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Factors Influencing Direct and Indirect Energy Use in U.S. Corn Production

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Abstract

The recent volatility of energy prices has numerous policy implications for agriculture. A better understanding of the factors associated with energy consumption as related to crop production management decisions and technology use may provide insight about how producers might respond to program or market incentives targeting energy use in particular, and soil and water conservation in general. Adoption of minimum tillage could reduce erosion and improved fertilizer management practices could reduce nitrogen runoff. Energy costs may be reduced with adoption of reduced tillage technology, improved drying and irrigation systems, or more careful attention to the application and timing of fertilizers.

Key words: energy, fuel, nitrogen, farm management, technology

JEL Classification: Q12, Q40

Introduction

Recent volatility in real prices for petroleum products has resurrected concerns about the vulnerability of the agricultural sector to rapidly rising energy costs. Energy-intensive farms are vulnerable to energy price shocks because prices paid by farmers for petroleum products, or direct energy, mirror the national energy markets (Figure 1). Furthermore, most agricultural producers purchase energy indirectly in other inputs, such as commercial nitrogen fertilizers. Fuel and electricity costs for field operations, irrigation, and drying combined with fertilizer costs account for a significant amount of the cost of production for many crops. Recent price increases are similar to the large energy price shocks of the mid-1970's and early 1980's that clearly stimulated economic research on energy use in the agricultural sector (Figure 2).

Prior to the 1970's, energy expenditure was a relatively modest share of agricultural production costs, and few studies appeared to focus on the role of energy in production agriculture. Soon after the 1973-74 price shock, journal articles appeared explaining the linkages between energy prices and the agricultural sector (e.g., Carter and Youde; Adams, et al.). During the 1980's, numerous applied studies on the impact of energy prices on production agriculture appeared (e.g., Harman, et al.; Gowdy, et al.; Adela and Hoque). Much of the earlier research on energy price implications for agriculture focused on operations research models such as input-output and linear or quadratic programming, partly due to the dearth of farm level surveys which collected data on energy-intensive crops, inputs, practices, and technologies (Havlicek and Capps). Some econometric studies regarding energy use by farms used aggregate, sector level data (Miranowski (1980); Zinser et al.).

Given the resurgence of energy price increases since 1999 (and the availability of detailed farm-level survey data), we would expect renewed interest in the economics of agricultural energy use. Indeed, recent analysis of farm input use and energy consumption include Miranowski (2005) and Raulston et al. It may also be hypothesized that sustained energy price increases (relative to other input prices) would encourage producers to eventually adopt energy-conserving production practices or cropping systems. For example, agriculture's response to changing price relationships would likely include: adoption of energy efficient farm tractors and machinery; improvement in monitoring and applying irrigated water; improvements in on-farm drying, storage, and cooling systems; employing minimum tillage systems; and more careful management of energy-intensive inputs, such as fertilizers (Carter and Youde). Most historical studies suggest that producers do not, or cannot, adjust energy use in the short run so that net income is adversely affected. In the long run, higher real energy prices cause producers to adjust their enterprise mix and/or production practices by adopting energy-conserving technologies.

This paper focuses on corn, a widely grown and energy-intensive crop, whose production is greatly affected by energy price shocks. In particular, we focus on direct and indirect energy used to produce the 2001 corn crop. Examples of direct energy use include fuel used by tractors, drying, and irrigation. Indirect energy consumption includes use of nitrogen fertilizers. Seventy to ninety percent of nitrogen (N) fertilizer manufacturing costs are attributable to the high temperatures required during its production (Fee). The objectives of this paper are to: 1) present survey-based information on the extent of adoption of energy-related production practices and technologies by U.S. corn producers in 2001; 2) identify farm and operator characteristics that influence per acre fuel expenditures and per acre nitrogen use in corn production; and 3) discuss the potential policy implications of the analysis. Our primary data source is the phase II 2001 Agricultural and Resource Management Survey (ARMS). This survey focuses on the costs associated with corn production on a given field. As research on field crop energy use has been very limited, the results of this research provide a basis for discussion of future changes in production practices that energy prices could affect and policies could encourage. The findings may also serve as a benchmark for other potential research concerning energy use in agricultural production.

Conceptual Framework

We use an empirical model to understand how crop producers might respond to changes in energy costs at the farm-level. Individual farm use of fuels and nitrogen fertilizer are determined by input demand functions and input prices. Given that the survey data used here are a cross section, input and output prices would have limited variation. Regional and farm characteristics that could result in variations are noted below. Thus, the major variations in input demand would arise from input marginal productivity.

Farm enterprise structure, operator attributes, household characteristics, and regional characteristics are hypothesized to influence demand for fuel and fertilizer. Assuming that producers are rational, profit maximizing agents, the following demand system specifies the empirical model:

(1) Direct fuel consumption:

Total Fuel Expenditures for field/field acres = $f(\mathbf{S}, \mathbf{M}, \mathbf{E}, \mathbf{H}, \mathbf{R}) + \varepsilon_{Fuel}$

(2) Indirect fuel consumption:

Nitrogen applied to the field/field acres = $g(\mathbf{S}, \mathbf{M}, \mathbf{H}, \mathbf{R}) + \varepsilon_{N}$

The dependent variable in equation 1 is the total fuel expenditures for the survey field normalized by field size. Total fuel expenditures is used to proxy fuel quantities used since this information was not available. The dependent variable in equation 2 is the nitrogen rate applied to the survey field normalized by field size. It is hypothesized that management decisions, and perhaps additional unobserved factors, may be correlated; $Cov(\varepsilon_{Fuel}, \varepsilon_N) = [\sigma^2_{Fuel}\ \rho\sigma_{Fuel}\sigma_N; \rho\sigma_N\sigma_{Fuel}\ \sigma^2_N]$, with $\rho\sigma_{Fuel}\sigma_N$ the covariance between the equations. Farm structural variables (**S**), field management decisions (**M**), household and operator characteristics (**H**), farm equipment (**E**), and regional characteristics (**R**) are hypothesized to influence energy consumption associated with corn production.

Farm structure (**S**)

Farm structure variables include the total farm corn acres grown in 2001 (and the square of those acres), the production revenue shares from livestock and corn sales, and a variable indicating whether the operator owned the corn field surveyed in 2001.

The total acres measures effects associated with economies or diseconomies of size. Volume discounts in price are one economy of size; another is the opportunity to more appropriately size machinery to field size. A diseconomy of size for fuel is the greater distance to move equipment and labor to outlaying areas for larger operations (Kay and Edwards). Both input demands may be subject to other economies associated with different productivities for different sizes.

The ownership variable identifies a situation where the inputs may have a higher productivity than a share lease. In addition, more fuel for weed control and more residual nitrogen has a more certain future value for owned land than leased land. Myyra, et al. recently reviewed literature and conducted an empirical analysis that supports this logic.

The revenue shares from corn and livestock measure production diversification. Katchova recently demonstrated that diversification reduces productivity. A larger share for corn would indicate that the farm can devote more managerial resources to this enterprise, which may influence input productivity. A larger share for livestock may have an opposite effect, resulting in less managerial attention to corn and other crops.

Management decisions (**M**)

Irrigation will increase the demand for both inputs—more energy will be required for irrigation and plant nitrogen uptake efficiency is increased for irrigated corn. Use of reduced tillage was measured by the percent of crop residue remaining on the survey field, which was estimated from the previous crop grown in the field and number and type of tillage operations, including planter type, for the 2001 corn crop. Over time, reduced tillage should result in higher residue and lower fuel costs. The effect on nitrogen is not so clear. Reduced tillage increases surface organic matter. As a result, more nitrogen is available from the soil and less may be applied. In other instances, more fertilizer nitrogen may be lost through leaching, denitrification, and volatilization so that more fertilizer may be necessary (Fullen and Catt, p. 129-131). A dummy variable for fall nitrogen contracting was included in both equations. A similar variable was not available for fuel contracting, so nitrogen contracting proxies that variable in the fuel equation. The usual expectation from contracting inputs in the fall is that it reduces cost because of lower fall prices (Huang, Uri, and Hansen). A dummy variable for crop insurance purchase is included to proxy risk preferences of the operator. More risk averse producers would more likely purchase crop insurance, and more risk averse producers would be more likely to use more (fewer) of inputs that are risk decreasing (increasing). Of course, purchase of crop insurance reduces risk faced by a producer so it could then have the opposite effects on input use.

Management decisions that may be associated with demand for fuel include use of custom services, use of Bt or herbicide-tolerant corn, distance to market, and whether corn grain is dried on the farm. Biotech corn plants may reduce insecticide or herbicide use (Fernandez, Klotz-Ingram, and Jans), which could result in fewer field operations and fuel used. Drying corn on the farm will typically increase fuel requirements, and distance to market should increase fuel for hauling corn. Use of custom operations should substitute for and decrease fuel use.

Management decisions that may be specifically associated with N application include: (1) use of advice from crop consultants, extension agents, or fertilizer dealers on application rates, (2) use of nitrogen soil tests on the field, (3) use of a nitrogen loss inhibitor (4) existence of a nutrient management plan, (5) use of variable rate technology to apply fertilizer, (6) application of manure to the field, (7) corn yield goal, (8) and the previous crop being clover, alfalfa, or soybean. A series of dummy variables also considered the effects split N applications have on the total amount of nitrogen applied.

Sheriff has a recent review of management decisions associated with fertilizer use that provides expectations on these decisions. While the usual presumption is that following outside advice will reduce fertilizer applications, it can increase application rates if the farmer does not apply an efficient amount without the advice. Such a view is particularly relevant for fertilizer dealers. Soil tests, nitrogen loss inhibitors, nutrient management plans, and variable rate technology are usually associated with lower fertilizer application rates. However, all these practices make fertilizer use more efficient and could therefore increase use. For example, variable rate fertilizer prescriptions may call for increased fertilizer rates in the most fertile parts of fields. A higher yield goal should increase fertilizer requirements. Manure is a substitute source of nitrogen so its use should reduce fertilizer use. Having legumes as the previous crop should also reduce requirements because of residual nitrogen. Split applications have different effects at different times. Fall N applications rates likely increase rates because of subsequent nitrogen losses during the winter and early spring. Applications after planting are when plants need nitrogen most and should reduce rates. Applications in the spring before planting should be somewhere between these two rates, and combined application times should be a combination of these separate rates.

Household and operator characteristics (**H**)

Operator and household characteristics include operator age, operator educational attainment as measured by college experience of the operator, and the proportion of total household income earned off–farm. Age and college are standard measures of human capital productivity effects. Off-farm income is another measure of specialization of the family resources. With more off-farm income, the family has fewer managerial resources to devote to farm enterprises, which should decrease the efficiency of farm inputs. This lower efficiency may result in higher input use because more inputs are required or fewer inputs because they have a lower productivity. Fernandez-Cornejo, Hendricks, and Mishra recently used similar logic to explain the adoption of herbicide-tolerant soybeans.

Equipment (**E**)

Tractor horsepower increases the fuel requirement per acre (Werblow) while use of diesel reduces fuel requirements (Miranowski, 2005). Planter row width should also reduce fuel use as the planter increases in size. Higher repair costs are usually associated with older machinery, which may be less fuel efficient. However, some repaired older machinery may have lower fuel requirements.

Regional attributes (**R**)

Regional variables are included in both equations to control for differences in farm structure, climate, access to and competitiveness of agricultural service markets, input and output price variation, and growing seasons that can affect resource productivity (Khanna). Corn prices have regional variations due to price basis differences. Input prices can also have some variation due to differences in input availability, distance from manufacturing and distribution points, and other factors influencing price. Input availability may also impact the particular type of energy used for irrigation and/or drying—electricity, natural and liquid petroleum gas, and other petroleum products are all used for these activities in different production regions.

Data and Methodology

The analysis uses the USDA's Agricultural and Resource Management Survey (ARMS), which is the only annual source of data on the finances and practices of a nationally representative sample of U.S. farms. The survey is collected in three phases. Phase I is a pre-survey screening of candidate respondents (the list frame). Phase II, conducted in the fall, focuses on the costs and practices associated with a specific crop on a specific field. Corn was the focus of the 2001 survey. The Phase III survey, conducted the following January-February, interviews the same households about operator and household characteristics, farm production and resources, and cost and returns at the farm enterprise level. After adjusting for non-response, the final sample size available for regression analysis is N = 1,721, representing 329,535 farms.

The influence that management decisions have on energy consumption at the farm level is modeled using a bivariate censored regression because some growers did not apply N and others incurred no fuel costs (Lee). The dependent variable for one equation is the per acre fuel costs for corn production, which includes petroleum products, electricity, and natural or LP gas, and for the other is nitrogen (N) applied per acre for corn. Equations (1) and (2) are estimated as linear, first order expansions of functions representing demand for fuel and nitrogen for corn production.

Because of the complex survey design of the ARMS, variances of estimated parameters are calculated based on standards established by the National Agricultural Statistical Service, using the delete-a-group jackknife variance estimator (Kott; Dubman). Details and implementation of this procedure are outlined in El-Osta, Mishra, and Ahearn. The delete-a-group jackknife procedure was used to estimate the variances of the coefficients and the equation in the censored regressions.

Results

Adoption levels of variables

The 2001 ARMS reveals a wide variation in the adoption levels of technologies and practices that influence direct energy use on farms producing corn. For example, over 95 percent of the farms use diesel tractors, 28 percent have on-farm crop drying facilities, but less than 10 percent irrigate (Table 1). The switch from less fuel efficient gas tractors to diesel is nearly complete, and most producers rely on solar (i.e., in-field drying) or off-farm energy for drying. The average crop residue left after planting was estimated at to be 24 percent, which is below the standard definition of conservation tillage (i.e., 30 percent residue cover). Thus, a significant potential remains for energy savings from the adoption of reduced tillage systems. Between 13 and 17 percent of the farms reported using Genetically Modified (GM) seed in 2001, but the adoption rate has increased significantly since then.

Indirect energy use, as reflected by N application rates on farms producing corn, is also affected by the use of various nutrient management practices, technologies, and information sources. Two substitutes for N, legumes (as a previous crop, primarily soybeans) and manure have different use rates. Farms planting corn following a leguminous crop (55 percent) were primarily located in the Eastern Cornbelt States. Manure was used on about 20 percent of the farms—especially those located near pork, beef, or dairy regions of the U.S. The timing, number of applications, type of applicator and N-inhibitor products are often promoted as nutrient management practices which affect yields as well as nutrient leaching or runoff. Nearly one fifth of the farms reported applying nitrogen in the fall, over half (54 percent) applied N in the spring before planting, and about 30 percent applied N after planting. Nearly 60 percent of the farms reported applying N during only one season (i.e., either in the fall, spring before planting or after planting), about one-fourth applied N in two or more seasons, while the remaining farms (about 20 percent) did not report applying any commercial N or only applied N at planting. The timing and number of application combinations ranged from one percent of the farms applying N in all three seasons to 35 percent applying only after planting. Neither N-inhibitors or VRT were widely used (i.e., less than 10 percent of the farms). Nutrient management information sources ranged from 29 percent of the farms using fertilizer dealers, 21 percent using soil-tests, 14 percent crop consultants, to only four percent using Extension services.

Regression results

The regression estimates for the fuel cost and nitrogen equations are reported in Tables 2 and 3, respectively. The log likelihood ratio (LR) test that all coefficients in the equation system were zero was rejected at the 1% level (LR = 608,096). The correlation coefficient between equations was .018, which is not significantly different than zero. Apparently, higher (lower) fuel costs were not associated with higher or lower (lower or higher) nitrogen application rates. The stochastic factors associated with these inputs appear to be independent.

Farm enterprise structure was measured by the total number of corn acres farmed by the operation, a dummy variable indicating field ownership, and the percent of total farm revenue from corn and from livestock. The latter three variables were not significant in either equation. Land tenure and enterprise specialization did not affect expenditures. In addition, farm size does not appear to be correlated with N application rates. The number of corn acres squared was significant and positive in the fuel equation. To interpret this coefficient, it is helpful to also consider the linear corn acres variable that is negative but not significant. These two coefficients together imply a minimum at 1,708 acres of corn. Only 68 farms (4% of the 1,721 records available for the regression), have more than 1,700 acres of corn. Thus, the effect of acres is negative and economies of size exist for most of the range of the acres variable with respect to fuel. Larger farms have machinery compliments that allow them to economize on fuel and/or receive volume discounts. The diseconomies above 1,700 acres may arise from longer distances from the farm headquarters to outlying fields as farm size increases. It is not surprising that the same results are not observed for nitrogen because it is not affected by similar technological effects.

Management variables included in both equations are dummy variables for irrigation, nitrogen contracting, and the reduced tillage variable. While it was not significant in the nitrogen equation, reduced tillage was negative and significant, which is consistent with the lower fuel costs associated with this practice. Irrigation was positive and significant in both equations. The marginal effects of irrigation in both equations are quite large. In the fuel equation, the marginal effect is about $39 per acre—irrigation is a major use of fuel on irrigated farms. In the nitrogen equation, the marginal effect is about 30 pounds per acre. Farmers use more nitrogen on irrigated corn because irrigation increases yield potential. In addition, more nitrogen is lost due to irrigation water runoff and percolation (Huang, Uri, and Hansen). Fall nitrogen contracting was significantly positive in both equations, which is opposite from typical expectations. However, energy prices were much higher in 2000 than in 2001 so that farmers who made spring purchases may have saved money (Figure 1).

Management variables included only in the fuel equation had mixed effects. Bt and herbicide tolerant varieties were not significant, suggesting that reductions in the frequency of pesticide application operations did not reduce fuel use. Distance to market, and custom costs also were not significant. On-farm drying did have a significant coefficient of about nine dollars per acre on fuel costs.

The fertilizer equation also had both significant and non-significant management variables. Some of these results are not consistent with usual recommendations associated with these practices; those that are not are discussed below. The use of advice from crop consultants, having a nutrient management plan, and variable rate technology were not significantly related to

N use. Variables measuring the effects of leguminous crops grown in the previous year were also not significant, which seems to be consistent with recent research on corn-soybean rotations in Illinois (Mulvaney, Khan, and Ellsworth). Manure had a significant negative effect of about 15.5 pounds. Yield goal had a small, but significant, positive sign. The soil test coefficient was significantly negative with a magnitude of about 10 pounds. The nitrogen loss inhibitor variable had a significant positive effect of about 20 pounds. This coefficient was hypothesized to be negative. However, there might be circumstances when this product could increase N efficiency and its marginal product that would lead to higher N use, which the results seem to support.

The coefficients for advice from dealers and extension are both significant and positive. The former sign is not surprising, but the latter is opposite the expected sign. The advice from extension appears to be associated with increases in N productivity rather than precluding over-application, which is the usual expectation (Sheriff). An alternative interpretation for the positive association of the extension advice with increased N use is that the farmers who obtain extension advice have higher managerial ability, which increases the productivity of nitrogen just like other inputs.

The N application timing coefficients also had some unexpected results. The coefficients of these dummy variables are orthogonally restricted as $\Sigma\delta = 0$. Therefore, they are interpreted as differences from the overall average N application rate. The summer-only application was about 13 pounds per acre less than the average application rate, as expected. The fall-only and spring-only had insignificant coefficients. The coefficients for multiple applications contrast with the single application results. Multiple applications resulted in higher application rates. The coefficient for applications at all three times was significantly positive. All else equal, farmers applying N in the fall and spring (before planting), and in the summer (after planting) applied 43 pounds per more than the average N application rate. The fall-summer and the spring-summer applications both were significantly positive with magnitudes of about 18 and 17 pounds per acre, respectively. The fall-spring application also was positive but not significant. One explanation is that nitrogen has a higher productivity for these farmers that led to higher applications.

Operator age, educational attainment (measured by a dummy variable for college attendance), and the proportion of total household income earned off–farm were included in the both equations. Age and off-farm income were not significant in either equation, but college attendance was significantly negative in the nitrogen equation. Higher human capital was associated with lower levels of nitrogen use (by about eight pounds per acre) compared to farmers who had not attended college.

The equipment variables in the fuel equation also had mixed effects. The number of planter rows was not significant. As expected, use of diesel fuel was significantly negative, and horsepower of the largest tractor was significantly positive. Repair costs were also significantly positive, which indicates that machinery with more cumulative use, or older machines, are less fuel efficient.

Regional dummy variables were included for the four major corn producing regions in both equations. The regional coefficients were also orthogonally restricted. Therefore, they test whether fuel or N use in a given region differs from the national average. In the fuel equation, the Northern Crescent region was significantly positive, but the reasons are unclear. Perhaps fields are smaller in this region, which reduces machine efficiency and increases fuel use. In the nitrogen equation, the Northern Crescent region was also significantly positive. Again the reason is unclear; perhaps, the soil is less fertile. Both the Northern Great Plains and the Prairie

Gateway had significantly lower use of about 23 and nine pounds, respectively. These regions have dryer climates so that dry land corn has lower and more uncertain yields, and nitrogen is less productive.

Conclusions

Analysis of the 2001 ARMS corn production and costs data confirmed some of the usual generalizations about technology and energy use in fuels and nitrogen fertilizer. Among these findings were that irrigation increased use of both inputs, on-farm drying increased fuel use, the number of acres of corn decreased fuel use, use of diesel reduced fuel use, reduced tillage decreased fuel use, soil tests decreased nitrogen use, operators with more education tended to use less nitrogen, yield goal increased fertilizer use, and manure use decreased fertilizer use. Other variables such as herbicide resistant plant varieties, distance to market, and use of custom machine operations in the fuel equation and use of variable rate technology, and previous crops being legumes were insignificant in the nitrogen equation. Some significant variables had the opposite sign than in usual expectations. Among these were fall purchases of inputs in both equations, nitrogen loss inhibitor in the nitrogen equation, and fertilizer application advice from extension in the nitrogen equation, all of which had positive signs.

The fertilizer timing variables revealed interesting patterns. Summer applications only had a significant negative coefficient as expected, but fall-only and spring-only had insignificant signs. Multiple applications all had significant positive coefficients, with the exception of fall and spring applications. Applications at all three times had a large marginal effect of about 46. These results suggest that multiple applications increase nitrogen use or that farmers with large planned uses have multiple applications.

If energy prices remain high, one would expect that some of these practices that reduce energy use will become more widely used. In addition, some practices that do not appear to be related to N use or fuel consumption may have the expected impacts with wider use and more experience. It must be stressed that simplistic generalizations about practices and input use may be incorrect, particularly in certain circumstances. Sheriff stressed this view in his recent article, and the results here reinforce this perspective.

A number of potential policy implications arise from our analyses of direct and indirect energy expenditures on farms producing corn. Clearly, the largest impact on energy expenditures is due to irrigation and on-farm drying. These suggests that any education, training, or cost-sharing programs geared toward improving the energy efficiency of these technologies would have significant economic payoffs for those farms utilizing these technologies and would also save energy. Our results suggest the need for an analysis of the costs and profitability of off-farm drying compared to on-farm facilities. Similarly, programs to encourage further adoption of conservation tillage systems, such as those offered through the CSP or EQIP, has energy-conservation potential.

Concerns about the impact of production agriculture on our water resources has led to a number of education and cost-share programs geared toward improved nutrient management (USGS). Our analyses attempted to isolate the impact of various nutrient practices, technologies, and information sources on N application rates while accounting for several key operator and farm characteristics, including expectations about yield. We found that practices such as soil-testing, use of manure, and N application after planting were associated with reduced N application rates. All of these practices are widely promoted by extension and are often encouraged when participating in many conservation programs. However, our analysis raised some interesting questions about several other nutrient management practices. For example, use of legume rotations or having a nutrient management plan did not affect N application rates. Of more concern were the variables associated with increased N application rates such as multiple season applications, use of N-inhibitors, and information from fertilizer dealers and extension. However, it should be noted that relatively few farms reported use of either N-inhibitors or extension. Nevertheless, these findings suggest topics for future research on factors associated with N use and management and implications for energy-conservation.

In addition to rapid changes in the energy markets, energy policies have recently undergone significant changes: the Farm Security and Rural Investment Act of 2002 and the Energy Policy Act of 2005 included several programs affecting the agricultural sector. The combination of energy market volatility and policy changes has numerous implications for the production and consumption of energy in production agriculture. In addition, some of these potential energy implications could impact agricultural soil and water resources. Adoption of minimum tillage could reduce erosion, and adoption of soil tests, nitrogen loss inhibitors, and other fertilizer management practices could reduce nitrogen leaching and runoff.

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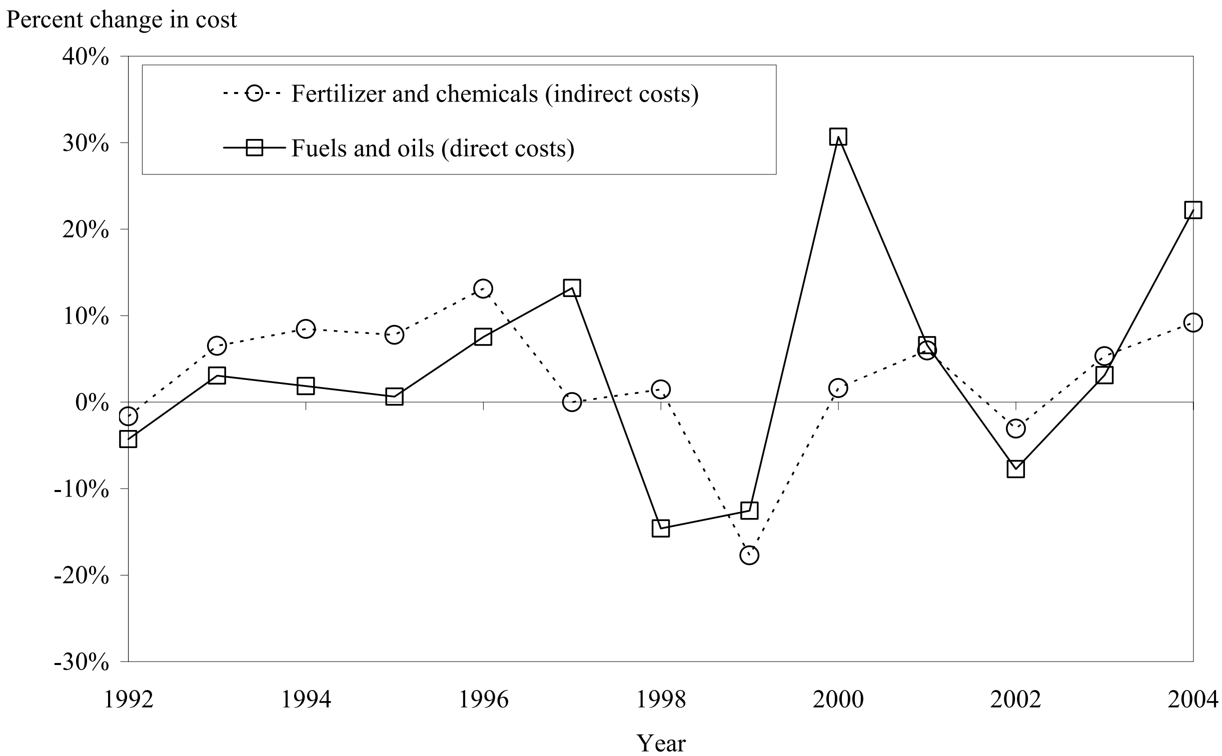
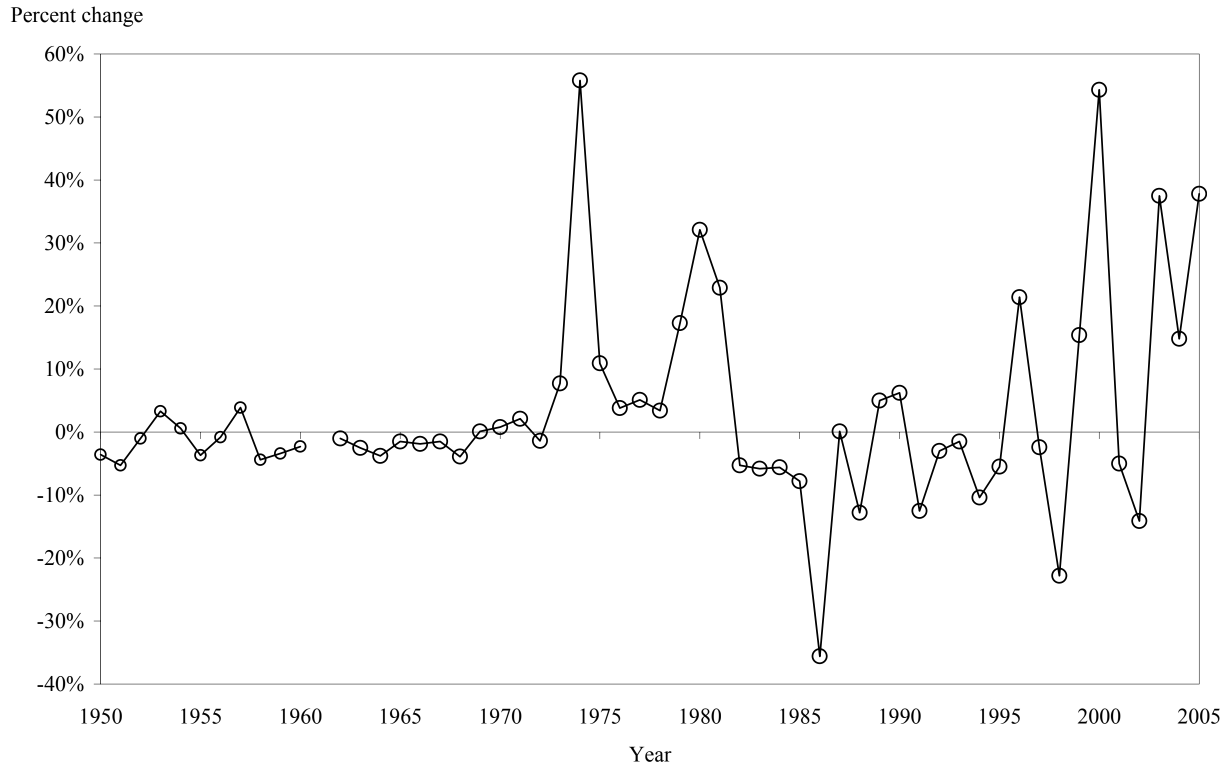


Sources: Farm Costs and Returns Survey (1991-1995) and ARMS (1996-2004)

Figure 1. Annual change in fuel and fertilizer costs for the US agricultural sector, 1992-2004



SOURCE: Department of Energy, 2005

Figure 2. Annual change in real fossil fuel prices, 1950-2005

Table 1. Sample means for corn producers, 2001

Variable	Description	Units	Mean	CV	1/
N_APPLIEDPERAC	N applied per acre	Pounds/acre	112	1.96	2/
FUELPERACRE	Fuel and lube costs per acre	$/acre	17.50	4.96	
CUSTCOSTPERAC	Custom costs per acre	$/acre	16.52	5.88	3/
CORNACRES	Corn acres planted	acres	211	3.00	
N_SOILTEST	N soil test	(1=yes)	21%	10.48	2/
P_CORN	Revenue share from corn	Percent	28%	3.50	
NUTRIENTMGT	Nutrient management plan	(1=yes)	12%	6.99	
VRT	Variable rate technology used	(1=yes)	5%	16.89	
BT	Bt corn planted	(1=yes)	13%	8.85	
HERBTOL	Herbicide resistant corn variety	(1=yes)	17%	8.19	
N_CONTRACT	N contract	(1=yes)	34%	3.88	2/
NSERVE	Used product to slow N breakdown	(1=yes)	6%	13.28	2/
NCROPCONSULTANT	N applied based on crop consultant recommendation	(1=yes)	14%	7.34	2/
NEXTENSION	N applied based on extension recommendation	(1=yes)	4%	19.4	2/
NDEALER	N applied based on dealer recommendation	(1=yes)	29%	6.84	2/
IRRIGATE	Irrigation used	(1=yes)	9%	22.31	
SHAREOFFINC	Off-farm income/total household income	Percent	59%	1.86	
SOMECOL	College education	(1=yes)	25%	6.90	
OP_AGE	Operator age	Years	52	0.80	
OWNEDACRES	Field owned	(1=yes)	58%	2.86	
YIELDGOAL	Yield goal	Bu./acre	125	1.32	
MANURE	Manure applied	(1=yes)	27%	4.70	
SPRING2000_LEGUME	Previous crop was a legume	(1=yes)	55%	2.69	
SPRING2000_OTHER	Previous crop, other	(1=yes)	17%	10.75	
Survey sample size (farms)	1,763 (338,854)				

Notes: 1/ Coefficient of variation = 100 x (jackknifed standard error/mean).
2/ Estimate based only on sub-group that applied N (N = 1660).
3/ Estimate based only on sub-group that used custom cost (N = 1227).
Source: ARMS 2001 Phase II/III.

Table 1. Sample means for corn producers, 2001 (continued)

Variable	Description	Units	Mean	CV 1/
N applied - 100	N applied before planting (fall)	(1=yes)	7%	8.09
N applied - 010	N applied before planting (spring)	(1=yes)	35%	3.14
N applied - 001	N applied after planting	(1=yes)	15%	9.05
N applied - 110	N applied before planting (fall, spring)	(1=yes)	7%	12.59
N applied - 111	N applied before (fall, spring) and after planting	(1=yes)	1%	33.67
N applied - 101	N applied before (fall) and after planting	(1=yes)	4%	13.53
N applied - 011	N applied before (spring) and after planting	(1=yes)	11%	19.42
RESIDUE	Crop residue load on field	Percent	24%	2.70
HP_LARGETRACTOR	Horse power of largest tractor	HP	160	2.41
DEISEL	Largest tractor used diesel	(1=yes)	97%	0.73
DRIED	Corn dried on farm	(1=yes)	28%	4.21
P_LIVESTOCK	Revenue share from livestock	Percent	40%	4.87
PLANTERROWS	Planter row width	Rows	6	1.80
DISTMKT	Distance to market	Miles	10	15.37
MACHREPCOST_PERAC	Machine repair costs per acre	$/acre	12.32	2.07
INSURANCE	Respondent has crop insurance	Percent	32%	4.15
Regional variables				
Heartland			52%	
Northern crescent			26%	
Great plains			4%	
Prairie gateway			9%	
Eastern uplands, fruitful rim			10%	
Survey sample size (farms)	1,763 (338,854)			

Notes: 1/ Coefficient of variation = 100 x (jackknifed standard error/mean).
Source: ARMS 2001 Phase II/III.

Table 2. Bivariate tobit results for fuel demand

Variable	Units	Estimate (t test 1/)	Marginal effect
Constant		2.791 (0.61)	
CORNACRES	Acres (1000's)	-4.048 (-1.46)	-3.396
CORNACRES2		1.185 (2.12)	0.994
RESIDUE	Percent	-3.398 (-1.86)	-2.851
HP_LARGETRACT	Horse power	0.016 (3.90)	0.014
DEISEL	(1=yes)	-3.286 (-2.38)	-2.756
N_CONTRACT	(1=yes)	2.380 (3.51)	1.997
BT	(1=yes)	-0.538 (-0.33)	-0.452
HERBTOL	(1=yes)	-0.553 (-0.61)	-0.464
DRIED	(1=yes)	9.766 (7.94)	8.193
P_LIVESTOCK	Percent	-17.3 (-0.08)	-0.145
P_CORN	Percent	32.0 (0.08)	0.269
PLANTROWWIDTH	Rows	-0.123 (-1.20)	-0.103
SHAREOFFINC	Percent	-41.6 (-0.37)	-0.349
SOMECOL	(1=yes)	0.167 (0.20)	0.140
OP_AGE	Years	-0.012 (-0.24)	-0.010
CTENURE	(1=yes)	0.082 (0.07)	0.069
INSURANCE	(1=yes)	0.852 (0.84)	0.714
DISTMKT	Miles	0.002 (0.22)	0.001
IRRIGATE	(1=yes)	46.488 (12.39)	38.996
MACHREPCOST	$/Ac.	0.801 (11.36)	0.672
CUSTCOSTPERAC	$/Ac.	0.016 (0.50)	0.014
HEARTLAND	2/	0.292 (0.29)	0.240
NOCRESCENT	2/	1.676 (2.19)	1.503
NOGRPLAINS	2/	-3.288 (-1.25)	-2.844
PRGATEWAY	2/	0.133 (0.05)	0.023
σ		12.989 (11.72)	

Notes: Dependent variable is fuel costs per acre. Log likelihood = -2,979,016, McFadden's R^2 = 0.09. Cross-equation correlation coefficient = 0.018, with a t statistic of 0.59.
1/ Critical t values at the 5% and 10% levels are 2.14 and 1.76, respectively.
2/ Regional dummy variables are specified as $\Sigma_i d_i = 0$. Therefore, they represent the difference from the national average.
Source: 2001 ARMS phase II/III.

Table 3. Bivariate tobit results for nitrogen demand

Variable	Units	Estimate (t test)	Marginal effect
CONSTANT1		103.975 (9.02)	
CORNACRES	Acres (1000's)	17.370 (1.58)	16.200
CORNACRES2		-2.943 (-1.31)	-2.745
RESIDUE	Percent	-8.176 (-0.92)	-7.626
N_SOILTEST	(1=yes)	-10.727 (-2.64)	-10.005
NSERVE	(1=yes)	21.886 (3.18)	20.412
NCROPCONSULT	(1=yes)	-6.184 (-1.31)	-5.767
NDEALER	(1=yes)	9.753 (2.23)	9.096
NEXTENSION	(1=yes)	14.004 (2.29)	13.061
P_CORN	Percent	9.251 (0.91)	8.628
NUTRIENTMGT	(1=yes)	-7.819 (-1.16)	-7.293
VRT_USED	(1=yes)	-9.734 (-0.74)	-9.079
N_CONTRACT	(1=yes)	8.843 (2.43)	8.248
INSURANCE	(1=yes)	1.135 (0.23)	1.058
IRRIGATE	(1=yes)	32.949 (5.13)	30.730
SHAREOFFINC	Percent	1.737 (0.56)	1.620
SOMECOL	(1=yes)	-8.749 (-2.82)	-8.160
OP_AGE	Years	-0.226 (-1.48)	-0.210
CTENURE	(1=yes)	3.139 (0.70)	2.927
YIELDGOAL	Bu./Ac.	0.174 (4.25)	0.163
MANURE	(1=yes)	-17.211 (-3.66)	-16.052
SPRING2000_LEGUME	(1=yes)	-6.007 (-0.88)	-5.603
SPRING2000_OTHER	(1=yes)	-0.435 (-0.08)	-0.406
N applied - 100	2/	-6.665 (-0.74)	-6.216
N applied - 010	2/	-4.622 (-0.95)	-4.311
N applied - 001	2/	-13.843 (-2.27)	-12.911
N applied - 110	2/	14.404 (1.68)	13.434
N applied - 111	2/	45.720 (1.83)	42.641
N applied - 101	2/	20.008 (2.36)	18.660
N applied - 011	2/	18.998 (3.38)	17.718
HEARTLAND	2/	3.685 (0.85)	3.437
NOCRESCENT	2/	7.642 (1.98)	7.127
NOGRPLAINS	2/	-23.298 (-4.88)	-21.729
PRGATEWAY	2/	-9.585 (-1.96)	-8.939
σ		48.921 (36.96)	

Notes: Dependent variable is nitrogen applied per acre. Log likelihood = -2,979,016, McFadden's $R^2 = 0.09$. Cross-equation correlation coefficient = 0.018, with a t statistic of 0.59.
2/ Regional dummy variables and nitrogen application variables are specified as $\Sigma_i d_i = 0$. Therefore, they represent the difference from the overall average.
Source: 2001 ARMS phase II/III.