

FACTORS INFLUENCING POTATO  
PRODUCTION IN NORTH DAKOTA

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Graduate School

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Title

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## **ABSTRACT**

Roberson Zetina, Zoë Taryn Margaux; M.S.; Department of Agribusiness and Applied Economics; College of Agriculture, Food Systems, and Natural Resources; North Dakota State University; May 2008. Factors Influencing Potato Production in North Dakota. Major Professor: Dr. Cheryl S. DeVuyst.

Spatial shifts and structural changes continue to occur in the United States agricultural industry. Researchers have documented that the potato industry has changed in response to demands of consumers, expectations of producers and improvements in research and development. The aim of this study was to provide empirical evidence that both institutional and infrastructural factors are important to potato production in North Dakota.

Using secondary county-level potato production data for North Dakota, an empirical model was designed to estimate the direction and impact of growers' expectations of prices, yields and costs on their decision to produce potatoes. The results confirmed that institutional relationships established between growers and processors, as well as the infrastructure that growers have in place from one growing season to the next, are statistically significant in determining the total number of potato acres planted.

## **ACKNOWLEDGEMENTS**

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## TABLE OF CONTENTS

ABSTRACT.....	iii
ACKNOWLEDGEMENTS.....	iv
LIST OF TABLES.....	vii
LIST OF FIGURES.....	viii
CHAPTER I. INTRODUCTION.....	1
Potato Industry Overview.....	1
Need for Study.....	4
Objective.....	5
Organization of Study.....	5
CHAPTER II. REVIEW OF LITERATURE.....	7
Spatial Shifts in Agriculture.....	7
The Potato Industry.....	8
The North Dakota Potato Industry.....	11
CHAPTER III. METHODOLOGY.....	16
Behavioral Model.....	17
Empirical Model.....	18
Data Description.....	21
CHAPTER IV. RESULTS.....	27
Introduction.....	27
Discussion of Findings.....	28
Past Acres Planted.....	29

Normalized Potato Prices.....	30
Water Used for Irrigation.....	31
Historical Yields .....	32
Individual County Fixed Effects.....	33
CHAPTER V. CONCLUSION.....	36
Introduction .....	36
Summary of Thesis.....	36
Summary of Findings .....	37
Implications and Recommendations.....	40
REFERENCES .....	42

## LIST OF TABLES

<u>Table</u>	<u>Page</u>
3.1. List of Variables.....	16
4.1. Results: Cross-Sectional Fixed Effects.....	28
4.2. Results: Individual County Fixed Effects.....	34
5.1. Result Summary.....	37

## LIST OF FIGURES

<u>Figure</u>	<u>Page</u>
3.1. Water used for irrigation for the counties of Kidder, Grand Forks, Benson, McHenry, and Pembina for the period 1995 to 2006.....	23
3.2. Water used for irrigation for the counties of Stutsman, Traill, Dickey, Ransom, Sargent, and Walsh for the period 1995 to 2006. ....	24
3.3. The nominal and real prices of potatoes in North Dakota over time. ....	25
3.4. The nominal and real prices of urea fertilizer.....	26
4.1. Map of North Dakota highlighting the eleven counties included in the study.....	27
4.2. Water used for irrigation for the period 1995 to 2006.....	32



# CHAPTER I

## INTRODUCTION

### Potato Industry Overview

Potatoes (*Solanum tuberosum* L.) are considered one of the most highly consumed vegetables in the United States today (USDA/ERS, 2007). Potatoes are categorized by shape and color. Categories of potatoes include Round Whites, Russets, and Reds (Salazar and Busch, 2001). Many varieties of potatoes are grown in the United States for specific uses, including frying, canning, dehydrating, chipping, and for sale on the fresh market as tablestock. Different varieties are more adaptive to particular growing conditions and geographical locations, making the selection of the right variety an essential part of a grower's decision for a productive growing season (Sieczka and Thornton, 1993). Additionally, growers must ensure that the chosen variety meets the needs of the end users.

In the United States, most potato production occurs in Idaho, Washington, and Oregon with Colorado, North Dakota, California, and Maine also producing large quantities (Lucier, Pollack, Ali, and Perez, 2006). In North Dakota, potatoes are planted in the spring and harvested in the fall. During the growth period, factors such as cultivation; water and fertilizer application; and weed, disease, and pest management are important (Sieczka and Thornton, 1993). During harvest, it is critical to avoid damage to potatoes due primarily to bruising. After harvest, potatoes are typically cured and stored until needed. Modern storage facilities are insulated and temperature controlled to minimize loss of quality and to prevent sprouting. This is a dramatic change from the partially underground facilities that were used in the past to store and cure potatoes.

The potato industry in the United States has changed dramatically since the introduction of potatoes. The entire production process has modernized to incorporate and satisfy the changing needs of end users and to meet the demand of consumers. Potatoes did not create a big impact in North America upon their introduction. It was not until the late 1800s that conscious efforts were made to improve production in response to the marked reduction in yields, due primarily to diseases and poor seed maintenance (Sieczka and Thornton, 1993).

Potatoes were traditionally sold on the fresh market. The production of frozen french fries on a commercial level started in the United States in the 1940s. The trend toward the processing of potato products increased in the late 1950s with the introduction of quick service restaurants (Plummer and Makki, 2004; Salazar and Busch, 2001). This increasing trend for processed potato products has been partially affiliated with the structural changes of households after World War II (Salazar and Busch, 2001) and the inclusion of women in the labor force. Since the 1940s, the number of households with both spouses participating in the labor force has increased (Hayghe, 1990). In 2003, 58% of married couples were participating in the labor force, compared to 44% in 1967 (Chao and Utgoff, 2005).

Berwick et al. (2001) noted that the potato industry continues to change as producers aim to satisfy the changing needs of consumers who are demanding more diversified and convenient products. Due to the lack of consistent production, graphical representation of the data was presented to conclude that the production of potatoes has migrated from the traditional production area in northeastern North Dakota to irrigated

areas in the central and south-central regions of the state. This move was said to be partly in an attempt to minimize risk associated with diseases and water availability.

Potato production at the commercial level is categorized as a highly-complex venture that necessitates growers to possess high degrees of technical and practical skills (Sieczka and Thornton, 1993). Further, the start up and operational costs of production are both substantial capital investments (Coon and Leistritz, 2001). As a result of these complexities, it is hypothesized that institutional variables are important in the potato industry. The combination of specific, key variables such as water accessibility, contract availability, expected prices, and expected yields are assumed to be important variables influencing growers' decision to plant potato acres. The hypothesized variables can be divided into two categories, namely institutional variables and infrastructural variables. However, these hypothesized variables are yet to be tested and quantified for direction and magnitude. The aim of this research is to quantify these variables and determine the significance and magnitude of each relationship.

Institutional economics is said to be inclusive of all human behaviors that influence the economy (Commons, 1931). In the case of the North Dakota potato industry, this would include water accessibility and contract availability. Sieczka and Thornton (1993) stated that the most important factor contributing to an increase in both yield and quality of potatoes is proper water management. The optimal amount of water to be applied using an irrigation system is dependent on factors including but not limited to soil type and water-holding capacity. In addition to water, fertilization of the soil is also important since most soils lack essential nutrients necessary for acceptable yields and consistent quality (Sieczka and Thornton, 1993). Inadequate water supply would typically result in tuber disorders,

namely, hollow heart, sugar ends and black spot; and could also lead to diseases such as late blight, pink rot and rhizoctonia.

Coon and Leistritz (2001) found North Dakota producers had the opportunity to become involved in growing irrigated potatoes because of the growing demand for frozen french fries, and also because processors wanted to secure more irrigated potatoes through contractual agreements. The infrastructural investments necessary to provide irrigated potatoes are high. According to Coon and Leistritz, the total investment in irrigation equipment was approximately \$23.1 million with an additional \$13 million for storage facilities and \$3.4 million for machinery. It is hypothesized that because the start-up cost of production is high, once growers have made the initial investments, they will continue to grow potatoes. Further, since the trend is increasing toward irrigated potato acres (Berwick et al., 2001) and growers are investing in irrigation equipment, there is also a need for growers to be able to secure water permits from the State Water Commission.

#### Need for Study

Potatoes are considered a highly-consumed vegetable in the United States with individual consumption of approximately 130 pounds annually (USDA, 2006). It is expected that the worldwide consumption of potatoes will continue to increase with the expanding frozen french fries industry, that in turn, increases the demand for potatoes (Guenthner, 2006). According to the USDA 2000 potato profile, the North Dakota potato industry was the sixth largest in the United States. By 2005, Farm and Ranch Guide (07-21-2005) reported that North Dakota's production ranked third nationally, even after total potato production decreased across the nation.

Potato production has become a big part of the North Dakota economy (Coon and Leistriz, 2001) and therefore, it is important to determine the factors that drive the industry. Evaluating and explaining the factors that are influencing the changes of potato production in North Dakota are important in understanding the economics behind growers' decisions to plant potato acres. An analysis of the trends and significant variables such as water and contract availability, fertilizer prices and expected yields will aid in better strategic planning.

### Objective

The objective of this study is to determine the factors affecting acres of potato production in North Dakota. Further, this study aims to explain if the relationships between the variables of interest are significant because of institutional economics and to what extent infrastructural factors are important.

It is expected that a better understanding of North Dakota's potato industry will be gained. Additionally, institutional variables such as water and contract availability, and infrastructural factors such as irrigation equipment and machinery, will be measured for statistical significance.

### Organization of Study

A summary of previous academic research and findings is reviewed in Chapter II. This literature review highlights the analysis of studies of the potato industry and also research conducted on factors affecting change in other agricultural sectors. Chapter II also examines the characteristics of the potato industry, briefly explaining some important factors to consider when growing potatoes such as water and contract availability. Chapter III explains the Methodology of this study, explaining the importance of each variable of

interest and introducing the econometric model used to analyze the data collected. The Results of the study are systematically documented in Chapter IV while Chapter V concludes the research with a summary of the major objectives, methodology, findings, implications, and areas of further research.

## **CHAPTER II**

### **REVIEW OF LITERATURE**

#### **Spatial Shifts in Agriculture**

Many factors have affected the development of the U.S. agricultural industry. Over the past several decades, shifts have occurred rapidly within the hog (Roe, Irwin, and Sharp, 2002) and dairy (Isik, 2004) industries. These changes have been well documented and have found contributing factors to include environmental regulations, access to rural transportation, location of processing facilities, and the improvement in technology as well as the combination of these variables.

Peterson (2002) showed that the presence of agglomeration economics, which look at the benefits a firm exploit from being located in close proximity to other firms in the industry, strongly influence the location decisions in the dairy industry. He also concluded that availability of inputs and markets were key in the decision making process regarding location of firms in the dairy industry. Likewise, Isik (2004) found that agglomeration economics have a significant impact on the shifts occurring in the dairy industry. Environmental factors were also shown to be statistically significant as facilities tend to move away from areas with stringent polices in favor of those locations with more relaxed environmental regulations. This conclusion was also drawn by Hearth, Weersink, and Carpenter (2005). They concluded that the shifts occurring in the livestock sector could be due to relative prices and infrastructural supports (Hearth, Weersink, and Carpenter, 2005).

Similarly, Adhikari, Harsh, and Cheney (2003) found that the pork industry changed due to the introduction of technology which effectively lowered operational costs. Advancement in technology brought about the industrialization of pork production and

transitioned the industry from traditional small enterprises to large specialized firms, that are better able to benefit from economies of scale. As a result of this modernization process, the industry structure changed with respect to distribution, ownership, location, and the control of inputs and outputs.

### The Potato Industry

Like other agricultural industries, the potato industry has reported significant changes. The United States Department of Agriculture (USDA, 2006) confirmed that in the early 1900s, potatoes were primarily grown in New York, Pennsylvania, and Ohio, with migration to Michigan, Wisconsin, and Maine. By 1990, Northeastern and Midwestern production dropped from 81% to 29% of the country's total production, while the Pacific Northwest's production rose from 3.4% in the early 1900s to 52% in the early 1990s (Sieczka and Thornton, 1993). The USDA asserted that the introduction of refrigerated rail cars and trucks allowed Oregon, Washington, Idaho, Colorado, and California to expand their production, since new markets were created. The Potato Association of America Handbook also concluded that this shift was in part due to improvement in the United States transportation system, more favorable weather conditions and lower power, tax, and labor costs of the Pacific Northwestern states also contributed to the shift. Additionally, the geographic shifts combined with advancements in technology and techniques led to higher yields.

Today, two thirds of fall potato production is grown in western states with Idaho and Washington producing approximately one half of total production (USDA, 2006). The highest potato yields per acre are reported in Oregon, Washington, and California. Total number of acres planted peaked in 1922 with a total of 3.9 million acres and have since



been declining. While the total acres planted today is approximately 1.1 million, total production has steadily increased with increasing yield per acre (USDA, 2006).

Since the 1950s potato processing has been steadily increasing (USDA, 2006). In 1959 only 19% of total production was processed, compared to the twenty-first century when processing accounted for more than two thirds of all potatoes sold. Processing since then has been primarily french fries, chips and dehydrated potato products. The introduction of fast food restaurants in the 1950s is credited with the increase in demand for frozen french fries, although small scale production began in the mid 1940s. The worldwide growth of the fast food industry is expected to continue and therefore, so will the demand for frozen potato products. While the world market has expanded, the major markets for frozen products are still the United States, the European Union, Canada, and Japan.

The USDA's potato briefing room reported that potatoes are the leading vegetable crop in the United States (USDA, 2007). It is also the most consumed vegetable, with each American eating approximately 130 pounds annually. The USDA reported that potatoes contribute about 15% of vegetable farm receipts and over one half of sales are to processors for fries, chips and other potato products. The remainder is sold on the fresh market. The USDA Economic Research Service (USDA, 2006), stated that the United States is the fourth largest potato producer worldwide (following China, Russia, and India), with growers grossing approximately \$2,000.00 per acre in potato sales. Total annual production is estimated at 45.6 billion pounds grown by approximately 5,500 growers (Best Food Nation, undated).

According to Walker, Schmiediche, and Hijmans (1999), potato yields in the United States experienced unexpected growth between 1934 and 1949. During this period, potato production shifted to regions with greater yield potential. This shift was made possible with the introduction of irrigation systems and the acceleration of mechanical technology. Research and development had also facilitated technological advancements in storage facilities since empirical studies had resulted in new temperature and humidity controlled storage necessities. Walker et al. (1999) contended that potato consumption has been influenced drastically by new technological advancements in the processing and preparation of food. This conclusion is also made by Plummer and Makki (2004), who further assert that the frozen potato industry is being driven by french fries which have expanded globally in correlation with the expansion of quick-service restaurants.

Hsiang-tai Cheng (2005) examined the price and production relationship among the major growing regions in northeastern North America. His research encompassed the main potato production areas, including Maine, Prince Edwards Island, New Brunswick, and Quebec. The research concluded that the potato industry has experienced intra-regional shifts. Increasing demand for french fries in the area as well as the expansion of the Cavendish and McCain Foods facilities led to these shifts. Additionally, vertical coordination in the form of contractual agreements between growers and processors also impacted the shifts. While econometric models were not utilized, graphical comparisons and knowledge of the industry were employed to draw decisive conclusions.

King and Stark (undated) found that, in order for producers to increase their net returns, increased efficiency was needed in the production process. Furthermore, producers depending on irrigation must also consider the increasing public awareness of water

conservation and quality. King and Stark also stated that irrigated potato production requires a reliable irrigation system that is capable of distributing a uniform but light amount of water in frequent intervals to potato plants. Potatoes are sensitive to water stress and over-irrigation or under-irrigation can result in unwanted results such as decreased yields. Therefore, King and Stark stressed that an efficient irrigation system will not only increase yields, but can also lower production costs, through water, energy and nitrogen fertilizer conservation.

### The North Dakota Potato Industry

The North Dakota potato industry is also changing with respect to location and irrigation use. According to a study of North Dakota's potato industry (Berwick et al., 2001), the potato industry is changing in an effort to meet the consumer demand for easier preparation methods. The industry has responded by offering a variety of products which impact the location of processing facilities, and in turn shifted the need for warehouses and transportation (highways and trucks). According to this research, the most important finding was that the production of potatoes in North Dakota is shifting from its traditional location in the northeastern part of the state to more central areas of the state due to the introduction of irrigation systems. This new introduction has allowed greater yields from both potatoes and the chosen rotation crops. A study by the Williston Area Development Foundation in 2000 (Berwick et al., 2001) estimated that there are approximately 194,290 acres within 150 miles of Williston that is suitable for growing potatoes. This could lead to another possible shift in the industry. While regression models were unsuccessful in ascertaining conclusive results, like the Cheng study, graphical demonstrations were made.

The study showed that irrigated production of potatoes continued to increase, while non-irrigated, or dry-land, potato acres continued to decrease.

At a Jamestown meeting in 2000 (Berwick et al., 2001), it was said that irrigation allowed processors to reduce supply risk since production can be spread over larger geographical areas. Additionally, irrigation has allowed growers the opportunity to receive higher returns for their crops since it aids in higher yields and quality. However, the cost of production under irrigation is substantially higher than on dry land (non-irrigated acres). The report further indicated that while dry land crops cost approximately \$750 to \$900 per acre, an acre under irrigation costs \$1350 to \$1500 to produce. This cost difference is from specialized irrigation equipment and the cost of energy. Water becomes critical for irrigation systems to be implemented. Further, proper implementation helps to ensure greater yields and improved quality for growers and less risk to processors.

In 2000, North Dakota ranked 6<sup>th</sup> in potato production, producing approximately 5% of the nation's total potato crop (USDA, 2000). The Red River Valley was the major producing area along with the northeastern, east central, central, and north central parts of the state. According to this profile, the use of irrigation technology is a common practice in North Dakota where the Russet Burbank variety is the most cultivated potato variety. Potatoes classified as Shepody, Frito-Lay, and Norland are also produced in North Dakota (Berwick et al., 2001). Each category is grown for specific end uses. For example, reds are sold primarily on the fresh market, while whites are sold to processors for chipping and dehydrating, and russets can be used for fresh market sales, french fries and dehydrated products (Scherer et al., 1999).

Potatoes grown in North Dakota are both irrigated and non-irrigated. Although research has recorded a trend toward irrigated acres (Berwick et al., 2001), the decision to convert acres to irrigation is not simple since the shift requires special equipment and machinery and a large capital investment (Scherer et al., 1999). Some important factors to consider when investigating the implementation of irrigation systems are: soil type; availability of water, and accessibility of water permits; capital needed for irrigation equipment, and other machinery; level of experience and knowledge in running an irrigation system and growing potatoes; profitability of potatoes and the chosen rotation crop, and the marketability of potatoes which included storage facilities, access to contracts or brokers, and transportation (Scherer et al., 1999).

According to Scherer et al. (1999), growing potatoes under contract reduced risk associated with marketing the harvested crop for producers. However, it also limited profitability. Nevertheless, contractual agreements are used to secure large quantities of potatoes used for processing. Scherer et al. stated that the characteristics of the potatoes grown under contract are important. For example processors desire a specific percentage of total solids and low sugar levels.

The shift to more acres of irrigated potatoes in North Dakota was a conscious decision made by a group of growers who seized the opportunity to improve profitability and intensity of agriculture in the area (Coon and Leistritz, 2001). These growers, recognizing the need for a “high-value” crop, and the increasing reliability on irrigation, organized themselves in order to introduce irrigated potato production and processing to the Jamestown area. Potatoes were chosen because of the increasing demand for processed potato products and the desire of processors to secure their supply under contracts.

Furthermore, it was also concluded that the area showed excellent potential for growing irrigated potatoes considering soil types and aquifers.

Coon and Leistriz also reported that because growers were unable to secure significant investment capital for constructing a processing plant, Aviko, a Netherlands based company, negotiated with the growers to construct a processing plant. This partnership resulted in the issuance of 33 grower contracts. This contract production necessitated 15,000 acres of potatoes, most of which were grown in Kidder and Stutsman counties.

Investment in potato production and processing has created a substantial economic impact on the economy of North Dakota, especially the Jamestown area (Coon and Leistriz, 2001). Approximately \$50 million was expended on plant construction, storage facilities, irrigation equipment and other specialized machinery. Coon and Leistriz concluded the annual economic impact was a \$47.7 million increase in personal income with an equal addition to retail sales. Further, business activities were said to have increased by \$147.6 million. While it is true that only 33 contracts were issued by Aviko, Coon and Leistriz concluded that the economic impact was far greater. It was estimated that for every \$1 spent during production and processing, \$2.66 was created in other sectors. This level of economic activity was considered important to the North Dakota economy.

Berwick et al. (2001) reported the presence of three processing facilities in the state of North Dakota, namely J. R. Simplot, RDO Foods Company, and Aviko. J. R. Simplot (a primary supplier of french fries for the United States fast food chains) is still located and operating out of their processing facility in Grand Forks, North Dakota. RDO Foods

Company (a manufacturer of dehydrated potato products) was closed in March 2008 (Bonham, 2008), and Aviko's plant, located in Jamestown, North Dakota, was purchased by Cavendish Farms of Canada in November 2001 (Quick Frozen Food International, 2002).

While Aviko and Simplot relied on contractual agreements with growers in an effort to ensure continuous operations, RDO preferred not to rely on contracts unless the forecasted supply of potatoes was low or the forecasted demand for potatoes was high (Berwick et al., 2001). Cavendish has continued issuing contracts in an effort to secure their supply of raw material (potatoes). However, in 2006, Stone reported that the Northern Plains Potato Growers Association was angry with Cavendish Farms for cutting contracts which caused negotiation to become more intense. Growers were concerned that with increased fertilizer and fuel prices, higher potato prices were necessary to keep farms operational. Price fluctuations increased risk to growers, enhancing loss potential for those with substantial capital investments for irrigation systems (Scherer et al., 1999).

## CHAPTER III

### METHODOLOGY

The methodology used in this study is described in this chapter. This chapter also encompasses definitions of both the dependent and independent variables along with a description of the dataset. This study utilized secondary data collected from the United States Department of Agriculture (USDA), National Agricultural Statistics Service (NASS), North Dakota Agricultural Weather Network (NDAWN), United States Department of Labor's Bureau of Labor Statistics, and the North Dakota State Water Commission.

Data were collected for the period 1995 to 2006 for 11 counties in North Dakota. These counties were Benson, Dickey, Grand Forks, Kidder, McHenry, Pembina, Ransom, Sargent, Stutsman, Traill, and Walsh. County-level data were collected for each variable listed in Table 3.1.

Table 3.1. List of Variables

Variable	Notation	Unit of Measure
Total Crop Planted	A	Acre
Total Area Irrigated	TAI	Acre
Total Area Harvested	TAH	Acre
Total Yield Per Acre	TYIELD	Hundred Weight
Irrigated Yield Per Acre	IYIELD	Hundred Weight
Total Production	TPROD	Hundred Weight
Water Used for Irrigation	IRRPCR	Acre Feet
Potato Prices	POTPRICES	Dollars/Hundred Weight
Urea Fertilizer Prices	FERT	Dollars



## Behavioral Model

Under the assumption that producers maximize expected profits, equation (1) gives the producers objective function.

$$(1) \quad \text{MAX } E[\pi] = E[P \cdot Y \cdot A - C(A)]$$

where  $E[\cdot]$  is the mathematical expectation operator,  $P$  is potato price,  $Y$  is yield,  $A$  is acres of potato planted, and  $C(A)$  is total cost as a function of acres. If prices and yields are independent and costs are known, equation (1) can be rewritten as

$$(2) \quad \text{MAX } E[\pi] = E(P) \cdot E(Y) \cdot A - C(A).$$

To achieve the largest possible economic profit, theory holds that factors of production must vary until further adjustments would result in no further increase in profits or until *Marginal Revenues (MR) = Marginal Cost (MC)* (Nicholson, 2002). This production point constitutes the first-order condition for a maximum and can be mathematically described as

$$(3) \quad \frac{dTR}{dA} - \frac{dTC}{dA} = 0.$$

The first-order condition for a maximum in North Dakota's potato industry is

$$(4) \quad \frac{dE[\pi]}{dA} = E(P) \cdot E(Y) - \frac{dC(A)}{dA} = 0.$$

This equality states that total revenue will be equal to total cost at the point where the revenue associated with selling one additional unit of product is equal to the cost associated with producing that additional unit (Nicholson, 2002). To ensure economic profits, the second-order condition must also hold. The following equation represents the second order condition for the North Dakota potato industry.

$$(5) \quad \frac{d^2E[\pi]}{dA^2} = -\frac{d^2C(A)}{dA^2} < 0 \quad \text{or} \quad \frac{d^2C(A)}{dA^2} > 0$$

The second-order condition affirms that marginal profit will be increasing for all values of  $A < A^*$  and decreasing for all values of  $A > A^*$ . In other words, potato growers will continue to increase the number of acres of potatoes planted as long as the marginal profit for producing an additional acre is increasing. When both conditions are satisfied there are sufficient conditions for maximizing profits meaning that production levels are at the optimum point ( $A^*$ ). This optimal production point is where marginal revenues are equal to marginal cost and where any further adjustments in inputs would create no further increases in the economic profits of the production process. Solving the first-order condition for  $A^*$  (the optimum number of acres of potatoes to be planted) gives:

$$(6) \quad A^* = A^*[E(P), E(Y), (\text{Parameters of Cost Function})]$$

In equation (6),  $E(P)$  is a function of potato prices. Considering that approximately 60% of potatoes in North Dakota are grown under contracts (Thompson, 2008), it is assumed that most potato prices are known at the start of the growing season. As a result, the average market price of potatoes in North Dakota are used to represent expected prices such that  $E(P) = POTPRICES$ . Also in equation (6),  $E(Y)$  represents a function of past acres planted, the amount of water used for irrigation and historical yields. The parameters of costs in the equation are energy derived and includes costs of chemicals, cost of fertilizers and cost of fuel.

#### Empirical Model

The parameters of the cost function are largely energy based, and therefore they are correlated. Further, potato prices are also correlated with energy prices given potato production's dependence on inputs such as fuel, fertilizers and other chemicals. Including both potato prices and input prices into a regression equation would result in problems of

multicollinearity. To correct for this foreseeable problem, potato prices were normalized by the price of urea fertilizer (a proxy for cost parameters). The independent variable,  $Log\left(\frac{POTPRICES}{FERT}\right)$ , measured the impact of the normalized real prices of potatoes in North Dakota with respect to urea fertilizer, ( $C$ ). This variable satisfied the need to include proxies for both expected potato prices and costs.

To incorporate the impact of expected yield in the empirical model, three independent variables were employed. These variables were the log forms of past acres planted, the amount of water used for irrigation and reported past yields. The log form of the total number of acres potatoes planted in the previous growing seasons,  $Log(A_{t-1})$ , was included to estimate the magnitude and direction of the relationship between the current growing season and previous growing seasons. It is expected that this relationship will be positive and estimated coefficient highly significant. This hypothesis is based on the idea that the best indication of what will occur in year  $t$  is what occurred in year  $t-1$ , *ceteris paribus*.

The log form of the total acre feet of water used for irrigation in each county, ( $IRRPER$ ) was multiplied by a dummy variable where  $WATERDUM =$

$\begin{cases} 1 & \text{if county } i \text{ grows irrigated potatoes} \\ 0 & \text{if county } i \text{ grows only dryland potatoes} \end{cases}$  The inclusion of the variable

$Log(IRRPER) * (WATERDUM)$ , allowed for the measurement of the importance of having access to water for irrigation in those counties where some or all of total potato production is grown under irrigation. Measuring the relationship and significance in select counties is important since water is not expected to be as important in counties where potato acreage was designated as dry-land. Therefore, determining the significance of water on the total number of potato acres planted under irrigation is valuable in the decision

process of how many acres to cultivate since accessibility of water is a limiting factor. It is expected that this variable will be significant and will positively impact growers' decisions regarding acres planted.

The final variable to be incorporated as a factor that determined expected yield is the historical yields reported. The variable,  $(TYIELD_{t-1})$ , measured the importance of potato yield per acre of land planted. Economic theory teaches that increasing outputs while decreasing inputs is the only feasible objective in the pursuit of profit maximization. As technology and research advance in agriculture, an important aspect is to minimize land inputs while at least keeping output constant. As a result, it is hypothesized that the expected yield of an acre of land will be vital in deciding the optimal number of potato acres to be planted. Again, the best indication of what to expect in year  $t$  is what was reported in year  $t-1$ ; therefore, the lagged form of historical yield per acre was included in the regression equation. It is expected that the coefficient will be negative, confirming that, as yield increases, the total number of acres planted can be decreased without lowering profits.

The empirical model was specified as

$$(7) \quad \begin{aligned} \text{Log}(A)_{it} = & \lambda + \alpha_i + \beta_1 * \text{Log}(A_{t-1})_{it} + \beta_2 * \text{Log} \left( \frac{\text{POTPRICES}}{\text{FERT}} \right)_{it} \\ & + \beta_3 * \text{Log}(\text{IRRPER})_{it} * (\text{WATERDUM})_{it} \\ & + \beta_4 * \text{Log}(TYIELD_{t-1})_{it} + \varepsilon_{it}, \end{aligned}$$

where  $\lambda$  is the based county fixed effect;

$\alpha$  is the individual county fixed effect for  $i - 1$  counties;

$\text{Log}(A)$  is the log of number of acres of potatoes and the dependent variable;

$\text{Log}(A_{t-1})$  is the log of number of acres planted in the past;

$Log\left(\frac{POTPRICES}{FERT}\right)$  is the log of normalized real price of potatoes;

$Log((IRRPER)(WATERDUM))$  is the log of water volume used for irrigation;

$Log(TYIELD_{t-1})$  is the log of historical yields;

$\mathcal{E}$  is the random error;

$i = 1 \dots N$  cross-section; and

$t = 1 \dots T$  time-series.

An unbalanced panel data set was created using the EViews software package to analyze the relationship between key variables of interest. A panel data set was used because the time period under review was relatively short and this format allowed for an increase in the number of observations which effectively created additional degrees of freedom. The panel was unbalanced since some cross-sectional (county) data was missing. Finally, a fixed-effect model was chosen since it assisted with correcting for having omitted variable problems. Choosing to fix only the cross-sectional data allowed for the assumption that omitted variables were fixed across counties (cross-sections) and therefore the individual effect of each county was invariant. The logarithmic functional form chosen for the regression estimation resulted in more appealing interpretations of the estimated coefficients. Using a logarithmic function allowed the estimated coefficients to be analyzed for the percentage change they create in the logged dependent variable total crop planted ( $Log(A)$ ).

### Data Description

Many factors affect the decision of what to plant, how much to plant and when to plant. However, in the potato industry it is hypothesized that the decision to plant is affected by institutional and infrastructural factors. The objective of this study was to

determine the magnitude and direction of the relationship between key variables such as water availability, yield per acre, potato prices, and previous planting decisions on the total number of acres of potatoes planted at the county level in North Dakota.

To measure the importance of water permits to potato growers in North Dakota, data was collected from the state water commission on the total amount of water reportedly used for irrigation in each county. This was used as a proxy for the importance of water in potato production. Figure 3.1 indicates that water used for irrigation showed a relatively constant slope with small fluctuations. This is with the exception of Kidder County where all potatoes are grown using irrigation systems. The data on water used for irrigation in Kidder County showed an increasing trend over time. In 1995 Kidder County reported a low of 5,599.50 acre feet of water used compared to 2006 when 19,297.40 acre feet was reportedly used. While the amount of water used for irrigation increased, so did the total acre of potatoes planted. The data collected showed a continuous upward trend in the number of acres planted starting with a low of 1,300 acres of potatoes planted in 1995 to a high of 8,300 acres in 2006.

The county of Grand Forks cultivated both irrigated and non-irrigated potatoes, with an increased trend towards the production of irrigated potatoes. The data indicated that 30% of total crop planted in 1995 were irrigated compared to 54% in 2005 when the most irrigated acres were reported. Although the data sets depicted fluctuations in production, there was a clear increasing trend towards growing more irrigated acres of potatoes. The least amount of water used for irrigation in Grand Forks was reported in 1995 with spikes in 1998 and 2006. The year 2006 stood out as the year when the most water was used for irrigation purposes in Grand Forks. The counties of Benson, McHenry

and Pembina all showed relatively constant level of water being used for irrigation.

McHenry reported 100% irrigated potatoes while Pembina reported no irrigated potatoes being grown.

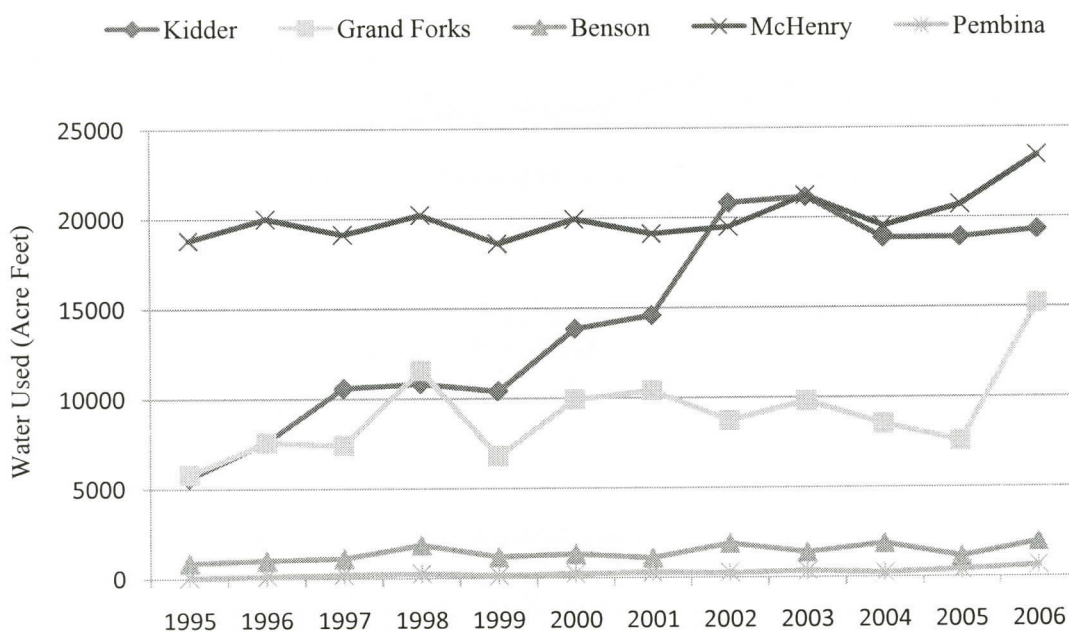


Figure 3.1. Water used for irrigation for the counties of Kidder, Grand Forks, Benson, McHenry, and Pembina for the period 1995 to 2006.

Figure 3.2 shows the water use reported for the counties of Stutsman, Traill, Dickey, Ransom, Sargent, and Walsh. The counties of Traill and Walsh reported the lowest amount of water use for irrigation. Walsh County reported no irrigated acres of potatoes while in Traill, all potatoes are grown using irrigation systems. While both counties' water use appeared fairly constant over time, Traill's potato production showed a fluctuating but somewhat increasing number of acre planted, and Walsh data indicated that the number of acres of potatoes being grown are fluctuating, but decreasing over time.

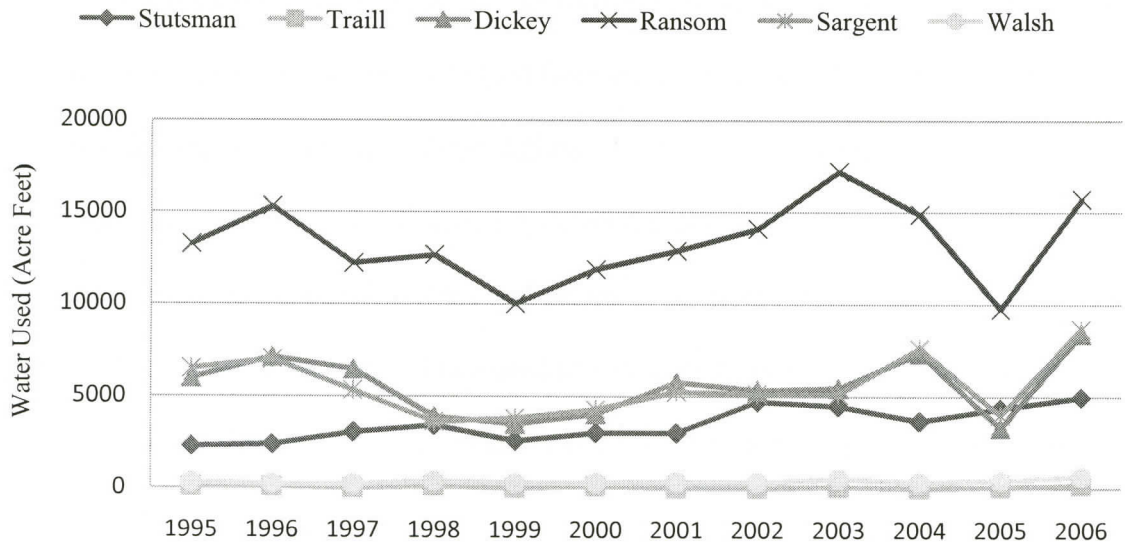


Figure 3.2. Water used for irrigation for the counties of Stutsman, Traill, Dickey, Ransom, Sargent, and Walsh for the period 1995 to 2006.

Figure 3.2 also indicated that Ransom county water use fluctuated with a decrease in 2005 when the least water was reportedly used. In Ransom, the number of acres of potatoes planted has steadily declined since 2000. The most acres planted was 3,300 in 1995, but by 2006 total acres dropped to a low of 1,100 acres. The amount of water used in Dickey County closely mirrored the amount used in Sargent County. Both counties showed a moderately constant water usage. Both counties had a seemingly negative sloping potato production trend that fluctuated over time. Dickey reported 100% irrigated production with an increasing trend in potato production since 2004. Sargent also reported an increase in the number of acres planted from 1997 to 2000. Contractual agreements are hypothesized as another factor affecting potato production. However, accessibility to relevant data were not feasible; therefore, the market price of potatoes in the state of North Dakota was collected from the USDA website and was used



to proxy the approximate prices growers received from processors. Producers' price index for Russet Burbank potatoes were collected from the Department of Commerce website and used to inflate potato prices to 2006 dollars. This was done primarily to simplify comparison of prices over time. Figure 3.3 shows the graphical representation of the difference between the nominal and the real prices of potatoes. Over time the real prices of potatoes, adjusted for 2006 prices, fluctuated showing sharp increases and decreases while the nominal prices depicted a more constant trend with a somewhat positive slope over time.

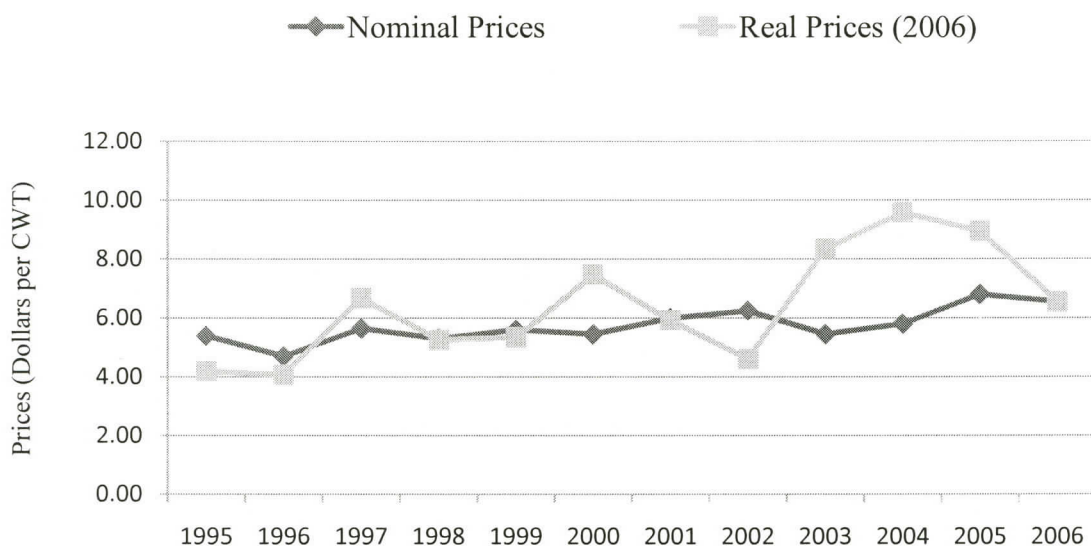


Figure 3.3. The nominal and real prices of potatoes in North Dakota over time.

The price of urea fertilizer was also collected. The data showed that the nominal price for fertilizer increased over time. The real prices fluctuated with a clear positive trend since 2002. Figure 3.4 shows a graphical representation of these data.

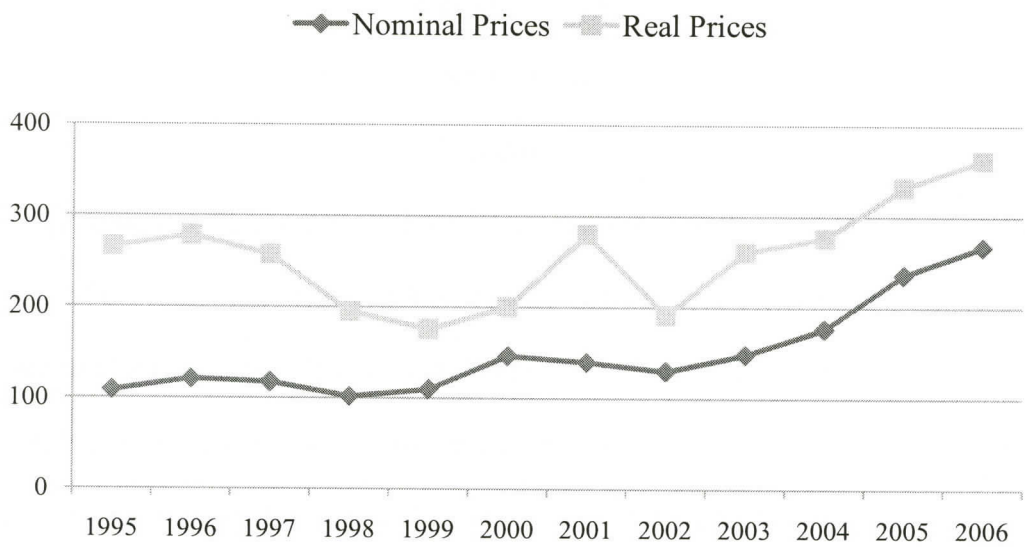


Figure 3.4. The nominal and real prices of urea fertilizer.

## CHAPTER IV

### RESULTS

#### Introduction

The results of the econometric model are presented in this chapter. In addition, a discussion of the magnitude and direction of each independent variable's influence on the total amount of potato acres planted is included. The model was used to determine the factors that are driving the production of potatoes in the counties of North Dakota. A total of 11 counties (highlighted in Figure 4.1) were a part of the unbalanced panel data set. It was assumed that growers seek to maximize their profits by making decisions regarding the optimal number of acres of potatoes planted in each growing season.

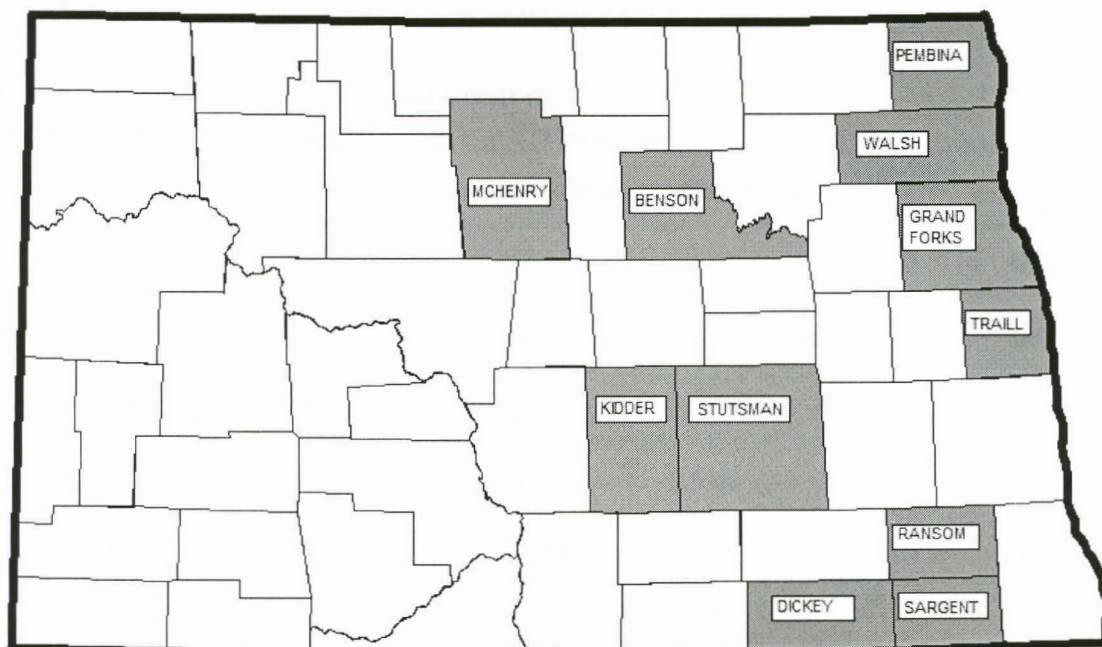


Figure 4.1. Map of North Dakota highlighting the eleven counties included in the study.

## Discussion of Findings

The EViews software package was used to estimate the distributed lagged model. The log of total crop planted (LOG (A)) was used as the dependent variable and as independent variables the log form of total crop planted in year  $t-1$  (LOG ( $A_{t-1}$ )), real potato prices normalized using real fertilizer prices (LOG (POTPRICES/FERT)), the number of acre feet of water used in each county multiplied by a water dummy for each county (LOG (IRRPER)\*(WATERDUM)), and the log form of historical yield per acre (LOG (YIELD<sub>t-1</sub>)).

The coefficients were estimated using an unbalanced panel of 11 counties over a period of 12 years with fixed cross-section dummy variables, resulting in 110 observations. The estimated results are summarized in Table 4.1.

Table 4.1. Results: Cross-Sectional Fixed Effects  
(Dependent Variable: Log of Total Crop Planted (A))

Independent Variable	Coefficient	t-Statistics	Standard Error	Probability Value
C	8.352*	7.137	1.170	0.000
LOG (A <sub>t-1</sub> )	0.456*	6.527	0.070	0.000
LOG (POTPRICES/FERT)	0.222**	2.419	0.092	0.018
LOG (IRRPER)*(WATERDUM)	0.010	1.536	0.006	0.128
LOG (YIELD <sub>t-1</sub> )	-0.346**	-2.321	0.149	0.022
Observations		110		
R-Squared		0.979		
Adjusted R-Squared		0.976		
Durbin-h Statistics		-0.821		

\* Significant at the 1% level.

\*\* Significant at the 5% level.

## Past Acres Planted

The estimated results indicated that the coefficient of the dependent variable, log of potato acres in year  $t$ , is most affected by past potato production relative to all other variables being constant. This conclusion is based on the size of the coefficient of the LOG ( $A_{t-1}$ ) variable which was reported as 0.456. This was the largest coefficient estimated. The corresponding t-statistic of 6.527 suggested that the number of past acres planted were highly significant in determining the optimum number of acres of potatoes to be planted in the given growing season (year  $t$ ). A reported probability of 0.000 supported this conclusion of significance. Since the functional form was logarithmic by design, the coefficient of 0.456 indicated that if the total number of acres of potatoes planted in the previous seasons increased by 1%, then the total number of acres of potatoes planted this season would increase by 0.456%. This positive relationship was as expected since increased production in year  $t_{-1}$  would translate into increased investments. This increase in investment could include the acquisition of additional land, specialized equipment for planting, irrigating or harvesting, or any other such fixed investments. The general idea is that growers make conscious decisions to invest in the expansion of potato acres. In doing so, growers intentionally decide to increase the number of acres planted in all future years or at least until the investment becomes obsolete.

In 1993, Scherer and Weigel estimated that the yearly total capital cost of a typical irrigation system was \$63.98 per acre. The initial investment for irrigation equipment including pipeline and wire, deep wells, pumps, and motors were estimated at \$75,000. The yearly capital cost was calculated using an annual straight line depreciation method with zero salvage value and an annual interest rate of 10%. Considering the high cost

associated with the installation of irrigation equipment, the decision to install such a system should be based on the growers desire to increase net farm income (Scherer and Weigel, 1993). The same is true for the purchase of specialized planting, harvesting, and storage machinery and facilities. As a result, it is unlikely that growers would choose to plant their entire cropland with potatoes in year t-1 and consequently plant zero potato acres for the next two years (a three-crop rotation is suggested). Another unlikely scenario is that growers enjoyed a good crop season in year t and then abandoned production in year t, having already invested in fixed factors of production in year t-1. Therefore, it is fair to assume that growers will rotate crops in an effective and efficient manner, planting optimal acres of potatoes each growing season in an effort to maximize profits while minimizing costs and risks associated with potato production. These results alone support the hypothesis that the amount of potatoes planted in a given growing season is dependent on the infrastructure that a grower had in place from previous growing seasons and on institutional relationships that were established previously.

#### Normalized Potato Prices

The coefficient of the log of the normalized real price of potatoes was estimated as 0.222. This indicated that the effect of a 1% increase in the ratio of the real price of potatoes to the real price of fertilizer would result in an approximate 0.222% increase in the total number of potato acres planted. In other words, if the expected price of potatoes increased at a quicker rate than the expected price of fertilizer in the same year, the results suggest that growers would have an incentive to increase the total number of acres of potatoes planted in that year. This positive relationship is as expected and follows the law of supply which states that, as price increases, suppliers will wish to increase their supply

to the market, hence increasing profits. Potatoes in North Dakota are sold either under contract or on the open market. The prices of those sold on contracts are negotiated prior to the growing season and therefore will directly influence the number of acres of potatoes that growers will plant. If strong relationships (an institutional factor) exist between growers and processors or other buyers of potatoes, it is expected that better prices could be negotiated, *ceteris paribus*. Those sold on the open market are priced at the time of the sale and therefore growers will plant according to what they expect prices and demand to be. The results of the regression further indicated that with a t-Statistic of 2.419, the coefficient is statistically significant at the critical value of 1.8%.

#### Water Used for Irrigation

Unlike the previous two independent variables, namely the logarithmic form of past potato acres planted and the normalized expected price of potatoes, the coefficient of the log of total water used for irrigation per county was not statistically significant at the 1% or 10% critical values. It was initially hypothesized that the amount of water available for irrigation in counties that produced irrigated potatoes would have been statistically significant to the potato industry. Instead, the estimated coefficient of 0.010 with a t-statistic of 1.536 suggested that the relationship is not statistically significant. Figure 4.2 shows the amount of water used for irrigation in counties of North Dakota. Observe that, while there are small fluctuations, most counties report a relatively constant quantity of water used over time with the exception of those counties that reported increased irrigated acres, for example Kidder County. For example, if a grower invested in three (3) irrigation pivots and implements a three (3) season crop rotation between grain and potatoes, the amount of water that would be used in year  $t$  and in year  $t-1$ , without extreme changes in

growing conditions such as drought, flooding or expansion of acres of potatoes, would not vary significantly because during any given growing season water would be used to irrigate two plots of grain and one plot of potatoes.

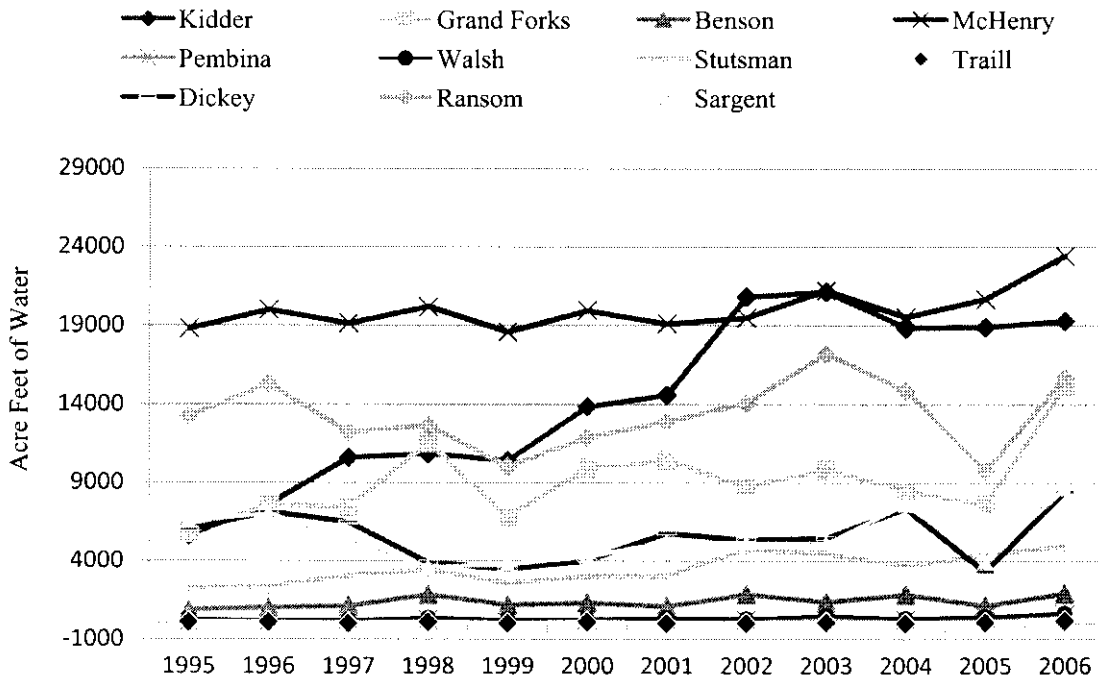


Figure 4.2. Water used for irrigation for the period 1995 to 2006. Note the similarities and low reported usage for the counties of Walsh, Traill, and Pembina.

### Historical Yields

As a proxy for growers' expected yield in year  $t$ , the historical yield per acre was used. The estimated regression reported a coefficient of  $-0.346$ . This estimation indicated a negative relationship between expected yields and the total number of acres of potatoes planted. It suggests that if expected yields per acre in year  $t$  would increase by 1% then the total acre of potatoes planted in year  $t$  would decrease by 0.346%. The conclusion is



uncomplicated, if growers expect higher yields in year  $t$ , based on estimations made from analyzing past yields, then in order for them to harvest the same number of hundred weights of potatoes as in year  $t_{-1}$ , the growers could plant less acres of potatoes in year  $t$ , *ceteris paribus*. The opposite is also true, if expected yields are forecasted to decrease; in order to harvest the same number of hundred weights of potatoes then more potato acres need to be planted. With a  $t$ -statistic of -2.321, the estimated coefficient of -0.346 with a probability value of 0.022 is statistically significant in helping to determine the optimal levels of total acres of potatoes to be planted.

#### Individual County Fixed Effects

The intercept term of the estimated regression ( $\beta$ ), represented the base county, Walsh. The coefficient was reported as 8.352, with a  $t$ -Statistic of 7.137 and a probability of 0.000. Based on these results, the coefficient was concluded to be statistically significant in determining the optimal number of acres of potatoes to be planted in North Dakota. The coefficient representing the county of Walsh's fixed effect in the model was recorded as being the largest intercept term. In other words, the remaining 10 counties showed a negative relationship to the base county. Furthermore, all the coefficients were statistically significant at the 1% critical value, with the exception of Pembina. Table 4.2 summarizes the reported coefficients,  $t$ -statistics, standard errors, and probabilities of the individual counties effect from running the cross-sectional fixed effects model.

Recall that the estimated equation, with the standard error reported in parentheses, is

$$\widehat{\log(A)}_{it} = \frac{8.352}{(1.125)} + \frac{0.456 \log(A_{-1})}{(0.070)} + \frac{0.222 \log(POTPRICES/FERT)}{(0.092)}$$

$$+ \frac{0.010 \log(IRRPER) * (WATERDUM)}{(0.006)} - \frac{0.346 \log(TYIELD_{-1})}{0.149}$$

n = 110, R-Squared = 0.978

Table 4.2. Results: Individual County Fixed Effects  
(Dependent Variable: Log of Total Crop Planted (A))

County	Coefficient	t-Statistics	Standard Error	Probability Value
BENSON	-1.742*	-6.447	0.270	0.000
DICKEY	-1.435*	-5.705	0.251	0.000
GRAND FORKS	-0.392*	-2.964	0.132	0.004
KIDDER	-0.684*	-3.347	0.204	0.001
McHENRY	-1.283*	-5.387	0.238	0.000
PEMBINA	-0.136	-1.633	0.083	0.106
RANSOM	-1.409*	-5.889	0.239	0.000
SARGENT	-1.594*	-6.029	0.264	0.000
STUTSMAN	-1.581*	-5.518	0.286	0.000
TRAILL	-1.444*	-7.180	0.201	0.000

\* Significant at the 1% level.

The reported R-Square of 0.978 and the adjusted R-Square of 0.975 indicated that 97% of the variation in the total number of acres of potato planted was explained by the independent variables included in the regression, suggesting a good fit. The Durbin-Watson statistic indicates the presence or absence of serial correlation and is reported as 2.048. Ordinarily, this figure would indicate that the model is free of problems associated with serial correlation. However, since the regression model contained lagged variables,

the Durbin-Watson statistics is no longer a good or accurate measure of serial correlation.

Therefore, the Durbin h statistic was calculated to test for the presence of serial correlation.

Using the formula

$$(8) \quad h = \left[1 - \frac{DW}{2}\right] \sqrt{\frac{T}{1-T[\text{var}\hat{\beta}]}}$$

(Pindyck and Rubinfeld, 1998), Durbin h was calculated as -0.082. Since this calculated figure is smaller than the critical value, the null hypothesis of no serial correlation cannot be rejected.

Based on the results obtained, it can be concluded that the most important factor for determining the optimum number of potato acres to be planted, is what was planted in previous years. Also important is the growers' expectation of both prices and yields, and to a lesser extent the availability of water for irrigation purposes.

## **CHAPTER V**

### **CONCLUSION**

#### **Introduction**

The first part of this chapter briefly summarizes the objectives of this study, the methodology employed and the results obtained. The second part gives an outline of the major findings and reaffirms the conclusions made. Finally, a section on implications and recommendations for further research is incorporated.

#### **Summary of Thesis**

Potatoes are grown commercially for specialty usage including frying, canning, chipping, dehydrating and tablestock. The process of production is said to be highly complex, involving vast investments and technical skills. Growers and processors are faced with selecting proper varieties as a basic first step to ensuring quality end products. Selection is important since different varieties are more adaptive to different end use, growing conditions, and processing methods.

The primary goal of this research was to determine the magnitude and direction of relationships between key variables of interest affecting the production of potatoes in North Dakota. Specifically, the objective was to answer the question “How does expected profit which is a function of growers’ expectations of prices, quantity, and cost, affect their decision of how many acres of potatoes to plant from one growing season to the next in North Dakota?”

Berwick et al. (2001) concluded that the potato industry in North Dakota was shifting from its traditional location in the Northeastern part of the state to more central areas. They asserted that this shift was in part due to the introduction of irrigation systems

as well as the desire of growers to minimize risks associated with diseases and water availability. Although an econometric model was not developed, it was graphically depicted that changes had occurred and the industry had evolved as consumer tastes and preferences changed.

This study collected secondary data at the county level, and built an econometric model. The model was based on the assumption that potato growers will seek to maximize profits by planting an optimum number of acres of potatoes ( $A^*$ ), at a cost that is dependent on the number of acres planted ( $C(A)$ ), while expecting to sell at price  $P$  and produce yield  $Y$  per acre. The regression equation estimated an unbalanced panel, fixed cross-sectional effects model in EViews. The logarithmic functional model included variables that measured the importance of how many potato acres were planted in the previous growing season ( $A_{t-1}$ ), the expected normalized real price of potatoes ( $P/C$ ), the importance of water available for irrigation ( $(IRRPER)*(WATERDUM)$ ), and the expected yield per acre of crop planted ( $YIELD_{t-1}$ ).

### Summary of Findings

Recall the regression estimated was  $LOG(A)_{it} = \alpha_i + \beta_1 * LOG(A_{t-1})_{it} + \beta_2 * LOG(POTPRICES/FERT)_{it} + \beta_3 * LOG(IRRPER)_{it} * (WATERDUM)_{it} + \beta_4 * LOG(YIELD_{t-1})_{it} + \epsilon_{it}$ . Recall also that the coefficients were estimated as shown in Table 5.1.

Table 5.1. Result Summary

Independent Variable	C	LOG ( $A_{t-1}$ )	LOG (POTPRICES/FERT)	LOG(IRRPER) *(WATERDUM)	LOG ( $YIELD_{t-1}$ )
Coefficient	7.346*	0.456*	0.222**	0.010	-0.346**

\* Significant at 1% level.

\*\* Significant at 5% level.

The relationships were all as expected with positive relationships being established between the dependent variable measuring the optimal number of acres of potatoes to plant in the current growing season, and the independent variables measuring the importance of past production acres, the normalized real prices of potatoes, and the importance of the availability of water permits in those counties that rely on irrigation systems in their production process. A negative relationship was established between the dependent variable and the expected yield per acre which was also as hypothesized.

The most interesting finding was the impact of the variable that measured the importance of the total number of acres of potatoes planted in the previous growing season. This coefficient was the largest (0.456) and was highly significant. Apart from being able to conclude that the best estimate of the number of potatoes acres growers will plant is how much was planted in the previous seasons, this variable also encompassed relationships that were established and tested over a period of time. In other words, the variable measuring the total number of acres of potatoes planted in the previous year also encompassed all the institutional and infrastructural variables that are necessary for the commercial production of potatoes in the state of North Dakota. This variable included the fixed factors of production such as total land used for growing potatoes, irrigation systems (if the county utilized irrigation for the production of potatoes), equipment necessary for planting, cultivating and harvesting, and storage facilities. Even further, this variable included the human factors that contributed to the institutional economics aspect of production. This included the relationships that exist between growers and processors, which allow growers to sell their produce at a predetermined price ensuring some fixed level of profitability. It also included the growers' abilities to secure water permits that allows for the pumping of

water to supply irrigation systems. Further, included in the number of acres of potatoes planted in the past are also the technical skills and the knowledge of potato producers. Growers establish a vast amount of knowledge of the industry and the production process over time. This knowledge is invaluable to their yearly management and production. Additionally, securing the right type and amount of labor, potato variety, chemicals and fertilizer and equipment is all incorporated in the process.

The variable that measured the nominal price of potatoes in North Dakota was significant at the 5% level. With a reported coefficient of 0.222, the results suggest that if potato prices increase at a quicker rate than the cost of urea fertilizer, then growers would have an incentive to produce more potato acres.

The importance of water to the potato production system was not as anticipated (0.010). One reason may be that the importance of having access to water is already incorporated in the variable that measures the total number of acres of potatoes planted in previous growing seasons. More likely, the statistical significance may not have been as expected because of the time period under review and the number of counties that are currently involved in irrigated acres of potatoes. Since the period under review included 12 years and not all 11 counties produced irrigated potatoes, it is possible that the regression suffered from lack of observations and therefore the true significance of the variable is not being fully captured.

Reported yields, with a reported coefficient of -0.346, also show statistical significance in growers' decisions of how many acres of potatoes to plant. The estimated coefficient suggested a negative relationship between total potato crop planted and the expected yield per acre. This follows the idea that growers are tied to contracts dictating

the supply of some quantity of potatoes and expecting higher yields, growers can achieve that predetermined quantity by planting fewer acres of potatoes. While this is possible, it would be interesting to test the hypothesis if this is the true relationship that exists or if higher yields would prompt potato growers to cultivate more acres and negotiate larger contracts with the expectation of larger profits.

### Implications and Recommendations

This study showed that institutional and infrastructural variables are important to the potato industry in North Dakota. The potato industry is highly technical and involves vast capital and technical investments. The results indicated that, while expected prices and expected yields are important to potato production independently, they are not as important as they are when their effects are captured in one variable ( $A_{-1}$ ). This study showed that the potato industry could be considered a conditionally fixed industry where growers' decisions are made for the long term. In other words, the investments made bind growers to the continuous production of potatoes until such time that they are able to sell their contracts, their investments become obsolete, or the necessary institutional factors are no longer in place.

It would be interesting to adopt the methodology used in this study and to apply the assumptions to the United States potato industry at the state level and determine if the statistically significant variables in this study occur throughout the potato industry. In the state of North Dakota, it would be interesting to access contractual agreements and data on the availability of contracts and to then model an equation that tests the direct impact of contracts on potato production. Finally, extending the time period under consideration



would be advisable. This could correct for limitations that may have contributed to statistical significance issues with the water availability variable.

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