvest Prices		100% Harvest Prices	
	Parameter Estimates	Marginal Effects	Parameter Estimates	Marginal Effects
Conventional Characteristics				
Test Weight (lb/bu)	0.025 **	0.042**	0.042 ***	0.071***
	(0.010)		(0.012)	
Moisture (%)	-0.005	-0.006	0.003	0.004
	(0.008)		(0.009)	
Protein (%)	0.015	0.024	0.044 ***	0.059***
	(0.015)		(0.017)	
Falling Number (min)	-0.013	-0.008	-0.061 ***	-0.037***
	(0.018)		(0.020)	
Milling Characteristics				
Thousand Kernel Weight (g)	0.003	0.009	-0.005	-0.015
	(0.011)		(0.015)	
Large Kernels (%)	-0.004 ***	-0.060***	-0.007 ***	-0.104***
	(0.002)		(0.002)	
SKCS Weight Standard Deviation (mg)	0.075 ***	0.094 ***	0.051 **	0.064**
	(0.018)		(0.021)	
SKCS Diameter Standard Deviation (mm)	-2.162 ***	-0.086***	-1.999 ***	-0.080***
	(0.577)		(0.695)	
SKCS Hardness (-20-120)	-0.010 ***	-0.094***	-0.012 ***	-0.112***
	(0.002)		(0.002)	
SKCS Hardness Standard Deviation (-20-120)	0.012 *	0.022*	0.006	-0.011
	(0.006)		(0.006)	
Baking Characteristics				
P/L Ratio	-0.238	0.068[a]	0.170	0.235[a]***
	(0.200)		(0.244)	
P/L Ratio^2	0.164 *		0.035	
	(0.087)		(0.110)	
Water Absorption (%)	0.061 ***	0.116***	0.065 ***	0.124***
	(0.010)		(0.012)	
Mixing Time (min)	-0.091 ***	-0.058***	-0.125 ***	-0.080***
	(0.026)		(0.030)	
Medium Mix Tolerance (2.5-3.4)	-0.009		0.004	
	(0.026)		(0.030)	

Table 2: Cont'd

	Specification 1 50% Prices		Specification 2 100% Prices	
	Parameter Estimates	Marginal Effects	Parameter Estimates	Marginal Effects
High Mix Tolerance (3.5-6)	0.026		-0.007	
	(0.036)		(0.045)	
Loaf Volume (100's cc)	-0.050 *	-0.031*	-0.006	-0.004
	(0.029)		(0.036)	
Medium Crumb Grain (2.5-3.4)	0.067 *		0.078 *	
	(0.038)		(0.045)	
High Crumb Grain (3.5-6)	0.134 ***		0.102 **	
	(0.040)		(0.049)	
Transportation Cost				
50% Harvest ($/bu)	-0.511 **	-0.135**		
	(0.222)			
100% Harvest ($/bu)			-0.361	-0.097
			(0.227)	
Constant	2.530 ***		2.829 ***	
	(0.804)		(0.884)	
Observations	1,287		1,287	
R-squared	0.965		0.974	
Number of Zip	305		305	
Zip Code FE	YES		YES	
Zip Code Cluster Robust SE	YES		YES	
Year Effect	YES		YES	

Robust standard errors in parentheses
Marginal Effects given one standard deviation
*** p<0.01, ** p<0.05, * p<0.1
[a] Joint marginal effect at the mean of P/L ratio level and quadratic terms.

Table 3: Regression results and marginal effects given one standard deviation for the elevator level fixed effects specifications

	Specification 3		Specification 4	
	50% Harvest Prices		100% Harvest Prices	
	Parameter Estimates	Marginal Effects	Parameter Estimates	Marginal Effects
Conventional Characteristics				
Test Weight (lb/bu)	0.019 *	0.032*	0.034 **	0.056**
	(0.012)		(0.015)	
Moisture (%)	0.006	0.007	0.022 **	0.027**
	(0.009)		(0.011)	
Protein (%)	0.001	0.001	0.052 **	0.071**
	(0.018)		(0.020)	
Falling Number (min)	-0.019	-0.012	-0.020	-0.012
	(0.023)		(0.029)	
Milling Characteristics				
Thousand Kernel Weight (g)	0.007	0.022	0.009	0.028
	(0.012)		(0.016)	
Large Kernels (%)	-0.003	-0.045*	-0.008 ***	-0.119***
	(0.002)		(0.003)	
SKCS Weight Standard Deviation (mg)	0.036	0.045**	0.005	0.006
	(0.022)		(0.027)	
SKCS Diameter Standard Deviation (mm)	-0.924	-0.038	-0.006	-0.000
	(0.697)		(0.828)	
SKCS Hardness (-20-120)	-0.007 ***	-0.067***	-0.010 ***	-0.096***
	(0.003)		(0.003)	
SKCS Hardness Standard Deviation (-20-120)	-0.001	-0.002	0.003	0.005
	(0.006)		(0.008)	
Baking Characteristics				
P/L Ratio	-0.583 **	-0.050[a]	0.020	0.137[a]
	(0.240)		(0.278)	
P/L Ratio^2	0.286 ***		0.084	
	(0.098)		(0.111)	
Water Absorption (%)	0.075 ***	0.139***	0.070 ***	0.130***
	(0.013)		(0.016)	
Mixing Time (min)	-0.070 **	-0.045*	-0.080 *	-0.052*
	(0.035)		(0.041)	
Medium Mix Tolerance (2.5-3.4)	0.010		-0.002	
	(0.032)		(0.037)	

Table 3 Cont'd

	Specification 3 50% Prices		Specification 4 100% Prices	
	Parameter Estimates	Marginal Effects	Parameter Estimates	Marginal Effects
High Mix Tolerance (3.5-6)	0.061		0.010	
	(0.044)		(0.064)	
Loaf Volume (100's cc)	-0.100 ***	-0.059***	-0.065	-0.039
	(0.032)		(0.054)	
Medium Crumb Grain (2.5-3.4)	0.131 **		0.155 **	
	(0.052)		(0.064)	
High Crumb Grain (3.5-6)	0.195 ***		0.170 **	
	(0.053)		(0.072)	
Transportation Cost				
50% Harvest ($/bu)	-1.129 ***	-0.280***		
	(0.358)			
100% Harvest ($/bu)			-0.884 ***	-0.176***
			(0.317)	
Constant	2.747 ***		2.450 **	
	(0.966)		(1.189)	
Observations	849		827	
R-squared	0.972		0.977	
Number of Elevator	219		215	
Elevator FE	YES		YES	
Elevator Cluster Robust SE	YES		YES	
Year Effect	YES		YES	

Robust standard errors in parentheses
Marginal Effects given one standard deviation
*** p<0.01, ** p<0.05, * p<0.1
[a] Joint marginal effect at the mean of P/L ratio level and quadratic terms.

Table 4: Regression results and marginal effects given one standard deviation for the grainshed level fixed effects specifications

	Specification 5		Specification 6	
	50% Harvest Prices		100% Harvest Prices	
	Parameter Estimates	Marginal Effects	Parameter Estimates	Marginal Effects
Conventional Characteristics				
Test Weight (lb/bu)	0.010	0.017	0.030	0.051
	(0.015)		(0.020)	
Moisture (%)	-0.008	-0.010	-0.002	-0.002
	(0.010)		(0.011)	
Protein (%)	0.013	0.017	0.044 **	0.059**
	(0.017)		(0.020)	
Falling Number (min)	0.008	0.005	-0.034	-0.021
	(0.024)		(0.026)	
Milling Characteristics				
Thousand Kernel Weight (g)	0.005	0.015	-0.001	-0.003
	(0.011)		(0.015)	
Large Kernels (%)	-0.004 **	-0.060**	-0.007 ***	-0.104***
	(0.002)		(0.002)	
SKCS Weight Standard Deviation (mg)	0.069 ***	0.087***	0.050 **	0.063***
	(0.015)		(0.019)	
SKCS Diameter Standard Deviation (mm)	-1.719 ***	-0.069***	-1.589 **	-0.064**
	(0.609)		(0.678)	
SKCS Hardness (-20-120)	-0.007 *	-0.066*	-0.009 **	-0.084**
	(0.004)		(0.004)	
SKCS Hardness Standard Deviation (-20-120)	0.017 **	0.031**	0.014 **	0.026**
	(0.008)		(0.006)	
Baking Characteristics				
P/L Ratio	-0.303	0.061[a]	0.028	0.211[a]*
	(0.372)		(0.420)	
P/L Ratio^2	0.196		0.098	
	(0.153)		(0.180)	
Water Absorption (%)	0.059 ***	0.112***	0.066 ***	0.126***
	(0.019)		(0.023)	
Mixing Time (min)	-0.114 **	-0.073**	-0.146 ***	-0.093***
	(0.042)		(0.050)	
Medium Mix Tolerance (2.5-3.4)	-0.025		-0.002	
	(0.043)		(0.054)	

Table 4: Cont'd

	Specification 5 50% Prices		Specification 6 100% Prices	
	Parameter Estimates	Marginal Effects	Parameter Estimates	Marginal Effects
High Mix Tolerance (3.5-6)	-0.007		-0.049	
	(0.076)		(0.087)	
Loaf Volume (100's cc)	-0.029	-0.018	0.007	0.004
	(0.062)		(0.072)	
Medium Crumb Grain (2.5-3.4)	0.074		0.080	
	(0.067)		(0.082)	
High Crumb Grain (3.5-6)	0.123		0.096	
	(0.074)		(0.094)	
Transportation Cost				
50% Harvest ($/bu)	-1.856 ***	-0.492***		
	(0.466)			
100% Harvest ($/bu)			-1.046 *	-0.280*
			(0.555)	
Constant	3.668 **		3.078	
	(1.539)		(1.933)	
Observations	1,287		1,287	
R-squared	0.960		0.971	
Number of Grainshed	42		42	
Grainshed FE	YES		YES	
Grainshed Cluster Robust SE	YES		YES	
Year Effect	YES		YES	

Robust standard errors in parentheses
Marginal Effects given one standard deviation
*** p<0.01, ** p<0.05, * p<0.1
[a] Joint marginal effect at the mean of P/L ratio level and quadratic terms.

Appendix I

Table 5: Year effect coefficient estimates.

	Spec 1 50% Prices	Spec 2 100% Prices	Spec 3 50% Prices	Spec 4 100% Prices	Spec 5 50% Prices	Spec 6 100% Prices
2013	0.367 ***	-1.114 ***	0.453 ***	-0.962 ***	0.422 ***	-1.082 ***
	(0.051)	(0.063)	(0.067)	(0.074)	(0.094)	(0.130)
2014	0.184 **	-2.589 ***	0.378 ***	-2.407 ***	0.554 ***	-2.397 ***
	(0.092)	(0.091)	(0.135)	(0.118)	(0.197)	(0.235)
2015	-0.890 ***	-3.607 ***	-0.767 ***	-3.498 ***	-0.817 ***	-3.583 ***
	(0.050)	(0.050)	(0.058)	(0.062)	(0.071)	(0.065)
2016	-3.670 ***	-5.561 ***	-3.565 ***	-5.437 ***	-3.528 ***	-5.439 ***
	(0.060)	(0.076)	(0.074)	(0.110)	(0.084)	(0.097)
2017	-2.695 ***	-4.616 ***	-2.620 ***	-4.528 ***	-2.577 ***	-4.575 ***
	(0.069)	(0.077)	(0.081)	(0.094)	(0.092)	(0.104)
2018	-1.594 ***	-2.601 ***	-1.548 ***	-2.532 ***	-1.348 ***	-2.486 ***
	(0.069)	(0.069)	(0.082)	(0.091)	(0.131)	(0.111)
2019	-2.085 ***	-4.280 ***	-1.983 ***	-4.219 ***	-1.859 ***	-4.176 ***
	(0.069)	(0.073)	(0.077)	(0.092)	(0.100)	(0.089)
F-test Results	848.270 ***	1040.33 ***	743.07 ***	637.86 **	416.97 ***	934.56 ***

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Appendix II

Table 6: F-test results for all specifications by characteristic group

	Conventional	Milling	Baking
Spec 1	2.07*	9.22***	8.20***
Spec 2	5.21***	9.01***	7.17***
Spec 3	0.89	1.92*	7.90***
Spec 4	2.85**	2.86**	3.72***
Spec 5	0.46	4.37***	4.69***
Spec 6	1.67	2.70**	3.46***

*** p<0.01, ** p<0.05, * p<0.1