A COST EFFICIENCY COMPARISON OF INTERNATIONAL CORN, SOYBEAN, AND WHEAT PRODUCTION

by

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ABSTRACT

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This paper seeks to compare production costs of similar farms to determine competitiveness across countries. A data envelopment analysis (DEA) approach was used to calculate efficiency indices for farms producing corn, soybeans, wheat, both corn and soybeans, and both corn and wheat. Technical efficiency, allocative efficiency, and cost efficiency were compared for all farms. The data consisted of a five-year (2013-2017) panel of 24 corn-producing farms, 15 soybean-producing farms, 38 wheat-producing farms, 13 farms producing both corn and soybeans, and 17 farms producing both corn and wheat. The *agri benchmark* network at the Thünen Institute (TI) of Farm Economics manages the dataset that was used in this analysis. Outputs were measured using revenue. Input costs included direct costs, operating costs, and overhead costs.

CHAPTER 1. INTRODUCTION

1.1 Competitiveness and Comparative Advantage

Global caloric needs are primarily met by three crops: wheat, rice, and maize (Reeves, 2004). Countries have become increasingly dependent upon trade to meet food demands. Global trade plays a balancing role, as population growth and food production expansion do not always occur in the same geographic region (Godfray et al., 2010). Additionally, even if agricultural production was able to match population growth in the same region; regional shocks in production still necessitate trade. For instance, droughts or floods can limit yields and necessitate imports to meet food demands in a region (Godfray et al., 2010). Reliance on trade to meet global food demands has been increasing. The percentage of food for direct human consumption that is traded has increased from 15 to 23 percent from 1986 to 2009 (D 'Odorico et al., 2014). As such, trade continues to play a role in matching food demand and supply on a global scale.

Measuring competitiveness accurately is crucial for developing efficient policy and decision-making. For instance, during accession into the European Union, countries are required to adjust their economies to ensure competition is fair across the countries. Understanding competitiveness between countries producing agricultural products is crucial to making the transition efficient (Frohberg & Hartmann, 1997). Moreover, accurately measuring competitiveness is important as trade becomes more liberalized. The global nature of agriculture creates an additional complication: exchange rates. Competitiveness and trade can be affected by fluctuations in exchange rates. Exchange rates create an additional obstacle to measuring competitiveness.

Comparative advantage was first introduced by David Ricardo. Ricardo argued that a country should specialize in producing commodities in which the country enjoys the greatest comparative advantage, even if one country has the absolute advantage and can more efficiently produce all commodities (Koo & Kennedy, 2005). Absolute advantage refers to the ability to produce an output using fewer inputs than competitors (Black et al., 2017). The less efficient country should produce the products where they have the smallest disadvantage (Koo & Kennedy, 2005). A country with a lower opportunity cost in the production of a commodity has a comparative advantage (Black et al., 2017).

1.1.1 Competitiveness in Agriculture

Identifying the lowest cost producers of a product can be challenging, and the task is even more complex when making comparisons across international borders. Policies, such as trade agreements and subsidies, directly affect competitiveness of production and vary across countries. Obtaining a clear picture of competitiveness without the effect of subsidies and distortions is a daunting task that is made difficult by accounting for exchange rates between countries.

If a firm is operating efficiently, that means that the minimum amount of inputs necessary to produce a given output are being employed, the firm is choosing the optimal output level and is using the optimal level of inputs, and is producing at the lowest cost possible. It is important to be mindful that efficiency is a relative measure, as efficiency is a comparison to other rival firms. Since this measure is relative, that implies firms maximize profits with varying degrees of success. Additionally, firms operate at different sets of market prices. Given movements in exchange rates, accurately measuring efficiency is complicated when comparisons are made across countries. Thus, the same input combination may not be the lowest cost combination for two different firms.

1.1.2 Measuring Competiveness

A widely agreed upon definition of competitiveness is lacking in existing literature. One popular definition of competitiveness, proposed by Freebairn (1987, p. 79), is the "ability to deliver goods and services at the time, place, and form sought by overseas buyers at prices as good as or better than those of other potential suppliers whilst earning at least opportunity cost returns on resources employed." Abbott and Brendahl (1994) identified one cause of variation in the definition: special interest groups want to define competitiveness in a way that is favorable to their cause. If an industry can successfully convince the government that they are at a competitive disadvantage, the industry will have a better chance of obtaining protectionist measures. These measures can include quotas, tariffs, or subsidies. The sugar industry illustrates what an industry stands to gain from convincing the government that they are in need of protection. The sugar industry benefits from price support through preferential loan agreements, domestic market controls, and tariff-rate quotas. The sugar policies in the United States have increased the price of sugar for domestic consumers (Worstall, 2017).

It is in the government's best interests to accurately measure competitiveness to avoid protecting and supporting industries that would otherwise survive without protections. Exchange rates affect competitiveness, and there is a need to accurately measure that effect. Accurately measuring this affect is challenging given that many countries also produce the same product. In the sugar example: Brazil, India, Mexico, and Colombia all produce sugar and would be competitors for producers in the United States.

1.1.3 Common Data Types

When measuring competitiveness among agricultural products, it is important to remember that exports play a large role in agricultural markets. When comparing competitiveness of countries, two data sources are commonly used: trade data and farm level data. Trade data can be advantageous, because transportation cost and marketing costs are accounted for and responses to supply and demand are already considered in the trade data simultaneously (Frohberg & Hartmann, 1997). Trade data tends to be more widely available than farm level data due to the more challenging nature of collecting data at the farm level. Frohberg and Hartmann (1997) discussed various indicators of competitiveness, including the real exchange rate. The real exchange rate is an indicator of how much international competitiveness has changed over the examined period. However, the authors acknowledge that this measure is primarily affected by capital movements, rather than the conditions of the relevant economies.

Feuz and Skold (1990) conclude there are three options for farm level research: analyzing data collected from a sample of individual farms, aggregate data, or by using synthetic farms. Individual farm data is a useful indicator of the competitiveness of that farm in particular. One can be fairly confident that results reflect reality for that group of farms, however broad generalizations based on that group of farms may be inaccurate if care was not taken to ensure the sample was randomized. Additionally, the data requirements for individual farm data is expensive and time intensive. Aggregate data is easy to obtain and low cost, however, it may not actually represent an average farm as variability may be averaged out. Synthetic farms are inexpensive to formulate but may overstate reality. For instance, production may be overstated. If production is overstated, then net income would also be overstated. An alternative is to create a set of typical farms, like *agri benchmark* has done (*agri benchmark*, 2018). *Agri benchmark* creates farms that are representative of national output shares for a typical farm. This thesis will be using typical farms. The appendix contains further information on typical farms in the *agri benchmark* network. Developing a set of typical farms poses challenges, as it can be difficult to develop criteria to classify farms and selection bias can be an issue.

Frohberg and Hartmann (1997) discussed additional issues with cost analysis, such as the challenge that accounting for joint products, such as manure or hides from livestock production, poses in the cost analysis. Gross margins do not necessarily account for quasi-fixed factors of production since this analysis is only done on a single commodity. Many farms produce more than one commodity, so accurately accounting for cost can pose a challenge. Marketing and transportation costs are often not accounted for in farm-level cost analysis, so results must be interpreted carefully. Commodities tend to be bulky and have high transportation costs, so this is a substantial downfall for this type of analysis. Additionally, policies and shocks to aggregate supply and demand can distort this comparison. Care must be taken to properly account for external factors affecting competitiveness at the firm level. Accurately measuring the effect of exchange rates on competitiveness at the farm level poses challenges due to the large amount of exogenous variables.

1.2 Objectives and Hypotheses

This thesis examines competitiveness of corn, wheat, and soybeans between countries for a five-year period (2013-2017). The problem addressed in this study is that governments need to know the competitiveness of their domestic agriculture, and exchange rates make this difficult to do. This study aims to improve government estimates of their agriculture sector's competitiveness by improving the understanding of the effect of exchange rates on cost of production benchmarks. Specific objectives include:

- Use input-oriented DEA methods to calculate technical, allocative, and cost efficiency for a sample of corn, wheat, soybean, corn and soybean, and corn and wheat producing farms for the 5-year average from 2013 to 2017.
- Calculate the efficiency scores for the first and last individual years: 2013 and 2017 and identify if there was under or over-performance in the individual years, relative to the 5-year average.
- Calculate input utilization ratios for direct, operating, and overhead costs to identify under-utilization or over-utilization of resources for each farm.
- Calculate correlation coefficients for farm characteristics and cost efficiency scores. Direct hypothesis testing is difficult, due to the non-parametric approach employed.

1.3 Thesis Organization

The rest of this thesis is organized as follows: Chapter 2 summarizes literature pertaining to efficiency. Chapter 3 provides a brief literature review on competitive advantage, strategic decision making, and exchange rates. Chapter 4 presents the data. Chapter 5 explains the methodology to be used. Chapter 6 presents the results. Chapter 7 provides a discussion and conclusions.

CHAPTER 2. EFFICIENCY LITERATURE REVIEW

2.1 Productivity and Efficiency

Productivity, in its simplest form can be defined as output produced divided by inputs used to produce that output. While this measure is sufficient for processes with a single input and output, an index of inputs or outputs is necessary for processes with multiple inputs or outputs (Coelli et al., 2005). Rising productivity indicates that either fewer inputs are required to produce the same output, or that a higher level of output is produced while inputs remain the same (Rogers, 1998). Total factor productivity involves all factors of production and all outputs, if applicable (Coelli et al., 2005). Partial measures of productivity focus on one factor of production, or output. Care must be taken when interpreting partial productivity measures independently of other inputs or outputs, as they can independently provide a misleading indicator of overall productivity (Coelli et al., 2005).

Productivity establishes the different input and output combinations that are possible, through a production frontier. The production frontier applies to a set of firms at a defined point in time (Rogers, 1998). Efficiency comes into play when identifying where a firm lies relative to that frontier. A firm is technically efficient if it operates on the production frontier. A production frontier may be used to define the relationship between the input and output, typically with the input on the x-axis and the output on the y-axis. Firms that lie below the production frontier are said to be technically inefficient (Coelli et al., 2005). Firms that are allocatively efficient choose a combination of inputs that are efficient. Farrell (1957) proposed that efficiency is comprised of technical and allocative (price) efficiency. Technical and allocative efficiency can be combined to provide a measure of economic (overall) efficiency. Full efficiency occurs when a firm is operating at such a level where no input or output can be improved without worsening some other input or output (Cooper et al., 2011). Cost efficiency is a representation of how much costs can be reduced while producing the same level of output (Lunik, 2015). The ratio of input costs associated with input vectors for the observed case and a technically efficient firm is an index of cost efficiency. If a firm is both technically and allocatively efficient, that indicates the farm is also cost efficient (Coelli et al., 2005). As efficiency rises, so does productivity (Rogers, 1998). Coelli et al. (2005) identify four major models used to study efficiency, a brief explanation of each follows. These four models can be broken into parametric and non-parametric models. Parametric approaches estimate a function using econometrics. Non-parametric functions are estimated using mathematical programming (Coelli et al., 2005).

2.2 Efficiency Types

Four types of efficiency are prevalent in the literature. These measures can be separated into input and output efficiency measures. Input-oriented efficiency measures will be the focus of this thesis. First, technical efficiency refers to the amount of excess inputs, or waste, that can be eliminated without making any input or output worse off (Cooper et al., 2011). A firm's ability to produce the maximum output for a given set of inputs, and thus be at the highest production frontier level, is technical efficiency. Next, cost allocative efficiency reflects the firm's ability to choose the optimal combination of inputs, given the prevailing input prices and technology available. Revenue and profit allocative efficiency can also be used, but the focus of this thesis will be on cost allocative efficiency. Allocative efficiency from this point forward refers to cost allocative efficiency. If a firm is both technically and allocatively efficient, it is cost efficient. Cost efficiency serves as an overall measure of economic efficiency. Cost efficiency is the product of technical and allocative efficiency measures. If a firm is cost efficient, that implies that it is producing at the lowest possible cost given a level of output (Coelli et al., 2005). Competitiveness has a cost connotation, as prices will change with exchange rates, but costs will remain similar. Thus, cost efficiency will be the focus of this thesis. Finally, scale efficiency refers to the size of the firm. If a firm faces increasing returns to scale, that indicates the firm is too small and should increase in size. If the firm is too large, the firm may operate with a decreasing return to scale production function. A firm could be allocatively and technically efficient and not have scale efficiency, due to size not being optimal (Coelli et al., 2005).

These measures of efficiency are relative, as the most efficient farm is limited by the data used to generate the benchmark. More efficient farms can exist, however the farms in the dataset will be benchmarked against the best performing firm in the data set (Jaforullah, 1999). Efficiency scores range from 0 to 1, with a score of one indicating that a firm is efficient (Hu et al., 2014).

2.3 Efficiency Models

The least-squares econometric production model is a parametric approach. Regression approaches specify production technology in the regression equation, the residuals are used to estimate total factor productivity (Lunik, 2015). This approach can be used to measure technical efficiency, but not allocative efficiency. When a parametric approach is used, a functional form is assumed. Solow (1957) concluded the Cobb-Douglas and semi-logarithmic forms were most representative, when looking at correlations, of the functional forms analyzed. Additionally, Solow (1957) found that a linear functional form was a systematically poor fit. There are drawbacks to a Cobb-Douglas functional form, such as assuming constant production elasticities across all units and only allowing a single aggregated crop and livestock output (Coelli et al., 2005).

Total factor productivity indices, a non-parametric approach, can be created and used across time or across firms or enterprises (Coelli et al., 2005). Binary comparisons can be conducted with the indices, such as comparing across two-time periods. There are multiple methods that can be used to calculate total factor productivity indices, such as the Fisher index, Malmquist index, or the Törnqvist index approaches. This approach is limited to measuring efficiency, technical change, or scale effects. However, this method can be used to compute total factor productivity change (Coelli et al., 2005).

Data envelopment analysis (DEA) uses linear programming and is used to create a non-parametric piece-wise linear frontier over the data (Coelli et al., 2005). A best practice benchmark is created using linear programming and data from one or more farms (Jaforullah, 1999). DEA can be used to calculate technical and allocative efficiency, technical change, scale effects, and total factor productivity change (Coelli et al., 2005). The efficiency measures are calculated relative to the piece-wise frontier. The original DEA model, proposed by Charnes, Cooper, and Rhodes (1978), used the efficiency measures developed by Farrell (1957). Charnes, Cooper, and Rhodes (1978) assumed constant returns to scale. Later papers proposed variable returns to scale models (Färe et al., 1983; Banker et al., 1984). The DEA frontier is flexible, which can be an advantage, relative to the other approaches summarized here. However, this can be a problem when working with small data sets as the weights assigned to variables may not be realistic. To remedy this problem, additional restrictions on shadow prices can be inserted into the model, as proposed by Dyson and Thanassoulis (1988) and Wong and Beasley (1990). The

DEA approach is limited by the sample, as the efficiency scores are relative to the best performing firms in the sample (Coelli et al., 2005).

The final approach Coelli et al. (2005) discuss is stochastic frontier analysis (SFA). SFA is a parametric approach and can account for noise. This method can be used to measure technical change and efficiency change, when using panel data. In 1977, two teams (Aigner, Lovell, & Schmidt; Meeusen & van den Broeck) proposed a stochastic frontier production function model form where the logarithm of output is a function of an error term, representing technical inefficiency, and a random error term, accounting for noise. Stochastic frontier models can be used to conduct conventional tests of hypotheses. A limitation of this approach is that a functional form must be specified for the production or cost function. Additionally, a distributional form must also be specified for the inefficiency term (Coelli et al., 2005).

Tauer and Hanchar (1995) used a Monte-Carlo simulation of non-parametric efficiency to test whether results of technical efficiency studies are different than randomly generated data. Results of efficiency studies can vary based on the number of firms, inputs, and outputs defined. Tauer and Hanchar (1995) found that when more firms are included in the analysis, efficiencies decrease. Additionally, when more inputs are added, more firms are technically efficient. For instance, Tauer and Hanchar found that more than half of the firms were technically efficient when 15 inputs and a single output were used. On average, less than 5 percent of firms were efficient when three inputs were used in the 200 firm scenario. This result was consistent across 25, 50, 100, and 200 firms. Additionally, Tauer and Hanchar (1995) found that when outputs increased from one to three, more firms were efficient. Dimensionality of the input and output spaces increases as the number of outputs increase, leading to an increase in efficiency scores.

2.4 Previous Applications

The techniques discussed previously have been used in many studies in both agricultural and non-agricultural applications. Agricultural applications include efficiency in the dairy industry (Jaforullah, 1999), Chinese agriculture (Mao & Won, 1997), and corn and soybeans (Lunik & Langemeier, 2015; Hu et al., 2014). Non-agricultural applications include electricity distribution (Kuosmanen et al., 2013), healthcare (Ozcan, 2014), and telecommunications (Giokas and Pentzaropoulos, 2008). Liu et al. (2013) identified five major applications of DEA: banking, health care, agriculture, transportation, and education.

There is ongoing debate on how farm attributes affect efficiency. The relationship between farm scale and efficiency has been extensively researched. One study analyzed farms producing corn, soybeans, livestock, and other crops and found small family farms tend to be less efficient than large farms (Paul et al., 2004). This study found other factors, such as farmer characteristics to have a less definitive impact on efficiency. Smaller farms tend to have relatively low labor productivity, causing higher inputs per acre (Steensland & Zeigler, 2017). Additionally, small-scale farms may over-utilize labor due to limited off-farm employment opportunities in rural areas. Another study found that small farms face heightened competition from large farms, as small farms are facing declining profitability and productivity when compared to larger farms (Mugera et al., 2016). Smaller farms also tend to be less technically efficient than larger farms (Mugera & Langemeier, 2011).

Baležentis, Kriščiukaitienė, and Baležentis (2000) concluded that crop farms were less efficient than more specialized farms, such as livestock farms. An inverse relationship between land productivity and farm size was also found by Li et al. (2013). This study found a positive relationship between labor productivity and farm size. The positive relationship could be caused by a lack of off-farm employment opportunities, and the tendency of farmers to ignore their own labor cost (Li et al., 2013).

The role of other farm characteristics on farm performance have also been studied. Issues such as farmer education (Wilson et al., 1998), levels of debt (Langton, 2012), and succession planning (Wheeler et al., 2012) can impact farm performance.

Previous research by Hu et al. (2014) used *agri benchmark* data to examine the cost efficiency of corn production in 2012 using DEA. Hu et al. (2014) used the quotient of gross revenue and corn price as a measure of output for the typical farms. Inputs were broken into eight categories: seed, nitrogen, phosphorus, potassium, plant protection, other direct inputs, labor, and miscellaneous. Five farms out of the 32 typical farms in the sample had a cost efficiency index of one, indicating those farms are operating at an efficient level. Farms operating at a cost efficiency one standard deviation below average had a higher input cost share for labor and miscellaneous cost. Furthermore, negative correlation was found between the input cost share for labor and cost efficiency. The authors concluded that labor was over-utilized, while direct inputs were under-utilized.

Lunik and Langemeier (2015) also used *agri benchmark* data in the analysis of corn and soybean production over a six-year time frame from 2008 to 2013. This analysis also calculated the implicit output quantity by dividing gross revenue by crop market price. Inputs were broken into seven categories: seed, fertilizers, crop protection, labor, land, fixed capital, and other direct inputs. Cost efficiency diminished over the time period for both corn and soybeans. Technical efficiency was a larger concern than allocative efficiency in most of the years analyzed. Fixed capital and seed tended to be over-utilized for corn and soybean production, respectively.

Lunik (2015) expanded the analysis of Lunik and Langemeier (2015) using *agri benchmark* data for the 2008 to 2013 period. Output was measured in two ways: implicit output (t/ha) and total output produced (t). Implicit output efficiency scores were lower than scores calculated using total output. When using implicit output for corn production, average allocative and technical efficiency scores were lowest in 2013. A similar situation was observed in the implicit output for soybean production, average allocative efficiency scores were lowest in 2013, and average technical efficiency scores were second lowest in 2013. When corn and soybeans were analyzed together, efficiency scores improved in comparison to the single-crop model. Geographical regions were significant in determining technical efficiency for soybean farms, as South American farms had a mean that was significantly different from North America and Europe. The geographical difference could indicate technology differences across the regions.

CHAPTER 3. COMPETETITIVE ADVANTAGE LITERATURE REVIEW

Individual farms in a particular country may have a comparative advantage due to competitive advantage, effective strategies, and/or exchange rates. Examples of competitive advantage are high quality soils, educated and experienced employees, and access to the latest technologies. Effective strategies involve choosing a direction for the farm that fully utilizes the business's strengths and that fits the current external environment. Changes in exchange rates can have a large impact on comparative advantage. Specifically, imports from countries with relatively weak currencies have a relative advantage. Whether this relative advantage pertaining to exchange rates is large enough to offset competitive disadvantages is an empirical question.

3.1 Competitive Advantage

Competitive advantage is achieved through innovation (Porter, 1990). Innovation includes new technologies and new methods, or ways of doing things. Sometimes ideas already exist, but are applied differently or were not pursued until recently. Once competitive advantage is achieved, the firm must continuously improve to sustain the advantage. Competitive advantage is impacted by a variety of macroeconomic elements. On an international scale; exchange rates, economies of scale, labor costs, and interest rates are all determinants of competitiveness (Porter, 1990).

Porter (1985) identifies three strategies a firm can use to obtain a competitive advantage: low cost, differentiation, or focus. If a firm pursues a low-cost strategy, the firm works towards becoming the lowest cost producer in the field. To become the low-cost producer, the firm needs to discover and exploit all possible cost advantage sources. To be obtain an advantage, the firm must be the only cost leader instead of competing with several other low-cost firms with the same strategy. This strategy is primarily useful if a firm obtains a major technological advantage and can change its cost position. Differentiation requires the firm to select one or several attributes that are important to buyers and positions itself to meet the needs of those buyers. Differentiation rewards uniqueness with a price premium. To sustain differentiation, the price premium must exceed the cost of differentiation. The final strategy Porter (1985) discusses is focus, where a firm excludes segments of the market to concentrate on one target segment. By limiting the market, the firm is able to provide the desired quality to meet the needs of the segment.

Porter (2008) establishes five forces that shape industry competition: rivalry among existing competitors, bargaining power of suppliers, bargaining power of buyers, threat of substitute products or services, and threat of new entrants. If an industry faces strong forces, then few companies earn attractive returns on investment. Rivalry is most intense if competitors are approximately equal in size and power or if there are many competitors. Additionally, slow industry growth increases rivalry. Exit barriers increase rivalry because firms stay in the market even when facing low returns or realizing a loss. Nearly identical products with low switching costs for buyers are most liable to price competition (Porter, 2008). This is the case within agriculture, as farmers are price takers and compete on the basis of cost (Miller et al., 1998). If competitors compete on the same dimensions of rivalry, zero-sum competition results. Porter (2008) points out that competition can increase profitability for an industry when competitors compete on different dimensions and are able to serve diverse customer groups.

3.2 Strategic Decision Making

To remain in business, farms need to be efficient and make strategic decisions in order to compete and reach long-term objectives (Boehlje et al., 2004). Farm businesses can create a competitive advantage that is sustainable by understanding the business' strengths and weaknesses. A sustainable competitive advantage is obtained when the business has a resource or capability that is valuable, rare, costly to imitate, and is non-substitutable by other businesses (Gray et al., 2004). Porter (1996) argues that the only way for a company to outperform rivals is if the company can establish a difference that it can preserve over time. A farm's internal strengths can be tangible, such as equipment or skilled employees, or intangible, such as reputation (Gray et al., 2004). Farm managers can cultivate a competitive advantage through strategic planning. Three strategic planning objectives are to: identify the desired state of the business in the future, hypothesize where the business will end up if the current business strategy is continued, and to recognize key assumptions about the future (Dobbins & Ehmke, 2004). Efficient operations and technology adoption help farms to do things right, strategic planning helps businesses to do the right thing (Miller et al., 1998). For many businesses, there is a gap between where the farm wants to be in the future and where it is currently (Ehmke et al., 2004). The focus of strategic planning is on making better decisions today in order to reach a desired future (Dobbins et al., 2004). For a plan to be effective, it must be implemented and continuously evaluated going forward (Miller et al., 1998).

To facilitate the strategic planning process, portfolio analysis and competitive analysis methods can be utilized. Portfolio analysis aids the decision maker in making allocation decisions when investing in different enterprises within the farm. From a strategic standpoint, determining what resources are available and deciding how to allot the resources in the best way is a crucial decision. Competitive analysis methods profile what other firms are doing and is used to evaluate the farm's weaknesses and strengths (Miller et al., 1998). Knowing the competitive position of a business aids the decision maker in determining the strategic option to use.

Benchmarking the farm's performance against the competition can also be used to aid strategic planning decisions. Benchmarking can highlight and promote adoption of best practices within the industry. However, Tucker et al. (1987) caution that benchmarking may not help a business beat competitors. Emulation would result in the business meeting, rather than surpassing, the competitor's performance. Horizontal benchmarking can allow a firm to compare enterprises within itself and is an option for farms making decisions on improving overall performance, rather than financial performance (Franks & Haverty, 2005).

3.3 Exchange Rates in Agriculture

An exchange rate is defined as "the number of units of foreign currency that can be purchased with one unit of the home currency" (Abel et al., 2011, p. 617). Thus, exchange rates are relative to the two currencies being compared. A strong currency is "a currency whose value compared to other currencies is improving as indicated by a decrease in the direct exchange rates for the currency" (NASDAQ). Thus, a weak currency would be defined as one whose value is declining compared to other currencies. Calomiris (1999) defines a weak currency as "one that will not retain its value against the dollar." However, as Adler and Dumas (1984) point out, the risk associated with currency is not necessarily determined by whether the currency is strong or weak, but rather, the unexpected exchange rate variations associated with the currency.

In 1974, Schuh wrote that exchange rates were an important variable that had long been omitted in prior research of agriculture and trade in the United States. Josling et al. (2010) hypothesize this gap in research could be caused by the prevalence of fixed exchange rates prior to 1969. Since then, the effect of exchange rates on agricultural trade and development in the U.S. has been of increasing interest to researchers.

Exchange rates can affect competitiveness within industries. As exchange rates change, prices also change and can effectively change the terms of competition for domestic exporters competing with foreign firms (Bodnar & Gentry, 1993). The influence exchange rates have on profitability varies by industry factors, such as reliance on international trade, type of markets inputs are obtained from, and foreign investments.

In general, when the U.S. dollar depreciates, agricultural exports increase as U.S. goods become relatively less expensive abroad (Headey, 2011). The weak dollar and increase in exports may lead to higher food prices domestically. Abbott et al. (2009) found that 50 percent of the food price increase in 2008 was due to the weak dollar at the time, although they admit that causality is difficult to determine. Commodity prices and exchange rates are affected by similar indicators and are determined at the same time. There is not a consensus on the size of the impact exchange rates have on determining agricultural prices and exports. Ojede (2015) argued that exchange rate shocks have a small impact on agricultural exports. Additionally, Ojede (2015) concluded that the shocks impact the service industry more than agricultural exports. Gilbert (2010) argues that exchange rate changes play a role in determining world agricultural prices. Although exchange rate effects are consistent over time, the impact on world agricultural prices is relatively small (Gilbert, 2010).

CHAPTER 4. DATA

4.1 Data Overview

The *agri benchmark* network provided the data for the analysis. The group collects data on fish, horticulture, swine, dairy, cash crops, beef, sheep, and organic production with 38 countries represented in the network. The *agri benchmark* network constructs typical farms for each region or country using a standard procedure for each country. Regional statistics and farm-level surveys are used to construct a representative typical farm for each country. The appendix provides additional detail on the *agri benchmark* typical farm methodology.

The analysis in this thesis will focus on direct, operating, and overhead inputs from 2013 to 2017 for samples of farms producing corn, soybeans, wheat, or both corn and soybeans or corn and wheat. This thesis will not include farms producing both wheat and soybeans, as only seven farms in this dataset produced both crops in every year analyzed. The data is provided for each crop the farm produces in a given year. Specifically, this thesis uses a sample of 24 corn producing farms representing 13 countries, 15 soybean producing farms representing 8 countries, 38 wheat producing farms representing 19 countries, 13 corn and soybean producing farms representing 6 countries, and 17 corn and wheat producing farms representing 12 countries. This thesis does not include all crops that each farm produced in this time period. For instance, one of the Argentinian typical farms, AR700SBA, produced soybeans, corn, wheat, and sunflowers. The sunflowers were not included in this thesis. The countries represented in each crop group are summarized in Table 4.1. All farms represented in this study have at least five years of enterprise level data available for the crop in question. The farm abbreviations used by *agri benchmark* indicate the country, size of farm, and location within the country. For instance, US1215INS indicates the farm is located in the United States, is 1215 hectares in size, and is in southern Indiana. The data are in nominal dollars. Given the relatively short time frame of this analysis (i.e., 5 years), the effect of inflation is assumed to be minimal.

Implicit prices were calculated for each year and each farm. If the relevant data were available, the implicit input price was calculated by dividing the cost by the input quantity. The implicit input prices were calculated for three cost categories: direct cost, operating cost, and overhead cost. Direct costs include seed, fertilizer, pesticides, crop insurance, irrigation, and interest on direct cost items. Operating costs consist of hired labor, family labor, contractor expense, diesel, energy, and machinery depreciation and interest. Overhead costs include land, building depreciation and interest, property taxes, and general insurance. Land quality varies as climate and soil variations exist on an international scale, this thesis assumes these differences are captured by the prices paid for land. For instance, this thesis assumes highly productive land would cost more than land of a lower quality in a less productive location. Quantity data was not available for every input, as shown in Table 4.2. All inputs were assumed to be variable.

Input prices were first calculated on an annual basis for each farm and each crop type. The discussion below applies to direct cost, operating cost, and overhead cost categories. The calculations that follow are necessary to aggregate the data into the three cost categories. The cost for a specific cost category is divided by quantity for each input, yielding the input price. For instance, in the direct cost category, the seed cost will be divided by the seed input quantity, yielding the price for seed. This will be calculated for each farm and each year. Where quantity was not available, the law of one price was assumed, as Chavas and Aliber assumed in 1993. The input prices are then averaged across all farms producing the respective crop. Each farm’s individual annual price is then divided by the average price across all farms, creating a price ratio for each input for each farm in every year.

The percentage of the cost category that each cost item accounts for is calculated next. For instance, the operating cost category consists of labor, machinery, diesel, and other energy. The machinery cost would be divided by the total operating cost for each farm, yielding the percentage cost share for each input.

The percentage cost share is then multiplied by the price ratio, discussed previously. The product of the percentage cost share and price ratio is summed across the cost category, yielding the weighted input price for the cost category. The weighted input price is then used as the price for the respective input category. The total cost of inputs within the category is divided by the weighted input price, yielding the input quantity for the farm.

Outputs were based on total revenue for each farm. Each farm's total revenue was divided by the crop price to yield the output quantity for each farm. Total revenue includes crop receipts, crop insurance indemnities, and direct government payments. The crop price used was the farm gate price. This thesis assumes variations in location of farms, specifically the proximity to grain buyers or ports, is captured within the farm gate price.

For three farms (Corn: CZ4000JC, Wheat: BG7000PLE and CA6000SAS), multiple data points, per crop, per year were available. For instance, in the case of the Canadian wheat farm, both durum and summer wheat were grown in a single year. To adjust the data accordingly, the average of the respective cost category was weighted by the acreage of each crop variety.

The exchange rate values also came from the *agri benchmark* network's data. Table 4.3 shows the exchange rate against the U.S. Dollar for the five-year time period being analyzed in this thesis. As such, the exchange rate for the U.S. Dollar appears as 1 in Table 4.3. The

Vietnamese Dong's average exchange rate against the U.S. Dollar in this time period was 0.000046, but appears as zero in Table 4.3 due to rounding. This thesis examines efficiency for the five-year period from 2013 to 2017, as well as the years 2013 and 2017 individually given the variance in exchange rates that appears between the two years.

4.2 Corn Overview

Twenty-four typical farms producing corn had data available for all five years. The following countries are represented in the analysis: Argentina (3), Bulgaria (1), Brazil (2), Czech Republic (1), France (2), Hungary (1), Poland (1), Romania (1), Ukraine (1), United States (5), Uruguay (2), Vietnam (1), and South Africa (3). If multiple typical farms from one country were included, different regions were represented. For instance, the United States farms in this sample were located in: Central Indiana, Southern Indiana, North Dakota, Kansas, and Iowa.

Table 4.4 contains details of the corn producing farms analyzed in this thesis. The values in Table 4.4 represent the mean of all corn farm's five-year average for each respective variable. On average, approximately one-third of the total farm acres were planted to corn. Gross margin is calculated as the gross revenue minus the total direct costs. Table 4.4 also shows that the mean gross margin was positive for the farms in this sample. Average implicit output per hectare multiplied by hectares in corn production is used as the output for the efficiency analysis. The mean of profit in the sample, as computed as return to management or economic profit was negative. Economic profit subtracts the three cost categories (direct, operating, and overhead cost) from total revenue. This measure of profit is not equivalent to accounting earnings, as it accounts for all factors employed in production, such as family owned inputs like labor and capital. A negative profit indicates the typical farm was operating at a loss in the production of that particular crop. Nine farms realized a positive average profit over this time period. All of the Argentinian farms analyzed in this thesis realized a positive average profit. The Ukrainian farm, Vietnamese farm, United States Kansas farm (US2025KS), and two of the South African farms (ZA1600EFS, ZA1700WFS) also had a positive average profit for corn production over the time period.

Figure 4.1 shows the relationship between average acreage and average profit in the time period analyzed in this thesis. In this data, smaller farms have a wider range of average profitability over this time period. The large, profitable outlier was the Ukrainian farm. Variable returns to scale are assumed in this thesis. Smaller corn farms had a wide range of profitability, compared to mid-sized or larger farms in this sample.

Detailed cost, price, and quantity information for the average of all of the corn farms included in the analysis are illustrated in Table 4.5. Standard deviations of zero and prices of one indicate that complete data were not available, hence the law of one price was assumed. In the case of potash; input and cost data were missing, or incomplete for 10 farms. A price of one was assumed for potash, given the missing data points. Because the data in Table 4.5 is on a per hectare basis, the input level for land is one for all farms.

Table 4.6 shows the cost, price, and implicit quantity for each of the three cost categories (direct cost, operating cost, and overhead cost) on a per hectare basis, for ease of illustration. The values calculated in Table 4.6 are based upon the five-year average for each of the corn producing farms analyzed in this thesis. Direct cost was the largest cost category for corn farms in this analysis. Direct cost, operating cost, and overhead cost accounted for 42%, 33%, and 24% of total cost, respectively.

Production costs, input prices, and implicit input quantities are shown in Table 4.7. These values were inputted into GAMS for the analysis of this thesis.

Figure 4.2 shows the input cost share for the three cost categories: direct cost, operating cost, and overhead cost in corn production. Direct costs included seed, fertilizer, pesticides, energy, irrigation, crop insurance, and finance cost. Operating costs included machinery, diesel, and labor. Overhead cost included buildings, land, and miscellaneous costs. On average, direct costs accounted for the largest share of direct costs, at 43.5 percent. Operating costs were the next largest category, at 32.4 percent of total costs. Overhead costs accounted for 24.1 percent of total costs in corn production. The typical farm in Kansas (US2025KS) had the largest percentage cost for direct costs, at 59.6 percent of total cost. The typical farm from Bulgaria (BG7000PLE) had the smallest percentage of total cost spent on direct cost, at 31.2 percent. The small Argentine farm (AR330ZN) had the lowest percentage of total cost spent on operating costs (20.8 percent), but the largest percentage of total costs spent on overhead costs (40.4 percent) in this sample of farms. The typical farm in Vietnam (VN3LM) had the highest percentage total cost spent on operating cost (51.1 percent) and the lowest percentage spent on overhead cost (12.9 percent).

4.3 Soybean Overview

Fifteen typical farms produced soybeans and had data available for every year in the five-year time period. Eight countries are represented in the soybean analysis: Argentina (3), Brazil, (2), Canada (1), Romania (1), Ukraine (1), United States (4), Uruguay (2), and South Africa (1). Table 4.8 details the soybean typical farm output in the sample. Eleven of the farms earned a positive average profit over the time period. Four farms earned a negative profit: one Brazilian farm (BR65PR), the Iowa farm (US700IA), one Uruguayan farm (UY360CEN), and the South African farm (ZA1600EFS). Average implicit output per hectare multiplied by hectares in corn production is used as the output for the efficiency analysis.

The relationship between profitability and acreage is shown in Figure 4.3. The range of profitability was smaller in comparison to corn, especially for smaller farms. One of the Brazilian farms (BR1300MT) and the Ukrainian farm (UA2600WU) were the largest soybean producers in this sample. Compared to corn farms, there appears to be more of an increasing returns to scale trend in the soybean producing farms in this sample. All farms producing more than 400 hectares of soybeans earned a positive profit.

Table 4.9 contains detailed information on soybean inputs in the sample on a per hectare basis. Since Table 4.9 is presented on a per hectare basis, the input quantity for land is 1.00, as land is measured in hectares. Seed was the largest direct cost over this time period for soybean producers on a per hectare basis. The typical farm from Romania had the highest seed cost per hectare. Three farms in the sample (RO6500IL, BR1300MT, BR65PR) had an average irrigation cost that was greater than zero, indicating irrigation was used in soybean production for those three farms. The Romanian farm average irrigation cost was approximately ten times higher than either of the Brazilian farms' average irrigation cost.

Table 4.10 shows the cost, input price, and implicit input quantity on a per hectare basis for direct cost, operating cost, and overhead cost. The table is on a per hectare basis, for ease of illustration. Total costs follow in Table 4.11. Direct cost, operating cost, and overhead cost accounted for 32%, 33%, and 35% of total cost, respectively.

Table 4.11 shows production costs, input prices, and implicit input quantities for soybeans. The information in Table 4.11 was inputted into the GAMS model to estimate efficiency indices.

Figure 4.4 shows the input cost shares for the three cost categories: direct cost, operating cost, and overhead cost in soybean production. On average, overhead costs accounted for the largest percentage of total cost at 35.1 percent of total costs. Direct costs accounted for 33.2 percent of total costs, and operating costs accounted for 31.8 percent. Direct costs ranged from 20.7 percent (AR700SBA) to 58.7 percent (BR65PR). Operating costs ranged from 21.7 percent (US1215INS) to 46.1 percent (US1215INC). Overhead costs ranged from 16.4 percent (BR65PR) to 51.8 percent (AR700SBA).

4.4 Wheat Overview

Data were available for thirty-eight wheat producing typical farms over the time period. Nineteen countries were represented in the dataset, as shown in Table 4.12.

Table 4.13 shows the farm characteristics for the typical farms producing wheat used in this thesis. Average implicit output per hectare multiplied by hectares in corn production is used as the output for the efficiency analysis. Fourteen of the 38 wheat producing farms earned a positive average profit over the five-year time period. Twenty-four of the typical wheat farms earned a negative average profit over this time period. The Japanese farm realized the largest average profit over this time period, at $1,988.46 per hectare. One of the Ukrainian farm (UK310WASH) had the largest negative average profit over this time period, at -$632.61 per hectare.

Figure 4.5 shows the relationship between profitability and acreage. The Japanese farm (JP45HO) was the most profitable over this time period, and produced a strikingly small acreage of wheat, at an average of just 15 hectares. However, it’s worth mentioning that the Japanese farm was small to begin with, as the total farm was 45 hectares. The typical Japanese farm was excluded from Figure 4.5 for clarity. The largest farm in the sample was the typical farm from Bulgaria (BG7000PLE), which earned a negative average profit of -29.62 dollars per hectare over the 5-year period. Farms producing less than 500 hectares of wheat had a much wider range of profitability than larger farms in the sample, like the soybean producing farms. This suggests that increasing returns to scale may exist in wheat production in this sample of farms.

Table 4.14 shows the average inputs used in wheat production on a per hectare basis. Nitrogen was the largest average input cost within the direct costs in this sample. The Japanese typical farm had the highest average cost for seed, nitrogen, phosphorus, potash, pesticides, irrigation, crop insurance, and other direct cost out of the wheat producing farms in this sample. Overall, the typical Japanese farm had the highest cost for all input categories except lime, other fertilizer, energy, finance cost, hired labor, other energy, and buildings. The Japanese farm had a much higher average profit than the other farms in the sample, due in part to the amount of subsidy payments received by the Japanese farms. The Japanese farm also had a smaller acreage in comparison to the other wheat farms in the sample.

Wheat production costs on a per hectare basis are shown in Table 4.15, and total wheat production costs follow in Table 4.16. Direct cost, operating cost, and overhead cost accounted for 34%, 37%, and 29% of total cost, respectively.

Table 4.16 shows the average wheat production costs, input prices, and implicit input quantities over the 5-year average time period. The information shown in Table 4.16 was inputted into the analysis.

Figure 4.6 shows the input cost share for the three cost categories: direct cost, operating cost, and overhead cost in wheat production. On average, operating costs accounted for the largest percentage of total cost at 36.6 percent. Operating costs ranged from 18.3 percent (US1215INS) to 56.1 percent (ZA1600EFS). Direct costs accounted for 34.1 percent of total costs, and ranged from 22.1 percent (DE120HI) to 46.6 percent (JP45HO). Overhead costs accounted for 29.3 percent of total costs and ranged from 17.6 percent (CZ4000JC) to 45.8 percent (AR330ZN).

4.5 Corn & Soybeans Overview

Data for the combined corn and soybean analysis was assembled in a similar way the single crop data was assembled, presented previously in Section 4.1. However, instead of weighting the values by acreage when multiple data points were present, all of the data were weighted by total cost. Two outputs will be used in the GAMS model: the implicit output for corn and the implicit output for soybeans. Table 4.17 illustrates the farm characteristics for farms that produced both corn and soybeans.

Thirteen farms produced both corn and soybeans every year between 2013 and 2017. Six countries are represented in the dataset: Argentina (3), Brazil (2), Romania (1), United States (4), Uruguay (2), and South Africa (1).

Table 4.18 shows the components of direct cost, operating cost, and overhead cost. Seed accounted for the largest share of direct costs in corn and soybean production in this sample. As indicated in Section 4.3, three farms in the sample (RO6500IL, BR1300MT, and BR65PR) had an average irrigation cost that was greater than zero, indicating irrigation was used in soybean production. In this sample, the Romanian farm (RO6500IL) had a positive irrigation cost in corn production, indicating the corn was also irrigated.

Table 4.19 shows the production costs, input prices, and implicit input quantities for the three cost categories on a per hectare basis. Direct cost, operating cost, and overhead cost accounted for 38%, 30%, and 32% of total cost, respectively.

Table 4.20 shows the production costs, input prices, and implicit input quantities for corn and soybeans. This information was used to estimate efficiency.

Figure 4.7 shows the input cost share for the three cost categories: direct cost, operating cost, and overhead cost in corn and soybean production. Direct costs accounted for the largest percentage of total costs, on average at 38.7 percent. Operating costs and overhead cost shares were very close, at 30.4 percent and 30.8 percent, respectively.

4.6 Corn & Wheat Overview

Information for corn and wheat production was compiled using the same method as corn and soybean production, presented in section 4.5. Seventeen farms produced both corn and wheat over the five-year time period: Argentina (3), Bulgaria (1), Brazil (1), Czech Republic (1), France (2), Hungary (1), Poland (1), Romania (1), Ukraine (1), United States (3), Uruguay (1), South Africa (1). As with the combined soybean and corn data, the corn and wheat data will use the two outputs shown in Table 4.21.

Table 4.22 shows the components of direct cost, operating cost, and overhead cost on a per hectare basis. The largest direct cost for corn and wheat production in this sample was seed at an average cost of 126.74, followed by nitrogen at 125.26 dollars per hectare. The largest component of operating cost was machinery. Land was the largest component of overhead cost per hectare.

Cost, input prices, and implicit input quantity for the three cost categories are shown in Table 4.23 for corn and wheat production on a per hectare basis. The largest cost category for corn and wheat production was direct cost. Direct cost, operating cost, and overhead cost accounted for 41%, 34%, and 25% of total cost, respectively.

Production costs, input prices, and implicit input quantities for corn and wheat production are shown in Table 4.24. These inputs will be used in the GAMS efficiency model for the three inputs.

Figure 4.8 shows the input cost share for the three cost categories: direct cost, operating cost, and overhead cost in corn and wheat production. On average, direct costs accounted for the largest percentage of total costs, on average at 41 percent of total costs. Operating costs accounted for 33.1 percent of total costs in corn and wheat production. Overhead costs accounted for the smallest share of total costs, at 25.9 percent.

Chapter 4 Figures:

Table 4.1. Countries Represented by Crop Type

Corn

Country	Abbreviations
Argentina	AR
Bulgaria	BG
Brazil	BR
Czech Republic	CZ
France	FR
Hungary	HU
Poland	PL
Romania	RO
Ukraine	UA
United States	US
Uruguay	UY
Vietnam	VN
South Africa	ZA

Wheat

Country	Abbreviations
Argentina	AR
Australia	AU
Bulgaria	BG
Brazil	BR
Canada	CA
Czech Republic	CZ
Germany	DE
Denmark	DK
France	FR
Hungary	HU
Japan	JP
Poland	PL
Romania	RO
Sweden	SE
Ukraine	UA
United Kingdom	UK
United States	US
Uruguay	UY
South Africa	ZA

Soybeans

Country	Abbreviations
Argentina	AR
Brazil	BR
Canada	CA
Romania	RO
Ukraine	UA
United States	US
Uruguay	UY
South Africa	ZA

Corn and Soybeans

Country	Abbreviations
Argentina	AR
Brazil	BR
Romania	RO
United States	US
Uruguay	UY
South Africa	ZA

Corn and Wheat

Country	Abbreviations
Argentina	AR
Bulgaria	BG
Brazil	BR
Czech Republic	CZ
France	FR
Hungary	HU
Poland	PL
Romania	RO
Ukraine	UA
United States	US
Uruguay	UY
South Africa	ZA

Table 4.2. Cost and Quantity Data Availability

Direct Inputs	Cost	Quantity
Seed	✓	✓
Nitrogen	✓	✓
Phosphorus	✓	✓
Potash	✓	
Lime	✓	
Other Fertilizer	✓	
Pesticides	✓	
Energy	✓	
Irrigation	✓	
Crop Insurance	✓	
Other Direct	✓	
Finance Cost	✓	
Operating Cost		
Hired Labor	✓	✓
Family Labor	✓	✓
Contractor	✓	
Machinery	✓	
Diesel	✓	
Other Energy	✓	
Overhead Cost		
Buildings	✓	
Land	✓	✓
Miscellaneous	✓	

Table 4.3. Exchange Rates

Currency		2013	2014	2015	2016	2017
Argentine Peso	ARS	0.183	0.124	0.109	0.068	0.060
Australian Dollar	AUD	0.968	0.902	0.753	0.744	0.766
Bulgarian Lev	BGN	0.678	0.679	0.568	0.566	0.576
Brazilian Real	BRL	0.465	0.426	0.305	0.288	0.313
Canadian Dollar	CAD	0.971	0.906	0.784	0.755	0.770
Czech Koruna	CZK	0.051	0.048	0.041	0.041	0.043
Danish Krone	DKK	0.178	0.178	0.149	0.149	0.152
Euro	EUR	1.328	1.329	1.110	1.107	1.127
U.K. Pound Sterling	GBP	1.564	1.648	1.529	1.356	1.287
Hungarian Forint	HUF	0.005	0.004	0.004	0.004	0.004
Japanese Yen	JPY	0.010	0.010	0.008	0.009	0.009
Polish Zloty	PLN	0.316	0.317	0.265	0.254	0.265
Romanian New Lei	RON	0.300	0.299	0.250	0.246	0.247
Swedish Krona	SEK	0.153	0.146	0.119	0.117	0.117
Ukrainian Hryvnia	UAH	0.121	0.085	0.047	0.039	0.038
U.S. Dollar	USD	1.000	1.000	1.000	1.000	1.000
Uruguayan Peso	UYU	0.048	0.042	0.037	0.033	0.035
Vietnamese Dong	VND	0.000	0.000	0.000	0.000	0.000
South African Rand	ZAR	0.104	0.092	0.079	0.068	0.075

Table 4.4. Corn Farm Characteristics

Variable	Units	Mean	SD	Min	Max
Average Planted Acres of Corn	Percentage of Total Planted Acres	33.59%	21.27%	3.54%	80.51%
Average Total Revenue	(USD/ha)	1,231.77	521.39	483.02	2,425.01
Average Price	Net farm gate prices (USD/t)	149.56	35.31	70.5	234.64
Average Implicit Output	Revenue divided by farm gate price (t/ha)	8.31	2.70	4.50	13.30
Average Gross Margin	Gross revenue minus total direct costs (USD/ha)	667.61	306.8	166.47	1,552.40
Average Profit	Economic profit (USD/ha)	-91.29	248.45	-731.87	264.14

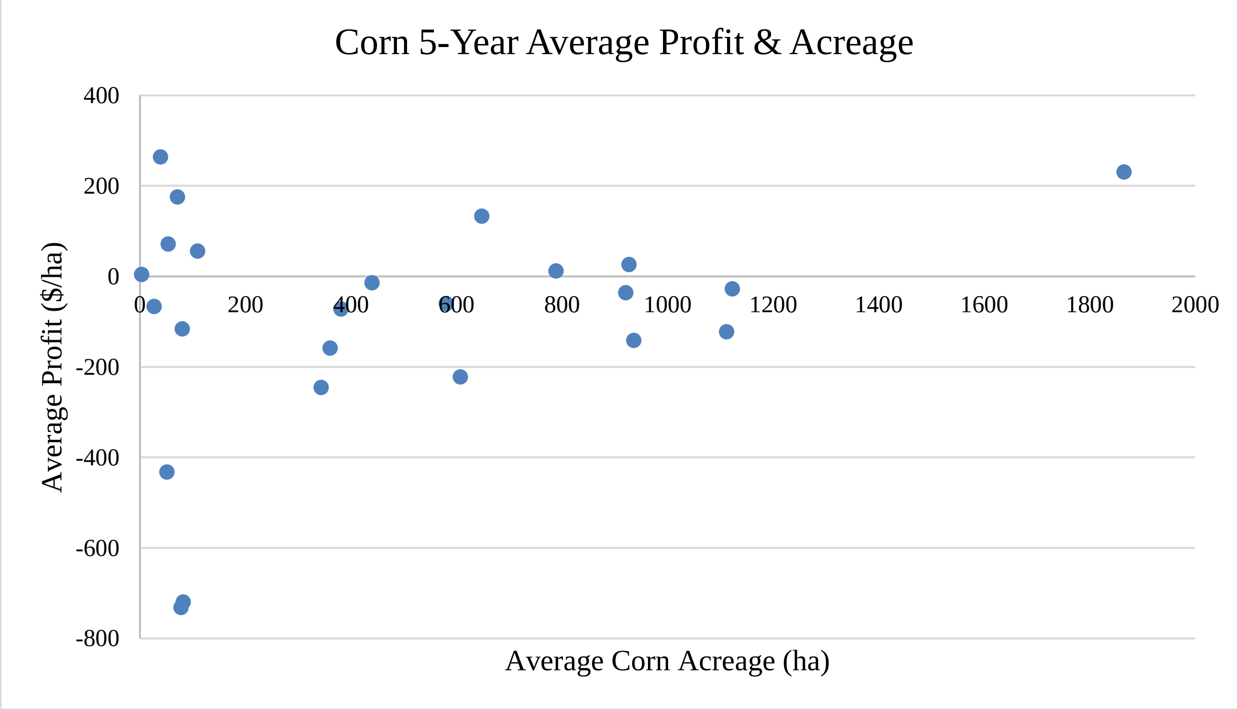

Figure 4.1. Corn Farm 5-Year Average Profit and Acreage (per Hectare)

Table 4.5. 5-Year Average Corn Inputs (per Hectare)

	Average Input Cost		**Average Price**		**Average Input Quantity**	
	Mean	SD	Mean	SD	Mean	SD
Direct Cost						
Seed	163.56	68.37	12.15	22.33	22.90	14.49
Nitrogen	137.07	53.90	1.03	0.27	141.31	65.12
Phosphorus	51.78	27.31	1.86	0.75	28.65	14.97
Potash	29.37	33.74	1.00	-	29.37	33.74
Lime	0.98	3.33	1.00	-	0.98	3.33
Other Fertilizer	2.77	8.16	1.00	-	2.77	8.16
Pesticides	80.32	28.32	1.00	-	80.32	28.32
Energy	35.17	87.65	1.00	-	35.17	87.65
Irrigation	21.16	51.15	1.00	-	21.16	51.15
Crop Insurance	13.65	18.47	1.00	-	13.65	18.47
Other Direct	18.17	41.27	1.00	-	18.17	41.27
Finance Cost	5.66	5.85	1.00	-	5.66	5.85
Operating Cost						
Hired Labor	74.17	127.57	9.64	7.48	29.51	93.41
Family Labor	73.38	123.62	11.97	12.42	14.77	57.01
Contractor	72.17	77.29	1.00	-	72.17	77.29
Machinery	155.88	122.07	1.00	-	155.88	122.07
Diesel	56.70	43.19	1.00	-	56.70	43.19
Other Energy	7.84	11.66	1.00	-	7.84	11.66
Overhead Cost						
Buildings	31.42	53.07	1.00	-	31.42	53.07
Land	232.47	162.03	232.47	162.03	1.00	-
Miscellaneous	54.87	65.41	1.00	-	54.87	65.41

Table 4.6. 5-Year Average Corn Farm Production Costs (per Hectare)

	Mean	SD	Min	Max
Direct Cost	559.65	267.77	304.18	1,222.93
Input Price	1.06	0.64	0.71	4.02
Implicit Input Quantity	586.44	295.21	96.46	1,333.41
Operating Cost	440.14	289.16	159.83	1,235.60
Input Price	1.07	0.25	0.3	1.46
Implicit Input Quantity	529.58	794.43	138.53	4,155.94
Overhead Cost	318.76	193.86	121.9	776.27
Input Price	1.06	0.62	0.53	2.81
Implicit Input Quantity	302.25	120.43	222.72	684.51

Table 4.7. 5-Year Average Corn Farm Total Production Costs

	Mean	SD	Min	Max
Direct Cost	233,922.04	199,918.21	2,617.85	660,451.58
Input Price	1.06	0.64	0.71	4.02
Implicit Input Quantity	225,995.88	193,757.78	2,536.65	622,323.39
Operating Cost	184,052.81	188,899.37	3,706.81	716,657.25
Input Price	1.07	0.25	0.30	1.46
Implicit Input Quantity	181,583.12	207,560.99	5,209.67	800,704.59
Overhead Cost	126,850.49	128,684.45	936.43	403,491.85
Input Price	1.06	0.62	0.53	2.81
Implicit Input Quantity	127,064.18	121,474.77	766.36	423,511.51

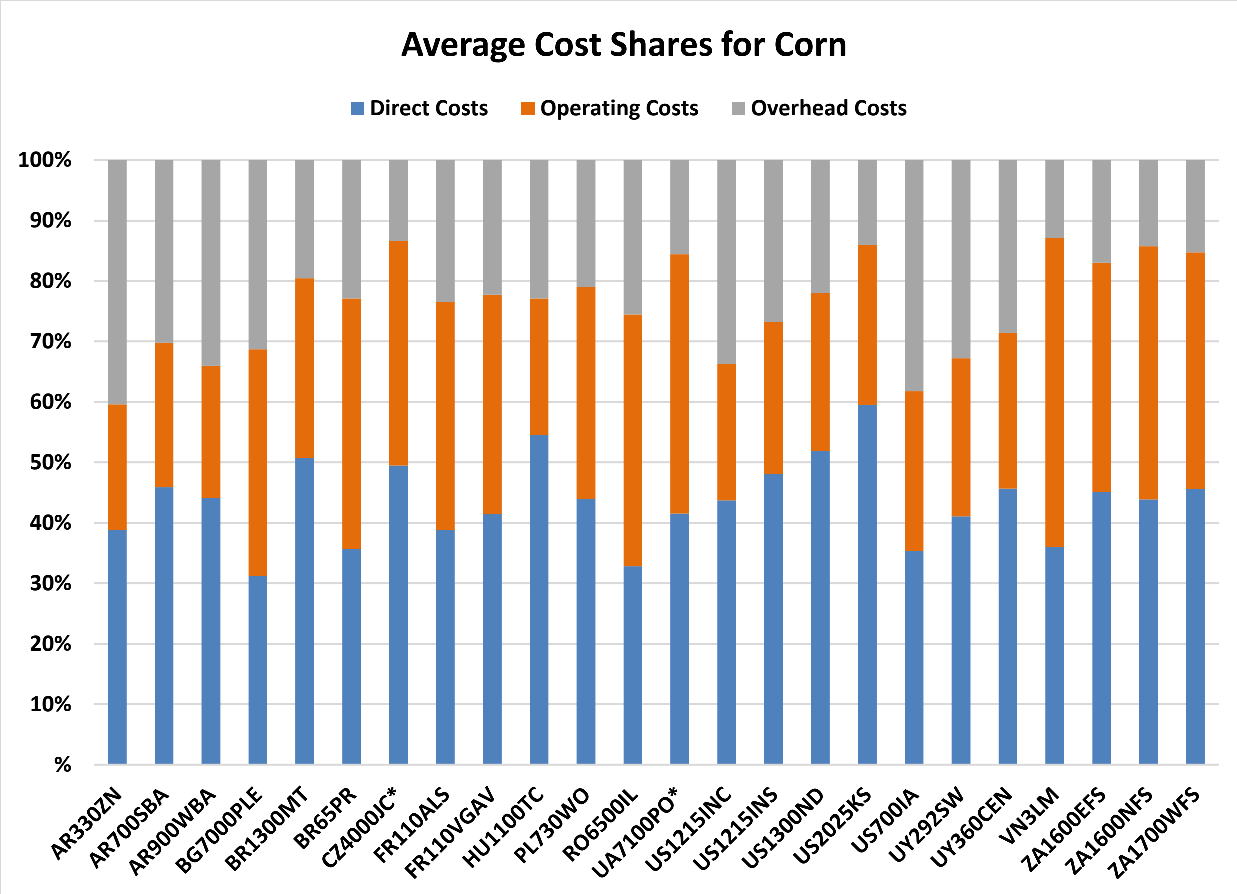

Figure 4.2. Corn Average Total Cost Shares.

Table 4.8. Soybean Farm Characteristics

Variable	Units	Mean	SD	Min	Max
Average Planted Acres of Soybeans	Percentage of Total Planted Acres	42.71%	16.87%	7.47%	62.54%
Average Total Revenue	(USD/ha)	944.19	313.72	463.67	1,476.84
Average Price	Net farm gate prices (USD/t)	333.23	66.91	199.29	436.03
Average Implicit Output	Revenue divided by farm gate price (t/ha)	2.86	0.77	1.68	3.94
Average Gross Margin	Gross revenue minus total direct costs (USD/ha)	655.68	221.65	345.56	1,042.38
Average Profit	Economic profit (USD/ha)	60.13	100.73	-159.02	203.13

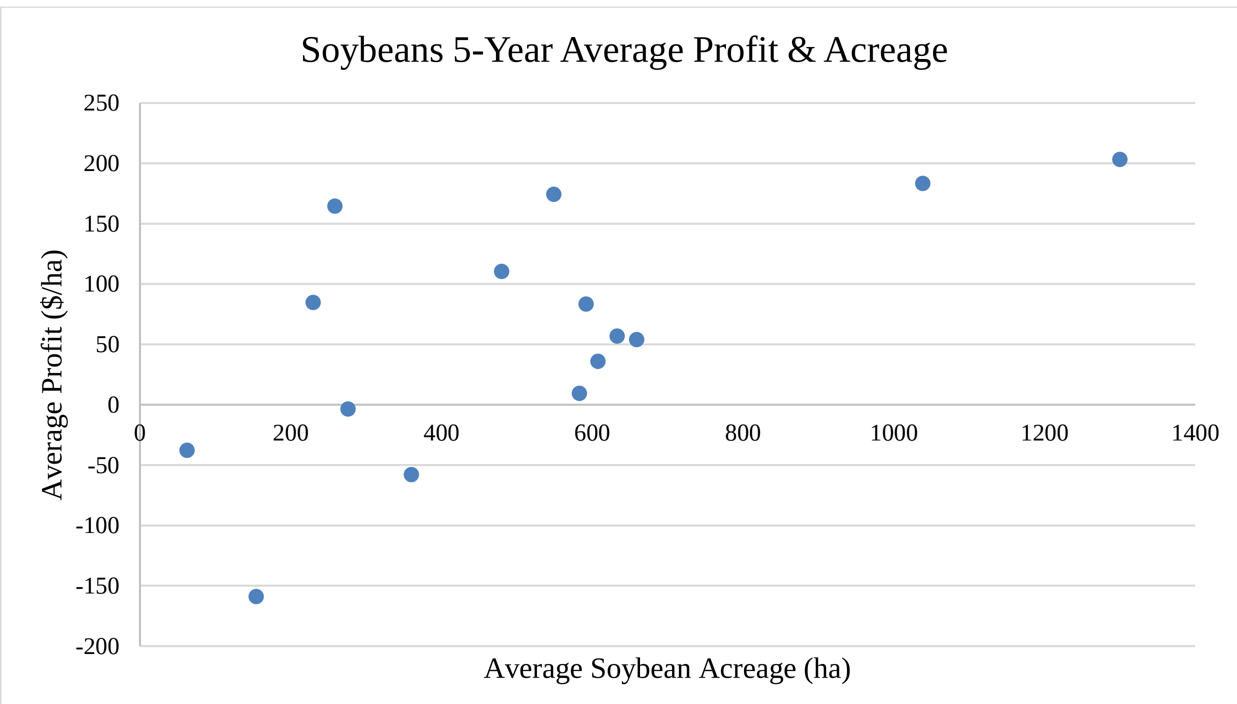

Figure 4.3. Soybeans 5-Year Average Profit and Acreage (per Hectare)

Table 4.9. 5-Year Average Soybean Inputs (per Hectare)

	Average Input Cost		Average Price		Average Input Quantity	
	Mean	SD	Mean	SD	Mean	SD
Direct Cost						
Seed	103.29	48.58	1.40	0.73	80.67	25.71
Nitrogen	5.55	6.68	1.01	0.19	5.92	8.63
Phosphorus	34.65	32.86	1.86	0.72	16.43	11.91
Potash	27.92	36.67	1.00	-	27.92	36.67
Lime	0.41	1.57	1.00	-	0.41	1.57
Other Fertilizer	0.00	0.02	1.00	-	0.00	0.02
Pesticides	83.92	40.36	1.00	-	83.92	40.36
Energy	0.61	2.35	1.00	-	0.61	2.35
Irrigation	3.23	9.63	1.00	-	3.23	9.63
Crop Insurance	14.27	17.77	1.00	-	14.27	17.77
Other Direct	7.66	12.65	1.00	-	7.66	12.65
Finance Cost	3.12	2.51	1.00	-	3.12	2.51
Operating Cost						
Hired Labor	41.22	50.24	12.89	7.76	11.87	24.37
Family Labor	29.19	35.03	12.54	13.04	2.23	5.08
Contractor	67.37	79.91	1.00	-	67.37	79.91
Machinery	120.78	102.71	1.00	-	120.78	102.71
Diesel	28.85	32.99	1.00	-	28.85	32.99
Other Energy	2.62	3.16	1.00	-	2.62	3.16
Overhead Cost						
Buildings	13.56	19.57	1.00	-	13.56	19.57
Land	256.31	194.08	256.31	194.08	1.00	-
Miscellaneous	35.66	26.46	1.00	-	35.66	26.46

Table 4.10. 5-Year Average Soybean Farm Production Costs (per Hectare)

	Mean	SD	Min	Max
Direct Cost	284.62	124.26	118.11	475.57
Input Price	1.04	0.24	0.70	1.46
Implicit Input Quantity	266.75	80.89	158.19	401.78
Operating Cost	290.02	134.75	157.21	586.89
Input Price	1.07	0.20	0.76	1.35
Implicit Input Quantity	296.40	194.55	140.94	727.09
Overhead Cost	305.53	191.00	107.51	754.22
Input Price	1.07	0.68	0.54	2.55
Implicit Input Quantity	284.24	47.43	192.91	381.80

Table 4.11. 5-Year Average Soybean Farm Total Production Costs

	Mean	SD	Min	Max
Direct Cost	157,331.30	153,951.63	22,686.44	618,236.22
Input Price	1.04	0.24	0.70	1.46
Implicit Input Quantity	145,140.98	123,507.24	20,824.32	496,176.92
Operating Cost	132,503.47	78,449.47	36,621.84	272,693.60
Input Price	1.07	0.20	0.76	1.35
Implicit Input Quantity	129,944.92	93,049.75	42,216.44	344,190.51
Overhead Cost	146,141.60	108,708.58	19,340.83	402,877.68
Input Price	1.07	0.68	0.54	2.55
Implicit Input Quantity	139,866.45	76,467.76	22,568.39	321,904.76

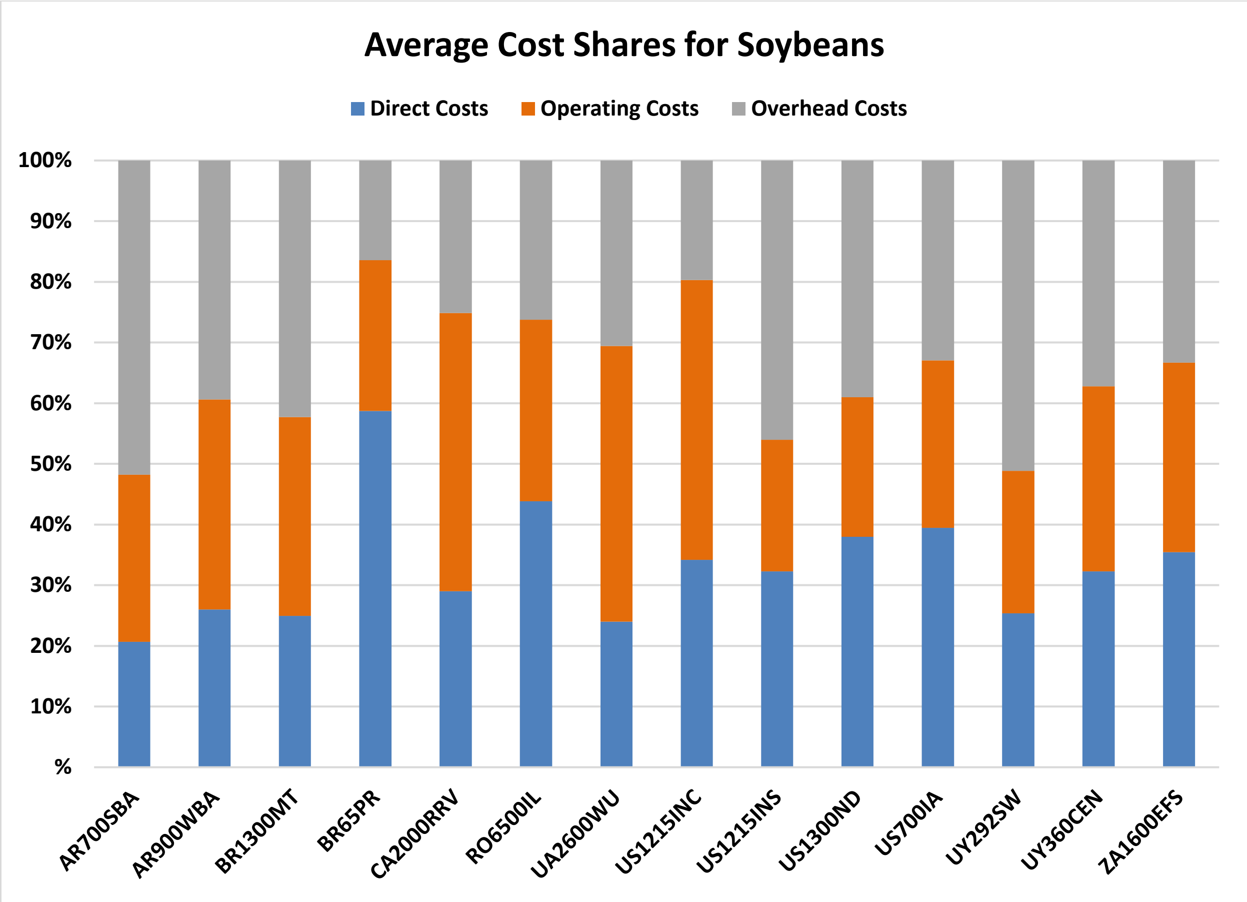

Figure 4.4. Soybean Average Total Cost Shares.

Table 4.12. Wheat Producing Farms

Country	Abbreviation	Number of Typical Wheat Farms
Argentina	AR	3
Australia	AU	1
Bulgaria	BG	1
Brazil	BR	1
Canada	CA	4
Czech Republic	CZ	1
Germany	DE	5
Denmark	DK	1
France	FR	3
Hungary	HU	1
Japan	JP	1
Poland	PL	3
Romania	RO	1
Sweden	SE	2
Ukraine	UA	2
United Kingdom	UK	3
United States	US	3
Uruguay	UY	1
South Africa	ZA	1

Table 4.13. Wheat Farm Characteristics

Variable	Units	Mean	SD	Min	Max
Average Planted Acres of Wheat	Percentage of Total Planted Acres	34.00%	14.83%	4.15%	67.09%
Average Total Revenue	(USD/ha)	1,290.42	1,133.09	340.25	7,352.68
Average Price	Net farm gate prices (USD/t)	193.97	56.01	87.24	463.47
Average Implicit Output	Revenue divided by farm gate price (t/ha)	6.26	2.92	1.95	16.22
Average Gross Margin	Gross revenue minus total direct costs (USD/ha)	823.89	771.61	115.37	4,854.96
Average Profit	Economic profit (USD/ha)	-78.01	415.86	-632.61	1,988.46

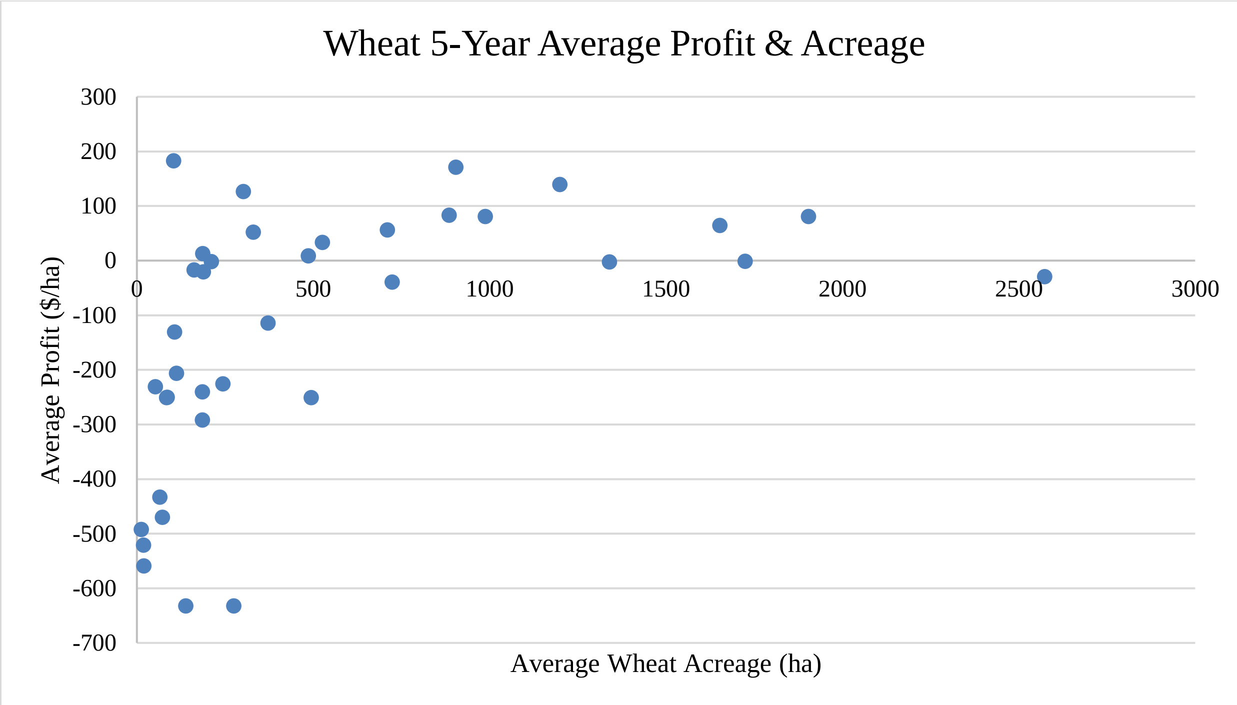

Figure 4.5. Wheat 5-Year Average Profit and Acreage (per Hectare) [1]

[1] The typical farm in Japan (JP45HO) was excluded, as profit earned was substantially higher than other typical farms in the sample. The farm had an average profit of $1,988.46 per hectare and planted an average of 15 hectares of wheat in the 5-year period.

Table 4.14. 5-Year Average Wheat Inputs (per Hectare)

	Average Input Cost		**Average Price**		**Average Input Quantity**	
	Mean	SD	Mean	SD	Mean	SD
Direct Cost						
Seed	75.68	33.87	0.56	0.36	150.45	59.06
Nitrogen	137.92	62.40	1.00	0.26	139.45	54.27
Phosphorus	45.04	99.80	1.65	0.58	24.98	35.28
Potash	12.69	15.92	1.00	-	12.69	15.92
Lime	4.48	13.88	1.00	-	4.48	13.88
Other Fertilizer	8.34	16.43	1.00	-	8.34	16.43
Pesticides	130.10	91.52	1.00	-	130.10	91.52
Energy	5.95	11.84	1.00	-	5.95	11.84
Irrigation	12.97	61.80	1.00	-	12.97	61.80
Crop Insurance	15.04	48.29	1.00	-	15.04	48.29
Other Direct	13.53	43.20	1.00	-	13.53	43.20
Finance Cost	2.85	3.72	1.00	-	2.85	3.72
Operating Cost						
Hired Labor	82.04	78.45	15.79	10.24	9.53	12.67
Family Labor	78.54	124.93	17.10	14.79	3.75	6.61
Contractor	54.30	90.98	1.00	-	54.30	90.98
Machinery	211.42	138.36	1.00	-	211.42	138.36
Diesel	68.41	47.23	1.00	-	68.41	47.23
Other Energy	8.57	9.25	1.00	-	8.57	9.25
Overhead Cost						
Buildings	40.69	41.97	1.00	-	40.69	41.97
Land	296.40	210.68	296.40	210.68	1.00	-
Miscellaneous	61.55	56.40	1.00	-	61.55	56.40

Table 4.15. 5-Year Average Wheat Farm Production Costs (per Hectare)

	Mean	SD	Min	Max
Direct Cost	464.61	377.07	136.00	2497.72
Input Price	1.01	0.16	0.73	1.60
Implicit Input Quantity	444.46	251.62	137.80	1607.93
Operating Cost	503.27	343.11	135.25	1824.73
Input Price	1.08	0.22	0.72	1.62
Implicit Input Quantity	479.20	330.16	113.15	1813.87
Overhead Cost	398.64	264.73	94.28	1041.77
Input Price	1.03	0.55	0.45	2.25
Implicit Input Quantity	363.12	92.87	197.51	563.62

Table 4.16. 5-Year Average Wheat Farm Total Production Costs

	Mean	SD	Min	Max
Direct Cost	162,241.39	169,005.60	3,726.11	867,363.63
Input Price	1.01	0.16	0.73	1.60
Implicit Input Quantity	177,047.11	201,954.74	3,170.55	1,020,903.92
Operating Cost	189,592.74	210,339.89	5,344.08	925,882.92
Input Price	1.08	0.22	0.72	1.62
Implicit Input Quantity	193,861.92	245,595.21	6,724.78	1,059,555.10
Overhead Cost	132,910.86	156,248.66	3,261.27	878,743.21
Input Price	1.03	0.55	0.45	2.25
Implicit Input Quantity	161,191.62	186,758.54	4,266.11	908,925.24

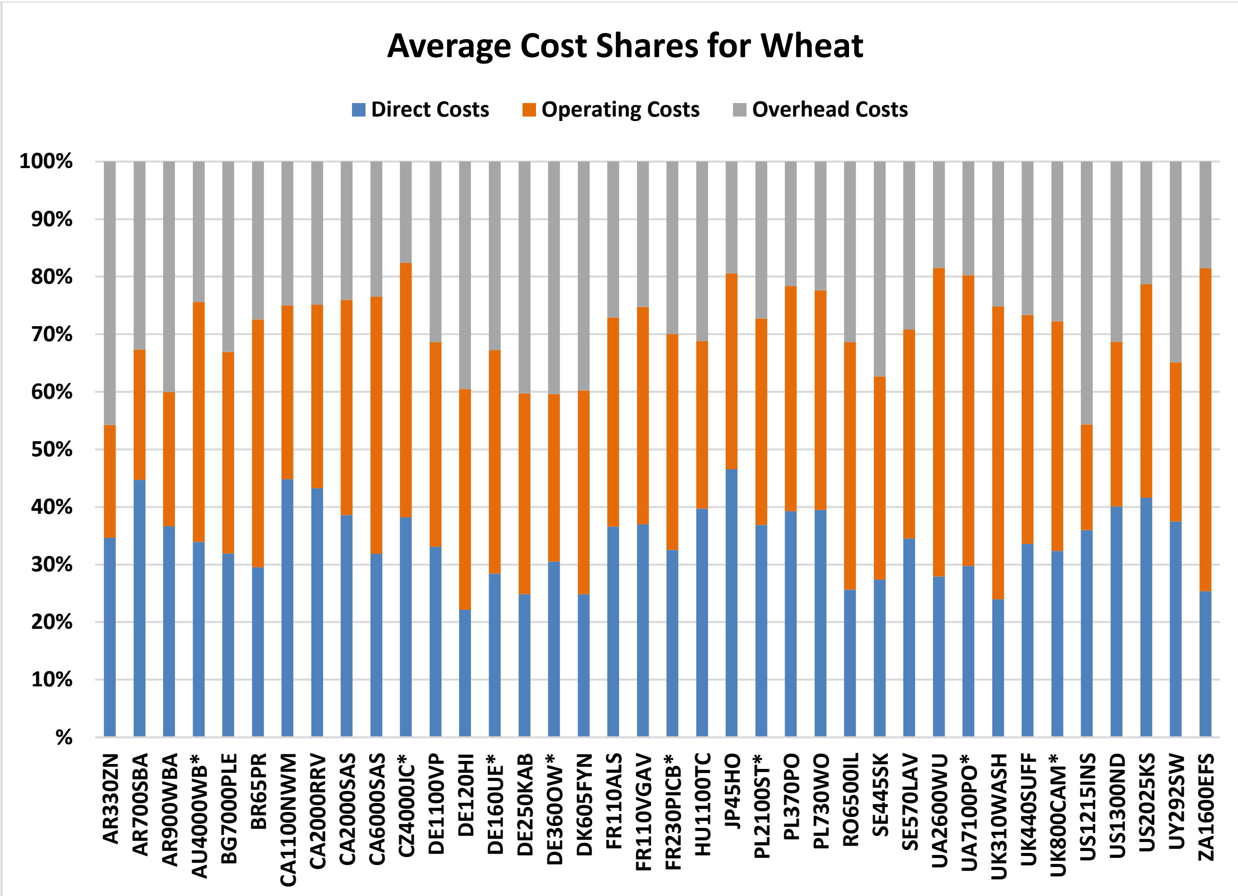

Figure 4.6. Wheat Average Total Cost Shares.

Table 4.17. Corn and Soybean Farm Characteristics

Variable	Units	Mean	SD	Min	Max
Corn					
Average Planted Acres of Corn	Percentage of Total Planted Acres	27.85%	0.18	3.54%	50.00%
Average Total Revenue	(USD/ha)	1105.54	433.19	483.02	1871.19
Average Price	Net farm gate prices (USD/ha)	136.61	26.16	82.44	178.05
Average Implicit Output	Revenue divided by farm gate price (t/ha)	8.11	2.62	5.04	12.75
Average Gross Margin	Gross revenue minus total direct costs (USD/ha)	618.11	261.18	166.47	1153.71
Average Profit	Economic profit (USD/ha)	-44.22	185.05	-432.23	264.14
Soybeans					
Average Planted Acres of Soybeans	Percentage of Total Planted Acres	45.23%	0.17	7.47%	62.54%
Average Total Revenue	(USD/ha)	963.08	332.42	463.67	1476.84
Average Price	Net farm gate prices (USD/ha)	329.60	71.11	199.29	436.03
Average Implicit Output	Revenue divided by farm gate price (t/ha)	2.95	0.79	1.68	3.94
Average Gross Margin	Gross revenue minus total direct costs (USD/ha)	669.47	235.96	345.56	1042.38
Average Profit	Entrepreneurial profit: family labor, land, etc. have been accounted for (USD/ha)	41.87	95.53	-159.02	203.13

Table 4.18. 5-Year Average Corn & Soybean Inputs (per Hectare)

	Average Input Cost		**Average Price**		**Average Input Quantity**	
	Mean	SD	Mean	SD	Mean	SD
Direct Cost						
Seed	145.00	60.48	3.52	1.73	43.35	9.58
Nitrogen	66.73	34.14	1.04	0.17	66.15	35.20
Phosphorus	44.29	19.58	1.98	0.62	21.87	5.39
Potash	25.91	32.20	1.00	-	25.91	32.20
Lime	1.33	2.65	1.00	-	1.33	2.65
Other Fertilizer	0.69	2.46	1.00	-	0.69	2.46
Pesticides	82.60	27.46	1.00	-	82.60	27.46
Energy	2.95	7.20	1.00	-	2.95	7.20
Irrigation	2.89	8.69	1.00	-	2.89	8.69
Crop Insurance	14.91	20.06	1.00	-	14.91	20.06
Other Direct	10.95	18.71	1.00	-	10.95	18.71
Finance Cost	5.06	4.69	1.00	-	5.06	4.69
Operating Cost						
Hired Labor	38.60	43.84	13.22	7.55	9.07	18.58
Family Labor	34.57	39.02	12.51	13.25	2.45	4.91
Contractor	77.88	82.14	1.00	-	77.88	82.14
Machinery	124.98	116.42	1.00	-	124.98	116.42
Diesel	38.20	40.88	1.00	-	38.20	40.88
Other Energy	2.54	3.33	1.00	-	2.54	3.33
Overhead Cost						
Buildings	14.35	19.61	1.00	-	14.35	19.61
Land	278.80	198.68	278.80	198.68	1.00	-
Miscellaneous	40.88	30.19	1.00	-	40.88	30.19

Table 4.19. 5-Year Average Corn & Soybean Farm Production Costs (per Hectare)

	Mean	SD	Min	Max
Direct Cost	403.32	165.96	242.88	708.42
Input Price	1.01	0.20	0.74	1.32
Implicit Input Quantity	385.99	89.30	289.89	543.71
Operating Cost	316.77	138.88	165.89	551.64
Input Price	1.09	0.18	0.80	1.31
Implicit Input Quantity	310.56	179.94	144.42	678.17
Overhead Cost	334.03	194.09	131.44	766.95
Input Price	1.06	0.63	0.50	2.35
Implicit Input Quantity	313.28	42.97	240.18	394.33

Table 4.20. 5-Year Average Corn & Soybean Farm Total Production Costs

	Mean	SD	Min	Max
Direct Cost	186,790.98	163,354.27	22,574.00	461,595.41
Input Price	1.01	0.20	0.74	1.32
Implicit Input Quantity	173,114.55	139,118.20	21,081.53	421,174.30
Operating Cost	137,365.18	117,059.89	27,173.23	405,977.17
Input Price	1.09	0.18	0.80	1.31
Implicit Input Quantity	132,690.90	129,193.41	24,581.18	478,139.39
Overhead Cost	140,804.80	126,207.38	17,218.19	403,233.71
Input Price	1.06	0.63	0.50	2.35
Implicit Input Quantity	128,420.42	94,325.83	20,562.99	323,051.39

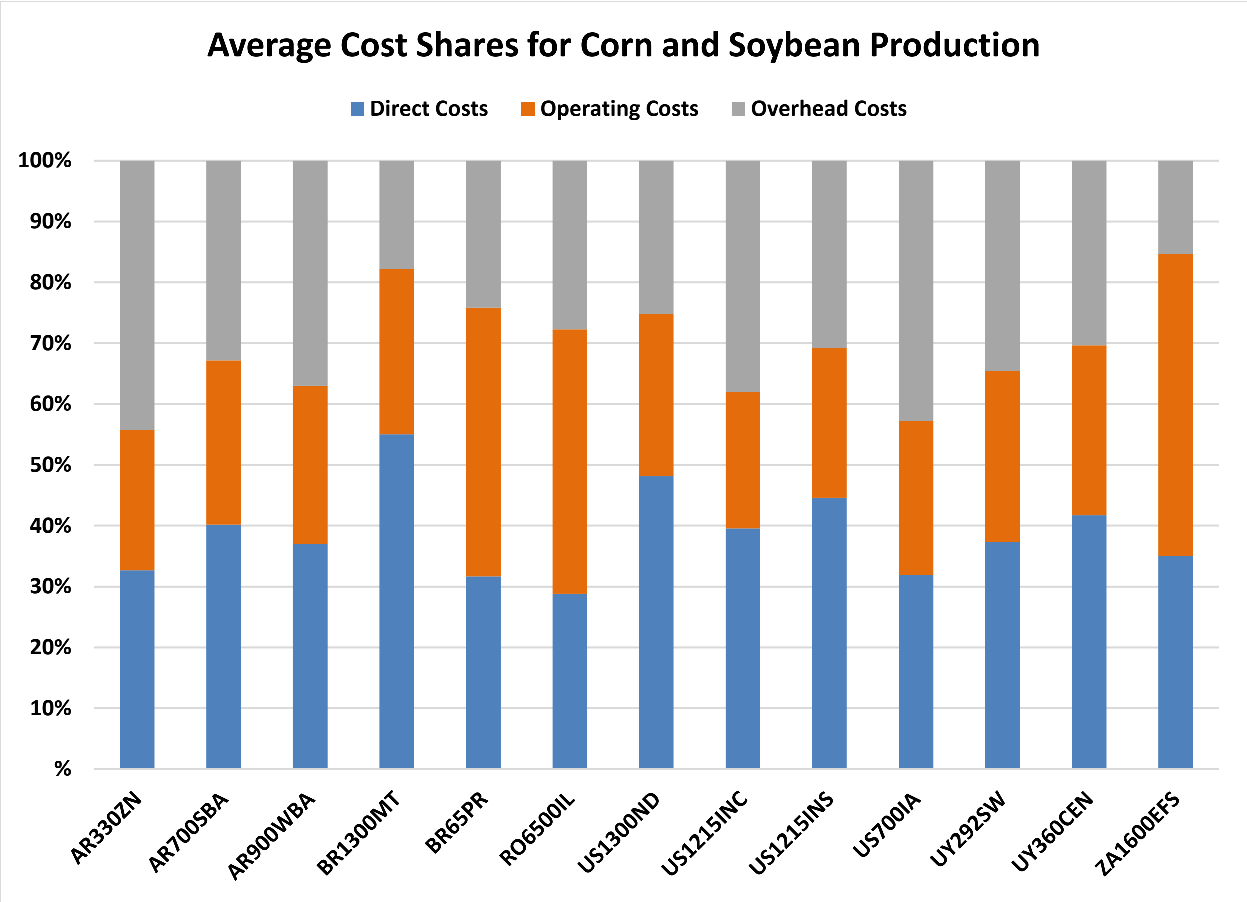

Figure 4.7. Corn and Wheat Average Total Cost Shares.

Table 4.21. Corn and Wheat Farm Characteristics

Variable	Units	Mean	SD	Min	Max
Corn					
Average Planted Acres of Corn	Percentage of Total Planted Acres	30.32%	0.22	3.54%	80.51%
Average Total Revenue	(USD/ha)	1211.26	436.63	768.05	2226.50
Average Price	Net farm gate prices (USD/ha)	143.60	28.01	70.50	178.05
Average Implicit Output	Revenue divided by farm gate price (t/ha)	8.50	2.37	5.58	13.30
Average Gross Margin	Gross revenue minus total direct costs (USD/ha)	644.32	204.46	266.66	1002.64
Average Profit	Economic profit (USD/ha)	-93.94	292.48	-731.87	264.14
Wheat					
Average Planted Acres of Soybeans	Percentage of Total Planted Acres	21.58%	0.09	4.15%	39.44%
Average Total Revenue	(USD/ha)	818.84	330.40	340.25	1353.65
Average Price	Net farm gate prices (USD/ha)	175.15	45.73	87.24	296.97
Average Implicit Output	Revenue divided by farm gate price (t/ha)	4.71	1.57	2.45	7.30
Average Gross Margin	Gross revenue minus total direct costs (USD/ha)	466.78	225.32	115.37	797.75
Average Profit	Economic profit (USD/ha)	-149.86	210.61	-559.04	80.48

Table 4.22. 5-Year Average Corn & Wheat Inputs (per Hectare)

	Average Input Cost		**Average Price**		**Average Input Quantity**	
	Mean	SD	Mean	SD	Mean	SD
Direct Cost						
Seed	126.74	48.97	1.93	0.96	76.28	32.72
Nitrogen	125.26	48.56	0.97	0.18	132.25	52.54
Phosphorus	47.57	18.69	1.77	0.65	29.63	15.82
Potash	19.50	23.37	1.00	-	19.50	23.37
Lime	2.07	6.50	1.00	-	2.07	6.50
Other Fertilizer	4.78	14.04	1.00	-	4.78	14.04
Pesticides	80.20	31.04	1.00	-	80.20	31.04
Energy	29.82	63.18	1.00	-	29.82	63.18
Irrigation	11.78	28.25	1.00	-	11.78	28.25
Crop Insurance	11.70	15.01	1.00	-	11.70	15.01
Other Direct	13.19	29.59	1.00	-	13.19	29.59
Finance Cost	5.06	5.61	1.00	-	5.06	5.61
Operating Cost						
Hired Labor	55.25	44.43	10.56	7.73	10.79	11.90
Family Labor	53.76	105.37	9.76	12.04	3.05	5.80
Contractor	67.35	65.67	1.00	-	67.35	65.67
Machinery	150.62	111.25	1.00	-	150.62	111.25
Diesel	57.44	42.89	1.00	-	57.44	42.89
Other Energy	8.95	12.22	1.00	-	8.95	12.22
Overhead Cost						
Buildings	34.00	51.42	1.00	-	34.00	51.42
Land	203.89	95.50	203.89	95.50	1.00	-
Miscellaneous	58.90	61.64	1.00	-	58.90	61.64

Table 4.23. 5-Year Average Corn & Wheat Farm Production Costs (per Hectare)

	Mean	SD	Min	Max
Direct Cost	477.67	227.77	279.35	1,015.69
Input Price	1.01	0.19	0.72	1.38
Implicit Input Quantity	471.40	207.35	228.70	948.35
Operating Cost	393.38	226.40	149.06	929.97
Input Price	1.11	0.25	0.86	1.57
Implicit Input Quantity	363.32	179.29	123.42	655.25
Overhead Cost	296.79	144.14	135.40	596.36
Input Price	1.04	0.40	0.63	2.35
Implicit Input Quantity	286.76	114.43	207.63	584.80

Table 4.24. 5-Year Average Corn & Wheat Farm Total Production Costs

	Mean	SD	Min	Max
Direct Cost	190,881.04	187,456.55	12,712.69	578,854.09
Input Price	1.01	0.19	0.72	1.38
Implicit Input Quantity	209,351.41	244,708.50	11,282.08	784,206.99
Operating Cost	181,028.82	232,889.27	12,496.98	727,014.73
Input Price	1.11	0.25	0.86	1.57
Implicit Input Quantity	190,016.19	267,307.88	10,921.54	828,942.32
Overhead Cost	121,432.83	154,437.70	9,273.91	588,813.67
Input Price	1.04	0.40	0.63	2.35
Implicit Input Quantity	121,286.37	143,021.08	8,952.55	443,917.03

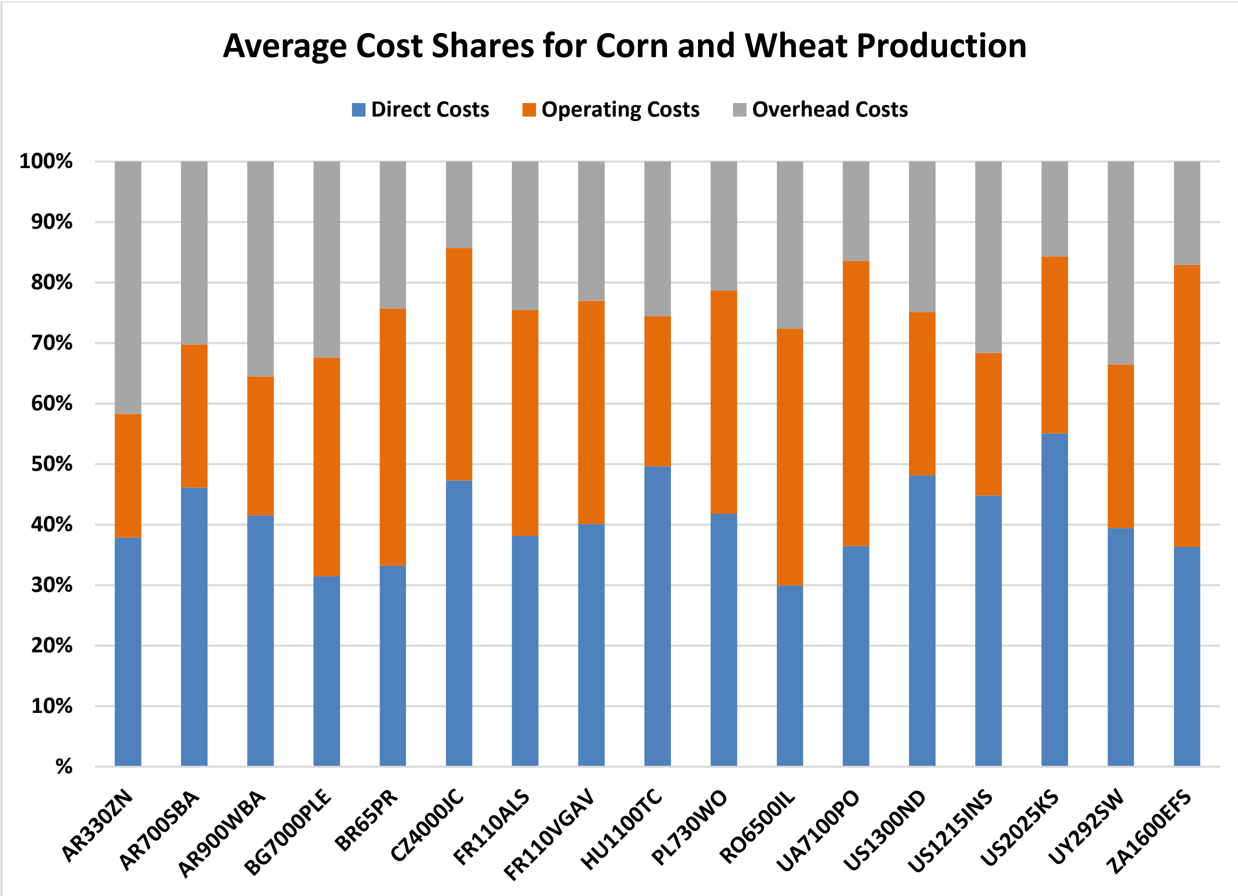

Figure 4.8. Corn and Wheat Average Total Cost Shares.

CHAPTER 5. METHODOLOGY

5.1 Model Overview

Data envelopment analysis (DEA) is a non-parametric approach that can measure technical, scale, and economic efficiencies (Charnes et al., 1978, Banker et al., 1984). This thesis will consider variable returns to scale (VRTS). Previous literature suggest using VRTS as a way to avoid confounding scale efficiencies (Färe et al., 1983; Banker et al., 1984). Methods for determining returns to scale are discussed by Cooper, Seiford & Tone (2000) and Read & Thanassoulis (2000). Technical efficiency is examined at different returns to scale, and the observed levels are analyzed to determine if the levels along the frontier correspond to a particular returns to scale (Ward et al., 2004). Assuming variable returns to scale is appropriate when firms face factors such as: imperfect competition, regulations, financial constraints, or suboptimal scale (Lunik, 2015). If the firms operated in perfect competition, constant returns to scale (CRTS) would be appropriate (Charnes et al., 1978). CRTS implies that a one percent increase in all inputs lead to a one percent increase in output. However, due to the international focus of this study, these assumptions may not hold (Lunik, 2015). As such, VRTS will be assumed.

Cost of production, used as a proxy for measuring competitiveness, for representative typical farms will be compared to determine which typical farm is the most efficient (cost competitive) in the group. Due to the input focus of the data, the DEA model will be input-oriented, rather than output-oriented. Input-oriented models show how much inputs can be reallocated to reduce costs for a firm, given the level of output and input prices. Output-oriented models show maximum outputs for a given level of inputs and prices (Lunik, 2015). An input-oriented constant returns to scale model was the first to be widely applied. Input-oriented models tend to be selected due to the tendency for input quantities to be primary decision variables (for instance, electricity generation firms have orders to fill). An output orientation is more appropriate when firms face a fixed level of inputs and need to maximize output. Orientation should be selected based on whether the manager has more control over input or output quantities (Coelli et al., 2005). Coelli & Perelman (1999) found that orientation choice has a small effect on efficiency. Aggregation of variables has implications on efficiency results, and should be avoided whenever possible (Preckel et al., 1997). The treatment of inputs as variable or fixed can effect efficiency scores as well (Preckel et al., 1997).

Disposability in inputs and outputs is assumed, meaning a firm can dispose of unneeded inputs and excess outputs without incurring a cost (Coelli et al., 2005). Other common properties of non-parametric functions are assumed in this thesis, including convexity of input requirements and production possibilities (Lunik, 2015). This thesis also assumes the data being analyzed is free of errors.

5.2 DEA Model

DEA is used to estimate cost efficiency frontiers. Input and output price and quantity data for each typical farm will be used to build the envelopment (cost) frontier. All observations will either lie on the cost curve or will be above the cost curve. Efficiency index values of one indicate the farm is one of the most efficiently operating farms, and will be on the cost curve. Farms with efficiency index values of one are called benchmarks, as they represent the most efficient obtainable performance inefficient farms can strive towards. Given the nature of benchmarking, it is possible that farms could operate more efficiently than those in the dataset with an index value of one, as more efficient farms could exist outside of this specific dataset.

Inefficient farms will be compared to the closest efficient farm on the frontier.

Data Envelopment Analysis (DEA) techniques will be used to compute efficiency scores for technical, allocative, and cost efficiency (TE, AE, and CE, respectively). An efficiency score of one indicates that the farm is as efficient as possible. The difference between one and the given efficiency score indicates the percentage of efficiency that could be gained by utilizing the optimal mix of inputs. Technical efficiency is computed as λ in the following linear program assuming variable returns to scale:

$$\lambda = Min\,\lambda$$

Subject to:

$$x_{n0}\lambda \geq \sum_{i=1}^{I} x_{ni}\ z_i \qquad n = 1, 2, 3 \ldots N\ inputs,$$

$$y_{k0} \leq \sum_{i=1}^{I} y_{ki}\ z_i \qquad k = 1, 2, 3\ \ldots K\ outputs,$$

$$\sum_{i=1}^{I} z_i = 1$$

$$z_i \geq 0$$

where: x_{ni} is a N x 1 vector of input quantities for each of the i = 1, 2, 3…I farms for n = 1, 2, 3…N inputs. x_{n0} is the N x 1 vector of input quantities for the firm being tested. y_{ki} is a K x 1 output vector for k = 1, 2, 3…K outputs for each of the i = 1, 2, 3… I farms. y_{k0} is the K x 1 vector of output quantities for the firm being tested. z_i is vector of weights for each farm.

The weight of the data of each farm, represented by variable z_i, and the nonnegative weighter are restricted to sum to one, as variable returns to scale are assumed. Additionally, the assumption ensures the inefficient firm's projected point on the DEA frontier is a convex combination of observed firms (Lunik, 2015). Since this is an input-oriented study, the technical efficiency indicates how a firm can change the input mix and produce the same output level.

Technical efficiency will be used to determine which farms in the subset are most efficient. Once this is determined, the other farms will be compared to the most efficient farm given their production mix. Cost efficiency will be calculated to measure the amount cost can be reduced, given input prices. This will be calculated starting with a cost minimization function C_i for the i^{th} firm to produce y output and will yield the optimal input mix, x_{ni}*, given an input price w_n. Variable returns to scale are still assumed (T_v). The following linear program illustrates the cost minimization function:

$$C_i(w, y, T_v) = Min_{x^*,z} \sum_{n=1}^{N} w_{n0}\, x_{n0}{}^{*}$$

Subject to:

$$x_{n0}^{*} \geq \sum_{i=1}^{I} z_i\, x_{ni} \qquad n = 1, 2, 3 \ldots N\ inputs,$$

$$y_{k0} \leq \sum_{i=1}^{\mathrm{I}} z_i\, y_{ki} \qquad n = 1, 2, 3 \ldots K\ outputs$$

$$z_i \geq 0$$

$$\sum_{i=1}^{\mathrm{I}} z_i = 1$$

where: w_{no} is the N x 1 vector of input prices confronting the firm being tested and all other notation is as before.

From here, a cost efficiency index (CE), indicated by ρ, is calculated by dividing minimum cost by actual cost. This shows the level to which costs can be reduced while maintaining output level (Lunik, 2015).

$$CE_i = \rho_i = \frac{\sum_{n=1}^{N} w_n \, x_{ni}^{*}}{\sum_{n=1}^{N} w_n \, x_{ni}}$$

Allocative efficiency is indicated by α_i and is calculated by dividing minimum cost calculated above with variable returns to scale by the actual cost. Actual cost is adjusted for technical efficiency, λ. Allocative efficiency can also be calculated by dividing the cost efficiency index (CE) by the technical efficiency index (TE), as shown in the following equation.

$$AE_i = \alpha_i = \frac{\sum_{i=1}^{I} w_n \, x_{ni}}{\sum_{i=1}^{I} w_n \, x_{ni} \, \lambda_i} = \frac{CE}{TE}$$

TE, AE, and CE indices will be completed three times for each of the five crop groups: using the five-year average data (2013 to 2017), 2013 data, and 2017 data. One-output models include corn, soybeans, and wheat. Two-output models include corn and wheat and corn and soybeans. Implicit output will be used in the model, which is revenue divided by the farm gate price, in tons per hectare. The five-year average will be used as a base case. The competitive position of the typical farm in 2013 and in 2017 will be compared to determine if the country's typical farm's competitive position has changed. The most efficient typical farm in the group will be identified in each analysis. Countries with stronger currencies are hypothesized to be less susceptible to exchange rate fluctuations, so in the analysis their competitive position should be relatively stagnant. Weaker currencies are hypothesized to be more susceptible to exchange rate fluctuations, so their competitiveness may be altered with changing exchange rates.

To determine if 2013 or 2017 are statistically significant than the 5-year average, two-tailed t-test will be used between each of the individual years and the 5-year average cost efficiency. Additionally, the ratio of each individual year's cost efficiency to the five-year average cost efficiency will be calculated. A ratio of less than one implies the farm was under-performing in the individual year, relative to the five-year average. If the ratio is greater than one, the farm was over-performing, or performing better than it was in the 5-year average, in the individual year, relative to the five-year average.

5.3 Efficiency Analysis

Differences in technical efficiencies have been explained by farm size in previous studies (Olson & Vu, 2009; Wadud & White, 2000; Balcombe et al., 2008). Olson & Vu (2009) also found that the land to labor ratio had a significant effect on technical efficiency in five of the 14 years analyzed. Yusuf and Malomo (2007) looked into utilization of inputs in poultry production (birds, labor, and feed) to determine which were underutilized. Similarly, this thesis will be using the three cost categories (direct, overhead, and operating) to determine over or under utilization. A utilization ratio will be calculated by dividing actual costs by minimum costs. For farms that are cost efficient, the ratio will be equal to one. The correlation coefficient of the utilization ratios to cost efficiency will be calculated. A positive correlation coefficient for a utilization ratio would indicate that the cost category is being under-utilized. A negative coefficient would indicate that the cast category is being over-utilized and is negatively effecting cost efficiency. Additionally, the correlation coefficient will be calculated to determine if any factors driving production influenced cost efficiency. Profit, yield, revenue, price, implicit output, gross margin, planted acres, and percentage total acres planted to the crop will be used in the correlation analysis.

CHAPTER 6. RESULTS

6.1 Results Overview

Efficiency scores and regression results examining the relationship between cost efficiency and key variables are presented in this chapter. Efficiency scores represent the percent efficient each farm is in the respective efficiency category. The scores range from 0 to 1, where 0 represents a farm that is 0 percent efficient, and 1 represents a farm that is 100 percent efficient. These scores were calculated using the 5-year average, and for the years 2013 and 2017 individually. The 2013 and 2017 results are used to examine the impact of weather variations and exchange rate fluctuations on relative efficiency measures across typical farms.

6.2 Corn Results

The results for the 24 corn producing farms are shown in Table 6.1. For the 5-year average, the standard deviation of cost efficiency scores was 0.22. The French farm from the Alsace region (FR110ALS) was the least cost efficient farm over the 5-years analyzed, and was 44.7 percent cost efficient.

The average technical efficiency for the 5-year average was 0.802, indicating that corn farms could reduce input use by an average of 19.8 percent if they were technically efficient. On average, allocative efficiency scores were higher than the technical efficiency scores. Allocative efficiency reflects the ability of a firm to choose the optimal combination of inputs given input prices and technology to produce the given output level. The average allocative efficiency score was 0.929 using the 5-year averages. On average, corn farms could reduce their input costs by about 7.1 percent if they were allocatively efficient. Using the 5-year averages, the average cost efficiency was 0.749.

Cost efficiency for each farm is graphed in Figure 6.1. As the figure shows, several of the farms are close to being cost efficient, although they do not reach 100 percent cost efficiency (the dashed line indicates 100 percent cost efficiency). Eleven farms have a cost efficiency greater than 90 percent using the 5-year averages.

Efficiency scores fluctuate, based on which years are analyzed. Table 6.2 summarizes which farms are cost efficient in the various time periods. Scores of 1 indicate 100 percent cost efficiency in the given time period. Three farms are cost efficient in every time period analyzed (AR700SBA, UA7100PO, and VN3LM). The corn acreage varies substantially between these three farms. The Vietnam farm was the smallest, planting 3 hectares of corn throughout the time period. The farm in Argentina was larger, planting an average of 39 hectares of corn throughout the time period. The Ukraine farm planted the highest average acreage of corn, at 1,865.20 hectares.

Two-tailed t-tests were performed between the individual years and the 5-year average. Cost efficiency in 2013 was statistically different than cost efficiency that used the 5-year averages at the 5 percent level. The cost efficiency in 2017 was not statistically different than the 5-year average cost efficiency at the 5 percent level. Additionally, cost efficiency in 2013 was not statistically different than cost efficiency in 2017 at the 5 percent level. Average cost efficiency was highest for the 5-year average (0.749). Average cost efficiency in 2013 was slightly higher than 2017; 0.691 and 0.672, respectively.

To compare cost efficiency within individual years, the ratio of the individual year cost efficiency to the 5-year average cost efficiency was calculated. A ratio of less than one implies a farm was under-performing in the individual year, relative to the 5-year average. A farm was over-performing, relative to the 5-year average, if the ratio is greater than one. A ratio of one indicates a farm was cost efficient in both the individual year and the 5-year average. When comparing 2013 to the 5-year average, 13 farms under-performed in 2013 relative to the 5-year average, while only 3 farms over-performed in 2013 relative to the 5-year average. In 2017, 13 farms were still under-performing relative to the 5-year average, but 4 farms were over-performing relative to the 5-year average. The average ratio of individual year cost efficiency to the 5-year average cost efficiency for 2013 and 2017 was 0.959 and 0.922, respectively. As both of these values are less than one, that indicates that farms were under-performing relative to the 5-year average in both 2013 and 2017.

Given the insignificant differences among the individual years and the 5-year average, the 5-year average will be the focus of the remainder of the analysis for corn. Table 6.3 shows the distribution of efficiency scores using the 5-year averages. The efficiency indices for corn farms were distributed on the upper end of the efficiency indices. Over 58 percent of the corn farms had a TE score of 0.7 or higher using the 5-year averages. All of the farms had an AE score of 0.7 or higher, and 50 percent of the corn farms had a CE score of 0.7 or higher.

The input utilization ratios for direct, operating, and overhead cost were calculated for corn producing farms. This ratio is calculated as actual costs divided by minimum cost of production. Direct costs include inputs such as seed, fertilizer, pesticides, crop insurance, irrigation, and interest on direct cost items. Operating costs consist of hired labor, family labor, contractor expense, fuel, energy, and machinery depreciation and interest. Overhead costs include land, building depreciation and interest, property taxes, and general insurance. An input utilization ratio greater than 1 indicates the farm is over-utilizing an input. Conversely, a ratio less than one indicates that the farm is under-utilizing the resource. Farms that have a cost efficiency of 1 will also have an input utilization ratio of 1, because they are operating at a cost efficient level relative to the other farms in the analysis. Table 6.4 summarizes the input utilization ratios for corn producing farms using the 5-year averages. None of the farms under-utilized direct costs. Operating costs were over-utilized for 12 of the 24 farms analyzed. Overhead costs were over-utilized for 17 of the farms for the 5-year average. Direct, operating, and overhead costs had average utilization ratios of 2.35, 1.42, and 1.28, respectively. The corn producing farm in Kansas had the largest utilization ratio observed for direct costs (6.22).

Table 6.5 provides summary statistics of the variables that were hypothesized to influence cost efficiency for corn farms over the 5-year period. The average direct cost utilization ratio is greater than one, indicating that on average direct costs are over-utilized. On average, farms were also earning a negative economic profit over the 5-year average on a per hectare basis and on the total farm level.

Individually, each of the variables in Table 6.5 do not fully explain a large amount of variation in the average cost efficiency in corn farms over the 5-year period. Each of the variables were regressed individually to find the correlation coefficient to cost efficiency and the sign and magnitudes of the respective correlations. Table 6.6 illustrates the correlation results. Average profit shows the return to management or economic profit, indicating that the opportunity cost for factors such as family owned labor, and land have been paid for. Individually, each variable did not have a remarkably high ability to explain the variation in the cost efficiency over the 5-year period. All three cost utilization ratios were statistically significant at the 1 percent level. On average, all utilization ratios were above one, indicating over-utilization of the input. The coefficients shown in Table 6.6 indicate that cost efficiency declines as the utilization ratios increase. Since costs were being over-utilized, it is intuitive that cost efficiency would decline as over-utilization increases. The percentage of total acres planted to corn had a coefficient of -0.415. The negative coefficient indicates that farms with higher percentage of acres planted to corn have lower cost efficiencies.

Table 6.7 breaks down the relationship between components of the three cost categories and cost efficiency in corn production over the 5-year period. Positive correlation values indicate the resource is under-utilized, while negative correlation values indicate the resource is being over-utilized.

At the 5 percent level, eight of the cost components were statistically significant. Although only one component (finance cost) of direct cost was statistically significant at this level, direct cost overall had a significant correlation to cost efficiency. Operating cost and three components of operating cost (machinery, diesel, and other energy) were significant at this level as well. The largest component of overhead cost (land) did not have a statistically significant relationship with cost efficiency of corn production. Machinery, diesel, other energy, and buildings are all correlated to average corn cost efficiency at the 1 percent level.

6.3 Soybean Results

Fifteen soybean producing farms were included in the analysis. Table 6.8 shows the average efficiency scores for these farms. Over the 5-year period, the Ukraine farm was the least cost efficient farm with a score of 45.7 percent. The standard deviation of cost efficiency over the 5-year average was 0.20.

Average allocative efficiency was higher than average technical efficiency for 2013, 2017, and the 5-year average. On average, using the 5-year averages, farms were 88.8 percent allocatively efficient. Over the 5-year period, farms on average were 86.1 percent technically efficient and 77.4 percent cost efficient. The Argentina farm located West of Buenos Aires Province (AR900WBA) and the Brazil farm in the Mato Grosso region (BR1300MT) were on the cost efficiency frontier in all time periods analyzed.

Figure 6.2 shows the 5-year average soybean cost efficiency. The average cost efficiency score was 0.774. The lowest cost efficiency score for soybeans was 0.457 for the Ukraine farm.

Table 6.9 summarizes cost efficiency in soybean production over the three time periods. Seven of the fifteen farms in the analysis had a cost efficiency score of one in at least one time period. The largest Argentinian farm and the largest Brazilian farm had cost efficiency scores of one in every time period. On average, 61.0 and 50.0 percent of total acreage was planted to soybeans for AR900WBA and BR1300MT, respectively.

Two-tailed t-tests were performed between 2013 and the 5-year average and 2017 and the 5-year average cost efficiency. No statistically significant difference was found between 2013 and 5-year average cost efficiency, 2017, and 5-year average cost efficiency, or 2013 and 2017 cost efficiency. The highest cost efficiency was 0.806 in 2013, followed by the 5-year average with a cost efficiency of 0.774. The cost efficiency in 2017 was 0.71.

The average ratio of individual year cost efficiency to the 5-year average cost efficiency was 1.042 and 0.962 for 2013 and 2017, respectively. This indicates that on average, farms were over-performing relative to the 5-year average in 2013 and under-performing in 2017. In 2013, five farms were over-performing compared to the 5-year average, as they had ratios greater than one. In 2017, three farms were under-performing relative to the 5-year average and had ratios less than one. If advances in technology were driving the changes in performance from 2013 to 2017, we would anticipate that farms would be over-performing in 2017, relative to the 5-year average, but this does not appear to be the case for soybean farms in this sample.

Given that the individual years showed no significant difference from the 5-year average, the 5-year average will be used in the remainder of the analysis for soybeans. Distribution of efficiency scores over the 5-year period are shown in Table 6.10. All of the soybean farms analyzed had a technical and allocative efficiency score above 0.6. A larger distribution was observed for cost efficiency, as three farms had a cost efficiency score below 0.6. Eighty percent of soybean farms had a cost efficiency score above 0.6.

Table 6.11 shows the input utilization ratio for direct, operating, and overhead cost for soybean producing farms over the 5-year period. Direct costs were not under-utilized by any soybean producing farm in this time period. One farm under-utilized operating costs, and another farm under-utilized overhead costs. However, overall most farms were over-utilizing in all three cost categories for soybean production. The average utilization ratio was 1.48, 1.62, and 1.18 for direct, operating, and overhead costs respectively. The largest utilization ratio observed (3.89) was for operating costs in the soybean producing farm in Romania.

Table 6.12 shows the summary statistics for soybean producing farms over the 5-year period. The tendency to over-utilize resources is reflected in the average cost utilization ratios being larger than one for all cost categories. Yield is presented on a per hectare basis. Acres of soybeans planted on each farm is expressed as a percentage of total crop acres and by average hectares planted over the 5-year average.

The variables presented in Table 6.12 are regressed on cost efficiency to calculate the correlation coefficient, shown in Table 6.13. As with corn, the utilization ratios were all statistically significant. Yield, implicit output, and percentage total acres planted to soybeans were also significant for the soybean producing farms in this sample. The positive sign indicates that farms with higher yields and implicit outputs had higher levels of cost efficiency. Additionally, farms with higher percentages of total acres planted to soybeans had higher cost efficiency levels.

Table 6.14 explores the relationship between cost category components and cost efficiency. Overall, eight of the correlations were positive, indicating under-utilization. There were more costs being over-utilized, since 16 correlations were negative. Four of the correlations were statistically significant at the five percent level: phosphorus, hired labor, diesel, and miscellaneous costs. Direct costs and overhead costs had one cost item that was statistically significant, nitrogen and miscellaneous costs, respectively. Hired labor and diesel were the two operating costs items with a significant correlation to cost efficiency.

6.4 Wheat Results

Nineteen countries were represented in a sample of 38 farms used in the wheat analysis. Average efficiency scores for these farms are shown in Table 6.15. Using the 5-year averages, the standard deviation of cost efficiency was 0.139. The South African farm had the lowest cost efficiency over the 5-year average at 44.4 percent. The Brazil wheat producing farm from the Parana region (BR65PR) was the only farm that was cost efficient in producing wheat in all three time periods.

As with corn and soybeans, allocative efficiency was higher than technical efficiency in all periods. On average, farms were 92.8 percent allocatively efficient and 89.8 percent technically efficient over the 5-year average. Cost efficiency ranged from 48.5 percent to 83.6 percent in 2017 and the 5-year average, respectively.

The 5-year average wheat cost efficiency is shown in Figure 6.3. On average, farms were 83.6 percent cost efficient. Seven farms had a cost efficiency of one over the 5-year period and 13 firms were at least 90 percent cost efficient over the 5-year period. The smallest Polish farm (PL370PO) had the lowest cost efficiency over the 5-year average, at 61.4 percent.

Wheat farm cost efficiency in the three time periods is summarized in Table 6.16. The lowest cost efficiency occurred in 2017 on the Uruguay farm, and was 8.20 percent cost efficient. This farm performed better in 2013 and over the 5-year period; 60.9 and 63.5 percent cost efficient, respectively. The Brazilian farm was 100 percent cost efficient in every time period, however 16 farms had a cost efficiency of 1 using the 5-year averages.

Using two-tailed t-tests, a statistically significant difference was found between cost efficiency in all of the time periods analyzed. Average cost efficiency was lowest in 2017 at 48.5 percent. Cost efficiency was 75.2 and 83.6 percent in 2013 and the 5-year average, respectively. No significant relationship was found between 5-year average cost efficiency and the 5-year average exchange rates, 5-year average cost efficiency and the percent change of exchange rates, or 5-year average cost efficiency and the standard deviation of exchange rates over the 5-years. Additionally, no significant relationship was found between either of the individual year cost efficiencies and the respective annual exchange rates.

The ratio of the individual year cost efficiency to the 5-year average cost efficiency was used to compare performance in the individual years. Overall, farms were under-performing relative to the 5-year average in both 2013 and 2017. The average cost efficiency ratio was 0.906 in 2013 and 0.567 in 2017. Farm performance was lower in 2017 than in 2013. In 2013, 29 farms were under-performing, relative to the 5-year average. By 2017, 34 farms were under-performing, relative to the 5-year average. Few farms over-performed in 2013 and 2017 relative to the 5-year period results. In 2013, seven farms were over-performing compared to the 5-year average. In 2017, only one farm out performed the 5-year average.

Given the similarities between the individual years and the 5-year average, the 5-year average will be used in the remainder of the analysis. Table 6.17 shows the distribution of the efficiency scores over the 5-year period. Technical efficiency and allocative efficiency scores were distributed towards the upper end of the spectrum, as 52.6 percent and 73.7 percent of firms had an efficiency score above 0.9 for technical efficiency and allocative efficiency, respectively. Cost efficiency had a wider distribution, as only 34.2 percent of farms had a cost efficiency greater than 0.9. Farms close to the frontier could be thought of as being on the frontier due to noise in the data. In this case, one French farm (FR230PICB) had a cost efficiency score of 0.996, this farm is close to being on the frontier, and could be thought of as being on the frontier.

The input utilization ratios for direct, operating, and overhead costs are shown in Table 6.18. Overall, under-utilization was not as prevalent as over-utilization in every cost category. In the overhead cost category, 71.1 percent of farms over-utilized overhead costs, and 10.5 percent of farms under-utilized overhead costs. Similarly, direct costs and overhead costs were over-utilized by more than half of the wheat producing farms at 55.3 percent and 65.8 percent of farms over-utilizing the respective inputs. Ten farms under-utilized direct costs, and six farms under-utilized operating costs. On average, the input utilization ratio was 1.12, 1.43, and 1.29 for direct, operating, and overhead costs, respectively. The highest utilization ratio, 4.34, was observed in the operating costs for the South African farm. Within the operating cost category, diesel, machinery, and hired labor were the largest expenditures for the South African farm.

Summary statistics for the wheat-producing farms are shown in Table 6.19. The average utilization ratio for direct, operating, and overhead cost were all greater than one, reflecting the tendency to over-utilize these resources. Average profit per hectare is negative over the 5-year average. On average, farms planted 34 percent of total acres to wheat.

Correlation coefficients are shown in Table 6.20. As with corn and soybeans, the cost utilization ratios were all significant for wheat farms. The negative sign indicates that cost efficiency and the utilization ratios are inversely related. The over-utilization of these resources negatively influences cost efficiency. The other variables investigated did not have a statistically significant relationship to the 5-year average cost efficiency in this sample of wheat farms.

Varieties of wheat planted were broken down into six categories: spelt, winter wheat, summer wheat, durum, winter and summer wheat, summer and winter wheat. These variables were inserted into a cost utilization regression as dummy variables, but were not significant. When types of wheat were regressed on cost efficiency, the coefficients were also not significant.

Correlation of cost components to cost efficiency are shown in Table 6.21. Under-utilization, as identified as positive correlation, occurred for six cost items (seed, potash, energy, finance cost, total overhead cost, and land). The other 18 correlations were negative, indicating over-utilization.

Six of the cost items had a statistically significant correlation with cost efficiency at the 5 percent level. Total operating cost was the only total cost category with a significant correlation to cost efficiency. Within total operating cost, diesel and other energy had a significant correlation with cost efficiency. In the direct cost category, lime and crop insurance had a negative correlation with cost efficiency. Miscellaneous costs were also significantly negatively correlated with cost efficiency. All of the correlations that were significant were negative, indicating over-utilization.

6.5 Corn & Soybean Results

Thirteen farms in the *agri benchmark* network produced both corn and soybeans in all five years. The efficiency results for these farms are shown in Table 6.22. Seven farms had a cost efficiency of 1, and all of the other farms had a cost efficiency greater than 0.8 in the 5-year average. Five farms were efficient in all of the time periods. The least cost efficient farm over the 5-year period was the farm located South East of Buenos Aires in Argentina, AR700SBA, and was 80.3 percent cost efficient. The standard deviation of cost efficiency over the 5-year average was 7.77 percent.

Average technical efficiency was highest over the 5-year period, at 98.3 percent. The lowest technical efficiency score, 42 percent, occurred in 2017 on the Romanian farm. Technical efficiency had a standard deviation of 4.18 percent for the 5-year average results. Allocative efficiency was highest in 2013, at 98.8 percent. The lowest allocative efficiency score, 65.24 percent, occurred in 2017 on the Romanian farm. For the 5-year average, the standard deviation of allocative efficiency was 6.24 percent.

Figure 6.4 includes a graph of cost efficiency. All of the farms had a cost efficiency greater than 0.8 using the 5-year averages. AR330ZN, AR900WBA, BR1300MT, BR65PR, and US1215INC were cost efficient in every time period analyzed.

A summary of cost efficiency in corn and soybean production over the three time periods is shown in Table 6.23. AR700SBA, US1215INS, and UY360CEN were the only three farms that were not 100 percent cost efficient in at least one time period. With the exception of the Romanian farm in 2017, cost efficiency scores were at or above 69 percent for every farm in every time period. In 2017, the Romanian farm had a cost efficiency of 27.4 percent.

Two-tailed t-tests were used to determine if a statistically significant difference existed between the individual years and the 5-year average cost efficiency. No significant difference was found between any of the time periods. Average cost efficiency was lowest in 2017 at 0.892, and highest in 2013 at 0.952.

To compare the performance in 2013 and 2017, the ratio of individual year cost efficiency to 5-year average cost efficiency was used. The average ratio of individual year cost efficiency to the 5-year average was 1.016 in 2013 and 0.956 in 2017. This indicates that farms were over-performing, relative to the 5-year average in 2013, and under-performing, relative to the 5-year average in 2017. Three farms under-performed in 2013, and four farms under-performed in 2017. Four farms over-performed in 2013 and in 2017. Based on these results, we focus on the 5-year average below.

The distribution of efficiency scores over the 5-year period are shown in Table 6.24. The table illustrates that the scores were concentrated in the upper end of the efficiency indices. No farms were below 0.8 for any efficiency measure. In comparison to the single crops, the percentage of farms that are 100 percent efficient is quite high. 76.92 percent are technically efficient, 53.85 percent are allocatively efficient, and 53.85 percent of farms are cost efficient. This is consistent with the findings of Tauer and Hanchar (1995). As more outputs are added, more firms become efficient, as dimensionality of the input/output spaces are increased.

Table 6.25 shows the input utilization ratios for direct, operating, and overhead costs for corn and soybean production over the 5-year period. The average input utilization ratio for direct, operating, and overhead costs were 1.11, 1.05, and 1.08, respectively. The averages are greater than one, which implies that over-utilization was more prevalent than under-utilization. The South African farm was the only one to under-utilize direct or overhead costs. Three farms under-utilized operating costs. The direct cost utilization ratio ranged from 0.875 on the South African farm (ZA1600EFS) to 1.551 on the Central region Uruguay farm (UY360CEN). The operating cost utilization ratio ranged from 0.750 on the southwest Uruguay farm (UY292SW) to 1.849 on the South African farm. The overhead cost utilization ratio ranged from 0.980 on the South African farm to 1.375 on the North Dakota farm (US1300ND). Given the South African farm's inefficient utilization of all costs, it is not surprising that it is the second least cost efficient farm over the 5-year average.

Table 6.26 shows summary statistics for corn and soybean farms for the 5-year average. The average input utilization ratios for all three cost categories are greater than one, indicating over-utilization of resources. The ratio of corn/soybeans was used for the rest of the variables. The average revenue (corn/soybeans) is 1.203, indicating that corn revenue, on average, is slightly higher than average soybean revenue. On average, farms planted fewer acres of corn than soybeans, 27.845 and 45.229 percent, respectively.

Table 6.27 shows the correlation coefficients for corn and soybeans. The direct cost utilization ratio had a significant relationship with cost efficiency at the 10 percent level. At the 5 percent level, the overhead cost utilization ratio had a significant relationship with cost efficiency. The negative correlation coefficient indicates there is an inverse relationship between cost efficiency and the overhead cost utilization ratio, indicating overhead costs are likely over-utilized, with a utilization ratio greater than one. There were three variables with a statistically significant relationship to cost efficiency at any level in the per hectare category. Average profit was significant at the 10 percent level. Average revenue and average gross margin were significant at the 5 percent level. All of the significant variables had a negative coefficient, indicating a negative relationship with cost efficiency. The per hectare results for average profit, average revenue, and average gross margin suggests that planting relatively more soybeans increases cost efficiency.

The relationship between costs and cost efficiency is shown in Table 6.28. For the corn and soybean joint analysis, the average cost share for revenue was used. Each cost item was divided by the sum of corn and soybean total revenue. The individual cost category relationships were not as significant as with the single crops. No variables had a significant correlation to cost efficiency at the 5 percent level. At the 10 percent level, only buildings had a significant relationship with cost efficiency. The positive correlation indicates that investment in buildings positively influences cost efficiency.

6.6 Corn & Wheat Results

Seventeen farms representing 12 countries are included in the corn and wheat analysis. Table 6.29 shows the efficiency results for these farms. Three farms (BG7000PLE, BR65PR, and US1215INS) were efficient in all three time periods. Average cost efficiency was lowest in 2017. The lowest value for cost efficiency was also observed in 2017 on the Ukrainian farm with a value of 0.459. For the 5-year average, the standard deviation of cost efficiency was 16.57 percent. The largest standard deviation for cost efficiency was observed in 2017, at 22.09 percent.

Allocative efficiency was highest, on average, in 2013, with a score of 0.924. For the 5-year average, nine farms had an allocative efficiency score of 1. The highest average technical efficiency scores were for the 5-year average, with an average of 0.936. Twelve farms for the 5-year average had technical efficiency scores of 1. The standard deviation of technical efficiency for the 5-year average was 12.65 percent.

Cost efficiency for corn and wheat production is graphed in Figure 6.5. The French farm from the Alsace region (FR110ALS) had the lowest average cost efficiency, at 0.602. Over half (52.9%) of the farms had a cost efficiency of 1.

Table 6.30 includes a summary of the cost efficiency scores for the farms over the three time periods. Seven farms did not have a cost efficiency score of 1 in any time period. Median cost efficiency was 0.877 in 2013, 0.878 in 2017, and 1 in the 5-year average. In 2013, 41.2 percent of farms had a cost efficiency score of 1. By 2017, that had dropped to 29.4 percent of farms.

No significant difference in cost efficiency between 2013, 2017, or the 5-year average was found using two-tailed t-tests. The highest average cost efficiency was observed in the 5-year average and was 0.602. The lowest average cost efficiency was observed in 2017 and was 0.459.

The ratio of cost efficiency in each individual year to the 5-year average cost efficiency was 0.972 in 2013, and 0.9 in 2017. This indicates that farms were under-performing, relative to the 5-year average, in both 2013 and 2017. Three different farms over-performed, relative to the 5-year average in 2013 and in 2017. More farms under-performed, relative to the 5-year average; 7 in 2013 and 10 in 2017. Given these results, the 5-year average will be the focus for the remainder of the analysis of corn and wheat farms.

Table 6.31 shows the distribution of efficiency scores over the 5-year time period. Although the scores have a larger distribution than the corn and soybean results did in Table 6.27, the scores are still skewed towards the upper end of the distribution. No farms had an efficiency below 0.6 in any of the efficiency indices. Additionally, over half of farms had an efficiency score of one for technical, allocative, and cost efficiency.

The input utilization ratio for direct, operating, and overhead costs for the 5-year period are shown for all corn and wheat producing farms in Table 6.32. The average input utilization ratios for direct, operating, and overhead costs are 1.15, 1.39, and 1.19, respectively. As with corn and soybean production, the ratios are all greater than one, indicating over-utilization is more prevalent than under-utilization. The South African farm (ZA1600EFS) was the only farm to under-utilize direct costs in the 5-year period, with a utilization ratio of 0.901. The North Dakota farm (US1300ND) was the only farm to under-utilize operating costs, with a utilization ratio of 0.901. The Polish farm (PL730WO) was also alone in under-utilizing overhead costs, with a utilization ratio of 0.9. The largest utilization ratios were 1.727 for direct costs, 3.053 for operating costs, and 1.793 for overhead costs. Two of the highest utilization ratios were observed on the South African farm. The largest utilization ratio for direct cost was observed on the Hungarian farm (HU1100TC).

Summary statistics for corn and wheat farms for the 5-year average are presented in Table 6.33. The average utilization ratio for the three cost categories is greater than 1, indicating a tendency to over-utilize resources. The ratio of corn to wheat was used for the remainder of the variables to incorporate information from both crops being analyzed. Average profit per hectare and average revenue per hectare are greater than one, indicating that corn generates more profit and revenue per hectare, on average. Farms in this dataset tended to plant a higher percentage of acres to corn than they planted to wheat. This is also reflected in the average planted acres, as it is greater than one, indicating more acres of corn are planted that wheat.

Correlation coefficients are shown in Table 6.34. The utilization ratios were all significant at the 1 percent level. The negative coefficients indicate that there is an inverse relationship between cost efficiency and the utilization ratios. The ratio of corn to wheat average gross margin was the only per hectare measure that was significant at any level. The percentage acreage planted to corn was significant at the 1 percent level. The negative coefficient indicates that percentage acreage planted to corn is inversely related to cost efficiency, when considering farms producing both corn and wheat.

Table 6.35 shows the relationship between the share of revenue each of the costs account for and cost efficiency. As with the previous joint analysis, the average cost share for revenue was used. The costs are presented as a share of the corn and wheat total revenue. At the 1 percent level, land was significant. The positive coefficient indicates cost efficiency is positively related to expenditure on land. At the 5 percent level, nitrogen, phosphorus, energy, irrigation, finance cost, other energy, and buildings are significant. Energy, irrigation, other energy, and buildings have an inverse relationship with cost efficiency. Nitrogen, phosphorus, and finance cost have a positive relationship with cost efficiency, as the correlation is positive. Seed and family labor were significant at the 10 percent level. Seed had a positive correlation coefficient, indicating a positive relationship with cost efficiency. Family labor had a negative correlation coefficient, indicating an inverse relationship with cost efficiency.

Chapter 6 Figures:

Table 6.1. Corn Farm Efficiency Results.

Time Period	TE	AE	CE	Cost Efficient Firms	Firms on CE frontier [a]
2013	0.770	0.896	0.691	5	AR330ZN, **AR700SBA**, CZ4000JC, **UA7100PO**, **VN3LM**
2017	0.743	0.873	0.672	7	**AR700SBA**, AR900WBA, BR1300MT, **UA7100PO**, US1215INC, US1300ND, **VN3LM**
5-Year Average	0.802	0.929	0.749	5	AR330ZN, **AR700SBA**, **UA7100PO**, US1215INC, **VN3LM**

[a] = firms on the frontier in all three periods are in bold.

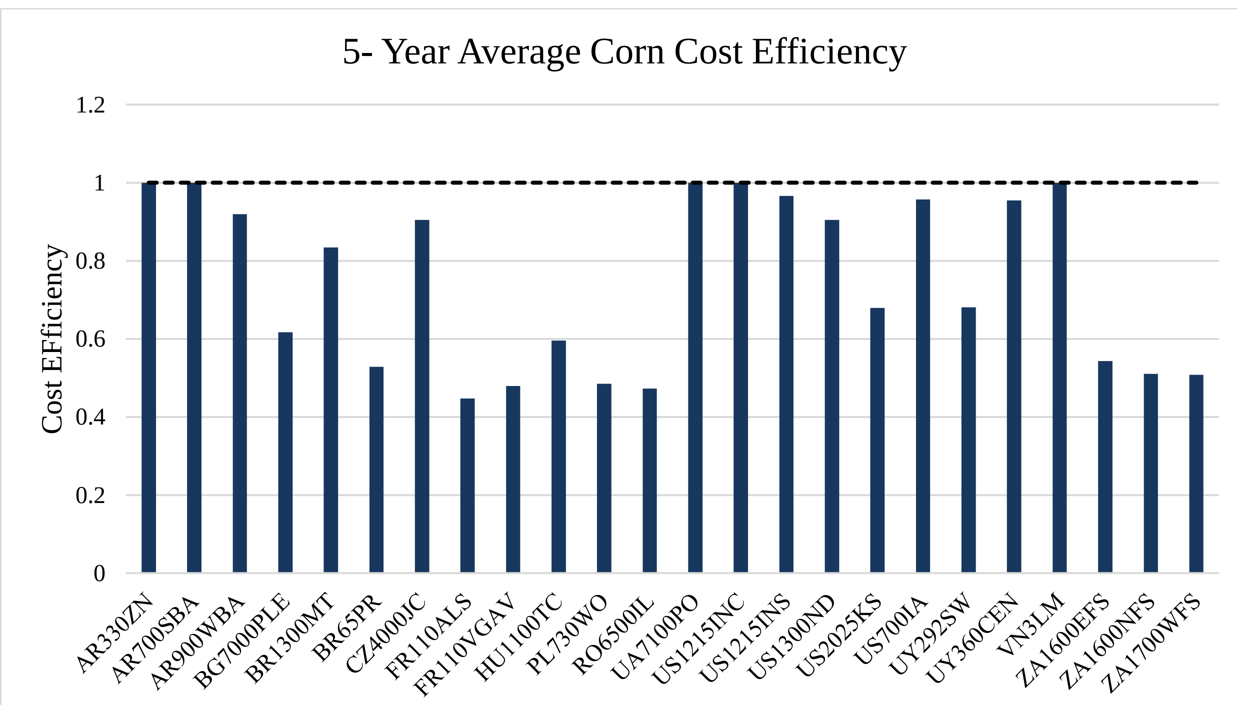

Figure 6.1. Corn 5-Year Average Cost Efficiency.

Table 6.2. Corn Cost Efficiency.

	2013	2017	5-Year Average
AR330ZN	**1.000**	0.673	**1.000**
AR700SBA	**1.000**	**1.000**	**1.000**
AR900WBA	0.910	**1.000**	0.919
BG7000PLE	0.762	0.409	0.617
BR1300MT	0.808	**1.000**	0.834
BR65PR	0.419	0.371	0.528
CZ4000JC	**1.000**	0.411	0.905
FR110ALS	0.371	0.281	0.447
FR110VGAV	0.390	0.252	0.479
HU1100TC	0.467	0.458	0.596
PL730WO	0.489	0.141	0.485
RO6500IL	0.481	0.147	0.473
UA7100PO	**1.000**	**1.000**	**1.000**
US1215INC	0.875	**1.000**	**1.000**
US1215INS	0.800	0.975	0.966
US1300ND	0.622	**1.000**	0.905
US2025KS	0.447	0.798	0.679
US700IA	0.729	0.814	0.957
UY292SW	0.755	0.455	0.681
UY360CEN	0.801	0.726	0.955
VN3LM	**1.000**	**1.000**	**1.000**
ZA1600EFS	0.502	0.898	0.543
ZA1600NFS	0.500	0.715	0.510
ZA1700WFS	0.446	0.615	0.508

Table 6.3. Distribution of 5-Year Corn Technical, Allocative and Cost Efficiency Indices.

	TE		AE		CE	
Efficiency Range	Number	Percent	Number	Percent	Number	Percent
=1	11	45.83	5	20.83	5	20.83
0.9 < 1	1	4.17	13	54.17	6	25.00
0.8 < 0.9	1	4.17	5	20.83	1	4.17
0.7 < 0.8	1	4.17	1	4.17	-	-
0.6 < 0.7	3	12.50	-	-	3	12.50
0.5 < 0.6	5	20.83	-	-	5	20.83
0.4 < 0.5	2	8.33	-	-	4	16.67
0.3 < 0.4	-	-	-	-	-	-
0.2 < 0.3	-	-	-	-	-	-
0.1 < 0.2	-	-	-	-	-	-
0 < 0.1	-	-	-	-	-	-
Sum	24	100	24	100	24	100
Mean Efficiency	0.802		0.929		0.749	
Median Efficiency	0.914		0.943		0.758	

Table 6.4. 5-Year Average Corn Input Utilization Ratio.

	Direct Costs	Operating Costs	Overhead Costs
AR330ZN	**1.000**	**1.000**	**1.000**
AR700SBA	**1.000**	**1.000**	**1.000**
AR900WBA	1.184	0.843	1.184
BG7000PLE	2.837	1.253	1.515
BR1300MT	3.687	0.565	1.236
BR65PR	1.271	5.363	1.320
CZ4000JC	2.520	0.727	0.668
FR110ALS	2.242	2.585	1.840
FR110VGAV	2.269	2.108	1.791
HU1100TC	2.493	1.026	1.464
PL730WO	1.988	4.016	1.184
RO6500IL	3.712	1.656	1.929
UA7100PO	**1.000**	**1.000**	**1.000**
US1215INC	**1.000**	**1.000**	**1.000**
US1215INS	2.877	0.573	0.749
US1300ND	1.511	0.650	1.385
US2025KS	6.217	0.587	1.081
US700IA	1.036	1.003	1.084
UY292SW	1.372	1.757	1.402
UY360CEN	1.613	0.530	1.536
VN3LM	**1.000**	**1.000**	**1.000**
ZA1600EFS	3.907	1.284	1.329
ZA1600NFS	3.873	1.361	1.629
ZA1700WFS	4.779	1.270	1.491

Table 6.5. Summary of 5-Year Average Corn Farm Variables.[2]

Variable Description	Mean	SD	Min	Max
Cost Efficiency	0.749	0.219	0.447	1.000
Direct Cost Utilization Ratio	2.350	1.407	1.000	6.217
Operating Cost Utilization Ratio	1.423	1.140	0.530	5.363
Overhead Cost Utilization Ratio	1.284	0.329	0.668	1.929
Average Profit per Hectare	-91.287	248.449	-731.868	264.143
Yield	8.035	2.568	4.500	13.300
Average Revenue	1,231.774	521.386	483.022	2,425.013
Average Price	149.562	35.313	70.500	234.643
Average Implicit Output	8.313	2.700	4.500	13.300
Average Gross Margin	667.612	306.803	166.465	1,552.398
Percentage Total Acres Planted to Corn	33.592%	21.268%	3.539%	80.512%
Average Planted Acres of Corn	484.403	480.277	3.000	1,865.200
Total Farm Profit	-10,117.296	107,815.510	-136,233.357	430,572.414

(n=24)

[2] Corn silage yields were excluded from this table. The Czech Republic typical farm (CZ4000JC) produced both corn silage and grain corn from 2013 to 2017 in every year. All other corn farms only produced grain corn.

Table 6.6. 5-Year Average Corn Cost Efficiency Correlation Results.

Variable Description	Variable[a b]		Correlation Coefficient
Utilization Ratios			
Direct Cost Utilization Ratio	-0.082	***	-0.529
	(0.028)		
Operating Cost Utilization Ratio	-0.112	***	-0.583
	(0.033)		
Overhead Cost Utilization Ratio	-0.490	***	-0.738
	(0.096)		
Measures per Hectare			
Average Profit	0.000	**	0.442
	(0.000)		
Yield	0.009		0.230
	(0.008)		
Average Revenue	0.000		0.028
	(0.000)		
Average Price	-0.002	*	-0.362
	(0.001)		
Average Implicit Output	0.021		0.258
	(0.017)		
Average Gross Margin	0.000		0.151
	(0.000)		
Total Farm Measures			
Percentage Total Acres Planted to Corn	-0.415	*	-0.404
	(0.201)		
Average Planted Acres of Corn	0.000		-0.072
	(0.000)		
Total Farm Profit	0.000		0.183
	(0.000)		

[a] Standard errors in parentheses.

[b] *, **, *** Statistically significant at the 10, 5, and 1 percent levels, respectively.

Table 6.7. 5-Year Average Corn Cost Relationship to Cost Efficiency.

Variable	Average Cost per Implicit Ton	Correlation to Cost Efficiency[a]	
Total Direct Cost	66.457	-0.506	**
Seed	19.832	0.093	
Nitrogen	17.025	-0.360	*
Phosphorus	6.236	-0.171	
Potash	3.178	-0.170	
Lime	0.085	0.328	
Other Fertilizer	0.356	-0.215	
Pesticides	10.289	-0.372	*
Energy	3.096	-0.374	*
Irrigation	2.028	-0.132	
Crop Insurance	1.428	0.003	
Other Direct	2.138	-0.202	
Finance Cost	0.766	0.402	*
Total Operating Cost	52.632	-0.509	**
Hired Labor	8.752	-0.019	
Family Labor	7.379	-0.247	
Contractor	9.603	0.182	
Machinery	18.803	-0.574	***
Diesel	7.167	-0.556	***
Other Energy	0.927	-0.635	***
Total Overhead Cost	36.722	-0.144	
Buildings	3.122	-0.574	***
Land	27.086	0.268	
Miscellaneous	6.514	-0.496	**

[a] * indicates statistically significant at the 10 percent level.
** indicates statistically significant at the 5 percent level.
*** indicates statistically significant at the 1 percent level.

Table 6.8. Soybean Farm Efficiency Results.

Time Period	TE	AE	CE	Cost Efficient Firms	Firms on CE frontier [a]
2013	0.889	0.899	0.806	5	AR330ZN, **AR900WBA**, **BR1300MT**, US1215INC, ZA1600EFS
2017	0.819	0.860	0.710	4	**AR900WBA**, **BR1300MT**, UA2600WU, ZA1600EFS
5-Year Average	0.861	0.888	0.774	5	AR330ZN, **AR900WBA**, **BR1300MT**, BR65PR, US1215INC

[a] = firms on the frontier in all three periods are in bold.

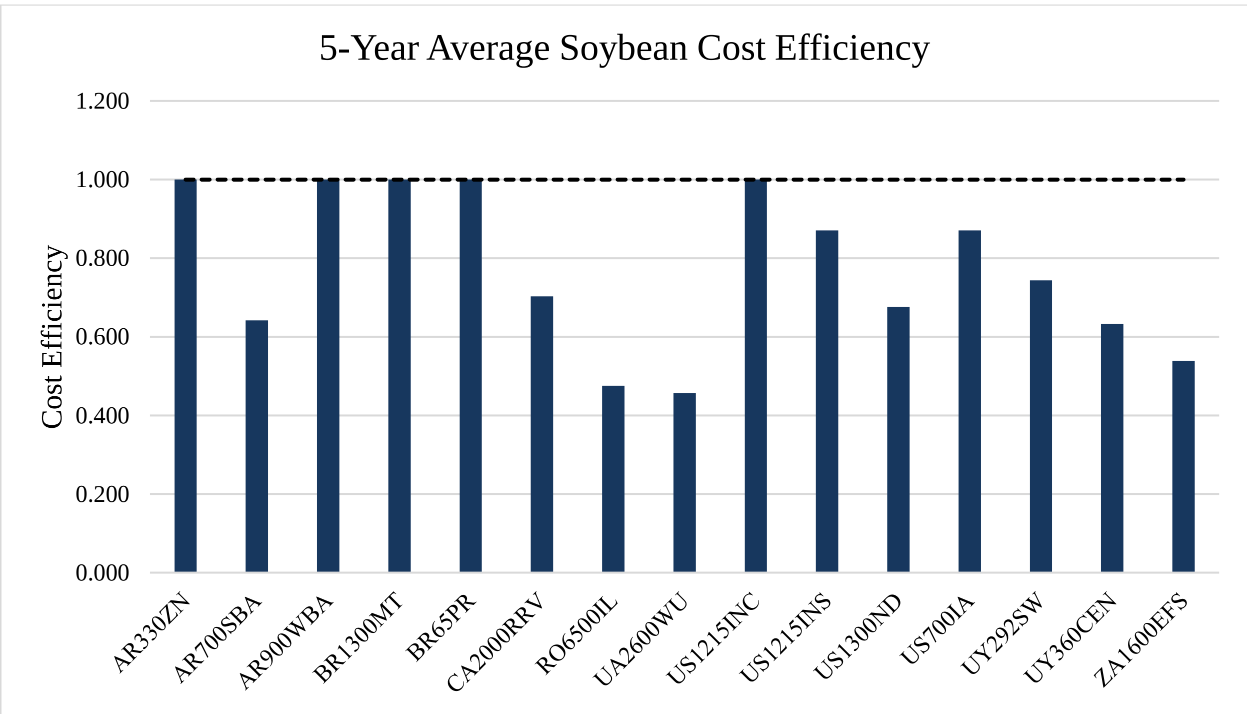

Figure 6.2. Soybean 5-Year Average Cost Efficiency.

Table 6.9. Soybean Cost Efficiency.

	2013	2017	5-Year Average
AR330ZN	**1.000**	0.830	**1.000**
AR700SBA	0.678	0.451	0.642
AR900WBA	**1.000**	**1.000**	**1.000**
BR1300MT	**1.000**	**1.000**	**1.000**
BR65PR	0.814	0.773	**1.000**
CA2000RRV	0.763	0.565	0.703
RO6500IL	0.487	0.530	0.476
UA2600WU	0.582	**1.000**	0.457
US1215INC	**1.000**	0.644	**1.000**
US1215INS	0.845	0.582	0.871
US1300ND	0.605	0.569	0.676
US700IA	0.772	0.611	0.871
UY292SW	0.820	0.550	0.744
UY360CEN	0.717	0.544	0.633
ZA1600EFS	**1.000**	**1.000**	0.539

Table 6.10. Distribution of 5-Year Soybean Technical, Allocative, and Cost Efficiency Indices.

	TE		AE		CE	
Efficiency Range	Number	Percent	Number	Percent	Number	Percent
=1	6	40.00	5	33.33	5	33.33
0.9 < 1	2	13.33	4	26.67	-	-
0.8 < 0.9	1	6.67	1	6.67	2	13.33
0.7 < 0.8	3	20.00	4	26.67	2	13.33
0.6 < 0.7	3	20.00	1	6.67	3	20.00
0.5 < 0.6	-	-	-	-	1	6.67
0.4 < 0.5	-	-	-	-	2	13.33
0.3 < 0.4	-	-	-	-	-	-
0.2 < 0.3	-	-	-	-	-	-
0.1 < 0.2	-	-	-	-	-	-
0 < 0.1	-	-	-	-	-	-
Sum	15	100	15	100	15	100
Mean Efficiency	0.861		0.888		0.774	
Median Efficiency	0.932		0.935		0.744	

Table 6.11. 5-Year Average Soybean Input Utilization Ratio.

	Direct Costs	Operating Costs	Overhead Costs
AR330ZN	**1.000**	**1.000**	**1.000**
AR700SBA	1.617	1.564	1.516
AR900WBA	**1.000**	**1.000**	**1.000**
BR1300MT	**1.000**	**1.000**	**1.000**
BR65PR	**1.000**	**1.000**	**1.000**
CA2000RRV	1.549	1.569	1.143
RO6500IL	1.803	3.892	1.348
UA2600WU	2.306	3.626	1.074
US1215INC	**1.000**	**1.000**	**1.000**
US1215INS	1.482	1.146	0.943
US1300ND	1.708	1.490	1.271
US700IA	1.178	1.503	1.025
UY292SW	1.839	0.965	1.479
UY360CEN	2.242	1.213	1.533
ZA1600EFS	1.474	2.306	1.380

Table 6.12. Summary of 5-Year Average Soybean Farm Variables.

Variable Description	Mean	SD	Min	Max
Cost Efficiency	0.774	0.202	0.457	1.000
Direct Cost Utilization Ratio	1.480	0.448	1.000	2.306
Operating Cost Utilization Ratio	1.618	0.942	0.965	3.892
Overhead Cost Utilization Ratio	1.181	0.217	0.943	1.533
Average Profit	60.129	100.730	-159.024	203.129
Yield	2.834	0.743	1.682	3.778
Average Revenue	944.187	313.717	463.669	1,476.842
Average Price	333.229	66.907	199.286	436.030
Average Implicit Output	2.863	0.775	1.682	3.942
Average Gross Margin	655.682	221.647	345.558	1,042.379
Percentage Total Acres Planted to Soybeans	42.711%	16.869%	7.472%	62.542%
Average Planted Acres of Soybeans	518.880	328.364	62.400	1,300.000
Total Farm Profit	50,989.744	79,133.587	-24,489.682	264,068.325

(n=15)

Table 6.13. 5-Year Average Soybean Cost Efficiency Correlation Results.

Variable Description	Variable[a b]		Correlation Coefficient
Utilization Ratios			
Direct Cost Utilization Ratio	-0.388	***	-0.861
	(0.064)		
Operating Cost Utilization Ratio	-0.171	***	-0.800
	(0.036)		
Overhead Cost Utilization Ratio	-0.629	***	-0.675
	(0.190)		
Measures per Hectare			
Average Profit	0.000		0.060
	(0.001)		
Yield	0.213	***	0.783
	(0.047)		
Average Revenue	0.000		0.409
	(0.000)		
Average Price	-0.001		-0.390
	(0.001)		
Average Implicit Output	0.202	***	0.776
	(0.046)		
Average Gross Margin	0.000		0.346
	(0.000)		
Total Farm Measures			
Percentage Total Acres Planted to Soybeans	0.892	***	0.745
	(0.222)		
Average Planted Acres of Soybeans	0.000		0.021
	(0.000)		
Total Farm Profit	0.000		0.000
	(0.000)		

[a] Standard errors in parentheses.

[b] *, **, *** Statistically significant at the 10, 5, and 1 percent levels, respectively.

Table 6.14. 5-Year Average Soybean Cost Relationship to Cost Efficiency.

Variable	Average Cost per Implicit Ton	Correlation to Cost Efficiency[a]	
Total Direct Cost	100.282	-0.099	
Seed	37.485	-0.292	
Nitrogen	2.332	-0.523	**
Phosphorus	11.818	0.351	
Potash	8.482	0.460	*
Lime	0.124	0.311	
Other Fertilizer	0.002	-0.452	*
Pesticides	30.085	-0.234	
Energy	0.315	-0.434	
Irrigation	1.020	-0.325	
Crop Insurance	5.039	-0.167	
Other Direct	2.397	0.149	
Finance Cost	1.186	-0.056	
Total Operating Cost	108.339	-0.497	*
Hired Labor	17.327	-0.533	**
Family Labor	9.551	0.237	
Contractor	27.899	-0.099	
Machinery	41.364	-0.225	
Diesel	11.207	-0.591	**
Other Energy	0.990	-0.375	
Total Overhead Cost	101.683	0.227	
Buildings	4.257	0.090	
Land	83.905	0.323	
Miscellaneous	13.520	-0.616	**

[a] * indicates statistically significant at the 10 percent level.
** indicates statistically significant at the 5 percent level.
*** indicates statistically significant at the 1 percent level.

Table 6.15. Wheat Farm Efficiency Results.

Time Period	TE	AE	CE	Cost Efficient Firms	Firms on CE frontier [a]
2013	0.853	0.883	0.752	4	AU4000WB, **BR65PR**, DE250KAB, UA7100PO
2017	0.592	0.812	0.485	4	BG7000PLE, **BR65PR**, SE570LAV, UA2600WU
5-Year Average	0.898	0.928	0.836	7	BG7000PLE, **BR65PR**, DE1100VP, DE250KAB, DE360OW, SE570LAV, US1215INS

[a] = firms on the frontier in all three periods are in bold.

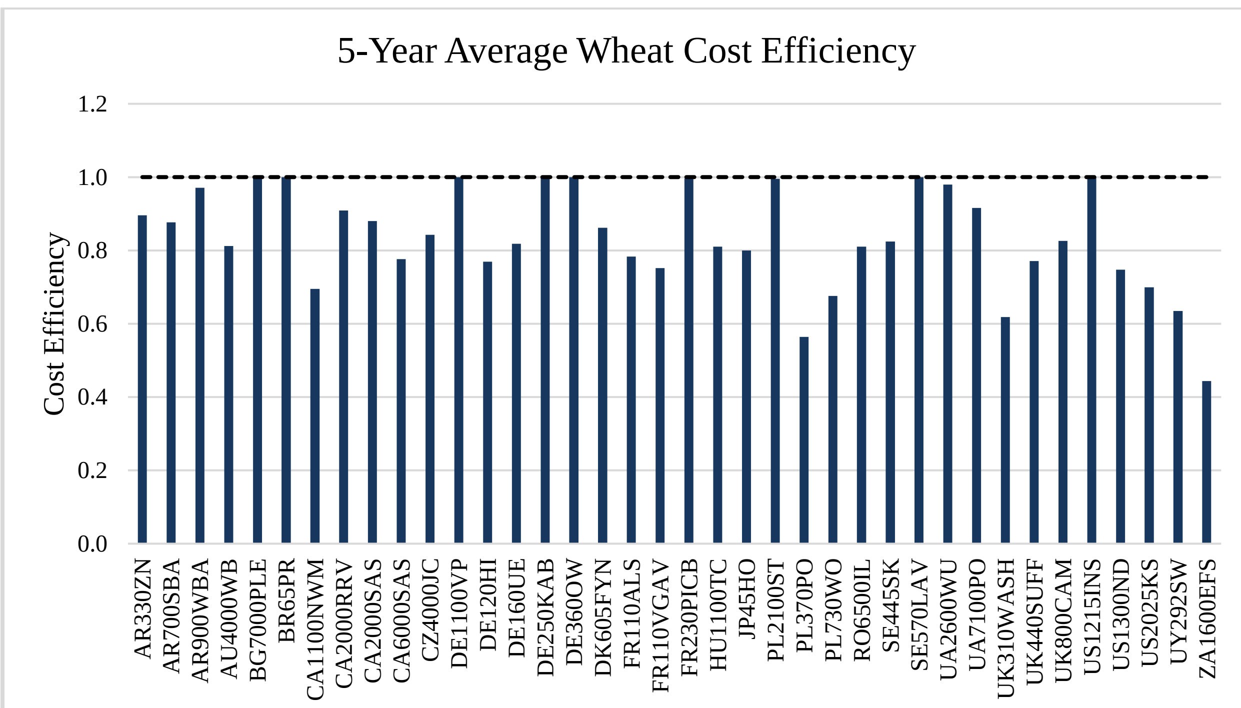

Figure 6.3. Wheat 5-Year Average Cost Efficiency.

Table 6.16. Wheat Cost Efficiency.

	2013	2017	5-Year Average
AR330ZN	0.706	0.429	0.896
AR700SBA	0.928	0.242	0.877
AR900WBA	0.638	0.625	0.971
AU4000WB	**1.000**	0.264	0.812
BG7000PLE	0.890	**1.000**	**1.000**
BR65PR	**1.000**	**1.000**	**1.000**
CA1100NWM	0.742	0.318	0.695
CA2000RRV	0.836	0.162	0.909
CA2000SAS	0.842	0.390	0.880
CA6000SAS	0.766	0.478	0.776
CZ4000JC	0.687	0.510	0.843
DE1100VP	0.975	0.664	**1.000**
DE120HI	0.697	0.364	0.769
DE160UE	0.742	0.379	0.818
DE250KAB	**1.000**	0.454	**1.000**
DE360OW	0.827	0.535	**1.000**
DK605FYN	0.677	0.542	0.862
FR110ALS	0.685	0.401	0.783
FR110VGAV	0.691	0.672	0.752
FR230PICB	0.832	0.540	0.996
HU1100TC	0.835	0.352	0.810
JP45HO	0.747	0.303	0.800
PL2100ST	0.874	0.809	0.995
PL370PO	0.511	0.268	0.564
PL730WO	0.625	0.490	0.676
RO6500IL	0.667	0.772	0.810
SE445SK	0.734	0.459	0.824
SE570LAV	0.606	**1.000**	**1.000**
UA2600WU	0.753	**1.000**	0.980
UA7100PO	**1.000**	0.367	0.916
UK310WASH	0.487	0.372	0.618
UK440SUFF	0.628	0.264	0.771
UK800CAM	0.622	0.593	0.826
US1215INS	0.848	0.487	**1.000**
US1300ND	0.650	0.349	0.747
US2025KS	0.706	0.368	0.699
UY292SW	0.609	0.082	0.635
ZA1600EFS	0.505	0.144	0.444

Table 6.17. Distribution of 5-Year Wheat Technical, Allocative, and Cost Efficiency Indices.

	TE		AE		CE	
Efficiency Range	Number	Percent	Number	Percent	Number	Percent
=1	16	42.11	7	18.42	7	18.42
0.9 < 1	4	10.53	21	55.26	6	15.79
0.8 < 0.9	10	26.32	7	18.42	11	28.95
0.7 < 0.8	6	15.79	2	5.26	7	18.42
0.6 < 0.7	2	5.26	-	-	5	13.16
0.5 < 0.6	-	-	1	2.63	1	2.63
0.4 < 0.5	-	-	-	-	1	2.63
0.3 < 0.4	-	-	-	-	-	-
0.2 < 0.3	-	-	-	-	-	-
0.1 < 0.2	-	-	-	-	-	-
0 < 0.1	-	-	-	-	-	-
Sum	38	100	38	100	38	100
Mean Efficiency	0.898		0.928		0.836	
Median Efficiency	0.919		0.933		0.825	

Table 6.18. 5-Year Average Wheat Input Utilization Ratio.

	Direct Costs	Operating Costs	Overhead Costs
AR330ZN	1.113	0.709	1.504
AR700SBA	1.225	0.715	1.736
AR900WBA	0.949	0.697	1.701
AU4000WB	1.023	1.134	2.216
BG7000PLE	1.000	1.000	1.000
BR65PR	1.000	1.000	1.000
CA1100NWM	1.516	1.284	1.521
CA2000RRV	1.114	0.913	1.467
CA2000SAS	0.962	1.130	1.632
CA6000SAS	0.979	1.332	2.097
CZ4000JC	0.921	1.693	1.067
DE1100VP	1.000	1.000	1.000
DE120HI	1.161	1.651	1.143
DE160UE	1.286	1.613	0.919
DE250KAB	1.000	1.000	1.000
DE360OW	1.000	1.000	1.000
DK605FYN	1.045	1.171	1.235
FR110ALS	1.241	1.524	1.085
FR110VGAV	1.370	1.534	1.069
FR230PICB	0.880	0.925	1.361
HU1100TC	1.107	1.315	1.358
JP45HO	1.637	3.110	0.477
PL2100ST	0.989	1.013	1.016
PL370PO	1.746	2.044	1.457
PL730WO	1.434	1.638	1.324
RO6500IL	0.877	1.482	1.394
SE445SK	1.060	1.415	1.178
SE570LAV	1.000	1.000	1.000
UA2600WU	0.715	1.584	0.709
UA7100PO	0.917	1.353	0.887
UK310WASH	0.999	2.601	1.379
UK440SUFF	1.066	1.751	1.165
UK800CAM	1.017	1.462	1.182
US1215INS	1.000	1.000	1.000
US1300ND	1.482	0.909	1.937
US2025KS	1.215	1.706	1.552
UY292SW	1.415	1.677	1.704
ZA1600EFS	1.214	4.339	1.732

Table 6.19. Summary of 5-Year Average Wheat Farm Variables.

Variable Description	Mean	SD	Min	Max
Cost Efficiency	0.836	0.139	0.444	1.000
Direct Cost Utilization Ratio	1.123	0.225	0.715	1.746
Operating Cost Utilization Ratio	1.432	0.691	0.697	4.339
Overhead Cost Utilization Ratio	1.295	0.375	0.477	2.216
Average Profit per Hectare	-78.014	415.862	-632.608	1,988.463
Yield	5.905	2.381	1.948	9.940
Average Revenue	1,290.423	1,133.091	340.253	7,352.682
Average Price	193.966	56.008	87.239	463.468
Average Implicit Output	6.257	2.921	1.948	16.219
Average Gross Margin	823.893	771.614	115.374	4,854.964
Percentage Total Acres Planted to Wheat	34.001%	14.862%	4.153%	67.09%
Average Planted Acres of Wheat	516.766	618.591	12.840	2,573.121
Total Farm Profit	608.666	69,175.716	-173,838.570	167,161.662

Table 6.20. 5-Year Average Wheat Cost Efficiency Correlation Results.

Variable Description	Variable[a b]		Correlation Coefficient
Utilization Ratios			
Direct Cost Utilization Ratio	-0.386	***	-0.626
	(0.080)		
Operating Cost Utilization Ratio	-0.146	***	-0.725
	(0.023)		
Overhead Cost Utilization Ratio	-0.156	***	-0.422
	(0.056)		
Measures per Hectare			
Average Profit	0.000		0.096
	(0.000)		
Yield	0.010		0.176
	(0.010)		
Average Revenue	0.000		0.006
	(0.000)		
Average Price	-0.001		-0.241
	(0.000)		
Average Implicit Output	0.006		0.124
	(0.008)		
Average Gross Margin	0.000		0.032
	(0.000)		
Total Farm Measures			
Percentage Total Acres Planted to Wheat	0.134		0.143
	(0.154)		
Average Planted Acres of Wheat	0.000		0.219
	(0.000)		
Total Farm Profit	0.000		0.239
	(0.000)		

[a] Standard errors in parentheses.

[b] *, **, *** Statistically significant at the 10, 5, and 1 percent levels, respectively.

Table 6.21. 5-Year Average Wheat Cost Relationship to Cost Efficiency.

Variable	Average Cost per Implicit Ton	Correlation to Cost Efficiency[a]	
Total Direct Cost	72.804	-0.296	*
Seed	13.023	0.096	
Nitrogen	22.576	-0.123	
Phosphorus	7.176	-0.201	
Potash	2.156	0.059	
Lime	0.809	-0.337	**
Other Fertilizer	1.285	-0.227	
Pesticides	19.278	-0.138	
Energy	0.914	0.016	
Irrigation	1.058	-0.074	
Crop Insurance	2.240	-0.340	**
Other Direct	1.678	-0.287	*
Finance Cost	0.612	0.136	
Total Operating Cost	78.442	-0.418	***
Hired Labor	12.817	-0.035	
Family Labor	10.355	-0.127	
Contractor	8.824	-0.204	
Machinery	34.042	-0.166	
Diesel	11.101	-0.492	***
Other Energy	1.303	-0.321	**
Total Overhead Cost	60.899	0.121	
Buildings	5.690	-0.148	
Land	46.110	0.243	
Miscellaneous	9.100	-0.332	**

[a] * indicates statistically significant at the 10 percent level.
** indicates statistically significant at the 5 percent level.
*** indicates statistically significant at the 1 percent level.

Table 6.22. Corn & Soybean Farm Efficiency Results.

Time Period	TE	AE	CE	Cost Efficient Firms	Firms on CE frontier [a]
2013	0.962	0.988	0.952	7	**AR330ZN**, **AR900WBA**, **BR1300MT**, **BR65PR**, RO6500IL, **US1215INC**, UY292SW
2017	0.932	0.943	0.892	7	**AR330ZN**, **AR900WBA**, **BR1300MT**, **BR65PR**, **US1215INC**, US1300ND, ZA1600EFS
5-Year Average	0.983	0.954	0.939	7	**AR330ZN**, **AR900WBA**, **BR1300MT**, **BR65PR**, RO6500IL, **US1215INC**, US700IA

[a] = firms on the frontier in all three periods are in bold.

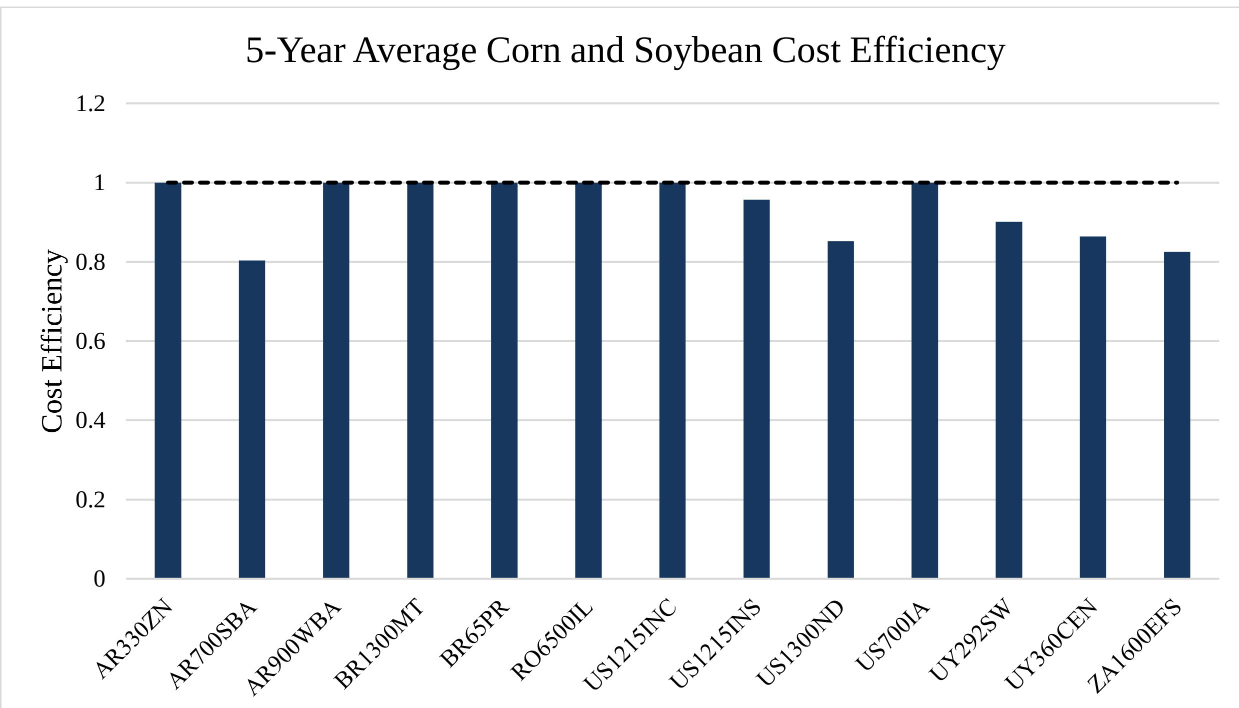

Figure 6.4. Corn & Soybean 5-Year Average Cost Efficiency.

Table 6.23. Corn & Soybean Cost Efficiency.

	2013	2017	5-Year Average
AR330ZN	**1.000**	**1.000**	**1.000**
AR700SBA	0.817	0.690	0.803
AR900WBA	**1.000**	**1.000**	**1.000**
BR1300MT	**1.000**	**1.000**	**1.000**
BR65PR	**1.000**	**1.000**	**1.000**
RO6500IL	**1.000**	0.274	**1.000**
US1215INC	**1.000**	**1.000**	**1.000**
US1215INS	0.931	0.970	0.957
US1300ND	0.743	**1.000**	0.852
US700IA	0.950	0.924	**1.000**
UY292SW	**1.000**	0.870	0.901
UY360CEN	0.934	0.872	0.864
ZA1600EFS	0.995	**1.000**	0.825

Table 6.24. Distribution of 5-Year Corn & Soybean Technical, Allocative, and Cost Efficiency Indices.

	TE		AE		CE	
Efficiency Range	Number	Percent	Number	Percent	Number	Percent
=1	10	76.92	7	53.85	7	53.85
0.9 < 1	2	15.38	3	23.08	2	15.38
0.8 < 0.9	1	7.69	3	23.08	4	30.77
0.7 < 0.8	-	-	-	-	-	-
0.6 < 0.7	-	-	-	-	-	-
0.5 < 0.6	-	-	-	-	-	-
0.4 < 0.5	-	-	-	-	-	-
0.3 < 0.4	-	-	-	-	-	-
0.2 < 0.3	-	-	-	-	-	-
0.1 < 0.2	-	-	-	-	-	-
0 < 0.1	-	-	-	-	-	-
Sum	13	100	13	100	13	100
Mean Efficiency	0.983		0.954		0.939	
Median Efficiency	1.000		1.000		1.000	

Table 6.25. 5-Year Average Corn & Soybean Input Utilization Ratio.

	Direct Costs	Operating Costs	Overhead Costs
AR330ZN	1.000	1.000	1.000
AR700SBA	1.311	1.244	1.174
AR900WBA	1.000	1.000	1.000
BR1300MT	1.000	1.000	1.000
BR65PR	1.000	1.000	1.000
RO6500IL	1.000	1.000	1.000
US1215INC	1.000	1.000	1.000
US1215INS	1.076	1.015	1.025
US1300ND	1.202	0.994	1.375
US700IA	1.000	1.000	1.000
UY292SW	1.448	0.750	1.286
UY360CEN	1.551	0.836	1.164
ZA1600EFS	0.875	1.849	0.980

Table 6.26. Summary of 5-Year Average Corn & Soybean Farm Variables.

Variable Description	Mean	SD	Min	Max
Cost Efficiency	0.939	0.078	0.803	1.000
Direct Cost Utilization Ratio	1.112	0.204	0.875	1.551
Operating Cost Utilization Ratio	1.053	0.264	0.750	1.849
Overhead Cost Utilization Ratio	1.077	0.130	0.980	1.375
Average Profit per Hectare (Corn/Soybeans)	4.132	9.672	(6.208)	28.094
Average Revenue (Corn/Soybeans)	1.203	0.392	0.462	2.113
Average Price (Corn/Soybeans)	0.425	0.080	0.258	0.547
Average Gross Margin (Corn/Soybeans)	0.966	0.382	0.302	1.885
Percentage Total Acres Planted (Corn/Soybeans)	95.816%	114.512%	6.690%	420.649%
Percentage Total Acres Planted to Corn	27.845%	17.707%	3.539%	50.000%
Percentage Total Acres Planted to Soybeans	45.229%	16.733%	7.472%	62.542%
Average Planted Acres (Corn/Soybeans)	0.958	1.145	0.067	4.206
Total Farm Profit (Corn/Soybeans)	0.164	3.651	(6.208)	9.304

Table 6.27. 5-Year Average Corn & Soybean Cost Efficiency Correlation Results.

Variable Description	Variable[a b]		Correlation Coefficient
Utilization Ratios			
Direct Cost Utilization Ratio	-0.204	*	-0.536
	(0.097)		
Operating Cost Utilization Ratio	-0.128		-0.436
	(0.080)		
Overhead Cost Utilization Ratio	-0.376	**	-0.629
	(0.140)		
Measures per Hectare			
Average Profit (Corn/Soybeans)	-0.004	*	-0.485
	(0.002)		
Average Revenue (Corn/Soybeans)	-0.117	**	-0.592
	(0.048)		
Average Price (Corn/Soybeans)	-0.299		-0.310
	(0.277)		
Average Gross Margin (Corn/Soybeans)	-0.134	**	-0.660
	(0.046)		
Total Farm Measures			
Percentage Total Acres Planted (Corn/Soybeans)	-0.013		-0.187
	(0.020)		
Percentage Total Acres Planted to Corn	0.079		0.181
	(0.130)		
Percentage Total Acres Planted to Soybeans	0.090		0.195
	(0.137)		
Average Planted Acres (Corn/Soybeans)	-0.013		-0.187
	(0.020)		
Total Farm Profit (Corn/Soybeans)	0.003		0.151
	(0.006)		

[a] Standard errors in parentheses.

[b] *, **, *** Statistically significant at the 10, 5, and 1 percent levels, respectively.

Table 6.28. 5-Year Average Corn & Soybean Cost Relationship to Cost Efficiency.

Variable	Average Cost Share	Correlation to Cost Efficiency[a]	
Total Direct Cost	0.353	0.032	
Seed	0.127	-0.202	
Nitrogen	0.044	0.071	
Phosphorus	0.040	0.185	
Potash	0.021	0.124	
Lime	0.001	0.010	
Other Fertilizer	0.000	0.241	
Pesticides	0.090	0.076	
Energy	0.002	0.349	
Irrigation	0.003	0.300	
Crop Insurance	0.011	0.065	
Other Direct	0.009	-0.447	
Finance Cost	0.005	-0.110	
Total Operating Cost	0.308	0.009	
Hired Labor	0.035	0.000	
Family Labor	0.027	0.282	
Contractor	0.112	-0.371	
Machinery	0.100	0.415	
Diesel	0.031	-0.008	
Other Energy	0.002	0.297	
Total Overhead Cost	0.318	0.158	
Buildings	0.012	0.511	*
Land	0.262	0.065	
Miscellaneous	0.044	-0.017	

[a] * indicates statistically significant at the 10 percent level.
** indicates statistically significant at the 5 percent level.
*** indicates statistically significant at the 1 percent level.

Table 6.29. Corn & Wheat Farm Efficiency Results.

Time Period	TE	AE	CE	Cost Efficient Firms	Firms on CE frontier [a]
2013	0.901	0.924	0.835	7	AR330ZN, AR700SBA, **BG7000PLE**, **BR65PR**, CZ4000JC, UA7100PO, **US1215INS**
2017	0.838	0.908	0.764	5	AR900WBA, **BG7000PLE**, **BR65PR**, **US1215INS**, US1300ND
5-Year Average	0.936	0.922	0.863	9	AR330ZN, AR700SBA, AR900WBA, **BG7000PLE**, **BR65PR**, CZ4000JC, UA7100PO, **US1215INS**, UY292SW

[a] = firms on the frontier in all three periods are in bold.

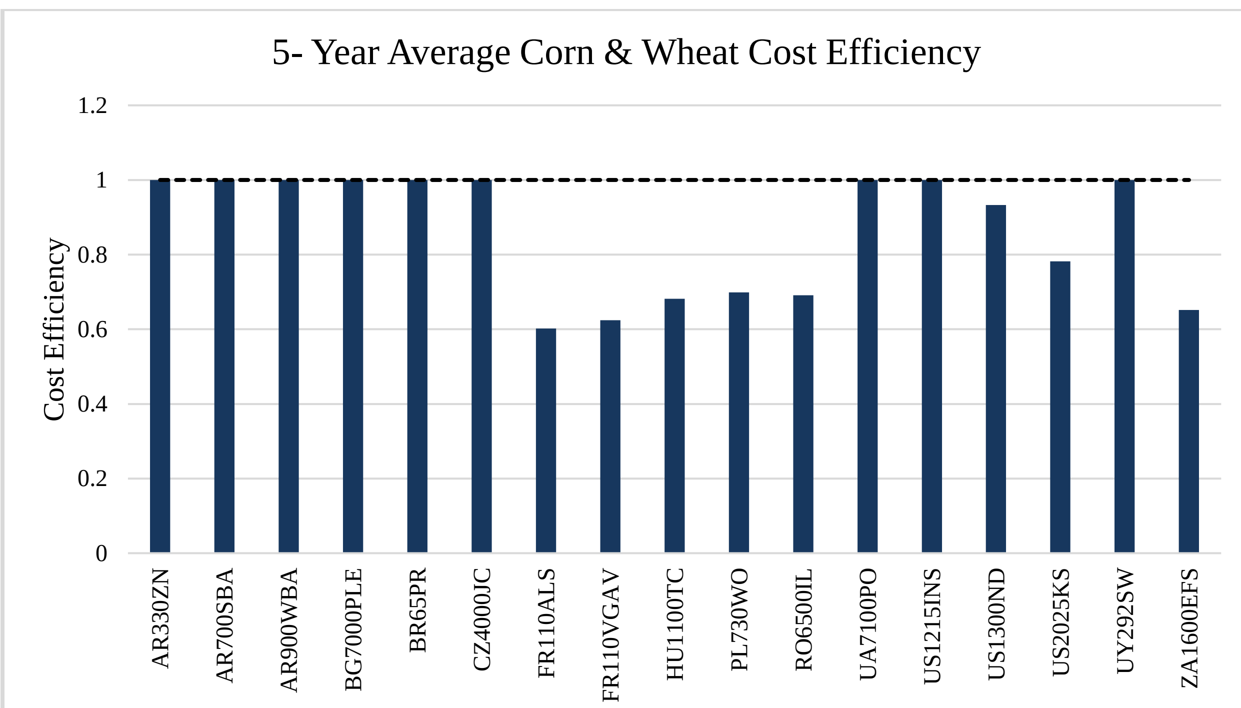

Figure 6.5. Corn & Wheat 5-Year Average Cost Efficiency.

Table 6.30. Corn & Wheat Cost Efficiency.

	2013	2017	5-Year Average
AR330ZN	**1.000**	0.893	**1.000**
AR700SBA	**1.000**	0.551	**1.000**
AR900WBA	0.877	**1.000**	**1.000**
BG7000PLE	**1.000**	**1.000**	**1.000**
BR65PR	**1.000**	**1.000**	**1.000**
CZ4000JC	**1.000**	0.912	**1.000**
FR110ALS	0.575	0.595	0.602
FR110VGAV	0.627	0.564	0.624
HU1100TC	0.634	0.646	0.682
PL730WO	0.626	0.499	0.699
RO6500IL	0.849	0.571	0.691
UA7100PO	**1.000**	0.471	**1.000**
US1215INS	**1.000**	**1.000**	**1.000**
US1300ND	0.779	**1.000**	0.933
US2025KS	0.608	0.956	0.782
UY292SW	0.901	0.459	**1.000**
ZA1600EFS	0.725	0.878	0.652

Table 6.31. Distribution of 5-Year Corn & Wheat Technical, Allocative, and Cost Efficiency Indices.

	TE		AE		CE	
Efficiency Range	Number	Percent	Number	Percent	Number	Percent
=1	12	70.59	9	52.94	9	52.94
0.9 < 1	1	5.88	3	17.65	1	5.88
0.8 < 0.9	2	11.76	2	11.76	-	-
0.7 < 0.8	-	-	1	5.88	1	5.88
0.6 < 0.7	2	11.76	2	11.76	6	35.29
0.5 < 0.6	-	-	-	-	-	-
0.4 < 0.5	-	-	-	-	-	-
0.3 < 0.4	-	-	-	-	-	-
0.2 < 0.3	-	-	-	-	-	-
0.1 < 0.2	-	-	-	-	-	-
0 < 0.1	-	-	-	-	-	-
Sum	17	100	17	100	17	100
Mean Efficiency	0.936		0.922		0.863	
Median Efficiency	1.000		1.000		1.000	

Table 6.32. 5-Year Average Corn & Wheat Input Utilization Ratio.

	Direct Costs	Operating Costs	Overhead Costs
AR330ZN	1.000	1.000	1.000
AR700SBA	1.000	1.000	1.000
AR900WBA	1.000	1.000	1.000
BG7000PLE	1.000	1.000	1.000
BR65PR	1.000	1.000	1.000
CZ4000JC	1.000	1.000	1.000
FR110ALS	1.481	2.324	1.332
FR110VGAV	1.496	2.032	1.321
HU1100TC	1.727	1.200	1.361
PL730WO	1.348	2.431	0.900
RO6500IL	1.180	1.625	1.573
UA7100PO	1.000	1.000	1.000
US1215INS	1.000	1.000	1.000
US1300ND	1.106	0.901	1.255
US2025KS	1.386	1.006	1.681
UY292SW	1.000	1.000	1.000
ZA1600EFS	0.901	3.053	1.793

Table 6.33 . Summary of 5-Year Average Corn & Wheat Farm Variables.

Variable Description	Mean	SD	Min	Max
Cost Efficiency	0.863	0.166	0.602	1.000
Direct Cost Utilization Ratio	1.154	0.240	0.901	1.727
Operating Cost Utilization Ratio	1.387	0.661	0.901	3.053
Overhead Cost Utilization Ratio	1.189	0.277	0.900	1.793
Average Profit per Hectare (Corn/Wheat)	6.267	15.116	(4.358)	50.915
Average Revenue (Corn/Wheat)	1.596	0.471	0.910	2.376
Average Price (Corn/Wheat)	0.856	0.201	0.397	1.176
Average Gross Margin (Corn/Wheat)	1.801	1.097	0.492	4.021
Percentage Total Acres Planted (Corn/Wheat)	214.557%	269.967%	10.484%	1103.992%
Percentage Total Acres Planted to Corn	30.325%	21.781%	3.539%	80.512%
Percentage Total Acres Planted to Wheat	21.576%	8.987%	4.153%	39.445%
Average Planted Acres (Corn/Wheat)	2.146	2.700	0.105	11.040
Total Farm Profit (Corn/Wheat)	9.970	20.202	(2.107)	70.898

Table 6.34. 5-Year Average Corn & Wheat Cost Efficiency Correlation Results.

Variable Description	Variable[a b]		Correlation Coefficient
Utilization Ratios			
Direct Cost Utilization Ratio	-0.504	***	-0.731
	(0.122)		
Operating Cost Utilization Ratio	-0.202	***	-0.804
	(0.038)		
Overhead Cost Utilization Ratio	-0.418	***	-0.700
	(0.110)		
Measures per Hectare			
Average Profit (Corn/Wheat)	-0.002		-0.192
	(0.003)		
Average Revenue (Corn/Wheat)	0.111		0.315
	(0.086)		
Average Price (Corn/Wheat)	0.058		0.070
	(0.212)		
Average Gross Margin (Corn/Wheat)	0.068	*	0.448
	(0.035)		
Total Farm Measures			
Percentage Total Acres Planted (Corn/Wheat)	-0.011		-0.175
	(0.016)		
Percentage Total Acres Planted to Corn	-0.472	***	-0.620
	(0.154)		
Percentage Total Acres Planted to Wheat	0.142		0.077
	(0.475)		
Average Planted Acres (Corn/Wheat)	-0.011		-0.175
	(0.016)		
Total Farm Profit (Corn/Wheat)	-0.001		-0.144
	(0.002)		

[a] Standard errors in parentheses.

[b] *, **, *** Statistically significant at the 10, 5, and 1 percent levels, respectively.

Table 6.35. 5-Year Average Corn & Wheat Cost Relationship to Cost Efficiency.

Variable	Average Cost Share	Correlation to Cost Efficiency[a]	
Total Direct Cost	0.455	-0.008	
Seed	0.123	0.419	*
Nitrogen	0.125	0.509	**
Phosphorus	0.050	0.590	**
Potash	0.015	-0.227	
Lime	0.002	-0.222	
Other Fertilizer	0.005	-0.252	
Pesticides	0.079	0.124	
Energy	0.021	-0.529	**
Irrigation	0.008	-0.595	**
Crop Insurance	0.011	-0.165	
Other Direct	0.011	-0.405	
Finance Cost	0.007	0.501	**
Total Operating Cost	0.367	-0.237	
Hired Labor	0.053	-0.096	
Family Labor	0.038	-0.436	*
Contractor	0.084	0.399	
Machinery	0.133	-0.202	
Diesel	0.051	-0.322	
Other Energy	0.007	-0.593	**
Total Overhead Cost	0.290	0.329	
Buildings	0.025	-0.557	**
Land	0.212	0.623	***
Miscellaneous	0.053	-0.346	

[a] * indicates statistically significant at the 10 percent level.
** indicates statistically significant at the 5 percent level.
*** indicates statistically significant at the 1 percent level.

CHAPTER 7. DISCUSSION AND CONCLUSIONS

7.1 Discussion of Results and Hypotheses

In total, 45 farms representing 20 countries were analyzed in this thesis. Table 7.1 summarizes the 5-year average cost efficiency for all farms and all crops in this analysis. Farms with a cost efficiency score of one are indicated using bold font. Using the 5-year averages, five farms were cost efficient at corn production, five farms were cost efficient for soybean production, and seven farms were cost efficient for wheat production. For the farms producing both corn and soybeans, seven farms were found to be cost efficient. Nine farms were found to be cost efficient in corn and wheat production. Overall, 18 farms were cost efficient in at least one crop. Of those farms, half were cost efficient at producing at least 2 of the crops. In total, nine farms produced all three crops over the 5-year time period: AR330ZN, AR700SBA, AR900WBA, BR65PR, RO6500IL, US1215INS, US1300ND, UY292SW, and ZA1600EFS. The cost efficiency results for the farms producing every crop are summarized in more detail in Table 7.2. The efficiency scores among the single crops and the combined corn and soybean, or corn and wheat production do not represent the same sample of farms, as not all wheat or soybean-producing farms also produced corn.

Farms producing both corn and soybeans scored the highest in technical, allocative, and cost efficiency. This reflects the conclusions of Tauer and Hanchar (1995), in that an increase in the number of outputs increases the dimensionality, and therefore increases efficiency scores. Farms producing both corn and wheat had the second highest efficiency scores for technical and cost efficiency. Agronomic factors could also be driving this increase in efficiency scores, as crop rotations tend to boost yields (Crookston et al.,1991). The lowest technical and cost efficiency were calculated for corn farms over the 5-year average. The lowest allocative efficiency was found in soybean farms. These findings are summarized in Table 7.3.

Table 7.4 summarizes the cost efficiency scores over the three time periods analyzed. 2017 was consistently a low performing year for all of the crops analyzed, as average cost efficiency was lowest for every crop analyzed. For soybeans and joint corn and soybean production, 2013 over-performed the 5-year average cost efficiency. Corn, wheat, and joint corn and wheat production had the highest cost efficiency scores using the 5-year averages. It is plausible that exchange rates are one factor driving the low cost efficiency in 2017. Every country had high exchange rates, relative to the U.S. dollar, in 2013 and 2014. From 2015 on, the exchange rate began to weaken for all countries in this analysis. This could be caused by the Dollar's relative strength in more recent years.

A significant difference between cost efficiency in all of the years was found in all time periods for wheat producing farms and between 2013 and the 5-year average corn cost efficiency. However, no significant relationship was found between wheat cost efficiency and exchange rates. This implies that climatic conditions may be driving the fluctuation, rather than exchange rates. Thus, competitive advantage is stronger than exchange rates and weather in determining competitiveness. For the wheat farms, 2013 and 2017 under-performed, relative to the 5-year average cost efficiency.

All of the average input utilization ratios over the 5-year average were greater than one, indicating a tendency to over-utilize inputs. Corn farms and farms producing corn and soybeans jointly had the highest utilization ratio for direct costs. For soybean, wheat, and jointly producing corn and wheat farms, the average input utilization ratio was largest for operating costs.

At the 5 percent level, diesel and miscellaneous overhead costs were the only factors of production that had a significant relationship with cost efficiency for corn, soybean, and wheat production. Total operating costs had a significant relationship at the 5 percent level for corn, 10 percent level for soybeans, and 1 percent level for wheat. All of the correlation coefficients for operating and diesel costs were negative for the individual crops.

Argentina and Brazil tended to be cost efficient in every time period, indicating that those farms are not as sensitive to annual fluctuations. With the exception of wheat, the other crops did not have a significant difference between the 5-year average cost efficiency and the individual years selected. As such, exchange rates and other annual factors influencing competitiveness, such as weather, do not appear to have a significant effect on cost competitiveness. For wheat, the only crop where t-tests indicated a difference in individual years and the 5-year average, there still was no significant relationship between exchange rates and cost competitiveness. The results of this thesis indicate that other variables may be better predictors than exchange rates in determining competitiveness, such as cost utilization ratios.

Five corn farms representing four countries were on the cost efficiency frontier in the 5-year average. Argentina, Ukraine, the United States, and Vietnam were represented on the cost efficiency frontier. Using data from the USDA Foreign Agricultural Service Production, Supply and Distribution database, global crop shares were analyzed. Together, these countries accounted for 40.3 percent of global corn production from 2013 to 2017. These four countries also accounted for 66.7 percent of corn exports from 2013 to 2017 (USDA-FAS, 2019).

Three countries were represented on the cost efficiency frontier for soybean production in the 5-year average. Five farms from Argentina, Brazil, and the United States were on the soybean cost efficiency frontier. These three countries accounted for 82.3 percent of global soybean production, and 88.3 percent of soybean exports from 2013 to 2017 (USDA-FAS, 2019).

Seven wheat farms were on the cost efficiency frontier in the 5-year average. Five countries were represented on the cost efficiency frontier: Bulgaria, Brazil, Germany, Sweden, and the United States. Of these countries, three are members of the European Union. The European Union, Brazil, and the United States accounted for 28.8 percent of global wheat production, and 33 percent of wheat exports from 2013 to 2017 (USDA-FAS, 2019).

From a competitive standpoint, one could assume that countries might specialize in the production of crops where they are cost efficient. The soybean production does seem to be concentrated in the countries that had cost efficient typical farms. With over 80 percent of exports and production coming from the three farms on the cost efficiency frontier, this could indicate farms in those countries are specializing in the production of the crops they are most efficient in. Agronomic and political factors may play a role in determining how much specialization occurs. Crookston et al. (1991) found a decline in yields when continuous soybeans were planted. As such, a farm may be unable to truly specialize in soybeans for an extended period.

7.2 Further Research

This study was limited by the data availability. African countries were relatively underrepresented in this study. Future research should also look to incorporate China into the analysis. Additional countries in this analysis would create more robust conclusions on a global level. Special attention could be paid to farms that are double cropping. Although the second crop may have relatively lower yields and lower competitiveness, compared to single cropped counterparts, the efficiency of such crops in the whole farm system should still be given attention. As such, a whole farm approach may be of particular interest going forward. Whole farm efficiency analyses could yield more robust results for this dataset. The whole farm level approach would also account for crops like sorghum or rapeseed, which this study omits. Future work could also incorporate a price index, rather than using a weighted input price.

Additionally, future work could be done to determine the effect of weather on competitiveness. In this study, we acknowledge that weather and exchange rates would influence competitiveness on an annual basis but lacked data to quantify this. Future work could pair cost efficiency analysis with weather and climatic data for each of the farm locations used to determine if a significant relationship exists between weather and competitiveness at the farm level. Additional work could be done on the comparative advantage of farms, but looking at the national production and export shares for the various crops.

If additional firms are added to the analysis, more flexibility would be gained in classifying inputs. For the purpose of this study, inputs were lumped into direct costs, operating costs, and operating costs. Cooper et al. (2000) states the number of firms should be at least three times the sum of total inputs and outputs. If additional firms are added to the analysis, there would be greater flexibility in input category classification.

Chapter 7 Figures:

Table 7.1. Summary of 5-Year Average Cost Efficiency.

	Corn	Soybean	Wheat	Corn & Soybean	Corn & Wheat
AR330ZN	**1.000**	**1.000**	0.896	**1.000**	**1.000**
AR700SBA	**1.000**	0.642	0.877	0.803	**1.000**
AR900WBA	0.919	**1.000**	0.971	**1.000**	**1.000**
AU4000WB			0.812		
BG7000PLE	0.617		**1.000**		**1.000**
BR1300MT	0.834	**1.000**		**1.000**	
BR65PR	0.528	**1.000**	**1.000**	**1.000**	**1.000**
CA1100NWM			0.695		
CA2000RRV		0.703	0.909		
CA2000SAS			0.880		
CA6000SAS			0.776		
CZ4000JC	0.905		0.843		**1.000**
DE1100VP			**1.000**		
DE120HI			0.769		
DE160UE			0.818		
DE250KAB			**1.000**		
DE360OW			**1.000**		
DK605FYN			0.862		
FR110ALS	0.447		0.783		0.602
FR110VGAV	0.479		0.752		0.624
FR230PICB			0.996		
HU1100TC	0.596		0.810		0.682
JP45HO			0.800		
PL2100ST			0.995		
PL370PO			0.564		
PL730WO	0.485		0.676		0.699
RO6500IL	0.473	0.476	0.810	**1.000**	0.691
SE445SK			0.824		
SE570LAV			**1.000**		
UA2600WU		0.457	0.980		
UA7100PO	**1.000**		0.916		**1.000**
UK310WASH			0.618		
UK440SUFF			0.771		
UK800CAM			0.826		
US1215INC	**1.000**	**1.000**		**1.000**	

Table 7.1 continued

US1215INS	0.966	0.871	**1.000**	0.957	**1.000**
US1300ND	0.905	0.676	0.747	0.852	0.933
US2025KS	0.679		0.699		0.782
US700IA	0.957	0.871		**1.000**	
UY292SW	0.681	0.744	0.635	0.901	**1.000**
UY360CEN	0.955	0.633		0.864	
VN3LM	**1.000**				
ZA1600EFS	0.543	0.539	0.444	0.825	0.652
ZA1600NFS	0.510				
ZA1700WFS	0.508				

Table 7.2. Cost Efficiency Summary of Farms Producing All Crops.

	Corn	Soybean	Wheat	Corn & Soybean	Corn & Wheat
AR330ZN	**1.000**	**1.000**	0.896	**1.000**	**1.000**
AR700SBA	**1.000**	0.642	0.877	0.803	**1.000**
AR900WBA	0.919	**1.000**	0.971	**1.000**	**1.000**
BR65PR	0.528	**1.000**	**1.000**	**1.000**	**1.000**
RO6500IL	0.473	0.476	0.810	**1.000**	0.691
US1215INS	0.966	0.871	**1.000**	0.957	**1.000**
US1300ND	0.905	0.676	0.747	0.852	0.933
UY292SW	0.681	0.744	0.635	0.901	**1.000**
ZA1600EFS	0.543	0.539	0.444	0.825	0.652

Table 7.3. 5-Year Average Efficiency Results.

Model	TE	AE	CE	Cost Efficient Firms	Firms on CE frontier [a]
Corn	0.802	0.929	0.749	5	AR330ZN, **AR700SBA**, **UA7100PO**, US1215INC, **VN3LM**
Soybeans	0.861	0.888	0.774	5	AR330ZN, **AR900WBA**, **BR1300MT**, BR65PR, US1215INC
Wheat	0.898	0.928	0.836	7	BG7000PLE, **BR65PR**, DE1100VP, DE250KAB, DE360OW, SE570LAV, US1215INS
Corn & Soybean	0.983	0.954	0.939	7	**AR330ZN**, **AR900WBA**, **BR1300MT**, **BR65PR**, RO6500IL, **US1215INC**, US700IA
Corn & Wheat	0.936	0.922	0.863	9	AR330ZN, AR700SBA, AR900WBA, **BG7000PLE**, **BR65PR**, CZ4000JC, UA7100PO, **US1215INS**, UY292SW

[a] = firms on the frontier in 2013, 2017, and the 5-year average are in bold.

Table 7.4. Summary of Average Cost Efficiency.

	Corn	Soybean	Wheat	Corn & Soybean	Corn & Wheat
2013	0.691	0.806	0.752	0.952	0.835
2017	0.672	0.710	0.485	0.892	0.764
5-Year Average	0.749	0.774	0.836	0.939	0.863

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APPENDIX

EXPLANATION OF DATA

The *agri benchmark* Network at the Thunen-Institute of Farm Economics (TI) provided the data for this thesis. The data provided is based on the premise of a typical farm. These typical farms are based in the most important regions of the country for agricultural production. The network focuses on the farms producing the bulk of the agricultural products in the region. The type and productive system of the typical farm are identified through consultation of local advisors and statistics. Relevant farm population and production systems are determined in the region based on regional statistics and consultation with local advisors. Size is determined by arable land used for farming (Zimmer & Deblitz, 2005).

Creating a typical farm for the region involves finding multiple typical farm models. If applicable, *agri benchmark* utilizes farm size regional statistics to determine the appropriate farm size for the region. Multiple farms are selected to use for the base of a typical farm. If production systems are similar, two different farm sizes are selected. If production systems differ, two farms of approximately the same size and different production systems are used. If possible, a large farm with top management, in terms of profitability, is included to show what could be feasible within the region. Three farms are necessary to participate in the global *agri benchmark* analysis. Standard selection of the three farms include: a large farm with top management, a large farm with average management, and an average-sized farm with average management. The number of farms required may vary based on factors such as: diversity of farms, size of country, and financial resources. After the data are collected, analysis tools are used to compute the typical farm. After computation, a panel and advisor review the data, if they are in agreement, the typical farm is added to the network. If not, the process repeats until agreement is reached (Zimmer & Deblitz, 2005).

The objective is to make typical farms that reflect an average level of management. However, since participation is voluntary, there is a potential upwards bias towards size, performance, and management skill level. Consultation with farmers is used to verify and help base typical farm data. In some cases, typical farm data can be based on individual farm data (Zimmer & Deblitz, 2005).

Typical farms are updated annually to reflect changes in prices and productivity. Both new farms and adjustments are based on three-year averages. Both prices and yields are updated every year. Every 2-4 years, the data set is updated in its entirety. Updates occur sooner if structural change or productivity change dramatically (Zimmer & Deblitz, 2005).

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