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Agriculture's Supply and Demand for Energy and Energy Products

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Agriculture's Supply and Demand for Energy and Energy Products

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Abstract

Rising energy prices and changing energy and environmental policies have transformed the relationship between the energy and agriculture sectors. Traditionally, the relationship has been one-way, with agriculture using energy products as an input in production; during the past decade, however, the energy sector's use of agricultural products as renewable-fuel feedstocks has increased substantially. This report examines both sector and farm-level responses to changing market and policy drivers such as the increased production of biofuel crops and other sources of renewable energy, together with changes in production practices to economize on energy-based inputs like fertilizer. We provide insight into how farmers have adapted to the changes and update and provide new data on the evolving linkages between the energy and agricultural sectors.

Keywords: energy, fertilizer, pesticides, fuel, biofuels, renewable energy, ARMS

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Summary

What Is the Issue?

Rising energy prices over the past decade, in tandem with evolving policies promoting renewable energy and onfarm conservation practices, have transformed the relationship between the energy and agriculture sectors. Traditionally, agriculture used energy both directly in the form of fuel and electricity and indirectly through use of energy-intensive inputs, such as fertilizers and pesticides. However, record-high energy prices and expanding biofuel policies have substantially increased the demand for agricultural products as renewable fuel feedstocks since the mid-2000s. As of 2012, corn-based ethanol and soybean-based biodiesel supplied almost 6 percent of U.S. transportation fuels, consuming 42 and 1 percent of U.S. corn and soybean production, respectively. Corn used for ethanol does generate a co-product, dried distillers grains with solubles (DDGS), which is sold into the market as livestock feed.

Even so, changing market economics and policies have brought about higher agricultural commodity prices and have increased the costs of agricultural production. This report surveys how farmers have adjusted which agricultural commodities to produce, how much of each to produce, and how to produce them to better understand how recent changes in energy prices and biofuel demand have affected the agricultural sector.

What Did the Study Find?

Farmers have adapted to rising energy prices and evolving policies by adjusting their use of energy-based agricultural inputs, altering energy-intensive production practices, and growing more energy-feedstock crops.

Farmers have expanded production of agricultural commodities used as energy feedstocks. In particular, corn production increased 13 percent from 2001 to 2012. A 28-percent increase in corn plantings over that time period came partly at the expense of acreage previously allocated to other crops (acreage grew more than production as average yields fell in 2012 as a result of the drought); barley, oat, and sorghum production each declined by 10 percent or more over 2001-12. The remainder of the increase in corn output came from the intensification of corn production.

The prices of all major field crops increased by more than 40 percent between 2001 and 2012 (in real terms). As production of other commodities decreased to accommodate increased corn production, increased competition for reduced supplies helped lead to higher prices for all major field crops.

Farmers adapted to higher energy prices and related energy and conservation policy incentives by shifting to more energy-efficient production practices and input use. Farmers reported that, to lower fuel expenses, they kept engines properly serviced and adopted production practices leading to fewer trips over their fields. To

reduce fertilizer expenses, they reported reducing the use of fertilizer and increasing the efficiency of fertilizer use by conducting soil tests.

The agriculture sector's use of energy and energy-intensive inputs generally remained constant or fell during 2001-11. Farmers were able to hold the line on energy use—while total output and the output share of corn, a highly energy-intensive crop, increased—by increasing the energy efficiency of production relative to 2001.

Nonetheless, energy-related agricultural production costs increased with rising energy prices. The share of energy-based input costs in total corn production costs increased from 27 percent during 2001-2005 to 34 percent for 2006-2011.

More farmers started producing onfarm energy, though the scale of production still remains very low. From 2008 to 2011, the number of farms with renewable energy generation increased 99 percent, to about 1.6 percent of farms.

How Was the Study Conducted?

This report provides new data on energy use by farmers and farmer behavior as energy prices change; it also updates previously published data. This report also draws from published reports, articles, and data products. When possible, trend and correlation analyses are used to identify relationships between energy and agricultural sectors. Because the actual changes in the agricultural sector's supply and demand for energy and energy products are a result of complex interactions among many influences, this report provides an overview of many of these factors using a variety of data sources. Historical energy prices from the Energy Information Agency and agricultural commodity production and price data from the USDA's National Agricultural Statistics Service (NASS) are used to establish baseline descriptions of the energy and agriculture sectors through 2012. Estimates developed by USDA's Economic Research Service of onfarm expenditures and productivity underlie the presentation of trends in energy-related crop inputs. Our analyses of changes in farm production practices and renewable energy use draw largely from farmer responses to USDA's Agricultural Resource Management Survey and the Census of Agriculture's 2009 On-Farm Renewable Energy Production Survey.

Introduction

Rising energy prices and changing energy and environmental policies over the last decade have altered the relationship between the agriculture and energy sectors. Traditionally, agriculture used energy both directly in the form of fuel and electricity and indirectly through use of energy-intensive inputs, such as fertilizers and pesticides. Triple-digit increases in energy prices since 2001 have greatly increased the cost of many agricultural inputs. These energy price shocks are coincident with expanded policies promoting biofuels, which have helped stimulate a substantial increase in energy sector demand for renewable-fuel feedstocks like corn and soybeans.

Energy use is determined by a complex set of factors that affect both agricultural input and output decisions. This report explores how farmers have adjusted *which* agricultural commodities to produce, *how much* of each to produce, and how to produce them.

Energy Market Context

Energy plays a large role in the production of many goods and services. Consequently, changes in energy prices can greatly affect all facets of the economy, including the agriculture sector. Agricultural producers purchase energy inputs, such as fuel and electricity (referred to as direct energy inputs), as well as energy-intensive inputs such as fertilizers and pesticides. Because the energy products from which these agricultural inputs are produced are oil and natural gas, we focus first on the price history for these energy sources, particularly over the 2001-2012 time period.

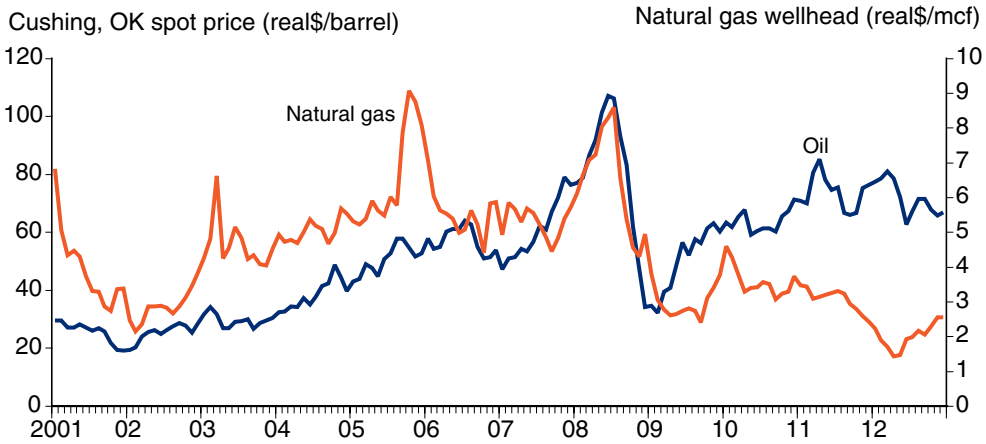
Energy Price Changes

Energy prices became much higher and more volatile during 2001-2012; from January 2001 to June 2008, the price of oil rose 262 percent in real terms (fig. 1). Although oil prices have retreated from their June 2008 high, the price of oil in December 2012 was still 126 percent higher than in January 2001. The price increase from 2001 to 2012 is largely attributed to a combination of falling U.S. oil production, rising global demand, and increased speculation in financial markets (Hamilton, 2009).

Energy price volatility also increased as measured by the coefficient of variation (CV) (see box, "The Importance of Volatility"). The CV for oil prices was 0.39 for 2001-2012, versus 0.21 for 1991-2000. Volatility in natural gas prices (in real terms) also increased from 2001-2012 (fig. 1), although by 2012, natural gas prices had returned to early 2000 levels. The overall decrease in natural gas prices since 2010 is largely a result of greater supply, mainly due to improved extraction technologies such as hydraulic fracking.

Figure 1

Oil spot price and natural gas wellhead price, Jan. 2001-Dec. 2012



Note: Cushing, OK, is the standard for quoting U.S. oil prices. Inflation adjustment via Consumer Price Index (January 2001=100) (Bureau of Labor Statistics, 2013).

Source: Energy Iinformation Administration (EIA), *Petroleum and Other Liquids* database (oil) (2011b) and EIA *Natural Gas* database (gas) (2011a).

The Importance of Volatility

Volatility refers to the movement of a series away from its average. Volatility is high if the price moves up and/or down frequently or by a large amount. Volatility is low if prices remain stable over time. One measure of volatility is the coefficient of variation (CV), which is constructed by dividing the standard deviation of a series by the average of the series—a larger CV indicates a larger distribution in prices. The CV is also a useful measure when comparing variation in one series to another. Volatile prices affect farmers due to the risk and uncertainty they introduce into production expenses and commodity prices.

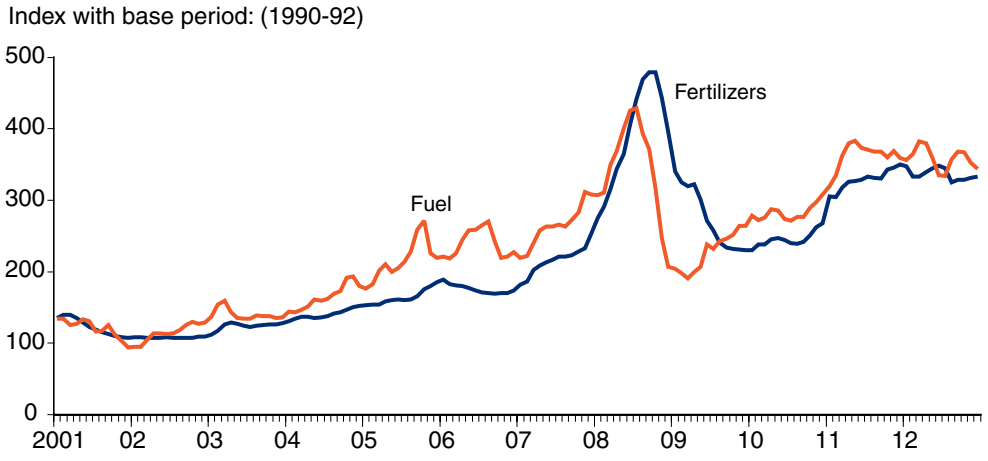
Energy and Energy-Intensive Agricultural Input Price Changes

Farmers witnessed an upward trend in the price of energy-related production inputs from 2001 to 2012. Oil (fig. 1) and fuels (fig. 2) exhibited similar price patterns over 2001-2012. The fuel price index (base year = 1990-92) tripled from January 2001 to July 2008 (from 134 to 429), although fuel prices over 2001-2012 were not as volatile as oil prices.

Natural gas represents approximately 70 percent of the cost in manufacturing fertilizer (Gellings and Parmenter, 2004), so the price trends tend to be parallel for natural gas (fig. 1) and fertilizer (fig. 2). The fertilizer price index (base year = 1990-92) increased from 135 in January 2001 to 253 in December 2007, and peaked in September 2008 (at 479). Although both natural gas and fertilizer prices have since declined, unlike natural gas prices, fertilizer prices did not fall back to their 2001 levels, partly due to high U.S. and global demand for fertilizer (Schnitkey, 2011) coupled with production constraints that limited expansion of U.S. fertilizer production as natural gas prices fell.

Figure 2

Index of prices paid by agricultural producers, Jan. 2001-Dec. 2012

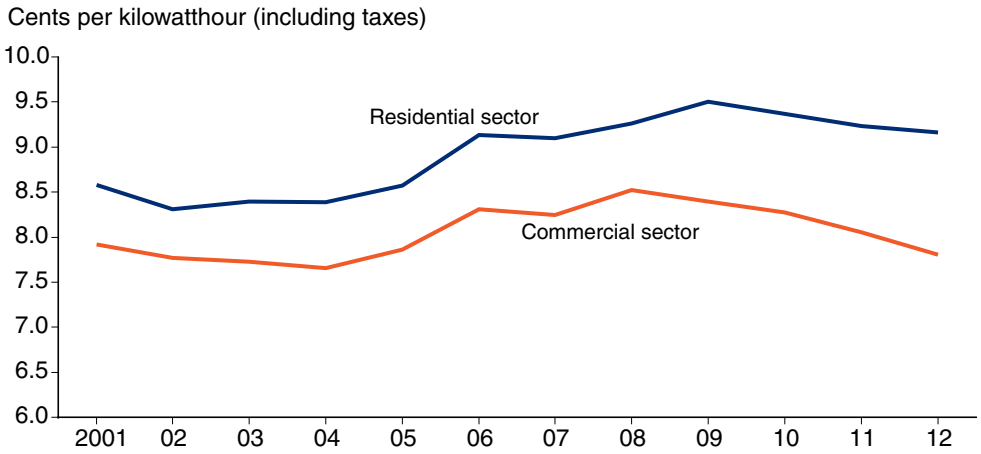


Source: USDA, National Agricultural Statistics Service, *Agricultural Prices* (2011b).

Electricity is the other main direct energy input used by agricultural producers. Figure 3 shows the inflation-adjusted annual national average retail price for both residential and commercial sectors—the two sectors most relevant for agricultural operations. Retail electricity prices vary little in the short term, relative to fuel (and fertilizer) prices, because retail electric rates are generally based on longer term averages of the cost to provide the power, which is dominated by the fixed costs of power plant construction (Energy Information Administration, 2011b; Gordon and Olson, 2004).

Figure 3

Average retail price of electricity (in real terms), 2001-12



Source: U.S. Department of Energy/Energy Information Administration, 2011, 2012.
Inflation adjustment via Consumer Price Index (2000=100) (Bureau of Labor Statistics, 2013).

Agriculture as a Producer of Energy

The recent energy price shocks first occurred when corn prices were relatively low and policies promoting biofuels were expanding, stimulating an increase in energy sector demand for agricultural products as renewable-fuel feedstocks. This heightened demand raised production levels and prices of major field crops across the United States.

Biofuel Production

At least 1 billion gallons of corn-based ethanol has been produced annually in the United States since 1992 (USDOE/EIA, 2012a). Production was limited until the mid-2000s, at which point it began increasing rapidly (table 1). Indeed, the production of ethanol far exceeded the original (2005) Renewable Fuel Standard (RFS1) volume mandates for U.S. consumption, which helped lead to a revised mandate in 2007 (RFS2) (see Appendix).

Biodiesel consumption is also mandated in the RFS2. The mandated levels are much lower than for ethanol because biodiesel production has historically been much smaller than ethanol production, and diesel is used much less than gasoline in the United States. U.S. biodiesel production increased gradually through 2008, then fell due to unfavorable market economics (USDOE EIA, 2010) before recovering to more than 1 billion gallons in 2011 and 2012 (table 2). The share of soybeans allocated to biodiesel production was a little more than 1 percent in 2012. (Soybeans provide a little more than half of biodiesel feedstocks, along with corn oil and animal fats.)

Table 1
Corn used for ethanol, ethanol output, and mandated volumes, 2001-12

Year	Corn used for ethanol	Ethanol production	Mandate amount	
			RFS1	RFS2
	Million bushels		*Billion gallons*	
2001	707	1.77		
2002	996	2.13		
2003	1,168	2.80		
2004	1,323	3.40		
2005	1,603	3.90		
2006	2,119	4.86	4.00	
2007	3,049	6.50	4.70	
2008	3,709	9.00	5.40	9.00
2009	4,591	10.60	6.10	10.50
2010	5,019	13.23	6.80	12.00
2011	5,011	13.90	7.40	12.60
2012	4,500	13.30	7.50	13.20

Note: Corn used for ethanol is based on marketing year, while ethanol production is calendar year. RFS1 represents the original Renewable Fuel Standard (2005) maximum amount of ethanol; RFS2 represents the revised amounts for total renewable fuel in the Energy Independence and Security Act of 2007.

Source: F.O. Licht (various articles); USDA, Economic Research Service *Feed Grains* database (2011c).

Table 2
Soybean oil for biodiesel, biodiesel output, and mandated volumes, 2001-12

Year	Soybean oil used for biodiesel	Biodiesel production	Mandate amount
	Million lbs.	——— *Billion gallons* ———	
2001	NA	0.00	
2002	NA	.02	
2003	NA	.02	
2004	NA	.04	
2005	NA	.12	
2006	NA	.25	
2007	2,979	.51	
2008	3,051	.81	
2009	1,876	.56	0.50
2010	1,141	.31	.65
2011	4,153	1.10	1.00
2012	4,023	1.10	1.00

Source: F.O. Licht (various articles); USDA, Economic Research Service *Feed Grains* database (2011c); ERS *Oil Crops* outlook (2011e). NA = Not available.

Crop Responses to Biofuel Production

The increase in biofuel production relied on an increasing amount of agricultural commodities used as feedstocks. In 2012, 4.5 billion bushels of corn were used as ethanol production feedstock—absorbing more than 42 percent of corn production (fig. 4). This major new component of demand is competing with traditional uses of corn—including for food and livestock feed, both within the United States and for export. In particular, the share of corn allocated to both exports and feed declined by more than one-third between 2001 and 2012. Corn used for ethanol does generate a co-product, dried distillers grains with solubles (DDGS), that is used for feed. This helped cushion livestock producers from the full effect of demand-driven feed-price increases.

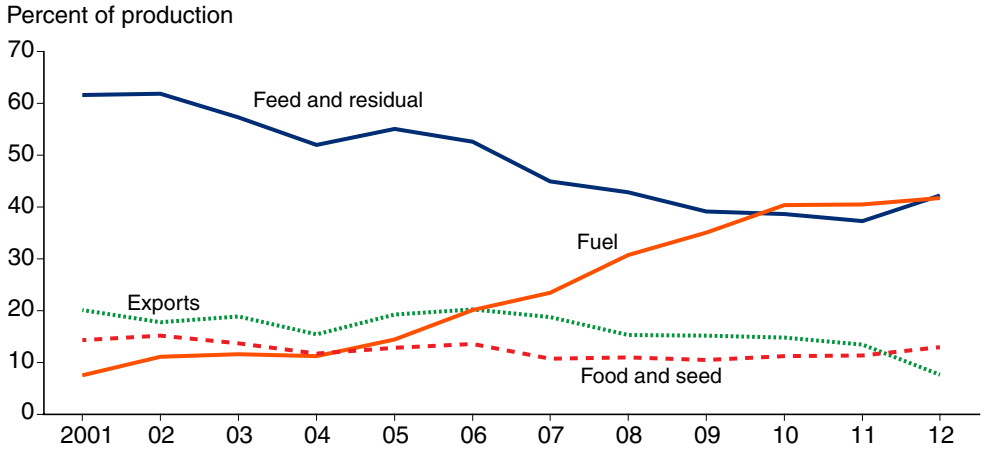
The increased demand for corn exerted upward pressure on corn prices, which increased 90 percent (in real terms) from 2001 to 2007 and then increased another one-third between 2007 and 2012 (fig. 5). Although biofuels contributed to this increase, there were other factors influencing agricultural commodity prices. According to the Congressional Budget Office (2009), about 20 percent of the increase in corn prices between 2007 and 2008 was due to domestic ethanol demand. Trostle (2008) notes that the increase in agricultural commodity prices was also due to slower production growth, rapid global demand for agricultural commodities, and a decline in the value of the U.S. dollar. These higher corn prices encouraged farmers to increase corn production. Between 2001 and 2012, U.S. corn production increased by 13 percent (from 9.9 billion bushels to 10.8 billion bushels, after peaking at 13.1 billion bushels in 2009) (fig. 6).

Farmers responded to the demand for corn partly by planting it on more acres, partly through expanded double-cropping, and partly through more intensive use of land and other inputs. (See Wallander et al., 2011, for a detailed discussion on these changes.)

The expanding demand for land to produce corn and, to a much lesser extent, soybeans for energy feedstocks meant other crops faced increased competition for land. All major field crops but corn, soybeans, and wheat experienced a decline in acreage over 2001-2012. Farms specializing in soybeans contributed most of the increase in corn acreage, while other farms shifted to soybeans (Wallander et al., 2011). As a result of the increased competition, the prices of non-feedstock crops were bid up along with the prices of feedstock crops. Most major field crops experienced price increases (in real terms) of over 100 percent between 2001 and 2012 (fig. 5).

Figure 4

U.S. corn use, 2001-12

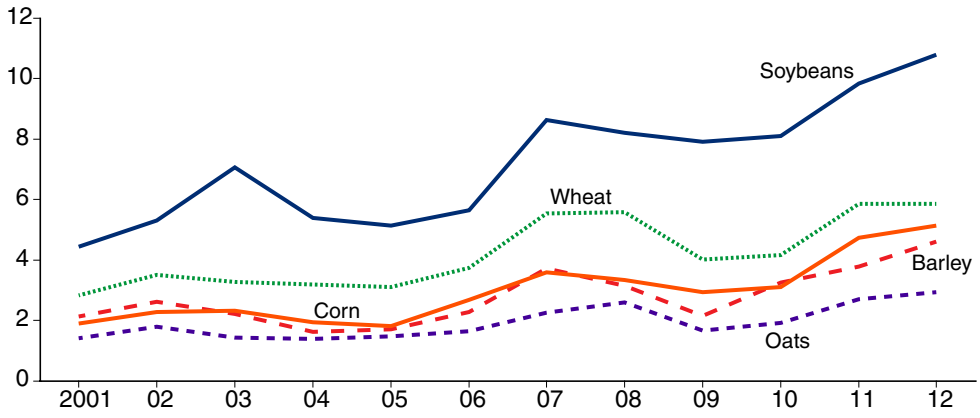


Note: Marketing years are used.

Source: USDA, Economic Research Service, *Feed Grains* database (2011c).

Figure 5

Selected crop prices (real $/bushel), 2001-12

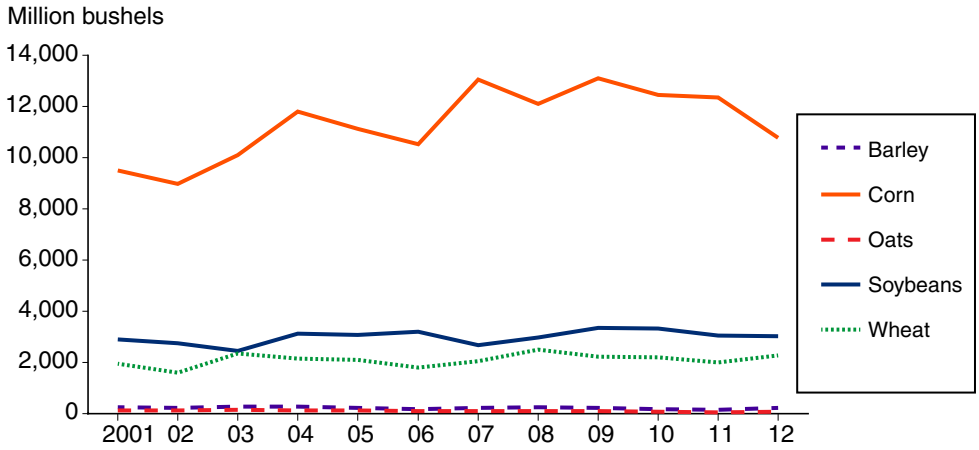


Note: Inflation adjustment via Consumer Price Index (2001=100) (Bureau of Labor Statistics, 2013). All commodity prices are calendar year.

Source: USDA, National Agricultural Statistics Service, *Quick Stats* (2012).

Figure 6

Selected crop production, 2001-12



Source: USDA, National Agricultural Statistics Service, *Quick Stats* (2012).

Agriculture as a User of Energy

Higher energy prices also affect farms in the form of higher input prices for energy-based products. And while the agriculture sector's demand for energy is historically less than 2 percent of total U.S. energy consumption, energy and energy-intensive inputs account for a significant share of agricultural production costs. Corn, sorghum, and rice farmers allocated over 30 percent of total production expenditures on energy inputs in 2011.

Direct and Indirect Uses of Energy

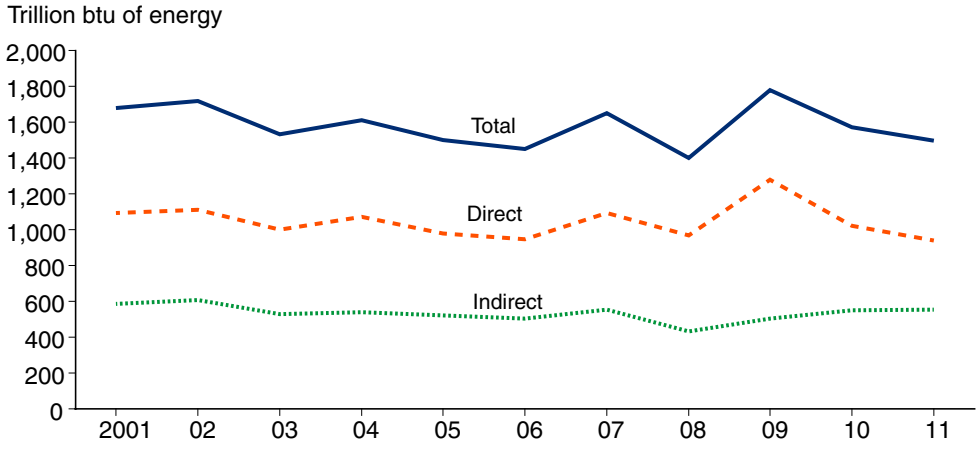
The use of energy on agricultural operations is typically separated into direct use of fuels and electricity and indirect use of energy through energy-intensive inputs, most notably fertilizer and pesticides. From 2001 through 2011, direct energy use consistently accounted for the majority of total energy use on agricultural operations (fig. 7). In 2011, direct energy use accounted for 63 percent of agricultural energy consumption, compared with 37 percent for indirect use.

Direct Energy Use

The dominant share of direct energy use on U.S. farms is fuels (including diesel and gasoline) to run machinery for field operations such as planting, tilling, and harvesting; to dry crops; for livestock use; and to transport goods (fig. 8). Fuel energy use was relatively consistent—with a slight upward trend—during the 2000s; however, the combination of lower fuel prices (fig. 2) and high commodity prices in

Figure 7

Direct, indirect, and total energy consumed on U.S. farms, 2001-11

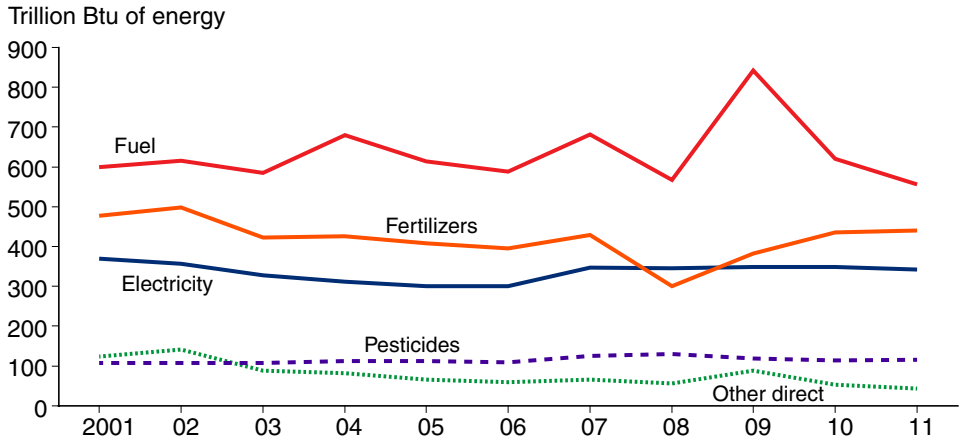


Note: Direct uses include onfarm use of fuels and electricity; indirect uses reflect the embodied energy in farm inputs, including fertilizer and chemicals. Energy consumed is calculated by taking the total yearly expenses, divided by the average yearly price and multiplying this amount by the energy conversion ratio. Average yearly prices are used, and years when intra-year prices are more volatile, such as 2006-09, should be viewed with more caution. This is because it is possible that purchases of energy were done when prices were at the low (high) end of the price range, which would skew the use of energy upwards (downwards). Btu = British thermal units.

Source: Miranowski (2005) and USDA Economic Research Service calculations.

Figure 8

Energy inputs consumed on U.S. farms, by component, 2001-11



Note: "Other direct" represents liquid petroleum and natural gas. Energy consumed is calculated by taking the total yearly expenses, divided by the average yearly price, and multiplying this amount by the energy conversion ratio. Btu = British thermal units.

Source: Miranowski (2005) and USDA, Economic Research Service calculations.

2009 (fig. 5) coincided with a large increase in the amount of fuel used by farmers that year. In 2011, higher fuel prices led to a subsequent decline in fuel use.

In contrast, electricity use remained steady across 2001-11, perhaps due to relatively stable prices (fig. 3). Electricity is often used for heating and cooling in livestock and dairy operations (Miranowski, 2005). For crop producers, irrigation pumps can be a large user of electricity. In 2007, 7.5 percent of U.S. cropland and pastureland acres were irrigated, but these acres were highly concentrated in the West (Schaible and Aillery, 2012). Less than 12 percent of corn acres were irrigated in 2010, and only 8.6 percent of soybean acres in 2006 were irrigated (ERS, 2012b).

Indirect Energy Use: Energy-Intensive Inputs

Fertilizer, an energy-intensive agricultural input, accounted for slightly more than half of indirect energy use on U.S. farms in 2011. Some of the decline in farm indirect use of energy over 2001-2011 (fig. 7) is a result of fertilizer manufacturers becoming more efficient in the use of natural gas feedstocks and energy in the production of fertilizer (Gellings and Parmenter, 2004).

Beginning in 2004, highly variable corn plantings and volatile fertilizer prices led to highly variable fertilizer consumption (fig. 9). Following an increase in the producer price index for all fertilizers of 82 percent from 2007 to 2008, commercial fertilizer use declined by almost 23 percent in 2009 relative to 2007. As fertilizer prices declined in 2010, consumption rebounded.

Fertilizer use can be grouped into three nutrient categories: nitrogen, phosphate, and potash. Nitrogen-based fertilizers represented 59 percent of total U.S. fertilizer consumption in 2010, compared to 21 percent for potash and 20 percent for phosphate (fig. 9). Corn—which uses fertilizer intensively—accounted for around 46 percent of U.S. fertilizer consumption in 2010.

Pesticides, the other energy-intensive agricultural input, accounted for slightly less than half of indirect energy used on U.S. farms in 2010. Pesticides include herbicides (to manage plants and weeds), insecticides (to manage insects), and fungicides (to manage fungi). Pesticide use increased from 2001 to 2010 mainly due to an increase in the herbicide usage, as use of all other forms of pesticides was steady or declined (fig. 10).

One reason why herbicide use increased from 2001 to 2010 might be because the share of corn, soybean, and cotton acreage planted with herbicide-tolerant (HT) seed has increased dramatically. For corn, use of HT varieties increased from 11 percent of planted acres in 2002 to 70 percent in 2010 (Livingston and Osteen, 2012).

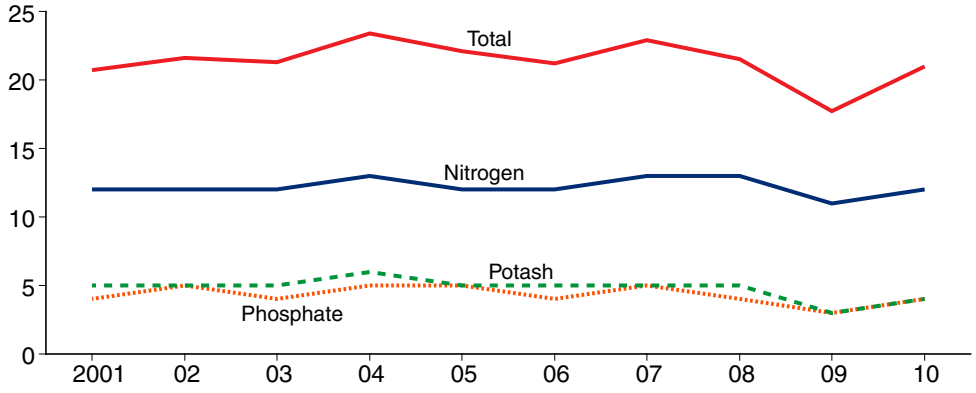
Changes in Production Input Intensity

The quantity of energy or energy-intensive agricultural inputs purchased tends to increase as output increases. However, improvements in the quality of inputs or

Figure 9

Total fertilizers consumed on U.S. farms, by type, 2001-10

Short tons (million)

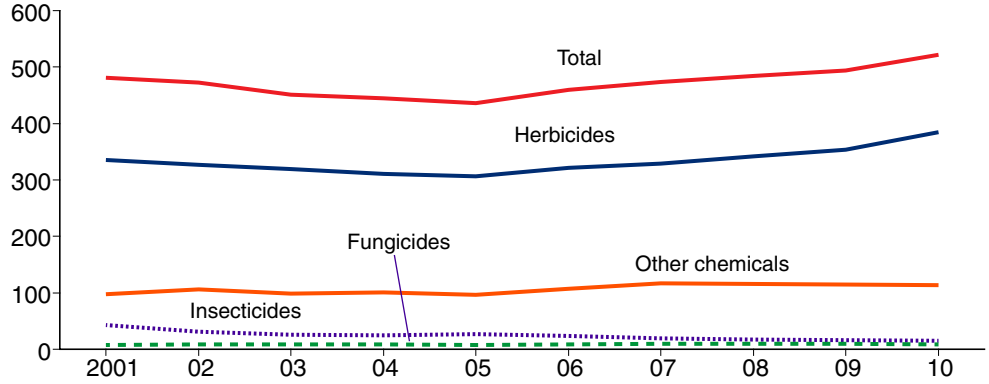


Source: USDA, Economic Research Service, *Fertilizer Consumption* database (2011d).

Figure 10

Pesticide use on U.S. crops, 2001-10

Million lbs. of active ingredient



Source: Livingston and Osteen, 2012.

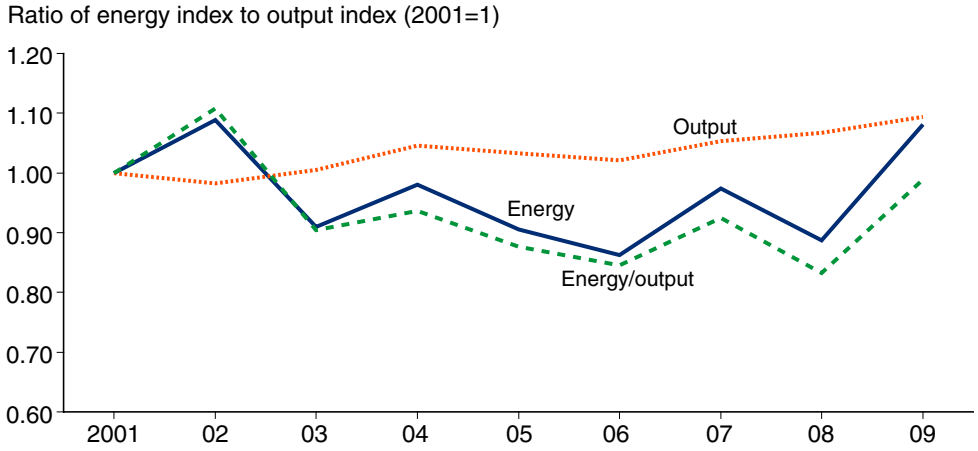
production technologies and practices can reduce the quantity of inputs per unit of output. For example, increasing the efficacy of pesticides or the active ingredient content of fertilizers means the same outcomes can be achieved with lower quantities of chemicals, as measured in physical units. Further, as the prices of particular inputs increase (or policies are adopted to discourage use of particular inputs), producers may alter production practices accordingly. For example, in response to higher energy prices, farmers may acquire more energy-efficient vehicles or adopt production practices that require fewer trips across the field.

U.S. farmers reduced quality-adjusted[1] energy inputs per unit of output over the last decade (fig. 11). The energy intensity of U.S. farm output was lower over 2002-09 (with the exception of 2002, a year in which output declined) relative to the 2001 rate, though the ratio of energy use to output varied from 11 percent higher (2002) to 17 percent lower (2008) than the 2001 rate.

For pesticides and fertilizer ("agricultural chemicals"), we use crop output as the basis of comparison, since livestock production for the most part does not use these inputs directly. Over 2001-09, the intensity of quality-adjusted chemical use per unit of crop output was higher than the 2001 rate in 4 of the 8 years (fig. 12). During the period, the ratio of agricultural chemicals to output ranged from 5 percent lower (2006) to 6 percent higher (2003) relative to the ratio in 2000.

Figure 11

Changes in energy inputs, output, and energy intensity on U.S. farms, 2001-09



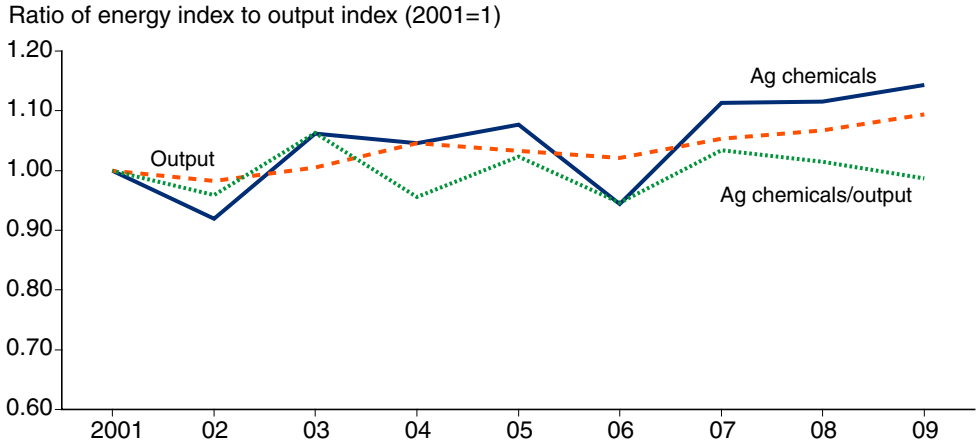
Note: Data are indices of agricultural sector output and energy input (fuel, lube, and electricity) and the ratio of the energy index to the output index (2001=1).

Source: USDA, Economic Research Service, data product "Productivity in the United States" (2012a).

[1]For the analysis, we use data from the ERS agricultural productivity dataset, where inputs are quality-adjusted. Consequently, as quality increases, the quality-adjusted quantities increase faster than quantities in physical units. For more information, see http://www.ers.usda.gov/data-products/agricultural-productivity-in-the-us.aspx

Figure 12

Changes in energy-intensive agricultural chemical inputs, output, and agricultural chemical intensity on U.S. farms, 2001-09



Note: Data are indices of agricultural crop sector output, agricultural chemical input (fertilizer and pesticides) and the ratio of the agricultural chemical index to the crop output index (2001=1).

Source: USDA, Economic Research Service, data product "Productivity in the United States" (2012a).

Expenditures on Energy and Energy-Intensive Inputs by Crop Producers

As energy prices and commodity production increased in the 2000s, total expenditures on energy inputs also increased. However, exposure to higher energy prices varies widely across crops.

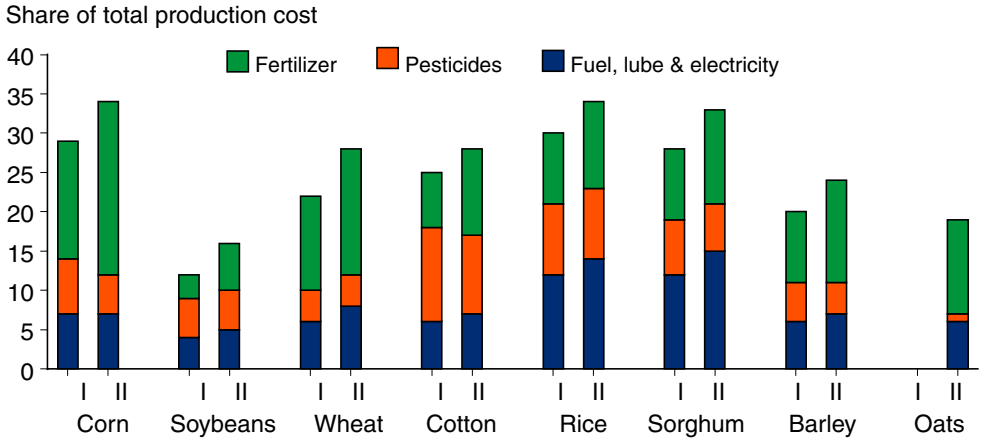
Figure 13 illustrates the share of production expenses spent on energy and energy-intensive inputs over two periods: 2001-05 and 2006-11 (see box, "ERS Costs of Production"). The second period corresponds to the large changes in input prices that occurred in the latter half of the 2000-2011 period. Among the major field crops, corn and rice—with sorghum and cotton close behind—had the highest cost shares for direct and indirect energy inputs over 2000-2011. Energy cost shares increased the most between periods for sorghum and wheat. In the latter period, the average share of energy inputs in total production costs was highest for corn, rice, and sorghum (33-34 percent), and lowest for soybeans (17 percent).

Indirect energy expenditures saw large share increases relative to direct energy expenditures between periods I and II, primarily due to higher fertilizer expenditures. For example, in period I, fertilizer expenditures were 15 percent of the average corn production costs; under the high energy prices of 2006-11, the share of fertilizer expenditures in total corn production costs increased to 22 percent. Rising fertilizer cost shares indicate that, though fertilizer use declined from 2006 to 2011, compared with 2001-05 (fig. 9), the percentage decline in quantity of fertilizer was less than the percentage increase in prices.

Though direct energy use constitutes a larger share of the energy content consumed on farms (fig. 7), *expenditures* on indirect uses represent a larger share of farm expenses (fig. 13). This is simply because indirect energy inputs cost more per unit of energy than direct energy purchases. Figure 14 illustrates this point, showing expenditures on inputs in 2011 as well as their cost per unit of energy.

Figure 13

Share of energy-based inputs in U.S. farm production costs, 2001-05 and 2006-11



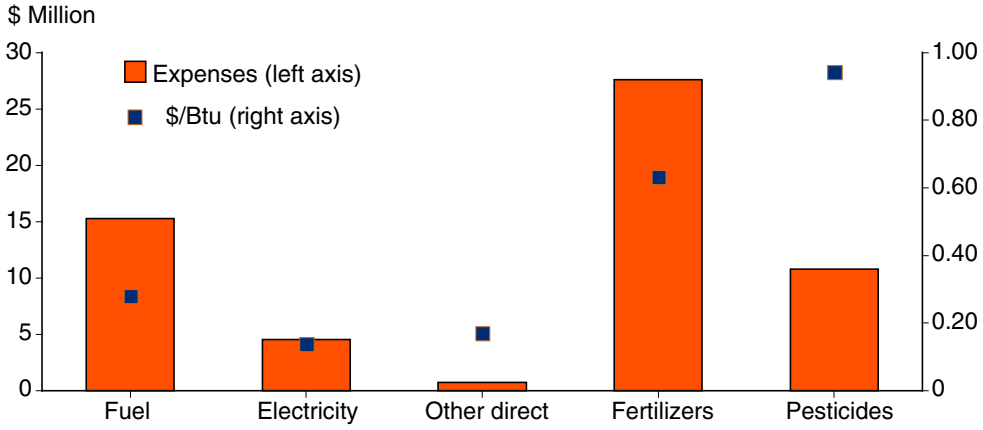
Period: I = 2001-05 II = 2006-11

Note: Total production costs include seed; fertilizer; chemicals; custom operations; fuel, lube, and electricity; repairs; purchased irrigation water; interest on operating capital; hired labor; opportunity cost of unpaid labor; capital recovery of machinery and equipment; opportunity cost of land; taxes and insurance; and general farm overhead.

Source: USDA, Economic Research Service, *Cost of Production* estimates, various years (2011b).

Figure 14

Total expenditures and cost of direct and indirect uses of energy, 2011



Source: USDA, National Agricultural Statistics Service, *Quick Stats* (2012). Btu = British thermal units.

ERS Costs of Production

USDA's Economic Research Service has estimated annual production costs and returns for major field crop and livestock enterprises since 1975. These cost and return accounts are based on the actual and implied costs incurred by producers. The costs and returns of all participants in the production process—including farm operators, landlords, contractors, and contractees—are included in the account.

The annual estimates are based on producer surveys conducted about every 4 to 8 years for each commodity and updated each year with estimates of annual price, acreage, and production changes. This update method implicitly assumes that the technology remains constant between producer surveys. For more information, see http://www.ers.usda.gov/data-products/commodity-costs-and-returns.aspx.

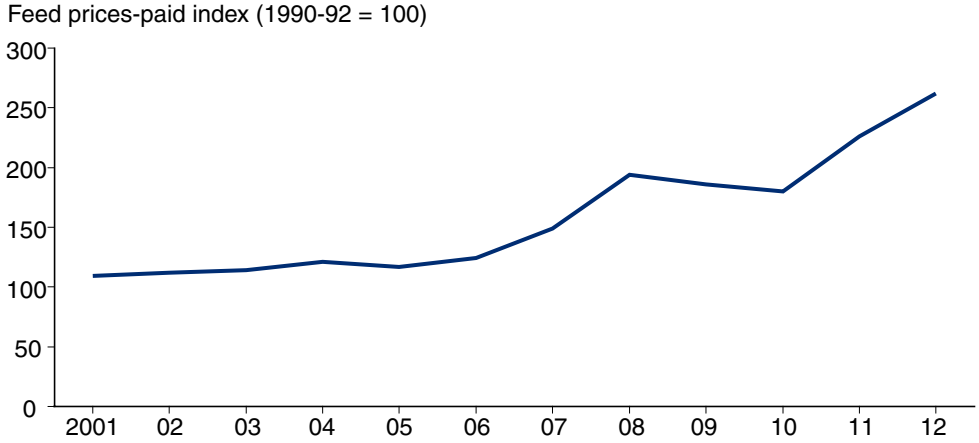
Expenditures on Energy and Commodity Inputs by Livestock Producers

Livestock producers are uniquely affected by the volatility in commodity and energy prices as they use agricultural outputs (for example, corn) as inputs—feed. Feed prices trended upward over 2001-2012 (fig. 15). Corn represents a little more than half of all livestock feed; thus, it is not surprising that changes in feed prices generally track corn price changes (fig. 5).

Higher feed and direct energy input prices affected livestock producers' average expenditures for these products. Livestock producers' expenditure on feed more than doubled from $24.8 billion in 2001 to $54.6 billion in 2011 (NASS, 2012). The share of direct energy inputs in production expenses saw modest increases for milk, hog, and cow-calf operations (fig. 16), whereas feed experienced a larger increase in share. In particular, the feed share of total milk production expenses increased from

Figure 15

Index for feed prices paid (1990-92=100), 2001-12



Source: USDA, National Agricultural Statistics Service, *Quick Stats* (2012).

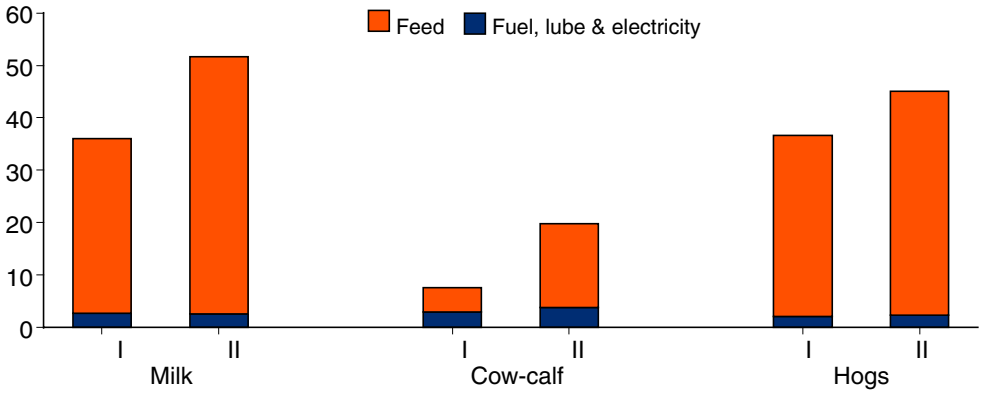
33 percent in 2001-05 to 49 percent in 2006-11. This made the total expenses due to feed and direct energy inputs more than half of total milk production expenses.

The production of dried distillers' grains with solubles (DDGS) has offset some of the increase in feed prices from higher corn prices. However, DDGS and corn are not perfectly substitutable due to livestock diet constraints (Beckman et al., 2012). The amount of DDGS available for feed increased from 2.9 million metric tons (mmt) in marketing year 2001/02 to 37.0 mmt in 2010/11 (Hoffman and Baker, 2011). This is compared to 111.8 mmt of corn used for feed in 2010/11.

Figure 16

Cost shares of feed and direct energy inputs in livestock production expenses, 2001-05 and 2006-11

Percent of total production cost



Period: I = 2001-05 II = 2006-11

Note: Feed for milk costs excludes grazed feed; feed for cow-calf costs includes supplemental feed, concentrates, and other feed.

Source: USDA, Economic Research Service, *Cost of Production* database (2011b).

Producer Responses to Changing Input Prices and Policy Incentives

Aggregate changes in the agriculture sector's energy use explored in the previous section are the result of changes in farm-level production practices and technologies. To better understand the trends, it is useful to look at changes in rates of adoption of farm production practices that affect use of energy-intensive inputs.

The extent to which producers can substitute away from energy-related inputs without compromising output levels depends on the availability of alternative production practices and technologies, assuming the cropping mix is fixed. Because some alternative technologies may involve investments in capital equipment or information technologies, the degree of substitutability tends to increase with longer timeframes for making adjustments, and the full impact of the recent price volatility may not be realized for some years to come.

Various USDA conservation programs provide economic incentives—including financial incentives, technical assistance, and education for farmers—to adopt practices that conserve on use of energy and other inputs. Notably, USDA farm conservation program expenditures almost doubled during 2000-10, which may partially offset the impact of higher energy prices.

Operator Stated Responses to Price Changes

In the short term, operators can change production practices to use energy and energy-intensive inputs more efficiently in response to changing energy prices and evolving energy and environmental policies.

Beginning in 2006, USDA's Agricultural Resource Management Survey[2] (ARMS) asked farm operators direct questions about how they adjusted their operations in response to higher fertilizer and fuel prices. For each year these questions were asked, it is possible to summarize the responses for a nationally representative sample of all farm types (2006), as well as for commodity-specific farms surveyed that year (2005-07, 2009-10).

All Farms

Nationally, 20 percent of farm operators reported in 2006 that they reduced fuel use in response to higher prices. Across all farm types, the most common adaptation strategies were to keep engines serviced (34 percent of farms) and to reduce trips over the field (24 percent of farms), while 7 percent of farm operators indicated they negotiated a price discount (fig. 17) (Harris et al., 2008). These findings are consistent with the decrease in fuel input use in 2006 reported earlier (fig. 8).

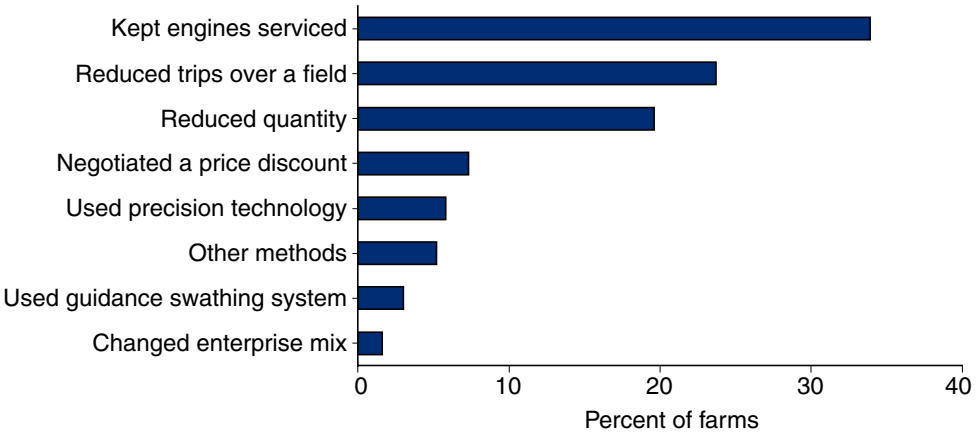
In response to higher fertilizer prices, 32 percent of farmers reported simply reducing their fertilizer use in 2006 (fig. 18). Producers used a variety of information technolo-

[2]The Agricultural Resource Management Survey is conducted by USDA's National Agricultural Statistics Service and Economic Research Service. More information regarding the survey and data can be found at: http://www.ers.usda.gov/data/arms/GlobalAbout.htm

gies to reduce fertilizer use with the least impact on yields, including conducting soil tests (23 percent of farms) and using precision technology[3] (11 percent of farms). In addition, 13 percent of farms reported negotiating a price discount.

Figure 17

Producers' reported responses to higher fuel prices, 2006

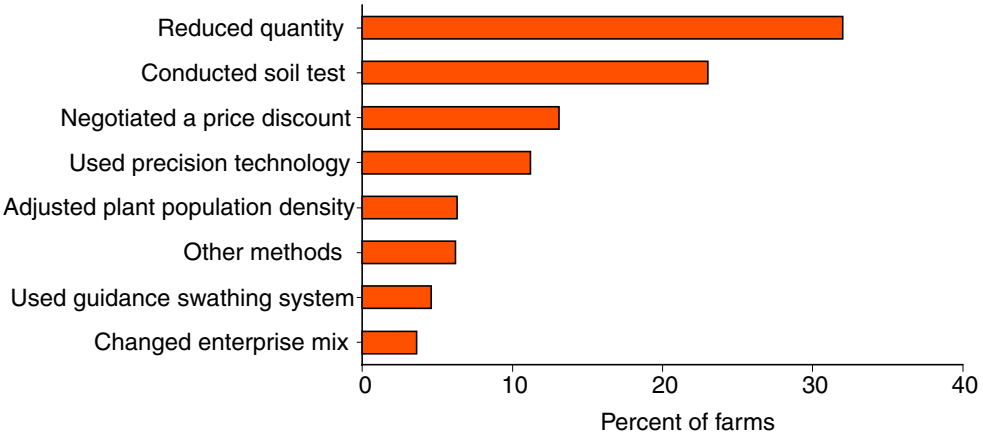


Note: The responses are not mutually exclusive.

Source: Harris et al., 2008.

Figure 18

Producers' reported responses to higher fertilizer prices, 2006



Note: The responses are not mutually exclusive.

Source: Harris et al., 2008.

[3]Precision technology is the use of modern information technologies (e.g., satellite maps) that help farmers to more efficiently use fertilizer, pesticides, and water resources by providing spatially detailed information about farm environmental characteristics (eg., soil type, elevation) and the ongoing status of plant growth (including pest pressure and water availability).

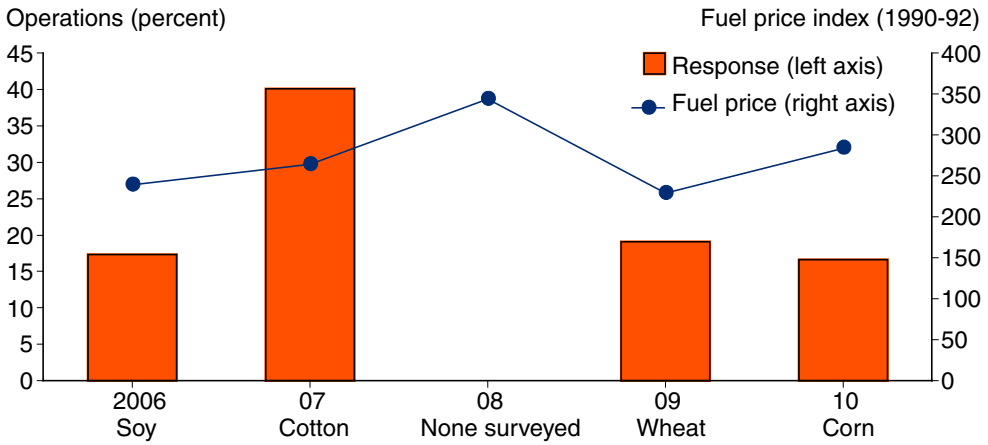
By Commodity

Similar questions were asked in the commodity-specific versions of ARMS.[4] Because crop needs vary, producer responses to increased fuel and fertilizer prices are likely to vary by crop. Across all crops, the most frequent response to higher fuel prices was to reduce the number of field operations—such as tillage, cultivation, or nutrient and pesticide applications—that use fuel to run machinery (fig. 19). For corn producers, 16.6 percent indicated in 2010 that they reduced the number of field operations in response to higher fuel prices. Among cotton producers, 40 percent indicated that they reduced the number of field operations in 2007, which coincides with the initial spike in fuel prices (fig. 2).

In response to higher fertilizer prices, the most frequent adjustment reported by commodity producers was to reduce the application rate of nitrogen (fig. 20), followed by managing fertilizer application more closely (for example, with soil testing, split applications, variable-rate applications, or soil incorporation). Soybean producers had the lowest response rates to these two questions, most likely due to lower fertilizer use on soybeans relative to the other surveyed crops. Some farmers also indicated that they increased the use of manure as a substitute for other fertilizer products. More corn producers (5 percent) than any other type of producer responded that they increased the application rate of manure, which is not surprising because they are the largest users of manure as fertilizer (Beckman and Livingston, 2012). Wheat producers (2009) reported that they reduced fertilizer use the most and by the largest amounts. These responses by individual crop producers are consistent with the national reduction in fertilizer use over 2005-11 (fig. 9).

Figure 19

Producers' reporting reduced field operations in response to higher fuel prices, by crop, 2006-10



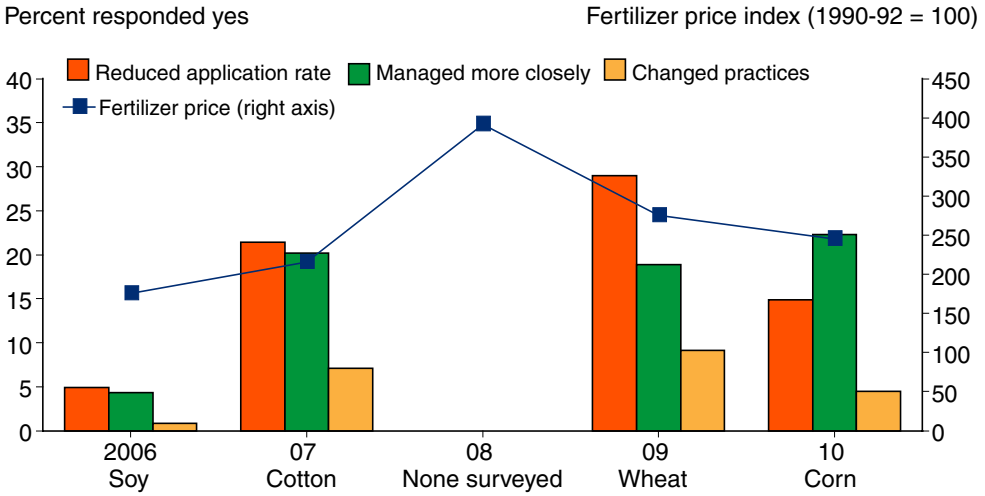
Note: Field operations include tillage, cultivation, or nutrient and pesticide applications.

Source: USDA, Economic Research Service and National Agricultural Statistics Service, Agricultural Resource Management Survey (2010).

[4]Each year a different set of crops is surveyed. To be classified, for example, as a corn farm, more than 50 percent of a farm's value of production must be from corn; consequently, total production on corn farms is not the same as total corn production.

Figure 20

Producers' reported responses to higher fertilizer prices, by crop, 2006-10



Note: Closer fertilizer management refers to practices such as soil testing, split applications, variable-rate applications, or soil incorporation.

Source: USDA, Economic Research Service and National Agricultural Statistics Service, Agricultural Resource Management Survey (2010).

Observed Changes in Production Management Practices

Advancements in technologies and adoption of best management practices on farms can reduce onfarm energy and energy-intensive fertilizer and pesticide use. Each year, the ARMS asks farm operators about adoption of best management practices designed to reduce input use and reduce pollutant discharges to the environment.

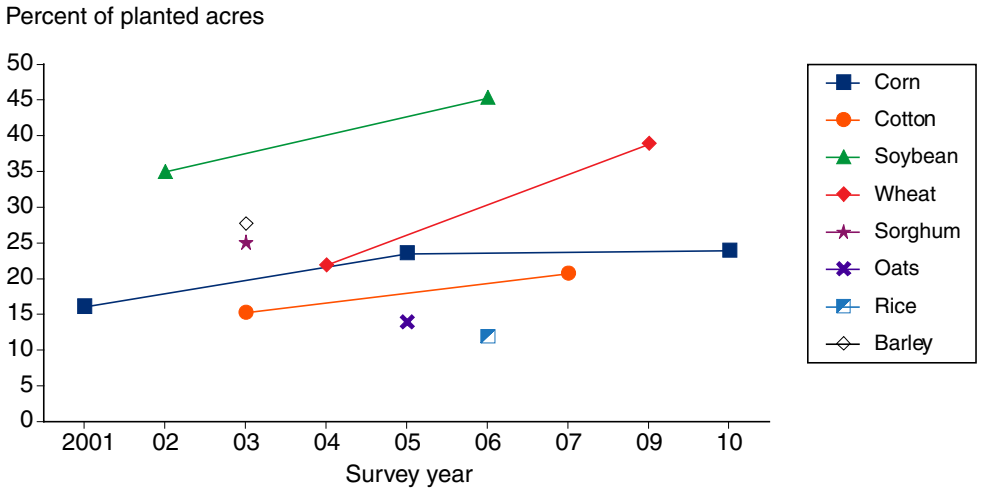
Conservation Tillage

Tillage practices on fields affect farms' energy use. Reduced tillage (versus traditional intensive tillage) may result in decreased trips over the field due to lower cultivation rates, but also increased use of the energy-intensive inputs—particularly pesticides—on HT seed varieties. Recent analysis using ARMS data reveals that one form of reduced tillage, no-till[5], generally increased over 2000-07 (Horowitz et al., 2010; authors' calculations). Soybean farmers (those who had the majority of their acreage in soybeans) had the highest percentage of planted acres with no-till (45.3 percent in 2006) (fig. 21), with wheat farmers in second place (38.8 percent in 2009). Corn farmers practiced no-till on 23.9 percent of planted acres in 2010. Cotton farmers practiced no-till on 20.7 percent of planted acres in 2007. For all crops with observations in multiple years, the percentage of no-till acreage increased during the 2000-2010 time period.

[5]A field is said to have no-till operations if none of the following categories of machinery are used on the field between harvest of the previous crop and the current year's planting: plows and disks, including moldboard plow, offset disk, and tandem disk; cultivators; harrows; bedder-shapers; packers; and any miscellaneous tillage equipment such as Land-all, Do-all, Mix-n-till, mulch treader, rototiller, soil finisher, or stalk puller.

Figure 21

Percent of planted acres that are no-till for major field crops, 2001-10



Source: USDA, Economic Research Service and National Agricultural Statistics Service, Agricultural Resource Management Survey (2010).

Precision Agriculture: Information and Variable-Rate Input Applicators

One way to increase efficiency in agriculture is through the adoption of precision technologies, which use information gathered during field operations, from planting to harvest, to calibrate the timing and location for applying inputs and economize on fuel and fertilizer use. Recent ARMS data show that use of yield monitors by corn farmers, often a first step in using precision technology for grain crop producers, has grown rapidly (Schimmelpfennig and Ebel, 2011). Usage jumped from 24 percent in 2001 to 42 percent in 2005 and 61 percent in 2010 (table 3).

Adoption of the complementary technologies that capitalize on the detailed information collected by yield monitors has increased, but it still lags behind yield monitor adoption. Adoption of variable-rate input (VRT) applicators increased from 9 percent in 2001 to 12 percent in 2005 and 23 percent in 2010 (or about one-third of those who had adopted yield monitors in 2010). With VRT applicators, farmers can apply seeds, fertilizer, and pesticides to suit different sections of a field depending on soil conditions, nutrient needs, and the severity of pest problems, thereby economizing on inputs without sacrificing yield.

Onfarm Renewable Energy Production

Another way farmers can protect themselves against high and volatile energy prices is through the adoption of onfarm renewable energy systems. The adoption of renewable energy technologies has been increasing. In 2008, an estimated 17,358 U.S. farms produced energy from "wind or solar technology, methane digester, etc." (ERS, 2008); by 2011, this number had nearly doubled (ERS, 2011a).

Adoption of these technologies on farms could have one of two impacts for onfarm energy use. The renewable energy installation could be used to offset energy use,

Table 3
Percent of planted corn acres using precision technology, 2001, 2005, and 2010

	2001	2005	2010
Precision agriculture used	3.72	49.4	72.5
Yield monitor used	23.9	41.6	61.4
Yield map created	9.0	19.4	33.9
Yield monitor information use: Monitor crop moisture	NA	36.2	51.7
Yield monitor information use: Conduct experiments	NA	17.4	20.4
Yield monitor information use: Document yield	NA	17.3	28.0
Yield monitor information use: Other uses	NA	15.9	23.2
VRT used for any purpose	9.4	11.5	22.5
VRT used for any fertilizing	8.2	10.1	19.3

NA = Not available.

Source: USDA, Economic Research Service and National Agricultural Statistics Service, Agricultural Resource Management Survey (2010).

thereby reducing the amount of electricity previously purchased from an electric utility. Or installed renewable energy technologies could supply power to farming operations or activities that previously were not powered.

According to a national survey of renewable energy-producing farm operators—the 2009 On-Farm Renewable Energy Production Survey (OFREPS)[6]—solar energy production is the most prevalent form of onfarm renewable energy, with an estimated 93 percent of farms with renewable energy generation reporting solar electric or solar thermal generating capacity (fig. 22). Solar technologies employed by farmers include photovoltaic (PV) panels, which generate electricity, and thermal solar panels used for such applications as crop drying, space heating, and water heating.

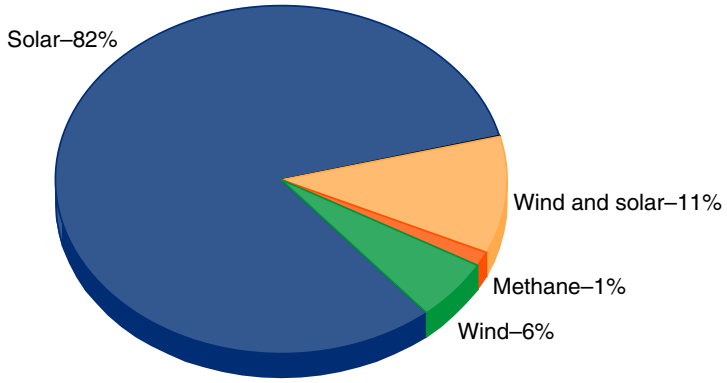
Wind is the second most prevalent onfarm renewable fuel source; 17 percent of farms with renewable energy capacity had wind generation in 2009 (USDA NASS, 2011a). Wind technologies can be used similarly to PV technology. For example, wind turbines can charge batteries for remote applications, or can be used to pump water for animals. Wind turbines can also be connected to the electric grid to offset electric purchases from the utility company (DOE/NREL, 2003).

A final source of onfarm renewable energy production is methane digesters, which collect and store manure for heat and electricity generation (Key and Sneeringer, 2011). The U.S Environmental Protection Agency AgSTAR program estimates that, as of September 2012, there were 192 operational anaerobic digesters in the United States, of which 178 generated electric or thermal energy (EPA, 2012). Farm operations with anaerobic digesters (1.4 percent of farms with renewable energy) are far less common than those with either wind or solar capacity (USDA NASS, 2011a). The economic incentives for installation and management of an onfarm methane digester result from the comparison with alternative waste management systems, and not primarily energy savings (Schnepf, 2007). To date, this technology

[6]The first national survey of renewable energy producing farm operators (2009 On-Farm Renewable Energy Production Survey (OFREPS)) obtained information on renewable energy production on U.S. farms and ranches (NASS, 2011a). This survey provides an overview of renewable energy applications on U.S. farms.

Figure 22

Farms with onfarm renewable energy production, by source, 2009



Source: USDA, National Agricultural Statistics Service, (2011a).

is most cost effective for large livestock operations; therefore, where adopted, the electricity output is often substantial relative to onfarm wind and solar generation. Rising energy prices, carbon offset sales, renewable energy legislation and revenues from co-products such as recovered nutrients and fiber could make this technology increasingly attractive to more farm types and sizes (for example Key and Sneeringer, 2011; Wang et al., 2012). Over 80 percent of the digesters are located on dairy operations, 12 percent on swine farms, and the remainder on poultry and beef farms (EPA, 2012).

Along with higher energy prices, favorable policies and funding may have induced the increase in renewable energy adoption (see Appendix). Almost 25 percent of farms with renewable energy reported that they received Federal funding for its production.

Conclusions

Rising energy prices and changing energy and environmental policies over the last decade have transformed the relationship between the agriculture and energy sectors. While the agricultural sector has traditionally used energy both directly in the form of fuel and electricity and indirectly through use of energy-intensive inputs, such as fertilizers and pesticides, over the last decade, it has become a supplier of energy inputs. This report investigates the recent changes in the agriculture sector's relationship with energy—both using energy as an input into agricultural production and supplying agricultural feedstocks for use in biofuel production. As these changes are occurring simultaneously with other (non-energy-related) market and policy developments, additional research is required to identify the relative strength of each factor in influencing the patterns of farmer decisions and aggregate outcomes.

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Appendix: Biofuel and Renewable Fuel Policies

Ethanol, the most prominent U.S. biofuel, began commercial-scale expansion in large part due to a blenders' tax credit of 40 cents per gallon provided in the Energy Policy Act of 1978 (Tyner and Taheripour, 2008). Between 1978 and 2011, the ethanol tax credit ranged between 40 and 60 cents per gallon. During this time, an import tariff on foreign ethanol complemented the tax credit in promoting domestic sources of ethanol; however, both the tariff and the tax credit expired at the end of 2011 as the ethanol industry matured.

Production of biodiesel, another form of biofuel, has also benefited from subsidies, including the introduction of a $1-per-gallon subsidy in 2004 via the American Jobs Creation Act, which still exists in 2012 (Yacobucci, 2011).

The Energy Policy Act of 2005 (EPACT), which mandated a floor for domestic biofuel use, boosted ethanol demand. EPACT created a national Renewable Fuel Standard (RFS1), which mandated domestic use of 7.5 billion gallons of biofuels by 2012. EPACT effectively banned the gasoline additive methyl tertiary butyl ether (MTBE); consequently, ethanol became the oxygenate of choice by spring 2006 (Babcock, 2008).

Two years later, the Energy Independence and Security Act of 2007 (EISA) expanded the biofuels blending mandate to 36 billion gallons of total renewable fuels per year by 2022, with additional volume requirements for other renewable fuels (see Schnepf and Yacobucci, 2012). The RFS2 also increased the maximum allowable amount for corn and the mandate amount for biodiesel starting in 2008 (e.g., tables 3-1, 3-2).

Policies promoting renewable electricity generation include State-level production mandates through a Renewable Portfolio Standard, Federal and State tax credits, and various State programs intended to reduce production barriers (Cunningham and Roberts 2011). In addition, some USDA conservation programs (e.g., Environmental Quality Incentives Program) provide funding for farm-based renewable energy operations. Small, customer-scale generation (such as that occurring on farms) has been supported by net-metering and interconnection standards, which most States have adopted in some form (DSIRE, 2011). State-level net-metering policies credit electric customers for electricity generated in excess of what they are using at the time of generation. Interconnection standards, designed to reduce technological barriers to renewable energy use, establish clear and uniform technical requirements for small distributed generation systems connecting to the electric grid, and reduce uncertainty and time delays in customer-utility interaction. State and utility incentive programs such as tax credits, rebates, grants, and low-interest loans are also in place to encourage customer-generated renewable energy.