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Regression analysis was used to examine the effect of a change in agricultural prices on land use and conservation. The planted acreage for each of three crops – corn, soybeans, and spring wheat – was regressed on the expected prices of the three crops, the input prices, and past land use in the United States for the period 1976-2007. Depending on the estimator, the respective ranges of the own-price elasticities of corn, soybeans, and wheat were 0.42 to 0.69, -0.31 to 0.41, and 0.10 to 1.10. The regression results were combined with nitrogen-fertilizer application rates to examine the effect of a price change on the amount of fertilizer applied in the Corn Belt. A $1 increase in the price of corn was found to increase the amount of nitrogen fertilizer use by 11%. A $1 increase in all three commodities of interest was found to increase the quantity of fertilizer by 17%. The number of acres enrolled in the Conservation Reserve Program (CRP), from 1986-2007, was regressed on the prices of corn, soybeans, and wheat, the rental rate paid to farmers for CRP enrollment, the wage rate, a land-quality indicator, and land use in the previous year. The elasticity of CRP
acreage fell between -0.06 and -1.01 with respect to the price of corn and between 0.05 and 0.07 with respect to the CRP rental rate. When dynamic estimators were used, the wage elasticity was strongly positive, and the land-quality elasticity was negative.
Crop Choice and Conservation: Implications of Increased Biofuel Demand

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I understand that my thesis will become part of the permanent collections of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

B. Sechrist, Author
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Background

Over the past several years, ethanol production in the United States has increased substantially due to greater demand for alternatives to petroleum-based fuels. Along with the desire for energy independence and the growing interest in using alternate fuels to mitigate climate change, the recent peak in crude oil prices has been a strong driving force for ethanol production. U.S. Energy Information Administration (EIA 2009) data show that crude oil prices averaged less than $20 per barrel throughout the 1990s and fluctuated between the low and high $20s from 2000 through most of 2004. Prices began rising rapidly in 2005, first topping $50 per barrel in June. An all-time high of $137 was attained in July of 2008. Oil prices then began to decline in August 2008, falling below $100 in September. Prices continued to fall through the remainder of 2008 and are now in the $80 range. Despite its recent decline, the trajectory of oil prices in the 21st century has brought energy independence to the forefront of national policy issues.

Ethanol mandates have become commonplace at both federal and state levels. The 2005 U.S. Energy Policy Act calls for increased production of biofuels, including ethanol and biodiesel, to meet its renewable fuels consumption target of 7.5 billion gallons by 2012 (Jaeger et al., 2007). The legislation did not provide liability
protection for methyl tertiary butyl ether (MTBE), a common additive to gasoline that has been found to contaminate drinking water. The lack of liability protection will, most likely, lead to a reduction in the use of MTBE in favor of ethanol. The Energy Independence and Security Act of 2007 set a renewable fuels standard (RFS) that requires the use of 36 billion gallons of ethanol per year by 2022. Up to 15 billion gallons can be corn ethanol, and at least 5 billion gallons must consist of biodiesel by the year 2012 (U.S. Energy Information Administration 2007). Twelve states have set their own renewable fuels standards with biofuel requirements (Pew Center, 2008). Furthermore, 39 states provide incentives for biofuel production such as tax exemptions, credits, or grants (Pew Center, 2008).

As a result of these government mandates and incentives, biofuel production has expanded. Ethanol production doubled from 2000 to 2005, going from less than 2 billion gallons to 3.9 billion gallons (Energy Information Administration 2007). Production further jumped to 5 billion gallons in 2006 and is expected to exceed 10 billion gallons by 2009 (Westcott 2007). Since corn is the primary source of ethanol, the increased production has a large impact on the agricultural sector. In 2006, ethanol represented only about 3.5% of gasoline consumption by motor vehicles in the U.S. However, 14% of the U.S. corn crop was used in ethanol production, and this number is expected to exceed 30% by 2010 (Westcott 2007). The fundamental economic principles of supply and demand posit that the increased demand for corn will drive up its price. This is indeed what has happened in recent years. From $2 per bushel in early 2006, the price of corn began to climb, topping $3 within one year. The price continued to rise until early 2008, reaching a peak above $5. In the past
year, the price of corn has fallen but is still well above historical levels. The United States Department of Agriculture (USDA), in its 10-year projection from 2007, predicts that the price of corn will peak in 2009-10 and then slowly decline over the following years as ethanol expansion slows (USDA 2007). In 2017, the price of corn is still expected to be above $3.25 per bushel.

Supply theory postulates that producers increase output in response to a price increase. Farmers are expected to respond to the economic incentive of a higher price of corn by increasing their plantings of corn. About 78 million acres of corn were planted nationwide in 2006; this figure jumped to 90 million in 2007 (USDA 2007). A price increase of approximately 50% paralleled the increase in acreage. USDA projects corn acreage above 90 million through 2016. For comparison, corn acreage hovered between 75 and 80 million between 2000 and 2004.

Changes in the price of corn will not only affect the acreage of corn but also the acreages of other crops that compete with corn for land. Soybeans are the most common crop to compete directly with corn and thus will likely decline in acreage as corn increases (Westcott 2007). Changes in rotational patterns may account for some of the shift in acreage from soybeans to corn. A typical rotation consists of corn being planted one year and soybeans the next; this practice may be altered to planting soybeans every third year (Westcott 2007). A reduction in soybean production would drive up the price of soybeans, which would subsequently lead to reduced soybean exports and a higher price of soybean oil (Westcott 2007). Soybeans are also used to manufacture a biofuel: canola biodiesel (Jaeger et al. 2007). While not produced at nearly the level of ethanol, biodiesel could further drive up the price of soybeans if
demand were to increase. Soybeans are not the only crop affected by the price of corn. Wheat, hay, cotton, and sorghum are among the other crops that may be planted alongside corn in some areas.

Changes in the planted acreage of crops may have a significant impact on environmental quality. The particular mix of crops planted determines the levels of chemical usage, soil erosion, and local carbon sequestration. Corn is one of the most chemically-intensive crops, so an increase in corn acreage may have negative environmental consequences (Langpap and Wu 2008). For example, an acre of soybeans is less likely to be fertilized than is an acre of corn, and, if fertilized, the acre of soybeans is likely to receive a smaller quantity of fertilizer (Economic Research Service 2008).

Besides direct environmental effects including chemical runoff and erosion, a change in commodity prices may affect the amount of land set aside for conservation. Begun in 1986, the Conservation Reserve Program (CRP) allows farmers to voluntarily idle environmentally-sensitive cropland in exchange for an annual rental payment and cost-share assistance for land improvements (Farm Service Agency 2009). The CRP has been shown to have a positive impact on the populations of numerous animal species including ducks, pheasants, and quail (Farm Service Agency 2008). It also improves water quality by decreasing nitrogen, phosphorus, and sediment runoff from fields (Farm Service Agency 2008). Crop prices are believed to affect the level of enrollment in the CRP. A price increase may make farmers less likely to enter a new CRP contract or to renew an expiring contract. Sufficiently high prices may even cause farmers to break existing contracts.
Objectives

The first objective of this thesis is to examine the effect of an increase in commodity prices on crop mix. Corn, soybeans, and wheat are considered. For each crop, econometric methods are used to estimate how its planted acreage is affected by a change in its own price and changes in the prices of the other two commodities. As an extension of the acreage response analysis, the results are integrated with data on nitrogen fertilizer application rates and average quantities of nitrogen fertilizer. The level of nitrogen fertilizer use is then estimated for different sets of commodity prices. Since nitrates are a good indicator of the environmental impact of agriculture, the environmental damages associated with a price change can be assessed. Finally, the CRP enrollment data are merged with the agricultural acreage data to study the effect of a price change on CRP acreage.

Study Description

This thesis differs from other studies of crop acreage response in its combination of geographic area and level of aggregation. It is a national-level study, but with county-level acreage data. Acreage response is analyzed through a set of panel data, where each county is a group. Other studies (see Chapter 2) have conducted time series analyses of crop response for the United States as a whole. Less aggregated studies have been confined to specific states or regions. Similarly, previous studies of CRP acreage response have been restricted to selected states or regions.
Thesis Organization

Chapter 2 reviews the existing body of literature in the context of acreage response to price variation, environmental damage due to agriculture, and the CRP response to a change in commodity prices. Chapter 3 explains the methodology used to achieve the objectives of the thesis. Chapter 4 presents the results, both in a written body and in tables. Chapter 5 contains a discussion of the results, followed by some concluding remarks.
CHAPTER 2

LITERATURE REVIEW

The existing literature on four topics was reviewed: farmers’ formulation of price expectations, agricultural supply response to price fluctuations, environmental impacts of agricultural chemicals, and Conservation Reserve Program enrollment as a function of crop prices.

Price Expectations

A farmer makes his planting decisions based on his expectation of the price level at the time of harvest. Since the chosen metric of agricultural supply is planted acreage, it is necessary to construct an expected price that simulates the expectations of the farmer. Most authors believe that price expectations involve some combination of the lagged market price, the futures price, and the government support price.

Houck and Ryan (1972), in their supply analysis of corn in the United States, intend to use both the lagged market price and the government support price, but instead choose only the support price due to its high correlation with the market price. They suggest that the correlation between the lagged market price and the support price is caused by the actions of policymakers who adjust price support programs based on the immediate past. If the market price in the previous year is depressed by a large crop, policymakers may decrease the support price for the current year to reduce production.
Gardner (1976) discusses the use of the futures price in place of the lagged market price. He argues that the futures price, which directly reflects the expectations of only those producers who make futures transactions, also captures the expectations of those farmers who refrain from futures transactions. Under rational expectations, those without futures contracts but whose expectations differ from the futures price have an incentive to enter. Hence, farmers not participating in the futures market likely have expectations similar to the futures price. Gardner also considers the timeline of planting and harvesting as it relates to the futures market. He suggests that the expected price should be the first futures price after the crop is harvested in the period immediately preceding the planting season. For acreage response models of soybeans and cotton, Gardner compares regression results using lagged market prices to those using futures prices. He concludes that the futures price “gave reasonable results and performed at least as well as Nerlovian lagged price, lagged dependent variable specifications.”

The case for futures prices is further buttressed by Just and Rausser (1981), who compare the results of price-forecasting econometric models and the futures market for various commodities. They find that the futures price dominates the econometric models for several commodities and is just as good for most other commodities. There are those, however, who believe that the futures price is a poor predictor of price. Bray (1981) declares that the “futures price is not in general a sufficient statistic” for information about the spot price. Grossman and Stiglitz (1980) argue theoretically that it is unrealistic to assume that the futures price captures all available information.
Chavas et al. (1983) consider the possibility that both cash markets and futures markets, along with government programs, may be useful in forming farmers’ price expectations. Like Gardner, they find that the futures price performs on par with the lagged cash price. The correlation coefficient between the two prices is found to be very high (0.87 for corn and 0.90 for soybeans), suggesting that multicollinearity would likely arise from their simultaneous inclusion in an estimate of supply equations. The high correlation also indicates that the lagged market price is a major determinant of the futures price, which Chavas et al. confirm by a regression of the futures price on other price variables. They find that a one-year lag of the market price has the most explanatory power for variation of the futures price. Chavas et al. also investigate the role of the government support price, which they find to have a non-significant effect on the futures price. This result suggests that the futures price does not capture the effects of the support price and may not be informationally efficient in the presence of government programs. Chavas et al. conclude that the futures price and the one-year lagged cash price are substitutable but do not reflect the influence of government programs. Hence, the government target price must also be considered when in place.

Shideed et al. (1987) combine the market and support prices to develop a measure of price expectations. This conditional expected price “defines the total effect of available information on supply response.” The authors assume normality for the distributions of both market and support prices and thus estimate the joint distribution of the expected price as a multivariate normal distribution. The mean of the conditional distribution of the market price (MP), given support price SP*, is
\[
E(MP | SP = SP^*) = E(MP) + r_{12} \left( \frac{\sigma_1}{\sigma_2} \right)(SP^* - E(SP))
\]

where \(SP^*\) is the annual announced support price, \(\sigma_1\) and \(\sigma_2\) are the standard deviations of \(MP\) and \(SP\), and \(r_{12}\) is the correlation between \(MP\) and \(SP\). Shideed et al. state that their price forecasts are conditional expectations which are based on all past observations of cash and support prices. In combining the market and support prices to overcome the statistical limitations of their autoregressive moving average (ARMA) model, Shideed et al. follow the methodology suggested by Chavas et al.

Shideed and White (1989) analyze six alternative forms of price expectations. Their main conclusion is that, a priori, no one method provides a “superior specification for price expectations for empirical supply response analysis.” The choice of method should ideally be based on the particular commodity being studied because each formulation typically performs well for some commodities but falls short for others. With changing farm programs and crop rotations, Shideed and White acknowledge the practical difficulty of matching a particular specification to a specific commodity. Ultimately, the authors, in looking at the response of corn and soybean acreage to price expectations, find similar elasticities whether using support prices, conditional expectations based on futures prices, or conditional expectations based on market prices.

Other authors have taken the approach of Chavas et al. Wu and Segerson (1995), for crops with government programs in place, define the expected price as the greater of the current target price and a linear function of the market price from previous years. Langpap and Wu (2008) specify the expected price of corn as the
“higher of the weighted target price and the average futures price in the corn planting season,” and that of soybeans, a non-program crop, as the average futures price during the planting season. They define the average futures prices as the averages of the first and second Thursday closing prices in March on the Chicago Board of Trade for December corn and November soybeans.

**Supply Response**

Numerous empirical papers have been published on the response of crop acreage to a price change. These papers differ widely in crops considered, time period, geographic area, aggregation level, and econometric methodology.

Houck and Ryan (1972) conduct a supply analysis of corn for the entire United States over the time period 1948 through 1970. They focus on the effect of government programs on the acreage of corn and find that more than 95 percent of acreage variation can be explained by government policy provisions. Their basic model is

\[ A = f(G, M, Z) \]

where \( A \) is corn acreage planted in the United States, \( G \) represents policy provisions, \( M \) represents market factors, and \( Z \) includes all other supply factors and random effects. Houck and Ryan ultimately drop the market price from their regression model due to correlation with the government support price. They find a significant, positive coefficient for the support price of corn when they regress corn acreage on corn and soybean support rates and diversion payments.
Gardner (1976) runs two regressions to analyze the soybean supply response in the United States for the period 1950-74. First, he regresses soybean acreage on its one-period lagged value, the futures price of soybeans, the futures price of corn, and a time trend. He finds short and long-run acreage elasticities of 0.61 and 1.36, respectively. Next, he substitutes one-period lags of market prices for futures prices. The resulting acreage elasticities, 0.56 and 1.04, are similar to those found when using futures prices.

Gallagher (1978), defining the expected price as a function of the current support price and the previous year’s market price, examines the supply response of corn to changes in the prices of both corn and soybeans. In the short run, he finds that own-price elasticities fall between 0.159 and 0.178, while cross-price elasticities fall between -0.080 and -0.065. Long-run elasticities with respect to corn and soybeans are 0.184 and -0.067.

Chavas et al. (1983) use a nonlinear least squares model to investigate the acreage responses of corn and soybeans to changes in futures prices, cash prices, and support prices. Their model is specified as

\[ A_t = a_0 + a_1(b_1 FPC_t + b_2 CPC_{t-1} + b_3 SPC_t) + a_2(c_1 FPS_t + c_2 CPS_{t-1} + c_3 SPS_t) + a_3 A_{t-1} + \ldots \]

where futures prices (FP), cash prices (CP) and effective support prices (SP) for corn (C) and soybeans (S) are each deflated by production costs. The futures prices are the weekly average futures prices during the week of March 15, the cash prices are one-year lagged average market prices, and the effective support prices are weighted averages of target prices and loan rates. Applying their model to the United States for
the period 1957-77, Chavas et al. find for corn that the own-price short-run elasticity is 0.441 and the cross-price elasticity (with respect to soybean price) is -0.206. Both elasticities are significant at the 5% level and have the expected signs. The coefficient on lagged corn acreage is positive but not statistically significant. Its small value indicates that the acreage response of corn happens very rapidly. For soybeans the own-price acreage elasticity is 0.590 and the cross-price elasticity is -0.584. Both are significant at 5%. Here, the coefficient (0.8862) for lagged acreage is large and significant, indicating a slower acreage adjustment that occurs over multiple time periods.

Shideed et al. (1987) use an autoregressive moving average (ARMA) model to investigate corn and soybean acreage responses to conditional price expectations, which take into account both market and support prices. For the 1951-86 period, they find that the own-price coefficients are both positive and significant at the 1% level, and the cross-price coefficients are both negative and significant at 5%. The respective $R^2$ values for the corn and soybean regressions are 0.92 and 0.98, and the null hypothesis of no serial correlation cannot be rejected. Short-run own-price elasticities are 0.137 for corn and 0.274 for soybeans, while the respective long-run values are 0.183 and 0.741.

Burt and Worthington (1988) focus on the supply response of wheat for 1949-77 and consider the U.S. as a whole, the Great Plains region, and the individual states that constitute the Great Plains. They run different models for classic and first order moving average (MA1) disturbances. All price elasticities are of the expected sign, and their values are higher for the plains than for the U.S. at large. The elasticities of
the eight individual states range from slightly less than to approximately twice the
elasticity of the Great Plains. Burt and Worthington note a more complicated
dynamic configuration than what is discussed in other studies. They find that the lag
response persists with an irregular structure for up to four years and then undergoes a
rapid geometric decline. The authors postulate that crop-rotation dynamics and latent
state variables, such as the planting of summer fallow on the Great Plains, lead to the
choppy lag structure.

Reed and Riggins (1981) distinguish their study of corn acreage response
from others through its level of disaggregation. Their stated purpose is to “investigate
the gain in explanatory power which can accrue to acreage supply functions for corn
when data is disaggregated beyond state level.” They divide the state of Kentucky
into 14 areas and then compare the results of each areal regression with the statewide
results. The level of disaggregation, along with the use of area-specific prices and
acreages, allows for increased accuracy in variable measurement and inter-areal
variability in the production function. The results show a large discrepancy between
the aggregate acreage response and those of the individual areas. At state level, the
own-price coefficient is actually negative (but not significant). The coefficient on the
price of soybeans is not significant. For 12 of the 14 area-specific equations, the
own-price coefficients are positive, with 5 being significantly different from zero.
Short-run elasticities range from 0.34 to 0.56 and long-run from 0.93 to 2.07.
Soybean-price coefficients are negative for all but one equation, and 5 of the 13
negative coefficients are significant. To explain the discrepancy between the state
and sub-state results, Reed and Riggins test the hypotheses that the slope coefficients
are equal and that the intercepts are equal (for the 14 area equations). Both hypotheses are rejected at the 1% level, indicating that some aspects of planted acreage vary between areas.

Langpap and Wu (2008) use parcel-level data from the Natural Resources Inventory (NRI) sites. The parcels cover the Corn Belt, the Lake States, and the Northern Plains, which together accounted for 86% of the nation’s corn acreage in 2002. The authors use a logit model to investigate farmers’ decisions to convert non-cropland to cropland. They find that -- for the Corn Belt, Lake States, and Northern Plains -- a 1% increase in the expected price of corn leads to respective increases of 0.2%, 0.1%, and 0.4% in the probability of parcel conversion to cropland. Langpap and Wu then use a multinomial logit model to estimate the acreage responses of corn, soybeans, wheat, and hay. The own-price elasticities are found to be positive for all crops in each region, while the cross-price elasticities may be positive or negative depending on the specific cross price and region.

Environmental Impact

The use of fertilizers, pesticides, and other chemicals in agriculture can have a significant effect on the environment. Nitrogen, a major component of inorganic fertilizers and manure, is especially dangerous to both humans and ecosystems. Unlike other common components of fertilizer such as phosphates and potassium, nitrogen does not locally accrue in soil if unused by plants (Nolan et al. 1997). Instead, it is typically converted into water-soluble nitrates that can leak into the water table (Nolan et al. 1997). Once a part of the groundwater, nitrates may remain
for decades while continuing to accumulate as additional nitrogen is applied to the
land surface (Nolan et al. 1997). The mobility of nitrates is dependent upon soil
properties. Nitrates can travel long distances under the right conditions. For
example, the Susquehanna River transports nitrates from its basin in New York and
Pennsylvania to the Chesapeake Bay (Pionke and Urban 1985). According to
Spalding and Exner (1993), regions “where well-drained soils are dominated by
irrigated cropland” have a tendency to develop large areas of groundwater with
nitrate concentrations exceeding the Environmental Protection Agency (EPA) limit of
10 milligrams per liter of NO₃N (nitrate nitrogen). Nolan (2005) states that NO₃N
concentrations are expected to be highest where well-drained soils “overlie
unconsolidated sand and gravel aquifers.” The geologic conditions of certain regions
make them more susceptible to high levels of contamination. The greatest
contamination risks generally occur west of the Missouri River, with the upper
Midwest, the High Plains of Nebraska, and northwestern Texas being particularly
vulnerable (Nolan et al. 1997). Some areas east of the Missouri, including parts of
the mid-Atlantic and the Northeast, are also at risk (Nolan et al. 1997). Spalding and
Exner (1993) describe Iowa as a transition zone to higher levels of contamination
going west.

Numerous studies have established a connection between agricultural land use
and nitrate pollution. Due to its mobility, nitrogen used as fertilizer may pollute not
only lakes and streams but also coastal waters. The U.S. Environmental Protection
Agency (EPA), in its National Water Quality Inventory, cites agriculture as the
leading source of pollutants for both rivers and lakes (EPA 2000). The U.S.
Geological Survey reports a correlation between fertilizer use and high concentrations of nitrogen in streams (Economic Research Service 2006). Several authors have studied the effect of fertilizer use in the Mississippi River Basin on nitrogen loading in the Gulf of Mexico. Goolsby et al. (1999) conclude that 65% of nitrogen loads entering the Gulf from the Mississippi Basin are of agricultural origin. The Economic Research Service (2006) estimates that as much as 15% of nitrogen applied to Basin cropland is transported to the Gulf. Excess nitrogen in surface waters leads to a higher population of algae in lakes and increased production by phytoplankton in the ocean (EPA 2000). The subsequent decay of these organisms reduces the level of oxygen in the bottom waters, resulting in fish kills if the oxygen depletion is too severe (Nolan, 2005). In the Gulf, this hypoxic zone covers up to 7,000 square miles in the summer and is a major threat to the commercial fishing and recreation industries (Wu and Tanaka 2005).

Nitrate pollution may also have a direct effect on human health. Groundwater is the source of drinking water for over 50% of the U.S. population, providing 39% of the public-water supply for cities and 96% of self-supplied domestic water (Nolan et al. 1997). For 12% to 46% of wells sampled in agricultural regions, nitrate concentrations exceed the EPA-established maximum contaminant level for drinking water (Hamilton and Helsel 1995). High levels of nitrate consumption by humans have been associated with “blue baby” syndrome, bladder and ovarian cancers, and non-Hodgkin’s lymphoma (Nolan 2005).
**CRP Acreage Response**

While many studies have looked at the supply response of crops to a change in agricultural prices, CRP acreage response has received relatively little attention. Tanaka and Wu (2004) analyze conservation policies using parcel-level Natural Resource Inventory (NRI) data for the upper Mississippi River Basin (UMRB) region. Using a LOGIT model, they estimate CRP participation probabilities with respect to the CRP rental rate, prior land use, variance of corn yield, land quality, wage rate, and climatic variables. They find that 1% increases in the CRP rental rate and the wage rate increase the respective probabilities of CRP participation by 2% and 5%. They find smaller but still positive elasticities with respect to the soil erodibility and the variance of the corn yield.

As part of their study on using easements and taxes to decrease nitrogen runoff in the UMRB, Wu and Tanaka (2005) develop a CRP supply curve as a function of the CRP rental rate. They find that the CRP acreage increases nonlinearly as a function of the rental payment. The acreage response is elastic if the rental rate is between $100 and $200 or above $250 per acre but inelastic below $100 or between $200 and $250. When the rental rate is below $250 per acre, few acres of corn or soybeans are enrolled in the CRP, though the respective profits per planted acre are only $200 and $150. The authors suggest three reasons why CRP enrollment requires a higher payment than the profit forgone. First, the CRP provides less than 50% of the participants’ costs to establish conservation covers on their land. Second, there may be a cost associated with returning land to crop production after a CRP contract expires. Finally, even if CRP rental rates cover the forgone agricultural profit, the
potential for development on some lands during the period of a CRP contract will likely preclude enrollment.

Secchi and Babcock (2007) model CRP enrollment as a function of the corn price. They construct CRP supply curves for the state of Iowa, which has over two million acres of CRP land and produces more corn than any other state, by estimating whether each land parcel currently enrolled in the CRP would earn more by remaining in the program or by being cropped for different levels of corn and soybean prices. The factors considered in constructing these supply curves are crop prices, crop yields, and CRP rental rates, the latter of which are approximated by Farm Service Agency (FSA) Soil Rental Rates (SRR). Secchi and Babcock find that, for a corn price of $3 per bushel, almost one million acres of CRP land would go back into production. Some of the returned production would consist of corn-soybean rotations instead of continuous corn. The authors estimate that an additional $314 million of CRP payments would be required to limit the CRP acreage loss to 200,000 acres in the case of $3 corn. Were the price of corn to reach $3.66 per bushel, almost 1.2 million acres would return to production, and even a doubling of the CRP rental rate would fail to save 675,000 CRP acres.

Secchi and Babcock use the Environmental Policy Integrated Climate (EPIC) model to assess the environmental impact of a reduction of CRP acreage. They find that “environmental impacts increase drastically as higher corn prices bring into production more and more environmentally fragile land.” For example, nitrogen losses, which hover around 11,000 tons with all current CRP acreage out of
production, would jump to over 50,000 tons at $5 corn. Similar negative environmental consequences are found for sediment and phosphorus losses.
CHAPTER 3

METHOD

Data Collection and Manipulation

The objective of this thesis is to investigate the land use adjustments that result from a change in agricultural prices. This is accomplished in two parts. First, regression analysis is used to examine the effect of a price change on planted acreage. Second, econometric methods are used to investigate the effect of a price change on CRP enrollment. The environmental impacts of land use change, due to different levels of fertilizer application, and CRP acreage adjustments are also considered. Several pieces of data were needed to accomplish these goals.

The first dataset compiled consists of planted acreage data for corn, soybeans, and wheat. The data, which were obtained from the USDA National Agricultural Statistics Service (NASS), cover the entire United States at county level for the period 1976-2007. 1976 was chosen as the first year of data collection due to data availability limitations in earlier years. Corn, soybeans, and wheat were chosen because they, along with hay, represent the four largest crops by acreage in the United States (U.S. Environmental Protection Agency 2007). Hay was excluded due to the unavailability of futures prices. Wheat was divided by seasonality into winter wheat and spring wheat. Winter wheat, which was planted in the fall and harvested in the spring, was not included in the dataset because its seasonal cycle is out of phase with the other crops. The crops included in the analysis – corn, soybeans, and spring
wheat – are all planted in the spring and harvested in the fall. The term “wheat” will hereafter refer to spring wheat.

A measure of farmers’ pre-planting expectations of harvest-time crop prices was constructed from a combination of futures prices and government support prices. For each year from 1976-2007, futures prices were obtained in the pre-planting season for the closest available post-harvest date. In accordance with Chavas et al. (1983), March 15 was chosen as the representative date at which price expectations are formed prior to planting. The closest post-harvest dates of futures-price availability are December, November, and September for corn, soybeans, and wheat, respectively. The futures prices were obtained from the Chicago Board of Trade (CBOT). Target prices, which were abolished in 1996 and reinstated in 2000, were chosen as the appropriate measure of government price supports. These were collected from Green (1990) for the period 1976-90 and from the USDA Economic Research Service (ERS) for 1991-95 and 2000-07. Since target prices are not applicable to 100% of a farmer’s land, the raw target prices were converted to weighted target prices through multiplication by the percentage of base acreage permitted for planting. Following Langpap and Wu (2007), a price expectation was defined as the greater of the weighted target price and the futures price in the planting season.

Some measure of the input price was also needed. The price indices for crop seeds, wages, agricultural chemicals, and fertilizer were obtained from NASS for the period of study. Both the expected prices and input prices were indexed to the 1992 price level.
To investigate the acreage response of CRP land to a change in crop prices, county-level CRP acreage data were needed. These were obtained from the USDA Farm Service Agency (FSA) for the period 1987-2007. Total CRP rental payments by state and year for the same time period were also collected. The acreage and payment datasets were combined, and average rental rates by state were calculated for each year.

The importance of nitrates in determining the potential environmental damage of crops was established in the literature review. Hence, the use of nitrogen fertilizer is the focus of the analysis of environmental effects. Nitrogen fertilizer data were collected from ERS for corn, soybeans, and wheat. Two sets of data were obtained: the first contains the percentage of acres that received nitrogen fertilizer for all year-state combinations, and the second gives the amount of nitrogen applied per fertilized acre. The datasets were combined multiplicatively to yield an average quantity of nitrogen applied per acre for any given state and year.

The four assembled datasets – crop acreage, crop prices, CRP cumulative acreage, and CRP rental rates – were imported into Stata. A master dataset was created for crops by merging the crop acreage and price data. This dataset contains county-level acreages and national-level expected and input prices for the years 1976-2007. A master CRP dataset was constructed by first merging the CRP acreage and CRP rent datasets and then merging that product with the master crops dataset for the period 1987-2007. The resulting dataset includes CRP and crop acreages at county level, CRP rent at state level, and crop prices at national level.
The crops dataset initially included data for 2,851 counties. Of these counties, 2,777 have a history of corn planting during the 32-year period for which data are available. The respective numbers for soybeans and wheat are 2,217 and 542 counties. Since corn is of primary interest because of its utility as a biofuel, the analysis was restricted to counties where corn was planted or has the potential to be planted given a sufficient price incentive. Since the data collected extend across the lengthy period of 32 years, counties in which corn was not planted during this period were deemed not to have the potential for corn planting. The assumption that these 74 counties are not suitable for corn planting is probably realistic, for most of them are located in parts of Florida, Nevada, Texas, Oklahoma, Idaho, and Montana where climate or terrain is inhospitable to corn growth. Consequently, these counties were dropped from the dataset.

**Theoretical Model**

*Crop Response*

Following Chavas et al. (1983), a general economic model for planted acreage is

\[ A^k = f(EP^k, EP^{-k}, IP^k) \]  \hspace{1cm} (1)

where \( A^k \) is planted acreage of crop \( k \), \( EP^k \) is the expected price of crop \( k \), \( EP^{-k} \) are the expected prices of other crops, and \( IP^k \) represents the input price of crop \( k \). Given the restrictions imposed on planting decisions by crop rotations, this model does not sufficiently capture the determinants of planted acreage. Dynamic elements, in the form of lagged acreages, must be included. Lagging the dependent variable allows
the acreage adjustment in response to a price change to occur over a period of more than one year (Shideed et al. 1987). The planted acreage of any crop is also dependent on the previous year’s acreage of other crops with which it may be rotated. Additionally, planting decisions depend on physical variables including land quality and weather conditions. A more appropriate model of dynamic acreage response is

$$A^k_t = f(A^k_{t-1}, A^{-k}_{t-1}, EP^k_t, EP^{-k}, IP^k_t, PV_t)$$ \hspace{1cm} (2)

where $A^k_t$ is planted acreage of crop $k$ at time $t$, $A^k_{t-1}$ is planted acreage of crop $k$ at time $t-1$, $A^{-k}_{t-1}$ are planted acreages of other crops at time $t-1$, and $PV_t$ represents physical variables, including land quality and weather conditions, at time $t$.

The three acreage response models were estimated independently rather than as a system. The system approach is preferable from a purely spatial perspective, but it does not allow for the use of the dynamic estimators that are most appropriate for the intertemporal dependence of the model. Since the temporal aspects were deemed to be of primary importance, the equations were estimated independently.

**CRP Response**

CRP enrollment should depend on the rental payments for CRP land and the opportunity cost of enrollment, which is determined by the price levels and input prices of crops that would otherwise be planted. The opportunity cost of enrollment for any parcel is also affected by soil quality, weather conditions, and other physical variables that may influence the parcel’s productivity. The general framework for a CRP acreage model is

$$ACRP = f(R, EP, IP, PV)$$ \hspace{1cm} (3)
where $ACRP$ is acreage enrolled in the Conservation Reserve Program, $R$ is the rental rate for CRP land, $EP$ represents the received prices of crops that may be planted on land not set aside for conservation, $IP$ represents the input costs of those crops, and $PV$ includes the physical variables that affect productivity. Like the crop acreage equation, the CRP acreage equation should include lagged acreages of the crops that compete with the CRP for land. Furthermore, a dynamic component in the form of the lagged CRP acreage allows the acreage adjustment to occur over more than one time period. The complete dynamic model is

$$ACRP_t = f(ACRP_{t-1}, A^k_{t-1}, R_{t-1}, EP_{t-1}, IP_{t-1}, PV_{t-1}) \quad (4)$$

where $ACRP_t$ is CRP acreage at time $t$, $ACRP_{t-1}$ is CRP acreage at time $t-1$, $A^k_{t-1}$ is planted acreage of crop $k$ at time $t-1$, $EP_{t-1}$ and $IP_{t-1}$ represent received and input prices of crops at time $t-1$, and $PV_{t-1}$ represents physical variables at time $t-1$.

**Crop Acreage Response**

*Econometric Model*

The data considered are panel data by definition, for there are both time series and cross-sectional components. In particular, the datasets are “wide” panels, the number of groups being much larger than the number of time periods. For a given crop (corn, soybeans, or wheat) at time $t$, the planted acreage should depend on its expected price, the expected prices of other major crops, the seed price, and agricultural chemical prices. The basic panel regression model is

$$A^k_{i,t} = a_i + b_1 EPC_t + b_2 EPS_t + b_3 EPW_t + b_4 Seed_t + b_5 Chem_t + e_{i,t} \quad (5)$$
where $A^k_{i,t}$ is the planted acreage of crop $k$ for county $i$ at time $t$, and $k=\text{corn (c), soybeans (s), or wheat (w)}$; $EPC_t$, $EPS_t$, and $EPW_t$ are the respective expected prices of corn, soybeans, and wheat at time $t$; $Seed_t$ is the seed price of crop $k$ at time $t$; $Chem_t$ is the price of chemical inputs to agricultural production at time $t$; and $e_{i,t}$ is the residual for group $i$ at time $t$. When dynamics are introduced, the model becomes

$$A^k_{i,t} = a_i + b_1EPC_t + b_2EPS_t + b_3EPW_t + b_4Seed_t + b_5Chem_t + b_6A^c_{i,t-1} + b_7A^s_{i,t-1} + b_8A^w_{i,t-1} + e_{i,t} \quad (6)$$

where the additional three terms represent one-period lagged acreages of corn, soybeans, and wheat, respectively.

This model is used for the acreage responses of corn, soybeans, and wheat. Several different estimators are used for each equation, and the results are reported, compared, and discussed in the chapter 4.

**Regression Analysis**

Heterogeneity between groups is an important consideration when working with panel data. Individual effects, represented by $a_i$ in equation 5, may be categorized as either fixed or random. A fixed effects (FE) model allows the $a_i$ to be correlated with the regressors. The $a_i$ are group-specific constant terms (Greene 2003). The random effects (RE) model requires that the $a_i$ be purely random, which implies that they are uncorrelated with the independent variables (Greene 2003). If the stronger condition of randomness in the individual effects is satisfied, there is a wider array of options for the consistent estimation of the model. The first step of the analysis was to determine whether the FE model or the RE model is appropriate.
Stata’s panel data procedure, xtreg, was used to estimate the model from equation 5 under both the FE and RE specifications. The Hausman test was used to determine which specification is correct. Under the null hypothesis of no correlation between the individual effects and regressors, both ordinary least squares (OLS) and generalized least squares (GLS) are consistent. Under the alternative, the least squares estimators are inconsistent (Greene 2003). Thus, if the null hypothesis is true and the individual effects are random, the OLS and GLS estimates should be similar because both are consistent (Cameron and Trivedi 2009).

By the Hausman test, the null hypothesis of random effects could not be rejected for the three crops considered. The presence of random effects means that the pooled OLS and pooled FGLS (or population-averaged) estimators are consistent.

The regressors are known to be uncorrelated with the individual effects, but, for the consistency of OLS to hold, they must also be uncorrelated with the error term \( e_{i,t} \). Cluster-robust standard errors, which are inflated relative to the default standard errors in order to account for clustering within groups, ensures that correlation within groups does not cause incorrect inference (Cameron and Trivedi 2009). Serial correlation over time, which is a problem in the acreage response model, must also be controlled for. One method of correcting for serial correlation is to lag the dependent variable. The lagged dependent variable eliminates the autocorrelation problem and incorporates a dynamic component into the model. Unfortunately, it also introduces inconsistency into the OLS estimate due to correlation between the dependent variable and the residual, so the results must be interpreted with an awareness of possible bias (Greene 2003).
The next estimator applied to the acreage equation was the pooled FGLS or population-averaged (PA) estimator. FGLS, in which the distribution of the population is not fully specified, is more efficient than pooled OLS, and error correlation restrictions are specified to control for serial correlation (Cameron and Trivedi 2009). Cluster-robust standard errors were used when running the pooled FGLS model.

The Arellano-Bond estimator, developed specifically for dynamic panels, is consistent for both FE and RE (Greene 2003). The Arellano-Bond method uses first differences to remove individual effects from the regression equation. It therefore has the additional benefit of removing the effects of land quality, weather conditions, and other physical variables from the model. Arellano-Bond is based on the generalized method of moments (GMM), which is a technique used when the number of moment conditions exceeds the number of parameters to be estimated. Under GMM, the parameters are chosen to minimize the total degree to which the moment conditions are violated while not necessarily satisfying any conditions explicitly. With the Arellano-Bond estimator, equation 6 becomes

\[ A_{k,t}^b - A_{k,t-1}^b = b_1(EP_{C_t} - EP_{C_{t-1}}) + b_2(EP_{S_t} - EP_{S_{t-1}}) + b_3(EP_{W_t} - EP_{W_{t-1}}) + b_4(Seed_t - Seed_{t-1}) + b_5(Chem_t - Chem_{t-1}) + b_6(A_{c,t-1}^c - A_{c,t-2}^c) + b_7(A_{s,t-1}^s - A_{s,t-2}^s) + b_8(A_{w,t-1}^w - A_{w,t-2}^w) + (e_{i,t} - e_{i,t-1}) \]  

(7)

where the notable feature is the lack of an individual effects term. Since it is valid for fixed effects, Arellano-Bond not only provides an additional comparison of results, but also results which are free of bias if the true model has fixed effects. The
Hausman test determined that the model is one of random effects, but the test results may be invalid under certain circumstances such as the presence of serial correlation (Cameron and Trivedi 2009). Arellano-Bond allows for the comparison of results generated by a RE-only method with those from an estimator which is immune to individual effects. Agreement between the results of these different estimators provides a check on the validity of the Hausman test result. The consistency of the Arellano-Bond estimator requires that the first-differenced errors be serially uncorrelated (Cameron and Trivedi 2009). In order to control for autocorrelation, it was necessary to add additional lags of the dependent variable and to classify the non-dependent lagged acreages as predetermined. Furthermore, because of autocorrelation, low-order moving-average (MA) models were applied to the error terms. The MA models allowed for a more complex error structure of the predetermined variables in order to more effectively control serial correlation.

CRP Acreage Response

Econometric Model

The basic regression model for the CRP acreage response is

\[ ACRP_{i,t} = a_i + b_1 R_{i,t-1} + b_2 W_{t-1} + b_3 EPC_{t-1} + b_4 EPS_{t-1} + b_5 EPW_{t-1} + \]

\[ b_6 Yld_{i,t-1} + e_{i,t} \]  

(8)

where \( ACRP_{i,t} \) is the CRP acreage for group \( i \) at time \( t \) and \( R_{i,t} \) is the CRP rental payment per acre for group \( i \) at time \( t \). \( EPC_{i,t}, EPS_{i,t}, \) and \( EPW_{i,t} \) are the respective expected prices of corn, soybeans, and wheat at time \( t \). \( W_{t-1} \) is the wage paid for agricultural labor at time \( t-1 \). It represents the primary input cost of growing crops on
a parcel of land. \( Yld_{i,t-1} \), which was used as a proxy for land quality, is the county-specific yield (bushels/acre) of corn. The correlation between the yields of different crops is high. The yield of corn was chosen as the indicator of land quality because corn is planted in nearly every county in the study. \( e_{i,t} \) is the residual for group \( i \) at time \( t \). When dynamics are introduced, the model becomes

\[
ACRP_{i,t} = a_i + b_1 ACRP_{i,t-1} + b_2 A_{i,t-1}^C + b_3 A_{i,t-1}^F + b_4 A_{i,t-1}^W + b_5 R_{i,t} + b_6 W_{t-1} + b_7 EP_{i,t-1} + b_8 EPS_{i,t-1} + b_9 EPW_{i,t-1} + b_{10} Yld_{i,t-1} + e_{i,t} \tag{9}
\]

where the additional four terms represent a one-period lag of CRP acreage and one-period lagged acreages of corn, soybeans, and wheat, respectively.

**Regression Analysis**

The process followed to analyze the response of the CRP acreage to a change in commodity prices closely parallels that for the response of crop acreage. FE and RE models were run first, and the Hausman test was applied to determine which model was appropriate. Here, the model was found to have fixed effects. The OLS estimator was run next. Then the regression equation was estimated with dynamic panel methods including the Arellano-Bond estimator and two moving-average estimators.

**Environmental Impact**

Chapter 4 includes a discussion of the environmental impact of a change in crop prices. This analysis is in the context of chemical use, with a focus on nitrogen fertilizer. Separate FGLS regressions were run for each state in the Corn Belt: Iowa,
Illinois, Indiana, Kansas, Kentucky, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, South Dakota, and Wisconsin. The resulting coefficients were then applied to each county within a state, and the planted acreages generated were summed to give the total planted acreage for the state under a chosen set of prices. The acreages for each state were then added together to get the total number of planted acres in the Corn Belt. Over the past two decades, the prices of corn, soybeans, and wheat have hovered around $2, $6, and $3, respectively. Hence, these values were chosen as baseline prices for the simulations. Initial acreages were then generated from the model. Using nitrogen fertilizer application data obtained from the USDA Economic Research Service, nitrogen quantities were calculated for the initial acreages of each crop and summed to get a total nitrogen quantity. Once the initial prices and acreages were set and the amount of nitrogen fertilizer was calculated, the model was perturbed by changing to a different price level. The resulting changes in acreage and fertilizer use were computed. Total nitrogen fertilizer use and use per acre in the final state were then compared to their initial values.

Agricultural prices may also impact the environment indirectly through their effect on the CRP. The idling of cropland under the CRP has been demonstrated to reduce field runoff and soil erosion, sequester carbon dioxide, and increase the populations of numerous wildlife species (Food and Agricultural Policy Research Institute 2007). As discussed in chapter 2, Secchi and Babcock (2007) constructed CRP land supply curves for the state of Iowa for several different prices of corn. The regression analysis performed here yields an estimate of the change in CRP acreage
that would accompany a given change in the price of corn, soybeans, or wheat. The resulting elasticities allow an assessment of the environmental damages that may occur due to price-driven CRP acreage adjustments.
CHAPTER 4

RESULTS

Crop Acreage Response

Econometric Results

Semi-log fixed and random effects estimators were applied to the acreage response models for corn, soybeans, and wheat. An estimated coefficient in the semi-log model represents a percent increase in acreage for a $1 increase in price. The RE results for corn acreage, shown in table 1, are as expected. The coefficient of the expected corn price, 0.29, is positive and significant at the 5 % level, and the coefficient of the seed price is negative and significant. The price elasticity of corn acreage, or the percent increase in corn acreage due to a 1 % increase in the price of corn, is 0.69. Table 1 also shows the results of the FE model. The Hausman test points to RE as the correct model, but the FE results do not differ from the RE results. The wheat acreage equation has a similarly positive own-price coefficient of 0.24 (table 5), while the coefficients on corn and soybean prices are not significant. A 1 % increase in the price of wheat would lead to a 0.10 % increase in the planted acreage of wheat. The seed price of wheat was not included in the regression due to its high correlation with the chemical price. The result for soybeans is unexpected: The own-price coefficient is negative (-0.13) and significant, but the expected price of corn has a positive and significant coefficient of 0.14 (see table 3). The associated own-price elasticity is -0.07. This result will be explained following the presentation of the dynamic results.
The acreage response for each crop was next estimated by pooled OLS with cluster-robust standard errors. The model was run with and without state-specific dummy variables. The only effect of the state dummies was to slightly increase the t statistics of the regression results. Tables 1, 3, and 5 display the results with state dummies included. The own-price coefficients for corn and wheat, 0.28 and 0.20 respectively, are similar to those from the RE model. One-percent increases in the prices of corn and wheat lead to respective acreage increases of 0.59 % and 0.55 %. Once again the own-price coefficient of soybeans is negative, with a value of -0.10 (for a price elasticity of -0.31). Autocorrelation is present to a high degree. Correlation coefficients between the residuals exceed 0.8 through a lag of 10 periods.

Autocorrelation can also be corrected for by lagging the dependent variable, though this may cause inconsistency in the estimate in the case of an endogenous regressand (Greene 2003). Despite possible bias, the introduction of a lagged dependent variable was deemed to be a worthwhile exercise because it brings dynamic effects into consideration. The influence of crop rotations is thus captured in the model. A lagged dependent variable, along with one-period lags of the other crops, was incorporated into each regression equation. The inclusion of two dependent lags eliminated autocorrelation in each model. As above, own-price coefficients for corn and wheat are positive and significant, and the seed-price coefficient for corn is negative and significant. The notable difference is in the own-price coefficient of soybeans, which has changed sign and is now 0.10. The respective own-price acreage elasticities are 0.42, 0.29, and 1.00 for corn, soybeans, and wheat. The coefficients for the one-period lagged dependent variables are all
positive and significant. They range in value from 0.67 for corn to 0.92 for soybeans. Second-period lags are smaller but still positive for all crops.

Because the model was determined to have random effects, the pooled FGLS estimator is consistent. Consistency of pooled FGLS requires that the individual effects be uncorrelated across regressors, so FGLS can be applied to a RE model. To run the population-averaged model, an error structure was specified with autocorrelation across two periods, and cluster-robust standard error calculations were used in case of a wrongly specified error configuration. As with the lagged OLS model, the resulting own-price coefficients are all positive and significant: 0.15 for corn, 0.05 for soybeans, and 0.34 for wheat (see tables 1, 3, and 5). The respective own-price acreage changes associated with 1% price increases are 0.42%, 0.41%, and 1.05%. The seed price of corn is negative and significant, but the seed price of soybeans is not significant.

The Arellano-Bond estimator was developed specifically to be consistent and efficient for dynamic panels. Arellano-Bond is valid for both RE and FE models but may be biased when serial correlation is present. The first run involved a single lag of the dependent variable in each equation. Log transformations were applied to both the dependent variable and the independent variables that have acreage dimensions. The resulting coefficients are positive and significant for own-price expectations but negative and significant for seed prices. The own-price elasticities are 0.60, 0.27, and 0.90 for corn, soybeans, and wheat, respectively. The lagged dependent variables have positive, significant coefficients ranging from 0.19 for corn to 0.66 for soybeans. Although these results are consistent with those of the pooled FGLS and lagged OLS
models, the presence of autocorrelation was detected. Therefore, it was necessary to alter the lag structure of the model and to consider the need for predetermined classifications of certain independent variables.

The Arellano-Bond estimator requires that all groups included in the regression have values for each lagged independent variable; that is, a county must have a history of planted acreage for all three crops in order to be used as part of the sample. Because wheat is planted in far fewer counties than corn and soybeans are, the lag of wheat acreage cuts the number of counties used in the Arellano-Bond estimate to approximately 10% of the total number in the study. As a robustness check, the estimator was rerun without the lag of wheat acreage. The results have less meaning because of the omitted variable bias, but it is worth noting that the own-price coefficients remained in the range established by the other estimators: 0.20 for corn and 0.04 for soybeans.

Allowing the error in previous periods to have some influence on the non-dependent lagged acreages (e.g. one-period lags of soybean and wheat acreages for the corn acreage equation) in later periods – i.e. setting these lags as predetermined – goes a long way toward correcting for autocorrelation. In the corn model, the predetermined acreages, along with a four-period lag of the dependent variable, successfully remove autocorrelation while showing a significant result for the own-price coefficient. The value of this coefficient is 0.29, and the associated elasticity is 0.64. This result is a good match for those obtained via the FGLS and one-lag Arellano-Bond estimators. Unfortunately, applying the predetermined condition to
the soybean and wheat models causes the regressors to lose their statistical
significance at the 5% level.

The final estimator applied to the crop acreage data involves the specification
of a moving-average error structure. An MA3 model, with the non-dependent lagged
acreages designated as predetermined, gives results which are very similar to those of
Arellano-Bond (see tables 1, 3, and 5). With the MA3 error configuration, the own-
price coefficients for all three crops are positive and significant.

\textit{CRP Acreage as a Regressor}

As a robustness check, the crop acreage model was run with CRP acreage as
an additional regressor for the period 1987-2007. CRP acreage is never statistically
significant and does not alter the results.

\textit{Nitrate Simulations}

As described in chapter 3, the regression results for the Corn Belt were
combined with usage data for nitrogen fertilizer to simulate the effect of a price
change on nitrate application quantities. The initial prices of corn, soybeans, and
wheat were respectively set at $2, $6, and $3 per bushel. These prices are typical of
market prices in recent years. Based on these prices, the Corn Belt initially has 68.4
million acres (MA) of corn, 49.8 MA of soybeans, and 9.5 MA of (spring) wheat.
The average quantities of nitrogen fertilizer applied are 132.5, 2.9, and 55.3 pounds
per acre (lb/A). Therefore, the total quantity of nitrogen fertilizer applied is more
than 4.8 million tons (Mt).
An increase in the price of corn to $3 per bushel would increase corn planting to 77.2 MA (see table 7), while soybean and wheat plantings would decline to 47.1 and 8.2 MA, respectively. The net change in total nitrate application is an increase to 5.4 Mt, which in percentage terms is an 11% increase. If the price of corn increases to $5, corn acreage would reach almost 95 MA. Despite corresponding decreases in soybean and wheat plantings, the total quantity of nitrogen fertilizer would be 6.5 Mt, a 33% increase from the baseline case.

While the corn price is of primary interest, a brief look at the effects of soybean and wheat prices is useful for comparison. An increase in the price of soybeans from $6 to $8 per bushel would increase the total quantity of nitrogen by less than 1%. This overall increase would be achieved due to more planting of both soybeans and wheat at the expense of very little corn. Were wheat prices to rise from $3 to $4, both wheat and corn acreage would increase. Only soybean acreage would decrease, and soybeans are by far the least fertilizer intensive of the three crops. The net result would be an increase of 6% in fertilizer application. If wheat prices hit $5, nitrogen use would go up by more than 11% over the base level.

In reality, the prices of different commodities adjust simultaneously, so it is a constructive exercise to conduct a few simulations in which the price of more than one commodity is variable. If corn and soybeans reach respective price levels of $3 and $8 while the wheat price remains at $3, there will be a 12% increase in total nitrogen fertilizer application. Were corn and wheat prices each to increase by $1 per bushel with a fixed soybean price, total nitrogen use would jump by more than 17% to 5.7 Mt. These increases would occur due to a combination of greater total planted
acreage and the replacement of soybeans with the more chemical-intensive corn or wheat. At $3 corn, $7 soybeans, and $4 wheat, corn and wheat acreages would increase, but soybean acreage would fall. The result is a 17% greater nitrogen application level relative to the baseline case. Finally, if $2 increases occurred simultaneously for both corn and soybeans while a $1 increase occurred for wheat, total nitrogen use would skyrocket by 28%. Several other scenarios are shown in table 7.

**CRP Acreage Response**

*Econometric Results*

The procedure followed to analyze the CRP acreage response was very similar to that used for crop acreage. The model was first tested for fixed versus random effects; FE was found to be appropriate, meaning that OLS and FGLS are inconsistent estimators. Though inconsistent, pooled OLS was still run for comparison purposes. Arellano-Bond and moving-average estimators were also applied to the model. The CRP acreage was regressed on the CRP rental rate, the wage rate, the yield of corn, and the prices received for corn, wheat, and soybeans.

As shown in table 8, the FE model yields significant coefficients for the CRP rental rate, the wage rate, and the prices of all three crops. The coefficient on CRP rent is 27. A 1% increase in the rental rate would lead to a 0.07% increase in CRP enrollment. The wage rate has a coefficient of -160, and its elasticity is -0.94. The price of corn has a negative coefficient of -2921, with an associated elasticity of -0.54. The prices of soybeans and wheat have coefficients of 391 and 1,275. Their
price elasticities are 0.18 and 0.32. The negative coefficient on the wage rate is unexpected and is discussed following the results of the dynamic models.

The coefficients on all prices but that of wheat are significant under pooled OLS with cluster-robust standard errors. The rental rate has a coefficient of 21, giving 0.05 as the rent elasticity of CRP acreage. The wage rate has a coefficient of -188 and an elasticity of -1.11. The price of corn has a coefficient of -5489, with a corresponding price elasticity of -1.01. The price of soybeans has a positive coefficient of 605 and an elasticity of 0.27. Curiously, the yield variable, an indicator of land quality, has a significant, positive coefficient of 103 and an elasticity of 0.83. The R-squared value is 0.34, suggesting that there are other factors that contribute to the variability of the data. As with the crop model, the consideration of dynamic effects is an important aspect of the CRP model’s explanatory power.

Arellano-Bond estimation, which features a lag of the dependent CRP acreage, results in significant coefficients for the wage, the prices of all commodities, and the yield. The wage coefficient is 384, and the wage elasticity is 1.12. The coefficients of corn, soybean, and wheat prices are -671, 948, and -536. Their respective elasticities are -0.06, 0.21, and -0.07. The coefficient of yield is -5.6, and its elasticity is -0.03. A full correction for autocorrelation was not achieved, so there may be some bias in these results.

The CRP acreage response was also estimated with the MA1 and MA3 error configurations. Under the MA1 specification, the coefficient of the CRP rental rate is 62, and the elasticity is 0.06. The wage rate also has a positive coefficient of 318 and an elasticity of 0.86. The prices of corn and wheat have negative coefficients of -
1,591 and -1,635, with respective elasticities of -0.14 and -0.19. The price of soybeans has a positive coefficient of 1,496 and an elasticity of 0.31. The yield variable has a coefficient of -8 and an elasticity of -0.03.
Table 1: Corn Acreage Response Coefficients

<table>
<thead>
<tr>
<th>VARIABLES</th>
<th>FE</th>
<th>RE</th>
<th>OLS</th>
<th>FGLS</th>
<th>Arellano-Bond</th>
<th>MA3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Expected Price of Corn</td>
<td>0.293**</td>
<td>0.292*</td>
<td>0.283**</td>
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Robust standard errors in parentheses; ** p<0.01, * p<0.05
Table 2: Corn Acreage Response Elasticities

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<th>VARIABLES</th>
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<th>OLS</th>
<th>FGLS</th>
<th>Arellano-Bond</th>
<th>MA3</th>
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<td>Expected Price of Corn</td>
<td>0.69*</td>
<td>0.59*</td>
<td>0.42*</td>
<td>0.60*</td>
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<td>Expected Price of Soybeans</td>
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<td>-0.21*</td>
<td>-0.03*</td>
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<td>-0.11</td>
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<td>Expected Price of Wheat</td>
<td>0.01</td>
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<td>Price of Corn Seeds</td>
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<td>-0.59*</td>
<td>-1.17*</td>
<td>-1.18*</td>
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<td>Acres of Corn (t-1)</td>
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<td>N/A</td>
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### Table 3: Soybean Acreage Response Coefficients

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<th>MA3</th>
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<tbody>
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<td>Expected Price of Wheat</td>
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<td>-0.063**</td>
<td>-0.116**</td>
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<td>(0.041)</td>
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<td>Price of Soybean Seeds</td>
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<td>0.028**</td>
<td>0.012**</td>
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<td>-0.012*</td>
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<td>(0.003)</td>
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<td>(0.006)</td>
<td>(0.005)</td>
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<td>-0.012**</td>
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<td>-0.007**</td>
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<td>(0.000)</td>
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<td>N/A</td>
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<td>Acres of Soybeans (t-1)</td>
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Robust standard errors in parentheses; ** p<0.01, * p<0.05
### Table 4: Soybean Acreage Response Elasticities

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<th>FGLS</th>
<th>Arellano-Bond</th>
<th>MA3</th>
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<tbody>
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<td>Expected Price of Corn</td>
<td>0.05*</td>
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<td>-0.25*</td>
<td>-0.17*</td>
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<td>Expected Price of Soybeans</td>
<td>-0.07*</td>
<td>-0.31*</td>
<td>0.41*</td>
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<td>Expected Price of Wheat</td>
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<td>-0.04*</td>
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<td>N/A</td>
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<td>N/A</td>
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Table 5: Wheat Acreage Response Coefficients

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<td>-0.007</td>
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Robust standard errors in parentheses; ** p<0.01, * p<0.05
<table>
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<th>VARIABLES</th>
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<th>OLS</th>
<th>FGLS</th>
<th>Arellano-Bond</th>
<th>MA3</th>
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<td>Expected Price of Corn</td>
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<td>-0.40*</td>
<td>-0.39</td>
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<td>0.23</td>
<td>0.11</td>
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<td>Expected Price of Wheat</td>
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<td>1.05*</td>
<td>0.90*</td>
<td>1.10*</td>
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<td>Acres of Soybeans</td>
<td>Acres of Wheat</td>
<td>Total Acres</td>
<td>Total Nitrates (tons)</td>
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<td>---------------</td>
<td>-------------------</td>
<td>----------------</td>
<td>-------------</td>
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<td>$5 corn, $6 soybeans, $3 wheat</td>
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<td>$2 corn, $8 soybeans, $3 wheat</td>
<td>68,328</td>
<td>53,157</td>
<td>10,491</td>
<td>131,976</td>
<td>4,892</td>
</tr>
<tr>
<td>$3 corn, $8 soybeans, $3 wheat</td>
<td>76,993</td>
<td>49,946</td>
<td>9,291</td>
<td>136,231</td>
<td>5,429</td>
</tr>
<tr>
<td>$2 corn, $6 soybeans, $4 wheat</td>
<td>71,410</td>
<td>49,300</td>
<td>12,325</td>
<td>133,035</td>
<td>5,142</td>
</tr>
<tr>
<td>$3 corn, $7 soybeans, $4 wheat</td>
<td>79,949</td>
<td>47,532</td>
<td>11,657</td>
<td>139,139</td>
<td>5,686</td>
</tr>
<tr>
<td>$4 corn, $8 soybeans, $4 wheat</td>
<td>88,488</td>
<td>45,765</td>
<td>10,990</td>
<td>145,243</td>
<td>6,231</td>
</tr>
</tbody>
</table>

Note: units in thousands of acres
### Table 8: CRP Acreage Response Coefficients

<table>
<thead>
<tr>
<th>VARIABLES</th>
<th>FE</th>
<th>OLS</th>
<th>Arellano-Bond</th>
<th>MA1</th>
<th>MA3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rent (t-1)</td>
<td>26.713**</td>
<td>21.076**</td>
<td>2.091</td>
<td>62.140**</td>
<td>43.582**</td>
</tr>
<tr>
<td></td>
<td>(6.000)</td>
<td>(7.926)</td>
<td>(5.296)</td>
<td>(16.983)</td>
<td>(12.354)</td>
</tr>
<tr>
<td>Wage (t-1)</td>
<td>-160.289**</td>
<td>-187.658**</td>
<td>383.545**</td>
<td>318.204**</td>
<td>395.048**</td>
</tr>
<tr>
<td></td>
<td>(17.183)</td>
<td>(30.386)</td>
<td>(63.337)</td>
<td>(116.622)</td>
<td>(121.479)</td>
</tr>
<tr>
<td>Price of Corn (t-1)</td>
<td>-2,921.081**</td>
<td>-5,489.432**</td>
<td>-671.444*</td>
<td>-1,590.738**</td>
<td>-1,419.304**</td>
</tr>
<tr>
<td></td>
<td>(201.049)</td>
<td>(625.577)</td>
<td>(337.332)</td>
<td>(523.078)</td>
<td>(500.730)</td>
</tr>
<tr>
<td>Price of Soybeans (t-1)</td>
<td>390.951**</td>
<td>605.180**</td>
<td>948.063**</td>
<td>1,496.101**</td>
<td>1,464.469**</td>
</tr>
<tr>
<td></td>
<td>(83.183)</td>
<td>(116.216)</td>
<td>(154.770)</td>
<td>(262.685)</td>
<td>(242.259)</td>
</tr>
<tr>
<td>Price of Wheat (t-1)</td>
<td>1,274.640**</td>
<td>-247.982</td>
<td>-536.082*</td>
<td>-1,635.037*</td>
<td>-1,377.832*</td>
</tr>
<tr>
<td></td>
<td>(126.151)</td>
<td>(330.574)</td>
<td>(255.979)</td>
<td>(703.500)</td>
<td>(660.928)</td>
</tr>
<tr>
<td>Corn Yield (lagged)</td>
<td>0.290</td>
<td>102.907**</td>
<td>-5.630*</td>
<td>-8.239*</td>
<td>-12.215*</td>
</tr>
<tr>
<td></td>
<td>(1.366)</td>
<td>(20.209)</td>
<td>(2.197)</td>
<td>(3.702)</td>
<td>(4.871)</td>
</tr>
<tr>
<td>Time trend (year)</td>
<td>253.731**</td>
<td>47.893</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>(16.808)</td>
<td>(56.450)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No signup period (dummy variable)</td>
<td>1,063.257**</td>
<td>830.903**</td>
<td>-33.673</td>
<td>-477.446*</td>
<td>-437.616**</td>
</tr>
<tr>
<td></td>
<td>(77.134)</td>
<td>(121.775)</td>
<td>(81.382)</td>
<td>(197.668)</td>
<td>(164.377)</td>
</tr>
<tr>
<td>Acres of CRP (t-1)</td>
<td>N/A</td>
<td>N/A</td>
<td>0.502**</td>
<td>0.506**</td>
<td>0.375**</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(0.030)</td>
<td>(0.046)</td>
<td>(0.074)</td>
</tr>
<tr>
<td>Acres of Corn (t-1)</td>
<td>N/A</td>
<td>N/A</td>
<td>0.020**</td>
<td>0.069**</td>
<td>0.051**</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(0.007)</td>
<td>(0.018)</td>
<td>(0.013)</td>
</tr>
<tr>
<td>Acres of Soybeans (t-1)</td>
<td>N/A</td>
<td>N/A</td>
<td>-0.003</td>
<td>0.000</td>
<td>-0.017</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(0.009)</td>
<td>(0.026)</td>
<td>(0.021)</td>
</tr>
<tr>
<td>Acres of Wheat (t-1)</td>
<td>N/A</td>
<td>N/A</td>
<td>-0.012</td>
<td>0.011</td>
<td>-0.005</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(0.007)</td>
<td>(0.015)</td>
<td>(0.011)</td>
</tr>
<tr>
<td>Constant</td>
<td>19,725.749**</td>
<td>12,823.948**</td>
<td>-20,743.647**</td>
<td>-17,916.985*</td>
<td>-19,409.844*</td>
</tr>
<tr>
<td></td>
<td>(1,178.783)</td>
<td>(2,187.494)</td>
<td>(4,463.376)</td>
<td>(8,198.860)</td>
<td>(8,225.807)</td>
</tr>
<tr>
<td>Observations</td>
<td>37754</td>
<td>37754</td>
<td>2296</td>
<td>2408</td>
<td>2408</td>
</tr>
<tr>
<td>R-squared</td>
<td>0.033</td>
<td>0.338</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Robust standard errors in parentheses

** p<0.01, *p<0.05
<table>
<thead>
<tr>
<th>VARIABLES</th>
<th>FE</th>
<th>OLS</th>
<th>Arellano -Bond</th>
<th>MA1</th>
<th>MA3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rent (t-1)</td>
<td>0.068*</td>
<td>0.054*</td>
<td>0.002</td>
<td>0.062*</td>
<td>0.048*</td>
</tr>
<tr>
<td>Wage (t-1)</td>
<td>-0.944*</td>
<td>-1.106*</td>
<td>1.115*</td>
<td>0.861*</td>
<td>1.187*</td>
</tr>
<tr>
<td>Price of Corn (t-1)</td>
<td>-0.54*</td>
<td>-1.014*</td>
<td>-0.062*</td>
<td>-0.136*</td>
<td>-0.134*</td>
</tr>
<tr>
<td>Price of Soybeans (t-1)</td>
<td>0.175*</td>
<td>0.271*</td>
<td>0.212*</td>
<td>0.311*</td>
<td>0.338*</td>
</tr>
<tr>
<td>Price of Wheat (t-1)</td>
<td>0.318*</td>
<td>-0.062</td>
<td>-0.067*</td>
<td>-0.189*</td>
<td>-0.177*</td>
</tr>
<tr>
<td>Corn Yield</td>
<td>0.002</td>
<td>0.834*</td>
<td>-0.021*</td>
<td>-0.028*</td>
<td>-0.046*</td>
</tr>
<tr>
<td>No signup period (dummy variable)</td>
<td>0.008*</td>
<td>0.006*</td>
<td>0.00</td>
<td>-0.002*</td>
<td>-0.002*</td>
</tr>
<tr>
<td>Time trend (year)</td>
<td>0.426*</td>
<td>0.08</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Acres of CRP (t-1)</td>
<td>N/A</td>
<td>N/A</td>
<td>0.579*</td>
<td>0.55*</td>
<td>0.452*</td>
</tr>
<tr>
<td>Acres of Corn (t-1)</td>
<td>N/A</td>
<td>N/A</td>
<td>0.051*</td>
<td>0.168*</td>
<td>0.137*</td>
</tr>
<tr>
<td>Acres of Soybeans (t-1)</td>
<td>N/A</td>
<td>N/A</td>
<td>-0.007</td>
<td>0.001</td>
<td>-0.043</td>
</tr>
<tr>
<td>Acres of Wheat (t-1)</td>
<td>N/A</td>
<td>N/A</td>
<td>-0.028</td>
<td>0.024</td>
<td>-0.013</td>
</tr>
</tbody>
</table>
CHAPTER 5

CONCLUSION

Interpretation of Results

Crop Acreage Response

Basic supply theory and previous empirical studies suggest that an increase in the expected price of a crop or a decrease in the input price leads to an increase in the acreage on which it is planted. For corn, this expectation was confirmed regardless of which estimator was employed or whether dynamics were considered. The own-price acreage elasticities of corn range from 0.42 to 0.69. When the scope of the analysis is restricted to the Corn Belt, the range of elasticities becomes 0.36 to 0.44. Previous studies, which were conducted at an aggregate level for the United States, found elasticities between 0.16 (Gallagher 1978) and 0.44 (Chavas et al. 1983).

In the existing literature, own-price elasticities of soybean acreage response fall between 0.27 (Shideed et al. 1987) and 0.61 (Gardner 1976). Here, the elasticities range from 0.27 to 0.41. The exception is the -0.31 elasticity computed from the pooled OLS estimator. Pooled OLS is a consistent estimator for this model specification, but it does not take into account the dynamic aspect of acreage response. The incorporation of a dynamic element, in the form of a lagged dependent variable, allows for the consideration of a “slow” acreage response that occurs over more than one time period. Arellano-Bond regression resulted in a coefficient of 0.66 (0.73 elasticity) for lagged soybean acreage. In contrast, lagged corn acreage has a coefficient of only 0.19 (0.07 elasticity). The lagged wheat coefficient, 0.44, approximately splits the difference between the corn and soybean coefficients, but its
elasticity is on the level of soybeans at 0.80. These results indicate that dynamic considerations are critical in the analysis of soybean and wheat acreage responses, but somewhat less important when examining the response of corn. It seems that farmers respond quickly (i.e. by the next planting season) to variations in the price of corn but may be much slower to respond if a price change occurs for soybeans or wheat. Chavas et al. (1983) noted an even larger discrepancy between the lagged acreages of corn and soybeans. They found a coefficient of 0.89 for soybeans but only 0.04 for corn.

Own-price elasticities for wheat acreage response are 0.55 under pooled OLS and range from 0.90 to 1.10 when the estimator includes dynamic effects. In the soybean model, the failure to account for dynamics leads to an own-price elasticity of the wrong sign. The bias is not so extreme for corn or wheat, but estimators in which dynamic effects are considered yield greater own-price elasticities. This result is expected given the above discussion of the lagged acreage coefficients for each crop. For corn the acreage response to a price change is rapid. Therefore, dynamic effects are small enough that their exclusion makes little difference in the computed elasticity. Soybean acreage may require multiple time periods to fully adjust in response to a price change, making the incorporation of dynamics critical. For the wheat equation, dynamic considerations are also important but perhaps not to the extent of soybeans. Ignoring dynamics leads to an elasticity which is approximately half of that obtained otherwise.
Environmental Effects

Simulations were conducted on the Corn Belt to investigate the effect of a change in commodity prices on the quantity of nitrogen fertilizer applied to soils. The simulation results suggest that an increase in the price of any commodity will lead to a greater application of nitrogen, though the effect may be very small with respect to the price of soybeans. With $5 corn instead of $3 corn, 67% of the total planted acreage will consist of corn rather than 53%. Since the average nitrogen fertilizer application rate is much higher for corn than for other crops, the total quantity of nitrogen applied will increase by 33%. An increase in soybean prices from $6 to $8 would bring about an increase in nitrogen application of less than 1%. Soybeans are by far the least nitrogen intensive of the three crops, but a higher soybean price leads to increases in both soybean and wheat acreage and only a small decrease in corn acreage. The additional nitrogen fertilizer due to the increase in total planted acreage is just enough to offset the loss associated with the small reduction in corn acreage. A jump in the wheat price from $3 to $4 would increase the quantity of nitrogen fertilizer by 6%. This increase occurs due to a combination of greater wheat and corn plantings. Prices of different commodities often move together. A simultaneous increase in the prices of corn and wheat leads to an especially large jump in the amount of nitrogen fertilizer applied to agricultural lands. Under the realistic scenario of $4 corn, $8 soybeans, and $4 wheat, the projected increase in nitrogen usage is about 28%.

As discussed in chapter 2, nitrogen fertilizer is an apropos representative of the environmental impact of agriculture because it is widely used and has the
potential to cause significant damage to ecosystems, including fish kills and algae
booms. Studies have linked nitrate contamination in drinking water to numerous
human health issues including methemoglobinemia, certain cancers, and several
reproductive issues (Ward et al. 2005). Because of the potential adverse effects of
nitrates, it is important to understand how economic incentives may alter the level of
nitrogen fertilizer usage in agriculture. The simulations conducted here only estimate
the effect of a price change on the amount of nitrogen fertilizer used. Actual damages
caused by nitrates are highly dependent on soil properties for which data are
unavailable at the level of aggregation used in this study. Hence, the simulation
results only suggest the change in the potential for environmental damage as a result
of a change in a commodity price.

**CRP Acreage Response**

The elasticity of CRP acreage is negative with respect to the prices of corn
and wheat but positive with respect to that of soybeans. The price elasticity of corn
falls between -0.06 and -0.54, with -0.14 being MA1 result. The extremes of this
range are the results of the Arellano-Bond and fixed effects estimators, respectively.
The price elasticity of soybeans falls between 0.18 and 0.34. The pooled FE model
produces the 0.18 value, while the MA3 model yields 0.34. The price elasticity of
wheat is significant in all models but OLS. Its value is positive in the FE model but
negative in the three dynamic models, with elasticities ranging from -0.07 to -0.19.

The wage elasticity of CRP acreage is -0.94 under the FE estimator and
-1.11 under OLS. These elasticities are expected to be positive, for a higher wage
rate increases the cost of planting crops and thus decreases the opportunity cost of enrollment in the CRP. Elasticities with the expected sign are found under the dynamic models. Respective wage elasticities are 1.12, 0.86, and 1.19 for the Arellano-Bond, MA1, and MA3 models. The corn yield is an indicator of land quality. More productive land should be less likely to be enrolled in the CRP program because the opportunity cost of enrollment is higher; hence, the yield elasticity is expected to be negative. OLS again fails to agree with the theory, but the dynamic models find that yield elasticities fall between -0.02 and -0.05. The elasticity of the CRP rental rate is also expected to be positive since a greater payment per acre is a direct increase in the benefits associated with CRP enrollment. As expected, the elasticity is positive and ranges from 0.05 to 0.07.

The dynamic models are clearly appropriate in this framework. The land-use system has substantial inertia, and dynamic models are able to account for the dependence of current land use on past land use. Furthermore, these models can detect changes in acreage that occur over multiple periods of time. Slow changes in response to an independent variable are not captured through fixed effects or OLS. As illustrated above, the failure to consider dynamic elements can drastically alter the results of a regression. Hence, in cases where the results of the dynamic and non-dynamic models diverge, those from the dynamic models should be considered more legitimate.

There are a number of shortcomings and limitations of this analysis. A CRP contract lasts between 10 and 15 years. It would be ideal to have a measure of long-term price expectations instead of simply an expected price for the current year.
However, constructing such a measure would be difficult, and it would be unclear whether or not this metric would actually capture the expectations of farmers. Another issue is that the CRP enrollment data are cumulative. It is only possible to observe the net change in enrollment from one year to the next. A more thorough analysis could be conducted if the annual change in CRP enrollment were separated into new contracts and expired or broken contracts.

CRP enrollment is capped at 25% of a county’s total crop acreage. If a county reaches its enrollment limit in some particular year, farmers would be unable to respond to a price incentive by enrolling additional land in the CRP. Ignoring this 25% limit could cause the econometric results to understate the true price elasticity of CRP acreage. If a county is pushing against its CRP cap in a given year, the model would incorrectly attribute its non-increase in CRP acreage to a lack of price responsiveness. The magnitude of this effect would vary depending on the number of times the limit is reached and the price levels of those years, but it would always result in a weakening of the econometric results.

The dataset does not contain total cropland for each county and year, but there is a way to check on the significance of the “cap effect”. Included in the data are corn, soybean, and wheat acreages. For the county-year combinations in which CRP enrollment is less than 25% of the sum of these three crops, the county must be below its CRP limit (since total cropland is at least as great as the sum of corn, soybeans, and wheat). More than 70% of observations meet this condition. The possibility that the remaining 30% of the observations is against the cap was tested by creating a dummy variable for the relevant county-year combinations. A re-
estimation of the model with the dummy variable yields results that are negligibly
different from previous estimates. The dummy variable is not statistically significant,
and the change in elasticity is only on the order of thousandths. Therefore, the
acreage cap on CRP enrollment is not an important consideration.

Policy Implications

Recent government mandates for biofuels have altered the demand structure
for corn and other crops. Increased demand drives up the prices of these
commodities. The supply response to a price change affects land use and
consequently the environmental footprint of agriculture. This thesis presents an
econometric model of the land use changes that would accompany a change in the
price of an agricultural product. It goes on to discuss potential environmental impacts
through the use of nitrogen fertilizer and the change in land set aside for conservation.

The econometric results show that, in agreement with the laws of supply and
demand, an increase in the price of corn, soybeans, or wheat would increase the
number of acres allocated to its planting. The respective price elasticities of acreage
for these three crops, from a population-averaged estimator, are 0.42, 0.41, and 1.05.
Simulation results show that an increase in the price of corn or wheat would
significantly increase the amount of nitrogen fertilizer applied to soils. A higher price
of corn leads to greater nitrogen use because corn is the most chemical intensive of
crops. The increase in fertilizer associated with additional corn acreage is more than
enough to overcome the decrease due to soybean and wheat reductions. If the price
of wheat increases, both wheat and corn acreages increase since the cross-price
elasticity with corn is positive. The resulting increase in nitrogen fertilizer dominates the decrease due to the loss of soybean acreage.

The Conservation Reserve Program provides a myriad of environmental benefits, which are valued at approximately $1.3 billion annually (Hansen 2007). These environmental benefits include improved water quality, erosion control, and increased wildlife populations. For the year 2007, the Food and Agricultural Policy Research Institute (FAPRI 2007) estimated that the 34.5 million acres of CRP land reduced field runoff and percolation of nitrogen and phosphorus by 278 million pounds and 59 million pounds, respectively. FAPRI also found that grass filters and riparian buffers constructed on CRP land intercepted 203 million pounds of nitrogen and 49 million pounds of phosphorus. According to the Farm Service Agency (FSA), the CRP reduced soil erosion by 470 million tons in 2007 relative to pre-CRP levels and sequestered over 50 million tons of carbon dioxide. The CRP has been shown to increase the populations of several bird species including prairie pothole ducks, ring-necked pheasants, and sage grouse (Farm Service Agency 2008). In this thesis, acreage enrolled in the CRP was found to have an elasticity between -0.06 and -1.01 with respect to the price of corn. This result suggests that an increase in the price of corn may cause a significant decrease in the quantity of conserved land and, hence, in the associated environmental benefits. The efficacy of the CRP in improving water quality, controlling erosion, and providing wildlife habitat may be limited in the coming years with the expectation of a high corn price.

Areas with high-quality agricultural land are clearly the most susceptible to a decline in CRP enrollment when the price of corn increases. One policy option that
may be used to prevent CRP land from returning to production is to increase the CRP rental rate paid to farmers. Like those of Secchi and Babcock (2007), the results here suggest that this policy would require a large increase in government expenditures to be effective. An increase in the wage rate associated with agricultural production, because it reduces the opportunity cost of CRP enrollment, may also help to temper the loss of CRP acreage. If the input cost of agricultural moves in step with the price of corn, it may provide a natural impediment to the decline in conserved land that results from an increase in the price of corn.

Extensions

This thesis focuses only on the land-use and environmental implications of agricultural price changes in the United States. Biofuel demand is thought to be a major driving force behind these price fluctuations, so a natural extension of this research would be to conduct similar analyses in other countries with significant ethanol production or the potential for significant production. In recent years, the U.S. and Brazil have been by far the largest producers of ethanol, together accounting for about 72% of the world’s production (Goldemberg et al. 2008). A myriad of factors must be considered in assessing the suitability of one country for ethanol production versus another. Brazilian ethanol is produced primarily from sugarcane, and sugar ethanol has an inherent advantage over corn ethanol in its energy balance of production and net emission of greenhouse gases (Goldemberg et al. 2008). The issue of food prices and availability, though outside the scope of this thesis, is a critical consideration that has received much attention in academic literature and the
news media. The environmental effect of increased ethanol production in Brazil may be significant. Land on which sugarcane is produced experiences the highest level of erosion of any agricultural land in Brazil (Pimentel and Patzek 2007). Compared to the production of other crops in Brazil, the production of sugarcane uses greater amounts of nitrogen fertilizer, herbicides, and insecticides (Pimentel and Patzek 2007). Since soybeans, the single largest crop planted in Brazil, take little or no nitrogen fertilizer, the replacement of soybeans with sugarcane could increase nitrogen application significantly (Martinelli and Filoso 2008). In assessing whether or not one country has a comparative advantage in ethanol production, subsidies must also be considered. Like the United States, Brazil has a history of subsidizing ethanol production. Pimentel and Patzek (2007) suggest that the total subsidy for ethanol accounted for about 50% of its production cost in 2005.

Conclusion

Recently, the push toward biofuels has been a major factor in determining agricultural prices. Inflated demand for corn drives up its price, leading to greater corn planting at the expense of other crops. Corn is the most chemically intensive of the crops with which it is rotated, so the substitution of corn for other crops is damaging to the environment. A higher price of corn also brings conserved land back into agricultural production. In addition to an increase in chemical application, this return to production leads to greater erosion of soils, decreased local carbon sequestration, and a loss of habitat for wildlife. Biofuel mandates and subsidies, if
not accompanied by substantial conservation incentives for farmers, may have negative consequences for the environment and land conservation.
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