Energy Substitution in Agriculture:

by
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Energy Substitution in Agriculture:
A Translog Cost Analysis of the U.S.
Agricultural Sector, 1992-2007

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ABSTRACT

Energy is an important input for production of all kinds, including energy. From 1992 to 2007, the agricultural market underwent many different changes with respect to the inputs they utilized, as well as the prices they paid for them. Among these changes, fuel prices displayed the most severe volatility. Using a Transcendental Logarithmic Production Function, the price elasticity of substitution was estimated for all agricultural inputs during the time period studied in order to determine how farms change production allocations due to increasing energy prices. It was found that price elasticities were very low between energy and other inputs, suggesting that farms do not change their input allocations due to increases in energy prices.
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OVERVIEW

One of the most important economic goods traded has been food. The first specialization of skills revolved around acquiring food, and the earliest civilizations were based on static agriculture. Although other areas of trade have come to prominence, agriculture has and will always be a critical sector for economic study. Therefore, it is always interesting as well as prudent to determine how changes in factors of production affect agriculture in our contemporary economy.

The field of Economics has been concerned with agriculture since its inception in the late 18th century. Malthus’s dire predictions on restricted food production with relation to population growth in his most significant work, *An Essay on the Principle of Population*, (1798) led the field of Economics to be called a “dismal science.” Some of the first recorded economic data in the United States concerned agricultural production. In the 20th century, models were created that began to analyze agricultural production as well as prices. Traditional production models have focused on the classic inputs land, labor, and capital. However, in recent decades, other inputs such as fertilizers and energy in the form of fossil fuels have been studied in conjunction with labor and capital to determine their influence.

Energy has become an important input with respect to economic study in the past few decades. Although labor and capital remain important factors of production, even with primitive mechanization, a source of energy is required for any level of production. The first sources of energy were animals, used to pull carts and drive plows. During the later years of the Roman Empire, ambient sources of energy such as water and gravity
began to be used to power machines. Wind began to be harnessed for milling during the Middle Ages. The true importance of energy became apparent, however, with the beginning of the Industrial Revolution. During this time, it became important to find sources of energy that could be tapped quickly and conveniently. Fossil fuels, a collection of substances that can contain and release large amounts of energy quickly and conveniently, came to the forefront. At the end of the 19th century, electricity became a popular source of power for stationary capital, with fossil fuels being regulated to generate this electrical power, as well as to power mobile capital.

It has taken the constriction of growth in energy resources, coupled with a lifestyle which has become more and more energy intensive, to force society to realize the critical importance of energy in all aspects of contemporary civilization. Many have mimicked Malthus in making dismal predictions, but agriculture has been replaced with energy as the source of their anxiety. Works such as “Thoughts on Long Term Energy Supplies: Scientists and The Silent Lie” by Albert A. Bartlett (2004) project dire predictions concerning the supply of energy in the long run. It is works such as Bartlett’s that encourage the idea that energy shortages have taken the place of food shortages as a source of human misery. It is even more vexing for Malthusians to recognize energy as not only a new source of human misery in its own regard, but also as a vital input for the production of food, which was the first Malthusian source of human misery!

Recent academic works have been written to study the relationship between energy usage and agriculture, but have only painted part of the picture. Some works, such as Catherine Morrison-Paul and James MacDonalds’ “Tracing the Effects of Agricultural Commodity Prices on Food Processing Costs”, (2003) touched partly on
this by studying input costs at the agricultural level and how they are affected by output prices. They do this through the employment of a general equilibrium model in which the price of agricultural output affects the demand for agricultural inputs. Elasticities were established between each input in question and the output, in order to gauge how changes in product prices would affect the employment of agricultural inputs.

Other works, such as R. McFall Lamm and Paul C. Westcott’s “The Changing Effects of Input Costs of Food Prices”, (1981) again touched on a different part of the picture. In the case of Lamm and Westcott, a “stage of processing” model is used to determine how inputs at different levels of production can affect final retail prices for goods. The use of this type of model contrasts with contemporary methods employed by the USDA. Lamm and Westcott were able to determine that the market for food behaves less like the perfectly competitive industry that conventional thinking had attributed to agriculture, and more like a monopolistically competitive industry with attributes not that different from the manufacturing sector.

These two works alone reveal parts of a picture that until recently had been considered false. Instead of an agricultural sector consisting of innumerable small identical firms farming identical products, works like those listed above reveal an agricultural sector that differs from other economic sectors in environment but not in behavior. The pastoral farm growing grain for market had been replaced by large operations that differed from manufacturing only by the differences in input combinations. Yet with all of these indications, few attempted to determine how the different components of agricultural production interacted with each other.
OBJECTIVES

One part of this picture, painting the relationship between energy usage and food production, has never been fully developed. It is, therefore, the objective of this project to attempt to model the substitutability of energy in agriculture. Using an econometric model, changes in energy prices, especially fuel prices, will be used in conjunction with labor, capital, and material prices to determine how input combinations change in agriculture as a result in price changes. When these affects of input prices on input combinations is determined, conclusions regarding the overall relationship between the price of certain inputs and the quantities of those inputs that are employed can then be made. With this analysis, we can attempt to answer the question; “Can energy be substituted for by other inputs in agriculture, and if so to what extent?” This question has become increasingly relevant given the recent supply issues with conventional energy sources.

In order to achieve this goal, it will be necessary to establish the price elasticities of inputs for agriculture, and how they are related to output. An advanced way to determine these price elasticities is through the use of a transcendental logarithmic (translog) cost model. A translog cost model is superior for estimating elasticities of substitution between inputs compared to other methods of estimation for several reasons. The first reason translog cost functions are superior is that translog cost functions do not oversimplify elasticities of substitution between inputs, which Cobb-Douglas cost functions tend to do since they employ linear cost functions. Another reason is that prices in the translog cost model are considered exogenous, which is more economically feasible than considering prices endogenous since individual firms are more likely to alter
production as a result of changes in input prices, not the other way around. It is therefore
the goal of this paper to construct a translog cost model using the most detailed data
available in order to determine price elasticities between inputs. This will tell us how
farms react to changes in input prices, including the price of fuel.

The next section of this paper, the literature review, will explain both the
inspiration for such research as well as the methodology in carrying it out. The data
section will describe the types of data employed in the model, as well as their sources and
how they have been prepared for use in the model. The model section will explain how
the translog cost function works, and why the model for this paper takes its current form.
The results section will display the results of running the data through the proposed
model, as well as how they are reformatted so that price elasticities for inputs can be
interpreted. The conclusion section of the paper will incorporate conclusions on how well
the model worked, how the results are interpreted, and ideas for expanding on in future
works.
LITERATURE REVIEW

In the course of exploring any research topic, it is first necessary to discover what, if any, work had been done on the subject. In the case of studying the effect of energy prices on food prices, literature regarding how such relationships are modeled is the most appropriate place to start. In the onset of any research, such literature provides direction and an intellectual backbone upon which the entire project will rely. Literature that supports the conclusions made by a paper is appropriate to mention, but first it is necessary to describe the works that provide the basis for the empirical methods employed by a paper.

The first and most critical paper to mention in this regard is “A Cost Function Approach to the Measurement of Elasticities of Factor Demand and Elasticities of Substitution” by Hans Binswanger (1974). In this work, Binswanger attempts to use cost functions as opposed to production functions in order to calculate the price elasticities of inputs, with respect to factor price elasticity and elasticity of substitution. He attempts this departure because he believes that traditional calculations based on production functions are flawed for several reasons, many of which are functional. Binswanger believes that the use of cost functions for a translog model is superior because it removes steps in estimation, or makes steps in estimation less prone to error. Also, Binswanger’s process removes many of the multicollinearity problems that plague conventional production models, but preserves the linearity inherent in logarithmic analysis.

Binswanger tests these theories by constructing a model in which there are four inputs and one output. Land, labor, capital, and fertilizer are employed to produce a
generic agricultural output. The data used is obtained from the state level Census of Agricultures every five years starting in 1949 and ending in 1964. Binswanger included dummies for geographic areas, and included the time periods as a dependent variable. He then ran the model with no restrictions, as well as inserted restrictions such as the Cobb-Douglas constraints to test the veracity of said constraints.

Binswanger concluded that most of his restrictions and dummies were valid, although he rejected a few of his assumptions as invalid (an example of his invalid assumptions ended up being the Cobb-Douglas constraint that inputs had a substitution elasticity of one). After making conclusions about which constraints were valid for use and how best to account for geographic and temporal variables, Binswanger finally interprets his findings concerning the input elasticities. Binswanger finds that the own factor price elasticities are negative, which he finds to be a logical outcome of the model. Binswanger then analyzes the elasticities of substitution between his inputs, in order to make conclusions about the relationship between inputs. Binswanger finds that fertilizer and land are relatively strong substitutes, but the other relationships surprise him. Binswanger concludes that many of the inputs are substitutes with each other, but their elasticities are so low that Binswanger makes the conclusion that the traditional assumptions about inputs are at the very least exaggerated. For example, although Binswanger finds that labor and capital are substitutes, the elasticity is low enough that the traditional assumption that labor and capital have a relationship of being net substitutes is wrong.

Binswanger’s work is important for two reasons. The first reason is the more obvious, in that Binswanger paves the way for cost functions to be employed in translog
functions, and how such models are superior to the contemporary models used at the time. This breakthrough is important not only in the analysis of the agricultural sector, but to any econometric analysis of any industry for which there is sufficient data for modeling. The second reason that Binswanger’s work is important lies with his results and conclusions. It was, up to that time, assumed that many inputs had a greater degree of substitutability in the agricultural sector. Land and labor could be substituted by fertilizer and equipment, respectively, but at a rate that was very high. Binswanger found that although his inputs were substitutes, they had a low degree of elasticity with respect to each other. Furthermore, the dichotomy assumed between pairs of inputs did not exist, and that changes in input allocations were made with respect to price changes for all inputs together. Price changes in fertilizer could affect labor and capital usage, and changes in capital could affect land usage, instead of only land and fertilizer or labor and capital having exclusive relationships in which other inputs had no bearing.

A subsequent work in agricultural economics is Ray Subhash’s “A Translog Cost Function Analysis of U.S. Agriculture, 1939-1977” (1982). In this work, Subhash also creates a cost function based translog model, inspired by Binswanger’s early work. Subhash diverges from Binswanger in that Subhash uses fewer inputs and has two competing outputs: crops and livestock. Subhash uses cost share equations for all inputs along with his two cost functions for crops and livestock in his model to determine substitution elasticities and price elasticities for factor inputs. Subhash uses different inputs than Binswanger, excluding land in favor of feed, seed, and livestock as an aggregated input. Subhash also uses data from a larger time period, from 1939 to 1977. Subhash used price data in an index form, as opposed to the actual nominal prices used
by Binswanger. Instead of using years as a dependent variable, Subhash employs a trend line to account for temporal changes. Subhash further does not include regional dummies in his model.

The results of Subhash’s model are similar to Binswanger, but with some differences. Obviously, there is no geographic significance as there is in Binswanger’s work since geography was not accounted for in the model. Furthermore, time appeared to have a different effect than what was observed in Binswanger’ model, which is logical given the different ways that time was accounted for between the two works. The relationships between inputs were different in some cases, with Binswanger finding complimentary relationships in some cases while Subhash found only substitutability. Estimates of elasticities between the two papers are also different, with Subhash having higher elasticities for some inputs while having lower elasticities for others. However, Subhash finds that substitutability between many of the inputs, especially labor and capital, are decreasing over time. Subhash calculates a steady increase in productivity of about 1.8% per year over four decades. Subhash concludes that the mechanization of agriculture is slowing down, but that the use of chemicals and/or fertilizers is accelerating.

The differences, as well as the similarities, between Subhash and Binswanger’s conclusions are instructive when taken in context with the different ways they accounted for time, geography, and how they aggregated their inputs. Differences in relationships and elasticities of inputs between the two works are the most prominent for the inputs that were aggregated differently. This can most readily be seen in the wide divergences between elasticities between fertilizer and land/raw material for Binswanger and
Subhash, respectively. If land and the raw materials (feed, seed, and livestock) were included as separate and distinct inputs in both models, the results of the two works might be more similar. Where Binswanger and Subhash find agreement, however, is in explaining the relationships between agricultural inputs. Binswanger and Subhash agree that inputs display a lower degree of substitutability for agriculture than originally thought. Also, both point to a highly automated, technically advanced agricultural sector in the United States, in which the traditional picture of the yeoman farmer was rapidly being replaced by large scale agribusiness.

It is at this stage of a literature review that one would ordinarily include more recent works based on what works had been listed above. However, in this case it is rather difficult to do so. In a search of literature that had sited either Binswanger or Subhash, it was found that most of the work employing the translog cost model in the agricultural sector had been done before 1990. Binswanger and Subhash are sited in many American works, but to the extent that their conclusions were used to support conclusions made in those works. Few papers site Binswanger and Subhash as a source for methodology, especially methodology related to the use of translog cost models for studying U.S. agriculture. The only recent papers that cite Binswanger and Subhash as a source of methodology do so in the study of other countries, and none of which are interested in agriculture. Although the primary purpose of this paper is to study substitutability of energy in U.S. agriculture, it seems that this paper may also serve as a rare update to the methods used by Binswanger and Subhash in studying American agriculture.
It should be noted that Binswanger’s and Subhash’s econometric models were not arbitrarily created, but are extensions of more basic works done in the past. These works tend to be entire books as opposed to research papers, since the components of such models take a great deal of time and print to explain. In the case of Binswanger and Subhash, it is helpful to discuss an earlier type of model used to analyze relationships between inputs and output: the input-output model. Input-output models were developed early in the 20th Century in the United States, Pioneered by Wassily Lionteiff with his “Quantitative Input-Output Relations in the Economic System of the United States” in 1936. This paper explains how the distribution of resources can be analyzed by studying which inputs in what quantities are used by industry for which outputs.

One economist who drew inspiration from Lionteiff was William H. Miernyk. In 1965 Miernyk began to revise and add on to some of his previous work, with the book *The Elements of Input-Output Analysis* being the result. In this book, Miernyk first describes the evolution of Input-Output analysis from the works of Quesnay in France in 1758 up through Lionteiff’s works in the 1930s, and describes how Input-Output analysis has assisted in economic analysis for nations with large, dynamic, and relatively integrated economic systems. Miernyk then spends time describing how Input-Output analysis works: through the use of complex tables in which output from all sectors of the economy are divided among all of the other sectors. The first sector explained is the processing sector, in which output of one sector is consumed by another sector as an input for that sector’s output. The second sector discussed is the final payments sector, in which foreign markets, government, and consumer expenditures are included to explain where output goes if not consumed by other production sectors. The third and most
important sector is the final demand sector, in which the final payments sector is included so that the changes in distribution of output can be matched with changes in expenditures. Once this complex table is created, many types of analysis can be conducted using this table. These analyses can then be interpreted so as to analyze sector structures, determine impact and employment multipliers, and to forecast the effects caused by shocks within the system. Miernyk goes on to explain that this type of analysis originated for use on the national level, but has gone on to include all levels from regional to international in application. While this type of analysis is exemplary for studying how resources are transferred and ultimately employed, it is still lacking in that input-output analysis cannot account for substitutability between inputs at any level of production.

Input-Output analysis as defined by Lionteiff and Miernyk has been used in works studying the agricultural sector in the United States. One such work is John M. Gowdy, Jack L. Miller, and Hamid Kherbachi’s “Energy Use in U. S. Agriculture: Early Adjustment to the 1973-74 Price Shock” (1987). In this work, Gowdy et al calculate the total energy employed in the agricultural sector, by determining the total direct and indirect expenditures on energy sources from farms in the United States from 1973 to 1977. The sources of energy included in their matrix included all forms of fossil fuels as well as electrical power. They determined indirect expenditure based on energy used to manufacture agricultural chemicals and fertilizers, as well as the obvious consumption of fossil fuels to create electricity.

Gowdy et al found that the OPEC embargo in 1974 and the subsequent shortage of oil forced farms to lower their direct consumption of energy, in the form of fuel. However, this reduction of fuel consumption was counteracted by increases in the use of
the aforementioned fertilizers and chemicals, which are in themselves derivatives along with fuel of crude oil. Farms were able to make efficiency gains and thus lower their per-unit output demands for energy, but nonetheless ended up consuming more fossil fuels over the period of time studied.

The Input-Output analysis that Gowdy et al employ in studying energy usage in agriculture is as interesting as well as relevant. Using Input-Output tables to tabulate how energy is employed is a good way to make general observations concerning changes in expenditures at the farm level as a response to changes in energy prices. Also, Input-Output analysis of this type allows for the study of indirect relationships that cannot be statistically captured in econometric models like the translog cost function employed by Binswanger and Subhash. However, this is where the advantages of Input-Output analysis end. Although changes in expenditures for inputs can be compared to corresponding changes in output, the underlying assumption of Input-Output models is that input combinations are constant and have no substitutability, at least to the extent that such substitutability can be calculated with any statistical significance. As econometric analysis of different types show, substitution between inputs not only occurs due to price changes in a given input, but often occurs due to prices for all inputs changing simultaneously.

It is also helpful in a paper to compare and contrast the results of a project with works that discuss the same topic but employ different approaches. Although these works do not support the methods used in a project, they can serve to indicate if the conclusions made based on the results of the employed methods agree conceptually with other studies in that field. Since the subject of this paper is the agricultural sector and
how it responds to changes in energy prices, it can be useful to study what works have
been done previously that pertain to agriculture and energy.

An interesting paper for this purpose is R. McFall Lamm and Paul C. Westcott’s
“The Effects of Changing Input Costs and Food Prices” (1981). In this paper, Lamm and
Westcott construct a model in which food prices are determined differently than what
was originally assumed by most economists as well as the government. In most classic
economic models concerning food, food is produced and sold in a competitive
environment. Lamm and Westcott propose that since most food in contemporary times
goes through at least some production and retail stages before reaching the consumer, the
final consumer food market should be considered not to be under conditions of perfect
competition.

The conclusions that Lamm and Westcott come to from running their model is
that the food market does indeed display behavior similar to other markets for
manufactured goods. Within the manufacturing sector, changes in prices for different
inputs will cause firms to select new optimal combinations of inputs. In the food sector,
Lamm and Westcott find that the prices of labor and energy will dominate how all inputs
are combined. Lamm and Westcott also have noted that changes in the price of food also
lag behind their respective change in the price for a given input.

Lamm and Westcott have created a working model which not only redefines how
food prices are set in a modern economy, but they also are the first to establish how
important other input prices such as the prices for raw materials and energy can be in
creating a model. Traditionally, production functions have consisted of labor and capital
Models like the one Lamm and Westcott have created are not only more explanatory, but also more powerful in explaining price changes for final goods like food. In essence, Lamm and Westcott’s model forms a foundation for the further study of the effects of energy prices on food production.

The second piece of literature that is critical to the analysis of energy prices and food prices is Catherine J Morrison Paul and James M. MacDonald’s “Tracing the Effects of Agricultural Commodity Prices and Food Costs” (2003). In this paper, Morrison and MacDonald explore how non-traditional inputs such as energy and raw materials affect food prices at the farm level. Morrison and MacDonald essentially created a Cobb-Douglas production function, only with four inputs instead of two. These four inputs were labor, capital, energy, and raw materials, and changes in the prices of these inputs were studied over a twenty year period.

The results of this model were insightful, and provided an explanation into the behavior of the agricultural industry over the past few decades. Morrison and MacDonald made several important conclusions based on these results. The first conclusion that Morrison and MacDonald made was that all inputs are price inelastic at the agricultural production level, and this elasticity is becoming more severe over time. This means that agricultural firms will not dramatically shift their input combinations based on relatively large changes in input price. Also, Morrison and MacDonald conclude that increases in the demand for food lead to larger than proportional increases in the demand for agricultural inputs. Morrison and MacDonald list the inputs in the following order based on relevance: Capital, Raw Materials, Labor, and Energy. Although energy is listed as the least powerful, the fact remains that an increase in
demand for food will lead to a proportionally greater demand for energy. Morrison and MacDonald also share agreement with Binswanger and Subhash in that agricultural inputs are generally price inelastic, which lends great support to their conclusions given that Binswanger and Subhash employed a very different model than Morrison and MacDonald.

Just as Lamm and Westcott created an overall model for input price effects on food, Morrison and MacDonald have created a detailed model for input prices on food at its first stage of production: the farm. Morrison and MacDonald have created a production model in which shifts in output quantity, output price, and input combinations can be predicted given a change in the price of a single input. This is important with respect to energy prices and their effects of food prices, as changes in energy prices can be directly applied to this model to predict changes in other input employment as well as output. Furthermore, Morrison and MacDonald’s model and conclusions support the other literature in this review in the following respects: that the price of energy is an important determinant in the price of food at the agricultural level, yet consumer food prices are not predominately determined by the price of farm level outputs. Although these two ideas would seem to be contrary to establishing energy’s role in determining food prices, these two ideas do set up the concept that will be established in other literature: that energy’s use as an input is ubiquitous in every level of production and distribution of food.

The third piece of literature that gives insight into the relationship between energy prices and food prices is Dale Jorgenson’s “Energy Prices and Productivity Growth” (1981). In this paper, Jorgenson studies the effect of changes in the price of energy in
changes in productivity during the period starting in 1973 and ending in 1976. Jorgenson created a rather unique model, in which he grouped industries not by output type, but by input intensity. Industries that were labor intensive, for example, were grouped together; industries that were capital intensive were grouped together, and so on. Jorgenson included four types of inputs: labor, capital, energy, and raw materials. Jorgenson therefore had multiple groupings in which one or more inputs were considered intensive. Then, Jorgenson studied how changes in these input prices affected changes in the productivity of those redefined sectors.

Jorgenson’s results were very interesting. Jorgenson first established that labor, capital, and energy prices shared an indirect relationship with productivity, while raw material prices shared a direct relationship with productivity. Therefore, an increase in energy prices will cause productivity to slacken. Second, Jorgenson established that the shortage of energy that was a result of the Arab-Israeli war in 1974 caused a massive decrease in productivity growth across all sectors. Jorgenson concluded that energy prices played as important a part in determining productivity as labor and capital costs.

Jorgenson’s findings are highly significant when discussing the relationship between food prices and energy prices. Jorgenson’s model displays the importance of energy as well as its tendency to be ubiquitous. Labor, capital, and raw material markets are highly heterogeneous if looked at from the perspective of an entire economy. Energy markets, however, are very homogeneous. Energy sources are mostly used to generate electricity, which every firm uses to some extent. Whereas an increase in the price of metal or interest rates may only hit some sectors while leaving other sectors unaffected, increases in energy prices will necessarily affect all industries. When one considers that
the food industry uses a great deal of energy, than decreases in productivity as a result of energy prices should therefore have a noticeable impact on food prices.

Another important paper to discuss is Carl Van Duyne’s “Food Prices, Expectations, and Inflation” (1982). In this paper, Van Duyne studies the changes in the price of food with changes in inflation rates, and determines whether or not the Biased Expectation Hypothesis, or the theory that changes in food prices will have an inordinately large effect on inflation estimates, holds. To do this, Van Duyne creates a model in which food prices are allowed to fluctuate, while prices in other manufactured goods change at a set rate. Van Duyne then analyzes whether or not the fluctuations in food prices have any effect on the actual rate of inflation.

Van Duyne’s model results were interesting in the way they contradicted traditional measures of inflation. Van Duyne found that changes in food prices did not affect inflation, and that consumers’ expectations concerning inflation were not based solely on food or energy prices, but on changes in their entire consumption combination. This meant that the traditional methods used by the Federal Government, such as price controls and quotas, were ineffective in staving off inflation.

These findings are relevant when discussing the relationship between food prices and energy prices. Although Van Duyne was concerned primarily with proving that the Biased Expectations Hypothesis (BEH) was incorrect, some of the findings Van Duyne used to prove this are useful in explaining the behavior of food prices as a result of energy prices. Both energy prices and food prices were considered to fall under the BEH, and Van Duyne attempted to prove that changes in these did not directly affect overall
inflation. While this is true, Van Duyne’s methodology of using flexprice-fixprice modeling can be applied to an econometric model, in order to study how shocks in energy prices can affect other prices.
DATA

In order to employ a translog cost function, it is necessary to gather two types of data: price data and expenditure/revenue data. Fortunately for the purposes of the objectives of this paper, data for the agricultural sector have been recorded over the longest period of time compared to other national economic statistics, are among the most detailed, and are among the most readily available for the United States. The Federal Government started tracking summary statistics for farming shortly after the Civil War, and has expanded the depth and breadth of these statistics ever since. Starting in the 1910s, the Department of Commerce began to take censuses of business and farms every five years. Part of these censuses covered two important types of data for the model used in this paper: expenditures and revenues. The other data that was crucial to the completion of the model were prices, which were acquired from the Department of Agriculture’s annual reports. It is important to discuss the types and qualities of the data so that proper interpretations of the model can be made.

The data used in this project covers the 15 year period starting in 1992 and ending in 2007. This time period was chosen for many reasons, but there are three factors that made studying this time period especially relevant. The first and most obvious is that this time period is the most recent available from the Census of Agricultures. The second reason this time period was chosen was the comparability of the raw data. Expenditure data for inputs are lumped into different categories between different decades, and going further back in time than the 1992 census would have created significant problems, not the least of which is the availability of stand-alone fuel expenditures. This phenomenon will be explained further when the actual categories are explained. The third, and
perhaps most strategic reason for the purposes of this project, is the behavior of fuel prices during this period. The price in real terms for fuel went through a wide change in those 15 years, starting with the lowest real fuel prices in recent history in 1992 and ending with the highest real fuel prices in recent history in 2007.

EXPENDIURES AND REVENUE

Expenditure and Revenue data were obtained from the 1992, 1997, 2002, and 2007 Census of Agricultures. The data was divided by state, and county level data was published for each state. This gives us roughly 3000 counties for which there is expenditure and revenue data for each time period. There are two limitations with this data set that had to be accounted for before the estimation of translog cost function: non-disclosed values and zero values.

The first, and by far the largest, source of missing data points was a deliberate result of policy on the part of the Department of the Census. According to Federal law, no economic census data can in any way put businesses at a disadvantage. When considering counties with a relatively small amount of agricultural firms, it would be possible with a complete data set to derive the actual revenues and costs of individual farms. For example, if there were 10 corn farms, 2 chicken farms, and one dairy farm, it would be possible given the expenditures to determine how much the dairy farm spends on cattle. Furthermore, if the owner of one of the chicken farms obtained the data, that owner could use the census data with his or her farm’s data to determine the costs of the other farm. Due to this, the Census Department and the National Agricultural Statistics Service (NASS) put the complete data set through a computer program that would
withhold any data that could possibly disclose the costs of individual firms in such a manner. In approximately 2000 of the 12000 total county-year data sets, there were one or more data points that were not disclosed.

The second source of missing data is a result of the need to take natural logarithms of the original expenditures and revenues. In approximately 40 of the 12000 county-year data sets there were expenditures or revenues of zero. When the natural logs of the entire database were taken for use in the model, these zero values created holes where the computer would not calculate the natural log of zero.

Since SAS could not import the database with missing values, any county-year sets that contained missing values were deleted. Unfortunately, this meant that approximately 17% of the database could not be used in the model. An omission of this size in proportion to the total database would ordinarily bring up concerns for bias, but such concerns should be easy to dismiss when the properties of the data are considered. The counties dropped are done so based on the small number of firms within them. There is no appreciable difference in proportion of counties dropped when geography or nature of production are considered. Also, it must be remembered that these counties are assumed to compete nationally in their output market, and purchase from a more localized state-level market for inputs, as will be explained later. Therefore, dropping counties with non-disclosed values or zero values should not create bias in the price elasticities that will be calculated.
As stated above, natural logs of these revenue and expenditure data points were calculated, and the following manipulations were done as they were required in order to create a proper model:

**Cost shares**, in which the percentage of the total cost a given input is, or:

\[ s_{i,t} = \frac{C_{i,t}}{TC_t} \]

For input \( i \) and year \( t \),

Given the inputs as they were listed in the Agricultural Census, fifteen inputs were able to be used for the model. Unfortunately, utilities and electricity were aggregated differently, and so were added to the Other input category. Except for this, all of the inputs are uniform for all time periods used in the model. The inputs cover a detailed array of farming expenses, and they are listed with a brief description below:

- **Feed**: grain, hay, or any other crop used to feed livestock
- **Seed**: seed (natural or genetically modified) used to plant crops
- **Livestock**: cattle, hogs, chickens, etc. purchased to expand herds for dairy or slaughter
- **Fertilizer**: nitrates, manure, or any substance used to accelerate growth or maximize size of crop
- **Chemicals**: pesticides, herbicides, or other chemicals used to destroy organisms that would blight or consume crops or herds
- **Fuel**: fuel, mainly diesel, employed directly on farm by equipment or trucks
- **Hired Labor**: Labor directly hired by farms for labor on farms
- **Contract Labor**: Labor indirectly hired by farms through intermediary, also covers non-field work (i.e. maintenance, construction, transport, etc.)
Customwork: Expenditures for customwork services, which are direct rentals of farming equipment. Direct investment on equipment by farms is grouped in this category by NASS.

Maintenance: Expenditures for any regular repairs or other maintenance on equipment on farms.

Tax: Property tax paid by farms for all land

Rent: Rent for land paid by farms to landowners

Interest: Interest payments for mortgages for which the land occupied by farms is the collateral

Other: Any other expenditures not covered by above categories, includes utilities like water, sewage, electric, etc.

Due to concerns with multicollinearity as well as the desire to simplify the model, several of these inputs were aggregated into categories. Inputs that were similar in nature, and that could only be priced using the national producer price index (PPI), were put together to make new categories. The combinations were made as follows:

Feed, Seed, and Livestock were combined into the new input FSL

Hired Labor and Contract labor were combined into Labor

Customwork and Maintenance were combined into Capital

Tax, Rent, Interest and Other into Land

This reduces the fifteen constant inputs observed in the 1992, 1997, 2002, and 2007 censuses into seven inputs for the purposes of the model. It must be noted that previous works aggregate their inputs in a similar way, but do not mention multicollinearity as a reason for doing so. Binswanger preferred to combine his capital and land costs together while leaving fertilizers
Figure 1: Cost Shares as percent of Total Cost by Year, 1992-2007

<table>
<thead>
<tr>
<th></th>
<th>FSL</th>
<th>Land</th>
<th>Labor</th>
<th>Fert</th>
<th>Fuel</th>
<th>Chem</th>
<th>Capital</th>
</tr>
</thead>
<tbody>
<tr>
<td>1992</td>
<td>34.63%</td>
<td>27.97%</td>
<td>9.24%</td>
<td>7.34%</td>
<td>5.89%</td>
<td>4.59%</td>
<td>1.21%</td>
</tr>
<tr>
<td>1997</td>
<td>34.65%</td>
<td>27.65%</td>
<td>9.31%</td>
<td>7.45%</td>
<td>5.41%</td>
<td>4.87%</td>
<td>1.27%</td>
</tr>
<tr>
<td>2002</td>
<td>33.24%</td>
<td>27.62%</td>
<td>9.72%</td>
<td>6.57%</td>
<td>4.86%</td>
<td>4.30%</td>
<td>1.35%</td>
</tr>
<tr>
<td>2007</td>
<td>34.55%</td>
<td>25.34%</td>
<td>8.53%</td>
<td>8.75%</td>
<td>6.94%</td>
<td>4.10%</td>
<td>1.26%</td>
</tr>
</tbody>
</table>

Note: The above inputs are sorted according to their proportions.

and chemicals as a separate combination, while Subhash preferred to lump fertilizers and chemicals with his land costs while leaving capital as a separate category. Binswanger and Subhash include fuel with their other raw materials. Therefore, the precise aggregations of data employed for this project is unique, although the idea of aggregating inputs is supported by previous works.

The expenditure and revenue data had interesting qualities with respect to their descriptive statistics. After the database had been edited to remove counties with missing or zero values, descriptive statistics were acquired on all expenditures and revenue employed in the model and listed in Figure 2. The descriptive statistics cover all time periods, as attempting to derive statistics for each time period would be far too complicated and the results not informative enough to warrant such a division.
Figure 2: Descriptive Statistics of Expenditures and Revenues


| Units represent descriptive statistics of the entire datasets of variables |

The first and perhaps most important descriptive statistics are the mean and standard error of the expenditures and revenue. As can be seen in Table 2, the average expenditures for inputs ranged from two to four thousand dollars per county for most inputs, with the exception of FSL which was much higher. Standard errors were relatively small for all of the inputs, which can be attributed to the size of the database as well as the relative proportional symmetry between inputs with respect to farm size. The means for the expenditures also match the cost shares for the inputs displayed in Table 1.

The median values for expenditures and revenue indicate what the expenditures and revenue are for the county that is at the 50th percentile of the database. The median values for all of the inputs are smaller than the mean. These values as well as the skew values indicate that there appears to be a relatively small amount of counties that produce...
a large amount of output, grouped with a relatively large amount of counties with smaller agricultural operations. This is logical, given that many regions will see their agriculture specialize in a specific type of output, and their output concentrated in a given area for climate, productivity, and distribution reasons.

The sample variances and coefficients of variation are rather large. This can be seen as a product of two different attributes of the database, size and scale. The database is rather large in and of itself, but the true source of this variance is the fact that the expenditure data is in units of thousands of dollars. This would cause massive amounts of variance to add up, even if agricultural operations are similar in their size and behavior with respect to expenditures. The scale of the database will also add to this, as counties with huge expenditures and revenues are comingled with counties with tiny expenditures and revenues. The coefficients of variation partially account for this, but are themselves rather large. This property can perhaps be best displayed by comparing the minimum and maximum values for expenditures and revenue in Figure 2.

Kurtosis is an indication of how much the data is grouped together with respect to a standard normal distribution. The kurtosis of the above data is extremely leptokurtic, with values in above 100 for most and above even 200 for some. Only FSL and Tax have values under 100, and even then are at 83 and 54, respectively. These extremely high values would indicate that a vast majority of counties have their expenditures and revenue values grouped very close to the median. This also serves to indicate that the counties with relatively large farming operations, and to a lesser extent the counties with relatively tiny farm operations, could be considered outliers. This indication of outliers makes sense given the size of the database. In general, the kurtosis for the expenditures
and revenues seems to indicate that a sizeable majority of counties have similarly sized agricultural operations within their jurisdiction, with few counties either having comparatively large or small operations with respect to the rest.

The skew of the expenditures and revenue tells as much of an interesting story as the kurtosis. The values for skew are small when compared to the values for kurtosis, but are nevertheless all positive. This means that the distribution is skewed to the left. This, when taken in context with the earlier described differences between the mean and median for each expenditure and revenue, would seem to support the idea that there are many counties with smaller operations which contrast with relatively fewer counties with large operations.

The range, minimum, and maximum values all indicate that there is a huge variety with respect to the size of agricultural operations at the county level across the United States. On the smallest end are counties with expenditures as low as $1,000 for the entire county and revenues of $87,000. Although these would seem to be absurdly low values, it must be noted that counties which are largely urban or are otherwise unsuitable for agriculture of any kind are included in the dataset. For example, New York City was included in New York’s dataset as a separate county. There appear to be enough florists and greenhouses in the city for it to qualify as a non-zero agricultural producer, laughable as it may seem. Counties in Alaska which are mostly tundra are also included, with essentially the same types of operations seen in NYC. At the other end of the spectrum appear counties that spend hundreds of millions of dollars, (up to a billion for FSL) with output exceeding three billion dollars a year. Many of these counties are large in geographic area, and contain large amounts of higher-end agricultural operations.
Counties in Minnesota or Wisconsin that specialize in dairy operations fit this category nicely. Other counties (primarily in the arid parts of the West) are geographically huge and have massive cattle grazing operations. Within these two extremes lie the majority of agricultural operations, which cover the majority of food production including grains, fruits and vegetables, and other agricultural outputs.

The last descriptive statistic is the confidence interval about the mean. The alpha for this interval is .05, meaning that we can be 95% confident that an expenditure or revenue value for a county is going to be within the interval about the mean. These values are relatively small when compared to the mean, which is not that surprising given the extremely high values for kurtosis that were discussed earlier. The other factor which contributes to the relatively small size of the confidence interval is the size of the database. The sheer magnitude of the database serves to lower the standard error, which is the primary factor in determining the confidence interval.

Overall, these descriptive statistics paint a picture of agriculture at the county level for the entire United States that is interesting upon first sight and logical upon further review. The different descriptive statistics agree in proportion and in orientation enough to indicate a huge market for agriculture, in which some counties are highly concentrated and specialized with huge expenditures which lead to massive revenues for those counties, while a majority of the other counties are similar in the size of their agricultural operations. This similarity stretches across the differentiation in outputs as well as geography. However, as earlier noted, the number of county-year entries dropped for zero values is tiny in proportion to the entire database. This indicates that agriculture is ubiquitous across the United States, even in the largest of cities or the most
inhospitable landscapes. It can reasonably be inferred that whatever effects are discovered from the model in this project are essentially going to be felt everywhere.

It must also be noted that 1 out of 6 entries had to be dropped for missing values, which is an indication of non-disclosure on the part of the National Agricultural Statistics Service and Census Department. Since this non-disclosure rule is firm-based, it can be inferred that a sizeable proportion of the counties dropped probably contained monopolies in production of specific outputs, or enough of a market domination to warrant non-disclosure. This means that the expenditure and revenue data used in the model are from counties that have some degree of competition in their output markets. Thus, we are forced by Federal law as well as technology to assume a significant degree of competition in agricultural markets when constructing and interpreting the model.

PRICES

The second type of data required for this model is price data. Since the study covers a long enough period of time in which inflation is possible (and in which inflation occurred), all price data has to be indexed to a certain year in order to derive real prices. Therefore, prices for inputs and output have been indexed to their 1992 levels. This allows for analysis of the changes in input combinations based on real prices, and prevents substitution effects from being biased.

A complication rose from comparing prices for inputs and output across different states, based partly on the nature of the Agricultural Census data. Per unit prices were not available from the Federal Government for any inputs. In most cases, it was possible to acquire actual prices for inputs by using the expenditure data at the state level and
divide it by the state level quantities employed. For example, expenditures on labor could be divided by quantity of persons employed as farm labor to determine the average cost employing a person for farm work. In other cases, quantities for inputs were either unavailable or impractical for determining per unit prices, and therefore national level producer price indexes were used. In most cases, using the national PPIs was appropriate anyway since many inputs, such as equipment, seeds, or output, are traded on a national market. These national PPIs were acquired from the Annual Agricultural Reports by the USDA.

Figure 3: Changes in Producer Price Indexes for Each Input, 1992-2007 (Base=1992)

Note: Inputs and Output sorted by proportion of change for viewability


See Figure 4 for Numerical Table

The quantities used to derive prices where applicable should also be mentioned.

In the case of feed and seed, exact quantities were unobtainable due to the
interchangeability of the two inputs with each other and within themselves. Therefore, the national PPIs were used. For livestock, the quantities purchased of chickens, cattle, and hogs were divided by expenditures on each. A state level weighted PPI was then calculated using these three prices. Afterwards, a FSL state level PPI was calculated using the PPIs employed for each three and the isolated cost shares for the combined three inputs.

Fertilizer and Chemicals are simpler, as they are simply the division of expenditures on fertilizer and chemicals by the total acreage covered by each respectively. These acre prices were then indexed against a weighted national average to standardize costs while allowing for comparability between states and time periods.

Labor was derived by dividing the wages paid out by the number of people employed. It must be noted that this would seem to indicate that some states pay drastically lower wages than others. It is impossible to determine how much each worker actually worked, but lower labor figures for the purpose of this project could be interpreted either as the tendency to employ labor for smaller amounts of time at similar wages, or as lower wages for a similar amount of time. An attempt was made to determine if the method used to index labor prices correlated with available farm wage data, attained from the annual USDA Farm Labor report. The average wages from three states from the Farm Labor report was indexed and compared to the PPIs for those states generated from the Census data and compared. The resulting tables are listed below:
Figure 4: Comparison of Price Indexes for Labor between Farm Labor Report and Census Data, 1992-2007

<table>
<thead>
<tr>
<th>Year</th>
<th>Florida</th>
<th>California</th>
<th>Hawaii</th>
</tr>
</thead>
<tbody>
<tr>
<td>1992</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>1997</td>
<td>123.69</td>
<td>117.28</td>
<td>104.94</td>
</tr>
<tr>
<td>2002</td>
<td>130.66</td>
<td>141.36</td>
<td>114.34</td>
</tr>
<tr>
<td>2007</td>
<td>148.08</td>
<td>159.47</td>
<td>132.26</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Year</th>
<th>Florida</th>
<th>California</th>
<th>Hawaii</th>
</tr>
</thead>
<tbody>
<tr>
<td>1992</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>1997</td>
<td>130.86</td>
<td>128.62</td>
<td>89.20</td>
</tr>
<tr>
<td>2002</td>
<td>184.74</td>
<td>178.99</td>
<td>110.92</td>
</tr>
<tr>
<td>2007</td>
<td>203.68</td>
<td>228.74</td>
<td>125.50</td>
</tr>
</tbody>
</table>

Numbers represent PPI indexes for each State, by themselves with no interstate weighting.

The indexes for labor appear to be vaguely similar, with one exception. Census figures rise more sharply for the states of California and Florida than they do for the Farm Labor Report through the time periods indicated. This difference in indexes is minor in starting in 1997, but grows more pronounced in 2002 and 2007. Indexes for all years appear similar for Hawaii. Since the Census data is essentially derived by dividing total expenditure for labor for the by the amount of people employed that year, with no listing of wage rates of number of hours employed, it is possible that the sharper increase seen in Figure 4 is a result of a combination of wage increases and a tendency to employ people for more hours in a given year.

However, this conclusion must be taken in context, as the Farm Report data is taken from state level sample surveys for those three states (all other states are included in regions), while the Census indexes are calculated from county level data. Also, it is possible that undocumented labor utilized in Florida and California may have created a
bias in the Farm Report data, as expenditures for illegal labor would be included in the Census data, but the wages for such labor would be excluded from the Farm Report data.

Capital was calculated by using a weighted PPI, which was calculated by using isolated expenditures on customwork and maintenance against their national PPIs. The land based expenditures (Tax, Rent, and Interest) were aggregated together with the Other inputs to form the last category: Land. Tax, Rent, and Interest prices were calculated by dividing the total expenditure of each by the total acreage of farms in each state. For Other, the national PPI from the Annual Agricultural Report was employed. These four prices were then combined to create a weighted PPI for land. The PPI was weighted in a similar fashion as the Labor and Capital PPIs: by expenditure in the base year on each of the four inputs in each county. The only difference between Capital and Land is that the base prices for Capital are National PPIs, while all but Other for Land are local prices per acre.

Figure 5: Comparison of Quantity Indexes and Producer Price Indexes, 1992-2007
(Base=1992)

<table>
<thead>
<tr>
<th>Quantity</th>
<th>FSL</th>
<th>Chem</th>
<th>Fert</th>
<th>Fuel</th>
<th>Labor</th>
<th>Capital</th>
<th>Land</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>1992</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>1997</td>
<td>90</td>
<td>114</td>
<td>115</td>
<td>103</td>
<td>101</td>
<td>99</td>
<td>112</td>
<td>111</td>
</tr>
<tr>
<td>2002</td>
<td>92</td>
<td>78</td>
<td>102</td>
<td>94</td>
<td>88</td>
<td>145</td>
<td>134</td>
<td>129</td>
</tr>
<tr>
<td>2007</td>
<td>109</td>
<td>95</td>
<td>62</td>
<td>60</td>
<td>76</td>
<td>144</td>
<td>172</td>
<td>141</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>PPI</th>
<th>FSL</th>
<th>Chem</th>
<th>Fert</th>
<th>Fuel</th>
<th>Labor</th>
<th>Capital</th>
<th>Land</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>1992</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>1997</td>
<td>135</td>
<td>90</td>
<td>88</td>
<td>98</td>
<td>93</td>
<td>116</td>
<td>108</td>
<td>109</td>
</tr>
<tr>
<td>2002</td>
<td>151</td>
<td>144</td>
<td>92</td>
<td>118</td>
<td>138</td>
<td>126</td>
<td>126</td>
<td>100</td>
</tr>
<tr>
<td>2007</td>
<td>194</td>
<td>163</td>
<td>139</td>
<td>368</td>
<td>191</td>
<td>152</td>
<td>161</td>
<td>139</td>
</tr>
</tbody>
</table>
The input price of the greatest interest to this project, fuel price, was not calculated in the same way as the other inputs. The Energy Information Administration, a part of the Department of Energy, keeps detailed statistics about state level prices. State level prices are available on a monthly basis, but yearly averages for the four time periods in the project were utilized. These prices reflect road prices, or prices which include federal and state fuel excise taxes used to finance road construction and maintenance. These taxes would not be applicable to fuel used on the farm, since little or no equipment would travel across roads. However, since the state and federal excise taxes are a per unit tax, and there is no appreciable change in the taxes at the state level during this time period, the road prices were used as a proxy. This is reasonable given that variations in prices over time will be a function of geography and time, since taxes of this sort change infrequently.

Figure 6: Descriptive Statistics of Producer Price Indexes, 1992 to 2007

<table>
<thead>
<tr>
<th></th>
<th>FSL</th>
<th>Chem</th>
<th>Fert</th>
<th>Fuel</th>
<th>Labor</th>
<th>Capital</th>
<th>Land</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>143.5949</td>
<td>119.413</td>
<td>100.181</td>
<td>166.332</td>
<td>124.86</td>
<td>122.653</td>
<td>121.654</td>
<td>111.524</td>
</tr>
<tr>
<td>St. Error</td>
<td>0.353626</td>
<td>0.70791</td>
<td>0.49025</td>
<td>1.07804</td>
<td>0.51834</td>
<td>0.181335</td>
<td>0.49801</td>
<td>0.14975</td>
</tr>
<tr>
<td>Median</td>
<td>137.6518</td>
<td>99.66</td>
<td>89.73</td>
<td>108.52</td>
<td>114.69</td>
<td>117.2517</td>
<td>111.373</td>
<td>100</td>
</tr>
<tr>
<td>St. Dev</td>
<td>36.83142</td>
<td>73.7319</td>
<td>51.061</td>
<td>112.281</td>
<td>53.9868</td>
<td>18.88668</td>
<td>51.8697</td>
<td>15.5968</td>
</tr>
<tr>
<td>Kurtosis</td>
<td>-0.07333</td>
<td>8.99129</td>
<td>7.40027</td>
<td>0.43073</td>
<td>0.32664</td>
<td>-0.937473</td>
<td>13.528</td>
<td>0.65338</td>
</tr>
<tr>
<td>Skewness</td>
<td>0.596453</td>
<td>2.44616</td>
<td>2.04056</td>
<td>1.22996</td>
<td>0.71736</td>
<td>0.459097</td>
<td>2.14999</td>
<td>1.05262</td>
</tr>
<tr>
<td>Range</td>
<td>228.6067</td>
<td>608.443</td>
<td>463.079</td>
<td>332.1</td>
<td>366.01</td>
<td>72.01928</td>
<td>859.495</td>
<td>38.78</td>
</tr>
<tr>
<td>Minimum</td>
<td>94.89407</td>
<td>27.5466</td>
<td>22.3106</td>
<td>90.54</td>
<td>20.4</td>
<td>100</td>
<td>37.2337</td>
<td>100</td>
</tr>
<tr>
<td>Maximum</td>
<td>323.5007</td>
<td>635.99</td>
<td>485.39</td>
<td>422.64</td>
<td>386.41</td>
<td>172.0193</td>
<td>896.729</td>
<td>138.78</td>
</tr>
<tr>
<td>Conf Mean</td>
<td>(a=.05)</td>
<td>0.693171</td>
<td>1.38764</td>
<td>0.96097</td>
<td>2.11315</td>
<td>1.01604</td>
<td>0.355449</td>
<td>0.97619</td>
</tr>
<tr>
<td>Coeff Var</td>
<td>0.26</td>
<td>0.62</td>
<td>0.51</td>
<td>0.68</td>
<td>0.43</td>
<td>0.15</td>
<td>0.43</td>
<td>0.14</td>
</tr>
</tbody>
</table>
The descriptive statistics for input and output prices, observed in Figure 5, tell as interesting story as the descriptive statistics for expenditures and revenue had. However, this is where the similarities between the two sets of descriptive statistics end. The descriptive statistics that cover prices are much simpler and have less agreement than the descriptive statistics that cover expenditures. Also, given that the prices are in the form of indexes, the values for prices are much tighter than those for expenditures, since variability is reduced to proportions instead of actual values. Since the descriptive statistics for expenditures and revenues cover all time periods, and given the descriptive statistics for nationally indexed prices would be worthless, the descriptive statistics for the price indexes also include all time periods.

The means and standard errors of the prices indexes are the first statistics to discuss, as they show important aspects of price changes during the time period studied. Since all means are above 100, it can be inferred that prices were increasing for output and all inputs during this period of time. Standard errors are quite low, which can be seen as a result of the size of the database as well as the result of indexing prices. Given these effects, the small size of the errors would indicate that price changes were relatively uniform throughout for all counties and time periods. The means themselves also indicate the relative scope of the price changes, as the inputs with the highest means had the greatest price changes, as can be seen when comparing the values in Figure 4.

The median values for the price indexes indicate what the price index for the 50th percentile county would be with respect to prices in other counties and time periods.
There is a great deal of variability here, as some counties have values lower than 100. This would seem to indicate that the weighted averages employed in the indexing of state level prices for most inputs created a situation in which many states have lower than average costs, and the number of counties with these lower price levels drag down the medians. Given the picture painted by the descriptive statistics for the revenue and expenditures, this is a logical conclusion.

Standard Deviations are also large with respect to their means, which is natural given the previously discussed properties of the distribution as well as the fact that all time periods are compared in the same data set. The largest standard deviations can be observed for the land based inputs. This is a function of geography as well as, to an extent, demographics. Farms located in sparsely populated counties had property values much lower than those in densely populated counties. This serves to lower the per-acre costs of taxes, rents, and interest payments. Therefore, if a state like Nevada has property values much lower than the national mean, this will be reflected in its state level PPI. As will be discussed at the end of this chapter, asset bubbles for real estate and energy led to massive increases in inputs based on those assets. This may also be a factor in the relatively large standard deviations, as the same inputs discussed also have the largest standard deviations.

Kurtosis values for the price indexes show the greatest departure from the values for kurtosis indicated in the analysis of expenditures and revenue. Unlike the extreme values observed in the expenditures and revenue section, kurtosis values for most inputs have an absolute value that is less than one. This would indicate that the price indexes have a relatively normal shape. The only relatively high kurtosis value is that for
property tax, which is at 25. Even this value, which is extreme compared to the other kurtosis values in this dataset, are nowhere near the values seen in the expenditures and revenue analysis.

Skew values for the price indexes also are quite different from the values for kurtosis seen for expenditures and revenue. Although all of the values for skew are positive, none are above four, only one is above three and over half are under two. A few of the values are under one. This would indicate that the distributions for the price indexes skewed to the left, but to a much lesser extent than the distributions for expenditures and revenue. The values for skew, taken together with the values for kurtosis, indicate that the distributions for prices seem to be relatively close to that of a standard normal distribution.

The range, minimum, and maximum values give some indication of to what extent the prices vary between place and time. When comparing these three values with those observed in table 5, it can be inferred that differences in geography and demographics are responsible for most of the magnitude of the range. The minimum and maximum values are proportionately high for any input price for which acreage was a factor, while the land based expenses have the most extreme values. It must also be noted that the indexes with little or no weighting for geography, mainly Other and Output, show the least extreme values.

As with the expenditures and revenue analysis, a confidence interval at alpha=.05 was taken for each mean. As with the expenditures and revenue intervals, the intervals
for prices were also narrow with respect to their means. This can be seen primarily as a function of the size of the database, as well as the relative standard error and deviations.

The data analysis of the price indexes, taken together with the data analysis of expenditures and revenues, paints a picture of a relatively competitive market in the agriculture sector over the time period studied. For a vast majority of counties in the United States, farms have competition within their county for any given output, and the prices farms pay or receive are relatively similar. The price similarities end when considering geography, but this can be explained by the geographic qualities of each county and how these qualities affect farming. Land prices can be seen not only as an indicator of demand for land for farming, but also for demand for land in general. This duality must be taken into consideration, as the lack of this duality will do nothing to explain why there are similar-sized operations in Nome, Alaska and New York, New York.

The more classic inputs, such as labor, capital, raw materials, or energy, display more variation as a function of time than the land-related inputs. Of these, the greatest variations in prices and expenditures occur with raw materials. A lesser degree of temporal variation occurs with capital, labor, and fuel with respect to expenditures, but with a greater degree of temporal variation in price. Since the behavior of expenditures and prices for these inputs change together with little regard to geography, the presumption that a relatively competitive national market for agriculture does indeed exist is valid. Therefore, despite the wide range of differences in price for some inputs, the similarity of production practices between different regions of the country can be assumed. As such, we can assume that a price change in fuel will cause a relatively
uniform response in each county, no matter what the characteristics of that county’s agricultural production may be. Also, given the assumption made earlier concerning the ubiquitous nature of agriculture, such effects will be felt simultaneously everywhere.

It must be noted that in two areas there is a great degree in change in price levels characteristic of the time period: land and fuel. Of these two input classes, fuel has the greatest degree of change. The price index more than triples during the period studied, which is a result of a combination of two historical factors. For the base year, 1992, oil prices were the lowest in the 20th Century in real terms, with OPEC dramatically increasing production in the 1980s and the concurrent fall of the Soviet Union. These factors served to dramatically increase supply and thus lower prices for oil and products of oil refining, including diesel fuel. However, the pendulum swings wildly in the other direction by 2007. During this time period, a combination of dramatically increased demand in the developing world coupled with a commodity price bubble served to increase prices dramatically. After the end of the Gulf War in 1991, a gallon of diesel cost $0.87 per gallon. However, that same gallon of fuel cost $4.89 per gallon in 2008, before the housing-induced credit crunch caused the economy to spin into turmoil in September of that year. Even with indexing for inflation, this amounts to a greater than 300% increase in real prices after only 17 years. Chemicals and Fertilizers, largely based on petrochemicals, also saw their prices tugged upwards during this period of time, although not to the dramatic extent seen with fuel prices.
Another asset bubble was building during this time period. A combination of government policy, loose credit standards, low interest rates, and continuing economic expansion lead to land prices in the United States to increase dramatically from the mid 1990s until 2008. This bubble effect can clearly be seen in the PPIs for the land based inputs (tax, rent, and interest). Since the expenditures take the form of a per-acre cost, the PPIs reflect how much extra per acre a given farm must pay for the given time period. The most pronounced changes occur with property tax. It is typical in most states for properties to be reevaluated for value every few years in order to calculate the property tax obligation of the property owner. Given that the census data is temporally spaced enough to account for this, such changes will likely be reflected in the PPI. The prices for rent and interest stay relatively static until 2007, where the increase in prices in proportion to the base prices catches up to the growth displayed by taxes.
It is interesting to note the changes in quantity of inputs employed over time, as can be seen in the quantity index in Table 5. The only input that is increasing in quantity employed is capital. The other quantities appear to be decreasing, with the most pronounced changes occurring with fertilizer and fuel. Given that cost shares do not appear to be changing that much during the same time period, this may indicate that farms attempt to purchase inputs based on some predetermined cost share scheme or budget, as opposed to determining usage based on quantities. Given that output quantities and inputs were also increasing during this time period, this may also indicate that farms were not changing their input expenditures radically, since the increase in prices coincided with an increase in overall revenue.
MODEL

The model that will be employed for this study is the transcendental logarithmic cost model, or translog cost as it is more commonly called in literature. The translog cost function is composed of a combination of vectors, constrained by sets of restrictions that tie in cost shares with prices in order to determine how expenditures on inputs change with respect to changes in input prices. It is therefore prudent to split this model into three sections for the purposes of discussion: the production vector, the cost share vectors, and the restrictions.

The production vector is the primary vector in which all of the factors of production are included, along with the several own and cross effects as well as any time or geographic variables that are appropriate to include. For this project, a time trend variable was added to the production vector by using the years in which an observation was taken. The vector is described as follows:

\[
\ln TC = a_0 + a_q \ln q + \sum_{i=1}^{n} \gamma_i \ln q \ln r_i + \sum_{i=1}^{n} b_i \ln r_i + 1/2 \sum_{i=1}^{n} \sum_{j=i+1}^{m} b_{ij} \ln r_i \ln r_j + \Delta_{year}
\]

Where \( TC \) = Total Cost,

\( a_0 = \) constant term

\( q = \) production quantity,

\( a = \) parameter for production

\( b = \) parameter for inputs i,j
\[ r_i = \text{input prices for input i} \]

This section allows us to capture the two elements that tell us a great deal about the farming production. These elements are the own-price elasticity and the cross-price elasticities for all inputs. These elasticities will help us to answer how firms in the agricultural sector react to changes in prices.

It may be of help to understand where this cost function comes from. To do this, it is appropriate to consider an extension of the traditional Cobb-Douglas production function:

\[ P = K^a L^b F^c \]

In which \( return = a + b + c \)

For production \( P \) using inputs \( K, L, F \) which represent Capital, Labor, and Fuel

When we take the natural log of such a production function, we get a form for which we can use regression analysis to derive the exponents of the Cobb-Douglas production function.

A firm attempting to minimize cost subject to a level of output will solve the following minimization problem

minimize \( TC = r*K + w*L + m*F \) subject to \( P = K^a L^b F^c \)

resulting in the Lagrangian

\[ \text{Lag} = r*K + w*L + m*F + \lambda(P - K^a L^b F^c) \]
solving this minimization problem gives us factor demands for K, L, and F as functions of r, w, m, and P and the parameters of the production function. Therefore, if firms are minimizing costs, we can think of a cost function being a function of input prices, output level, and parameters of the production function.

This cost function can be a complicated function of those values. A translog cost function provides a second order approximation to any cost function.

In empirical work, translog cost models are typically estimated as a system of equations instead of a single equation. This allows for a more efficient estimate of the parameters (Binswanger 1974 and Subhash 1982.) Cost share equations are typically added to the actual cost function. Following Shepard's lemma, the forms which the cost share functions take for our model are as follows:

\[ s_i = b_j + \sum_{j=1}^{n} b_{ij} \ln r_j + \gamma_i \ln q \]

Where \( s = \) cost share of input i

\( b = \) beta for inputs i,j

\( r = \) price for input j

There are some restrictions that are required in order to make the system, agree with theory on how cost functions work. The first restriction is the homogeneity of the cost function with respect to input prices restriction, for which
\[ \sum_{i=1}^{n} \sum_{j=1}^{m} b_{ij} = 0 \quad \text{for all inputs } i \text{ to } j, \text{ and} \]

\[ \sum_{i=1}^{n} b_i = 1 \quad \text{for all inputs } i. \]

\[ \sum_{i=1}^{n} \gamma_i = 1 \quad \text{for all inputs } i. \]

and a symmetry restriction where

\[ b_{ij} = b_{ji} \]

These restrictions force the betas for the inputs to add to zero, which means that we are making the assumption that if all input prices doubled then costs would double for a given level of output. These restrictions also serve to allow us to ensure that the cross price elasticities between two inputs are reciprocally equivalent. Because of the restrictions, we need to drop one of the cost share equations from the system in order to avoid perfect multicollinearity.

This linear system of equations generates output that can be interpreted using a method employed by Binswanger and Subhash. This method will be discussed further in the results and interpretation section. The system consisting of the cost function and seven of the eight factor shares was estimated using a seemingly unrelated regression in SAS. (see appendix for a discussion on the software choice and a copy of the SAS code used in this paper.)
RESULTS AND INTERPRETATION

The output parameters of a statistical model are the objects of interest that must be discussed before they can be interpreted. Although there are more outputs than those listed below, the own and cross effects are the only parameters of consequence for this project, with one exception. The time variable that was included in the model, which accounted for the change in years, needs to be discussed. Although the parameter estimate for the time trend was statistically significant, the parameter itself was virtually zero. Since the time trend was added to a system in which price indexing had already partially accounted for the change in time, this seemingly odd result should not take away from the rest of the model.

This leaves us with creating a matrix to display the parameter estimates. Creating this matrix has several practical purposes. The first and most obvious is that it will be necessary to create a matrix in order to translate the parameter estimates into Allen partial elasticities, and further into price elasticities. The second reason that a matrix is created is that it allows for the parameter estimates between different inputs to be compared and contrasted more easily. Table 1, displayed below, serves these purposes by displaying the inputs in the horizontal axis so they can be compared with their cross inputs in the vertical axis. When the input category in both the horizontal axis and vertical axis are the same, than the output represents an effect for that input on itself.
Table 1: Parameter estimates for the Trans-Log Model

<table>
<thead>
<tr>
<th></th>
<th>FSL</th>
<th>Chem</th>
<th>Fert</th>
<th>Fuel</th>
<th>Labor</th>
<th>Capital</th>
<th>Land</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>X</strong></td>
<td><em><strong>-0.01568</strong></em></td>
<td><em><strong>-0.004109</strong></em></td>
<td><em><strong>0.009914</strong></em></td>
<td><em><strong>-0.00565</strong></em></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FSL</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chem</td>
<td><em><strong>0.044109</strong></em></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fert</td>
<td><em><strong>-0.00434</strong></em></td>
<td><em><strong>-0.03042</strong></em></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuel</td>
<td><em><strong>0.0012</strong></em></td>
<td><em><strong>-0.00543</strong></em></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Labor</td>
<td><em><strong>0.02623</strong></em></td>
<td><em><strong>-0.01435</strong></em></td>
<td><em><strong>0.0371</strong></em></td>
<td><em><strong>-0.00643</strong></em></td>
<td><em><strong>0.018005</strong></em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Capital</td>
<td><em><strong>-0.01847</strong></em></td>
<td></td>
<td><em><strong>0.118344</strong></em></td>
<td><em><strong>0.081217</strong></em></td>
<td><em><strong>-0.10774</strong></em></td>
<td><em><strong>-0.06476</strong></em></td>
<td></td>
</tr>
<tr>
<td>Land</td>
<td>0.000854***</td>
<td><em><strong>-0.01524</strong></em></td>
<td><em><strong>-0.00753</strong></em></td>
<td><em><strong>-0.02537</strong></em></td>
<td><em><strong>0.01748</strong></em></td>
<td></td>
<td><em><strong>-0.018141</strong></em></td>
</tr>
</tbody>
</table>

Numbers above represent parameter estimates $b_{ij}$ and $b_{ij}$ from model output

*** indicates $\alpha < .01$

** indicates $\alpha < .05$

* indicates $\alpha < .10$

As can be seen from Table 1, most of the own and cross effects are significant, and all but one of the significant parameter estimates are significant beyond the 1% level. Indeed, a vast majority of the parameters were reported by SAS to be significant beyond the 1/100 of 1% level, the lowest number of significance that SAS is programmed to report. Although this level of confidence would ordinarily raise red flags as to the significance, it should be noted that this level of confidence is natural given the size of the database from which this model is run.

The only potential trouble with the output is that a few of the potentially interesting relationships are not statistically significant. Among these is the own effect of fuel, which would have been useful for the purposes of this project when calculating the
own price elasticity of fuel. Another interesting thing to note is that the parameters that are not significant are all either reported as absolute zero or much closer to zero than the other parameters. This may indicate that the variance in the data for these particular inputs is too high compared to the data for the rest of the inputs.

Now that we have the output for the seemingly unrelated regressions from SAS, we can now combine this output with our data to establish Allen partial elasticities for the inputs. Allen partial elasticities, as employed by Binswanger and Subhash, are partial elasticities of substitution in which one determines the direction and proportion of the change in the cost share of an input as a result of a change in the price of another input. Binswanger established that partial Allen elasticities can be derived by combining the β’s from the cost share equations with the average cost share value for each input in order to establish the elasticity between those inputs. For example, in order to derive the partial elasticity between fertilizer and fuel, we would take the β for fuel from the fertilizer regression and multiply it by the average cost share of fertilizer. The formulas used to calculate these Allen partial elasticities are taken directly from Binswanger’s work:

Own Allen Partial Elasticities

\[
a_{ii} = \left(\frac{1}{s_i^2}\right)(b_{ii} + s_i^2 - s_i)
\]

Where: 

- \(a_{ii}\) is the own Allen partial elasticity
- \(s_i\) is the cost share for input i
- \(b_{ii}\) is the parameter estimate for own effects generated by the statistical model
Cross Allen Partial Elasticities

\[ a_{ij} = \left( \frac{1}{s_i \cdot s_j} \right) b_{ij} + 1 \]

Where:

- \( a_{ij} \) is the cross Allen partial elasticity
- \( s_i, s_j \) are the cost shares for inputs i,j
- \( b_{ij} \) is the parameter estimate for cross effects generated by the statistical model

Since equivalency restrictions were included in the statistical model, this operation is reversible for any given pair of inputs. For example, the cross Allen partial elasticity of Fuel to Labor will be equivalent to the cross Allen partial elasticity of Labor to Fuel, because the parameters were restricted to be equivalent in SAS. The Allen partial elasticities are determined using the actual cost shares, so the figures for the elasticities should be interpreted as the percent change in cost share of one input as a result of a 1% change in the price of another input. Although the primary object of this paper is to determine how changes in energy prices affect food prices, it is appropriate as well as interesting to briefly interpret this intermediate matrix of elasticities. The matrix derived from the SAS output through Binswanger’s process is displayed below:
Table 2: Allen Partial Elasticities of Inputs

<table>
<thead>
<tr>
<th>Price</th>
<th>FSL</th>
<th>Chem</th>
<th>Fert</th>
<th>Fuel</th>
<th>Labor</th>
<th>Capital</th>
<th>Land</th>
</tr>
</thead>
<tbody>
<tr>
<td>FSL</td>
<td>-1.69</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chem</td>
<td>3.73</td>
<td>-40.39</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fert</td>
<td>1.48</td>
<td>-0.93</td>
<td>-20.68</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuel</td>
<td>0.94</td>
<td>-1.61</td>
<td>-0.94</td>
<td>-18.19</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Labor</td>
<td>1.06</td>
<td>-1.99</td>
<td>7.00</td>
<td>-0.08</td>
<td>-6.34</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Capital</td>
<td>-1.19</td>
<td>0.66</td>
<td>101.46</td>
<td>72.63</td>
<td>-41.92</td>
<td>-180.22</td>
<td></td>
</tr>
<tr>
<td>Land</td>
<td>1.01</td>
<td>-0.34</td>
<td>0.49</td>
<td>-0.80</td>
<td>1.56</td>
<td>1.26</td>
<td>-2.43</td>
</tr>
</tbody>
</table>

Generated using SAS and Microsoft Excel

Numbers represent Allen partial elasticities of substitution

A rather glaring issue must be clarified concerning the own partial Allen elasticities in Table 1. For many of the own partial Allen elasticities, especially those for Capital, Fuel, Fertilizers, and Chemicals, the values may at first glance seem to be rather large. However, when one factors in the original price shares for those inputs, the figures seem more reasonable. For example, the value for Chemicals indicates that for every 1% increase in the price of Chemicals, the original cost share of Chemicals falls by 40%. This may seem drastic, but one must remember that the original price share for Chemicals was 5%.
Therefore, Ceterus Paribus, a 1% increase in Chemical prices will shift its cost share from 5% to 3%. When compared to the original cost share figures, it can be observed that the own Allen partial elasticities become more dramatic as the cost share for the input shrinks.

The cross Allen partial elasticities are also interesting, as they indicate the basic relationship between inputs. As with traditional price elasticities, a positive value for the elasticity indicates that the two inputs are net substitutes, while a negative value indicates that the two inputs are net compliments. As with the case of the own Allen partial elasticities, the proportion of the value is a function of the cost shares for the given inputs as well as their actual substitutability. These cross Allen partial elasticities are interesting in and of themselves, and each deserves discussion.

Raw materials (FSL) appear to be net substitutes with all other inputs except for capital. The Allen elasticities for FSL are rather low with respect to the other inputs, which is not surprising given that FSL makes up a considerable portion of total costs. Chemicals shares a more varied set of relationships with the other inputs, acting as a net substitute with FSL and capital, but acts as a net compliment to fertilizers, fuel, labor, and land. A notable aspect of Chemicals can be observed when comparing proportions: the values are relatively small compared to the other inputs with single digit cost shares. Fertilizer shares what may be thought of as a more intuitive set of relationships with other inputs, since fertilizer is shown to be a net compliment with chemicals and fuel while being a substitute to everything else. The other notable aspect of the values for Fertilizer is that Fertilizer is the first input to display the large Allen elasticity with respect to capital.
The input of the greatest interest to this project, fuel, also seems to share intuitive relationships with the other inputs. While fuel is a net substitute to FSL and Capital, it is a net compliment to everything else. Like Chemicals, the Allen elasticities for Fuel with respect to other inputs are small, with the notable exception of Capital. This similarity between Chemicals and Fuel is rather interesting, given that the only realistic source for both inputs is crude oil. Labor shares some surprising relationships with other inputs if one assumes the classic substitutability paradigm: it is a net compliment of Capital while being a net substitute with everything else (except FSL). Traditionally, Capital and Labor are usually considered to be net substitutes, but in this case the opposite is true. Labor elasticities also display the same behavior as most of the previous inputs with respect to proportions in that all but the Capital values are rather small.

The cross Allen partial elasticities for Capital are, as mentioned earlier, quite large due to the nature of the calculations from which the values were derived. The relationships between Capital and the other inputs are otherwise mostly intuitive, with capital acting as a net substitute with everything except for FSL, Labor, and Land. The cross Allen partial elasticities for Land are also mostly intuitive, with Land having net substitutability with every other input with exception to Fuel and Chemicals.

While the Allen partial elasticities are interesting in and of themselves, it is of more interest to the goal of this paper to obtain the price elasticities for the inputs. The difference between the Allen partial elasticities and the price elasticities is straightforward. Allen partial elasticities measure the change in the cost share for an input as a result of a change in price for another input, while price elasticities measure the percentage change in quantity of an input employed as a result of the change in price of
another input. Fortunately, Subhash finds a way to do this in his work by adding on to what Binswanger had accomplished. Quite simply, Subhash finds that if the Allen partial elasticities are multiplied by the cost shares for the input in question, the product is the own or cross price elasticity, respectively. The formula Subhash uses in his work, and that this project uses unmodified, is written below:

\[ e_{ii} = a_{ii} \times s_i \]  
for the own price elasticity

\[ e_{ij} = a_{ij} \times s_j \]  
for the cross price elasticity

Where:  

\( i, j \) are the inputs,

\( e_{ii} \) is the own price elasticities of inputs,

\( e_{ij} \) is the cross-price elasticities of inputs

\( s_i, s_j \) are the average cost shares for inputs, and

\( a_{ii}, a_{ij} \) are the Allen partial elasticities, found using Binswanger’s method

The resulting matrix of this operation, the price elasticity matrix, was then calculated in Microsoft Excel and generated here:
Table 3: Price Elasticities of Substitution for Inputs

<table>
<thead>
<tr>
<th></th>
<th>FSL</th>
<th>Chem</th>
<th>Fert</th>
<th>Fuel</th>
<th>Labor</th>
<th>Capital</th>
<th>Land</th>
</tr>
</thead>
<tbody>
<tr>
<td>FSL</td>
<td>-0.65</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chem</td>
<td>1.44</td>
<td>-1.69</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fert</td>
<td>0.57</td>
<td>-0.04</td>
<td>-1.11</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuel</td>
<td>0.36</td>
<td>-0.07</td>
<td>-0.05</td>
<td>-0.94</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Labor</td>
<td>0.41</td>
<td>-0.08</td>
<td>0.38</td>
<td>0.00</td>
<td>-0.73</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Capital</td>
<td>-0.46</td>
<td>0.03</td>
<td>5.47</td>
<td>3.77</td>
<td>-4.81</td>
<td>-3.94</td>
<td></td>
</tr>
<tr>
<td>Land</td>
<td>0.39</td>
<td>-0.01</td>
<td>0.03</td>
<td>-0.04</td>
<td>0.18</td>
<td>0.03</td>
<td>-0.66</td>
</tr>
</tbody>
</table>

Generated from Table 1 using Subhash’s method in Excel

Numbers represent price elasticities of substitution

As can be seen here, the price elasticities indicate an industry in which there is a great deal of rigidity, and price changes for most inputs are responded to primarily by changing consumption of Capital. Raw material (FSL) is relatively price inelastic with its other inputs, with the exception of Chemicals. Chemicals are also price inelastic, with the aforementioned exception of FSL and its own price elasticity. Fertilizers are inelastic with everything but capital, and has a modest own price elasticity.

Fuel, the input of concern, shares the lowest elasticities with all of the other inputs. Some of the Fuel values even approach zero (elasticity between Fuel and Labor IS zero), indicating near perfect inelasticity. Only the values associated with Land are this low, which is to be expected considering the obvious nature of production. The
notable exception here is with Capital, a detail that will be discussed further in subsequent discussion. Also notable is that Fuel approaches unit elasticity with respect to its own price elasticity, although as reported earlier the figure is not statistically significant.

Labor follows the trend of previously discussed inputs in that it is price inelastic with all other inputs except for capital. Of particular interest is the relatively high elasticity between Labor and Capital. The high elasticity as well as the sign indicates that Labor and Capital are compliments, and that fluctuations in input prices for either will cause sharp changes in the employment of the other. However, these conclusions must be taken in context with the labor pricing problem explained in the data section, and illustrated in Figure 4. Capital shares this volatile with many of the other inputs as well, as noted earlier, but the Labor-Capital relationship is the only one in the matrix that displays a highly elastic complementary relationship. Capital and its price elasticities with other inputs have been discussed at length, so we will move on to Land. Land, next to Fuel, shows the lowest elasticities in the matrix. It is a net compliment with chemicals and fuel and a substitute with everything else. The very low elasticities should not be surprising, due to the nature of agricultural production.

Although the methods of Binswanger and Subhash were closely emulated in this paper, it is nonetheless hard to compare and contrast the results due to differences in definitions for the actual data. Each of the three works (this paper, Binswanger’s paper, and Subhash’s paper) subdivides the inputs differently, as well as consolidates inputs into categories differently. Upon close inspection of the methodology of data consolidation, it can be seen that even if the labels are the same for an input, that input may actually
represent different groups of real materials from paper to paper. For example, Binswanger grouped raw materials and maintenance with land and labeled this combination Land, while leaving Capital separate. Subhash, on the other hand, placed raw materials within its own category, and placed maintenance and capital with land in the Land category. This paper keeps everything separate, with the exception of combining maintenance with capital. Therefore, comparing the resulting elasticities for Land, Capital, or Raw Materials between the three papers is akin to comparing baskets with different combinations of fruits together.
CONCLUSIONS

Now that the price elasticities and Allen partial elasticities have been established, they can be used with the descriptive statistics to paint the picture which explains how energy prices affect agricultural production. The picture painted is one that does not fit the traditional paradigm assigned to agriculture. Instead of having a labor and land intensive industry in which productivity is increased through the use of physical capital, much like what may have been the case in the 19th and early 20th Centuries, we have a different beast entirely. The industry described by the data is a highly automated industry, in which labor and capital are strong compliments, and productivity is enhanced through the use of chemicals and fertilizers. Instead of employing more land to increase production, farms use more advanced technology in capital, fertilizers, chemicals, and raw materials to increase the productivity of each acre. Fuel is an integral part of this process, as it is the source of energy from which all other inputs draw in order to be utilized.

It seems at best simplistic to reiterate that energy is the basis on which all economic activity rests, but the truth of this idea is borne out by the results of this project. Fuel prices rose sharply during the period studied, which caused farmers to attempt to shift production so as to substitute away from fuel. The ways to do this were as inventive as they were varied. The high capital elasticities displayed in the results section indicated a traditional approach to minimizing fuel consumption: increase the fuel efficiency of the equipment. As the price of fuel tripled, investment in newer, more fuel-efficient equipment also seems to have increased.
Farmers also attempted to substitute away from fuel by increasing the productivity of the land under cultivation. This was done in several ways. The first and most obvious is through the increasingly extensive employment of chemicals and fertilizers. Fertilizers increase the amount of crop per acre, or in the case of ranching increases the amount of feed per acre available for grazing. Chemicals, mainly pesticides of various types, are then employed to protect the crop from nefarious wildlife of all kinds. Chemicals also include preservatives that help to keep the crops from decaying before they reach the market. Both chemicals and fertilizers began to be improved drastically during this time period, as farmers attempted to use more technically advanced formulas to increase crop yields at the lowest cost.

Another interesting development, one that isn’t covered extensively by this project but should be noted as it began to occur in the time period specified, is the advent of genetically modified organisms. Beginning in the late 1980s, genetic modification of certain crops began to be tested in the United States. Genetic modifications began to be done that serve to make a crop more productive without the use of fertilizers or chemicals. GMOs that needed less water, or could endure lower temperatures, or have higher yields, began to be planted. The moral and ethical debate surrounding this continues to rage in society, but the result of this development has a curious affect on this project. Whereas in the 1970s feed and seed were essentially bulk grains that were analogous, in the 21st Century this is no longer the case. Farmers used to hold back some of their harvest as seed for the next year. Now, farmers purchase seed from a company that is tailor-fit to the farm’s needs and that cannot reproduce. In essence, the market for seeds transformed overnight from a perfectly competitive, self-supplying and relatively
static market into an oligopolistic, externally sourced, and rapidly changing market. This could not be adequately captured by this paper, but should be kept in mind when considering that such developments serve to allow farms to substitute away from fuel consumption, as GMOs make farming more productive per acre.

The only two inputs that did not see much technical change during this period were labor and land. However, the technical changes in the other inputs imply that labor also had to change. In most cases, labor employed at the agricultural level before this time period could have been relatively unskilled. Since most of the inputs employed during this period began to become more technically advanced, it is relatively intuitive to assume that labor had to become more skilled. This shows best in the cross-price elasticity between labor and capital. Traditionally net substitutes, the figure derived by the model depicts a labor market in which relatively skilled labor ran the advanced machines and applied complex combinations of fertilizers and chemicals to already enhanced plants. This contrasts with the traditional picture of unskilled farmhands employed in relatively menial tasks, which was the case throughout most of history.

The picture thus can be simplified into the following scenario: as fuel prices rose, farms substituted by employing better equipment while employing more fertilizers and chemicals to lower the land usage, and therefore fuel consumption. The amount of land under cultivation shrank as production rose. However, as chemicals and many fertilizers share the same sources as fuel, namely that they are all refined petro products, their prices were closely tied. Therefore, farmers were again forced to substitute away from those inputs by using new modified crops.
However, as indicated by the relative price inelasticities of substitution derived from the model, farms could not substitute much from the use of fuel. Fuel powers the machines that allow all of the other inputs to be employed. Therefore, as fuel prices rose, demand for other inputs rose, which caused their prices to rise as well. In the end, even given the greater production from the agricultural sector, food prices ended up rising. The end result of this was the commodity prices in 2007, during which time prices for grains had effectively doubled from their 1992 levels during which time fuel prices had effectively tripled.

It can be concluded, then, that rising fuel prices affect agriculture because fuel is a necessary input that does not have a close substitute. Farmers tried to substitute fuel inputs with other inputs in various ways, but were only partially successful. In the end, the only way to substitute away from fuel consumption is to either employ a method of production that does not use capital, or to use capital that has its own source of energy. As either alternative is not even remotely cost effective, the relationship between energy prices and food production is likely to be with us for quite some time.
FUTURE WORKS

This project was ambitious in both its complexity and in its scope. Nonetheless, there are still many areas in which this paper can be improved upon. Binswanger and Subhash employed longer periods of time for study, but this was not possible for this project because their focus was not on fuel prices, which was not available in the Census of Agriculture until the 1990s. However, since fuel prices are included since the 1992 Census, and are likely to remain included as a separate expenditure for the foreseeable future, this model can employ new data as the Census is done every five years. In essence, the current model can be updated in its current form simply by including another time period.

Other improvements are more structurally based, but are also worth mentioning. It is disappointing that the time trend was effectively zero for the time period, but this may be a result of the dataset. Since significance was so strong in the actual cross effects, it may be that the price indexes acted to preclude the time trend, as the price indexes partially account for time changes anyway. Binswanger and Subhash reported positive time trend values, but used much smaller datasets over longer periods of time. It is possible that a time trend would show a non-zero value over a longer period of time than 20 years, but at this point such an idea is purely conjecture. It would be possible to go further back in time, but at the cost of oversimplifying the input categorization. This simplification would include the removal of fuel as an independent input, which as stated earlier negates the purposes of this project.
Another structural improvement would be the regionalization of the model by including regional dummies. Binswanger and Subhash do this, but use only five or six regions respectively. The price indexes employed in this project partially account for regionalization, as the indexes are calculated for all inputs at the state level, or are weighed at the state level. However, it would be instructive as well as interesting to see how different states react to changes in fuel prices in their agricultural production. Originally this was meant to be done for this project, but the technical limitations of Microsoft Excel, namely the limit on the number of columns in a spreadsheet, did not allow for all of the log values, cross effects and prices for inputs to exist with dummy variables for all fifty states. Regionalizing into five or six sections based on climate might have been appropriate, but it might have clashed with the partial regionalization characteristic in the weighting of the price indexes.
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DATA SOURCES


1990-2008 State Diesel Prices, Department of Energy
APPENDIX

There are relatively few software suites that are able to calculating systems of equations. Two of these software suites were available: Gretl and SAS. Gretl was used for preliminary work for this project, but was quickly set aside because of chronic breakdowns due to the size of the database employed. This left only SAS as the program used to calculate the above model.

SAS is a statistical package that employs command scripts as opposed to more conventional systems which use menus and functions. This means that SAS can be cumbersome to use, especially when considering the relatively sophisticated vectors and restrictions necessary for creating a translog cost model such as the one used for this project. However, the utility and versatility that SAS provides for this type of modeling cannot easily be matched. Indeed, many of the works cited for this paper, especially those of Binswanger and Subhash, suffered in their methodology because of the limitations of the software and hardware used. It can easily be claimed that the above modeling using such a large cross section would not be possible without the use of SAS.

SAS can calculate the above system of equations in two different ways: through the use of either a SYSLIN or a MODEL statement. The SYSLIN statement is designed solely for the calculation of systems of equations, but is limited in what can be done with the output. However, the summary statistics generated by the SYSLIN procedure allowed for close attention to be paid to how the vectors and restrictions interacted with each other. Therefore, the SYSLIN statements were used in the preliminary modeling stages, in order to test the appropriateness of the homogeneity and other restrictions. Also, the SYSLIN statement would show where multicollinearity became a problem in
the different vectors, as multicollinearity would be indicated by dropped variables in the system of equations.

The MODEL statement is a looser, more flexible procedure which allows not only for the translog model to be calculated, but also for the output to be printed on a separate data file so that it can be manipulated using Subhash’s method in order to generate own and cross-price elasticities. The MODEL statement did not give as much information pertaining to the feasibility of the model and its restrictions, so it was used later in the modeling process after the viability of the different linear restrictions was already established. The results for the own and cross elasticities were then transferred to an Excel file so that they could be better displayed in the results and interpretation section.

CODE UTILIZED IN SAS

```sas
proc model data=XUSA;
   /* imposing homogeneity and symmetry and adding-up restrictions */
   restrict
   bfs1 + bchem + bfert + bfuel + blabor + bcapital + bland =1;
   bfs1f1 + bfs1chem + bfs1fert + bfs1fuel + bfs1labor + bfs1capital + bfs1land=0;
   bfs1chem + bchemchem + bchemfert + bchemfuel + bchemlabor +
   bchemcapital + bchemland=0;
   bfs1fert + bchemfert + bfertfert + bfertfuel + bfertlabor +
   bfertcapital + bfertland=0;
   bfs1fuel + bchemfuel + bfertfuel + bfuelfuel + bfuellabor +
   bfuelcapital + bfuelland=0;
   bfs1labor + bchemlabor + bfertfsl + bfufert + blaborlabor +
   blaborcapital + blaborland=0;
   bfs1capital + bfs1chem + bfs1fert + bfs1fuel + bfs1labor +
   bcapitalcapital + bcapitaland=0;
   bfs1land + bchemland + bfertland + bfuelland + blaborland +
   bcapitaland=0;
   gfsl+gchem+gffert+gffuel+gllabor+gcapital+gland=0;
```

67
\[
\ln\text{Total} = k + a \cdot \ln\text{Output} + \frac{1}{2} \cdot d \cdot \ln\text{Output} + 2 \cdot \text{bfsl} \cdot \ln\text{PFSL} + \text{bchem} \cdot \ln\text{PChem} + \text{bfert} \cdot \ln\text{PFert} + \text{bfuel} \cdot \ln\text{PFuel} + \text{blabor} \cdot \ln\text{PLabor} + \text{bcapital} \cdot \ln\text{PCapital} + \text{bland} \cdot \ln\text{PLand} + \frac{1}{2} \cdot (\text{bfslfsl} \cdot \ln\text{PFSL} + \text{bfslchem} \cdot \ln\text{PChem} + \text{bfslfert} \cdot \ln\text{PFert} + \text{bfslfuel} \cdot \ln\text{PFuel} + \text{bfsslabor} \cdot \ln\text{PLabor} + \text{bfsslcapital} \cdot \ln\text{PCapital} + \text{bfsslland} \cdot \ln\text{PLand} + \text{bchem} \cdot \ln\text{PChem} + \frac{1}{2} \cdot (\text{bfslfert} \cdot \ln\text{PFert} + \text{bfertfert} \cdot \ln\text{PFert} + \text{bfertfuel} \cdot \ln\text{PFuel} + \text{bfertlabor} \cdot \ln\text{PLabor} + \text{bfertcapital} \cdot \ln\text{PCapital} + \text{bfertland} \cdot \ln\text{PLand}) + \text{gchem} \cdot \ln\text{Output};
\]

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\text{CSFSL} = \text{bfsl} + \text{bfslfsl} \cdot \ln\text{PFSL} + \text{bfslchem} \cdot \ln\text{PChem} + \text{bfslfert} \cdot \ln\text{PFert} + \text{bfslfuel} \cdot \ln\text{PFuel} + \text{bfsslabor} \cdot \ln\text{PLabor} + \text{bfsslcapital} \cdot \ln\text{PCapital} + \text{bfsslland} \cdot \ln\text{PLand} + \text{gchem} \cdot \ln\text{Output};
\]

\[
\text{CSChem} = \text{bchem} + \text{bfslchem} \cdot \ln\text{PFSL} + \text{bchemchem} \cdot \ln\text{PChem} + \text{bchemfert} \cdot \ln\text{PFert} + \text{bchemfuel} \cdot \ln\text{PFuel} + \text{bchemlabor} \cdot \ln\text{PLabor} + \text{bchemcapital} \cdot \ln\text{PCapital} + \text{bchemland} \cdot \ln\text{PLand} + \text{gchem} \cdot \ln\text{Output};
\]

\[
\text{CSFert} = \text{bfert} + \text{bfertfsl} \cdot \ln\text{PFSL} + \text{bfertfert} \cdot \ln\text{PFert} + \text{bfertfuel} \cdot \ln\text{PFuel} + \text{bfertlabor} \cdot \ln\text{PLabor} + \text{bfertcapital} \cdot \ln\text{PCapital} + \text{bfertland} \cdot \ln\text{PLand} + \text{gfert} \cdot \ln\text{Output};
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\text{CSFuel} = \text{bfuel} + \text{bfslfuel} \cdot \ln\text{PFSL} + \text{bchemfuel} \cdot \ln\text{PChem} + \text{bfertfuel} \cdot \ln\text{PFert} + \text{bfuelfuel} \cdot \ln\text{PFuel} + \text{bfuellabor} \cdot \ln\text{PLabor} + \text{bfuelfcapital} \cdot \ln\text{PCapital} + \text{bfuelland} \cdot \ln\text{PLand} + \text{gfuel} \cdot \ln\text{Output};
\]

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\text{CLabor} = \text{blabor} + \text{bfsslabor} \cdot \ln\text{PFSL} + \text{bchemlabor} \cdot \ln\text{PChem} + \text{bfertfsl} \cdot \ln\text{PFert} + \text{bfuelfert} \cdot \ln\text{PFuel} + \text{blaborlabor} \cdot \ln\text{PLabor} + \text{blaborcapital} \cdot \ln\text{PCapital} + \text{blaborland} \cdot \ln\text{PLand} + \text{glabor} \cdot \ln\text{Output};
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\text{CSCapital} = \text{bcapital} + \text{bfscapital} \cdot \ln\text{PFSL} + \text{bfslchem} \cdot \ln\text{PChem} + \text{bfslfert} \cdot \ln\text{PFert} + \text{bfslfuel} \cdot \ln\text{PFuel} + \text{bfsslabor} \cdot \ln\text{PLabor} + \text{bcapitalcapital} \cdot \ln\text{PCapital} + \text{bcapitalland} \cdot \ln\text{PLand} + \text{gcapital} \cdot \ln\text{Output};
\]

\[
\text{CSLand} = \text{bland} + \text{bfssland} \cdot \ln\text{PFSL} + \text{bchemland} \cdot \ln\text{PChem} + \text{bfertland} \cdot \ln\text{PFert} + \text{bfuelfert} \cdot \ln\text{PFuel} + \text{bland} \cdot \ln\text{PLand} + \text{gland} \cdot \ln\text{Output};
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\text{fit}\ \ln\text{Total} \ \text{CSFSL} \ \text{CSChem} \ \text{CSFert} \ \text{CSFuel} \ \text{CLabor} \ \text{CSCapital} \ \text{CSLand}/ \ \text{sur}
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\text{outs}=\text{rest}\ \text{outest}=\text{fin2}
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\text{out} = \text{resid2};
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\text{bchem} \ \text{bchemchem} \ \text{bchemfert} \ \text{bchemfuel} \ \text{bchemlabor} \ \text{bchemcapital} \ \text{bchemland}
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\text{bfertfert} \ \text{bfertfuel} \ \text{bfertlabor} \ \text{bfertcapital} \ \text{bfertland}
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bfuel fuel blabor labor bcapital capital bland land

Run;