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## ENERGY USE IN U.S. AGRICULTURE: EARLY ADJUSTMENT TO THE 1973-74 PRICE SHOCK

John M. Gowdy, Jack L. Miller, and Hamid Kherbachi

### Abstract

Using input-output tables for 1972 and 1977 we examine direct and indirect energy use in the production of fourteen U.S. agricultural products. We find that between 1972 and 1977 energy use increased in absolute terms but decreased in terms of Btus required per dollar of output.

Although this trend is encouraging in terms of the long-run ability of U.S. agriculture to adjust to higher energy prices, the following caveats should be mentioned; (1) a large part of the decrease in primary energy intensity is attributable to one sector, meat animals, (2) there was a substantial increase in electricity intensity in almost all sectors, and (3) there was an increase in the use of energy embodied in fertilizers and agricultural chemicals in the very important food grain and feed sectors.

*Key words:* energy, input-output, technological change.

One of the most striking trends in modern agriculture is its increasing dependence on non-renewable forms of energy. Since World War II, productivity increases have come, for the most part, from substituting energy and capital for labor and Ricardian land. In terms of kilocalories used per acre, there has been a tremendous increase in energy use since World War II due to massive increases in the direct use of energy as well as in the indirect use embodied in fertilizers, insecticides, and herbicides (Pimentel et al.). The increased application of energy to a more or less fixed amount of land is beginning to show a diminishing output-energy ratio. According to Rutan, increased usage of fertilizer, an energy-intensive factor of production, accounted for a yield gain of two bushels of corn per year per

hectare between 1955 and 1965. By the early 1980s, higher levels of fertilizer use were accounting for less than half a bushel per hectare per year. He writes, "The gains in productivity growth that can be expected from traditional sources will be inadequate to meet even the relatively slow growth in demand for U.S. agricultural commodities that is now anticipated over the next several decades" (Rutan, p. 781). Lamm and Westcott found that energy price increases were a major contributor to the large increases in agricultural prices during the 1970s. Ball found that the cost shares of direct energy and of agricultural chemicals increased much more rapidly between 1948 and 1979 than the cost shares of any other intermediate inputs to agricultural production.

There are, of course, arguments against a pessimistic view. Rising resource prices will call forth substitutes and new techniques that will offset at least some of the negative effects of increasing resource scarcity (Barnett and Morse). The question is whether technological advances, reflected in the substitution of renewable for non-renewable resources, can keep pace. Also, the income effect of rising energy prices makes it harder to finance alternative technology.

There have been several economic studies dealing with the role of energy in agricultural production. Most of these are for specific agricultural commodities in particular regions of the country. Several studies have examined specific uses of energy, for example, the Madgdon et al. study of the irrigation demand for electricity. Adams et al. examined the effects of energy cost increases on the production of field crops in California. They found that the energy cost of producing these crops, as a percentage of total variable costs, were substan-

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tial, ranging from 9 percent to 30 percent. The bulk of these energy costs was due to the costs of pesticides and fertilizer. Unfortunately, their calculation of per acre energy costs of these inputs included the total costs of fertilizer and pesticides, not just the energy contribution to these costs. Nevertheless, their results suggest that the impact of energy prices is substantial both in terms of overall production and in terms of product mix. Weaver, in a study of a U.S. wheat region (North Dakota and South Dakota), used a production function framework to examine substitution possibilities among a number of inputs. The outputs Weaver considered were food grains, feed grains, and livestock and the inputs were labor, fertilizer, capital services, materials, and petroleum products. Estimated cross-elasticities of demand indicated substantial complementarity among inputs and outputs. In general, Weaver found that all inputs and outputs are reduced when any input price increases. With an increase in fertilizer prices, only wheat production and capital services in South Dakota showed a predicted increase. Only wheat production in South Dakota was positively related to an increase in the price of petroleum products. The demand for both fertilizer and petroleum products was relatively inelastic with respect to their own prices, again indicating limited substitution possibilities. Also, technological change was found to be fertilizer-using relative to capital, materials, and petroleum inputs. These results appear to be confirmed by other studies, although the results are somewhat mixed. Binswanger found complementarity between labor-fertilizer and machinery-fertilizer. In another multiple-input, multiple-output study, Ray found low own-price elasticities for fertilizer but substitution possibilities between fertilizer-labor and fertilizer-capital. The own-price elasticities and the elasticities of substitution reported in these studies suggest that, although significant substitution possibilities exist between energy and non-energy inputs to agricultural production, such substitution will be less easy than in the economy as a whole.

The results of the above studies would be strengthened if the observed patterns still

hold when indirect as well as direct energy use is taken into account, and when the energy content of fertilizers and agricultural chemicals is isolated. By using input-output analysis, we are able to capture the indirect as well as direct energy used in the production of various agricultural products, and we are able to isolate the energy content of fertilizer use. The major limitation of the analysis is the assumption of fixed input proportions. Because of this we are unable to calculate elasticities of substitution to compare with those presented in the above studies. In this paper we use the latest available Input-Output (IO) data for the U.S. economy to consider the following questions: (1) how did the use of energy in agriculture, both direct and indirect, adjust to rising prices between 1972 and 1977, that is, before and after the 1973 oil embargo, and (2) to what extent did the energy embodied in petroleum-based fertilizers and agricultural chemicals contribute to changing patterns of energy use during this period?

## ENERGY INPUT-OUTPUT ANALYSIS

Our energy use estimates are based on the 1972 and 1977 IO tables. It is unfortunate that later IO tables are unavailable (the 1977 tables were not published until 1984), but at least we can get some idea of the initial response to the first energy price shock. Input-output analysis involves a system of linear equations, each of which describes the distribution of output of a particular industry throughout the economy. There are three basic types of IO tables. The commodity-by-industry transactions table shows the interindustry flows of commodities throughout the economy in total dollar values. The direct requirements table is the transactions table divided by industry output in each sector and shows the amount of input of each commodity required to produce a dollar's worth of output of a given industry. Finally, the Leontief inverse shows the amounts of each commodity required directly and indirectly to deliver a dollar's worth of final demand of the product of a given industry.<sup>1</sup> In our analysis we aggregated the U.S. input-output transactions tables for 1972 and 1977 (U.S. Department of Commerce, 1979 and 1984) into 150 sectors. With these tables we

<sup>1</sup>Together with the information described in the "make" matrix, the table of commodity-by-industry direct requirements may be used to describe four types of total requirement matrices. These are commodity-by-industry requirements, commodity-by-commodity requirements, industry-by-commodity requirements, and industry-by-industry requirements. The construction of these matrices is described in detail in Miller and Blair.

examined 14 agricultural sectors in terms of their direct and indirect use of primary (coal mining, petroleum, and natural gas extraction) and secondary (petroleum refining, electricity, and natural gas utilities) energy.

The "use" matrix,  $U$ , used in this study is defined to include only the commodity-by-industry flows.<sup>2</sup> It is sometimes referred to as an absorption matrix. The commodity-by-industry accounts were devised to deal with the problem of secondary production. Industries are classified according to the output which is most representative of them. In energy IO accounts it is desirable to isolate the actual commodities consumed by industries, as opposed to all the inputs from a given industry. This is accomplished by defining the rows as commodities and the columns as industries. The entries in a row labeled "steel," for example, would show the use of the commodity steel by the industries listed in the columns at the top of the table, no matter from which industry the steel originated. Entries in the column labeled "steel" would indicate the commodity inputs needed to support the output of the steel industry, including all secondary products produced by that industry. In this study, the number of industries equals the number of commodities so that we are always dealing with a  $150 \times 150$  square matrix. The commodity-by-industry direct requirement technical coefficient is defined as:

$$(1) \quad b_{ij} = \frac{u_{ij}}{X_j},$$

where  $u_{ij}$  is an element of  $U$  and represents the amount of commodity  $i$  used by industry  $j$ ; total industry output,  $X_j$ , is equal to the value of total intermediate inputs plus value-added, that is,  $X_j = u_{1j} + u_{2j} + \dots + u_{nj} + VA_j$ ; and  $b_{ij}$  represents the amount of commodity  $i$  required (in dollars) to produce one dollar's worth of the output of industry  $j$ .

In matrix form equation (1) becomes:

$$(2) \quad B = U(\hat{X})^{-1},$$

where  $B$  is the  $150 \times 150$  commodity-by-industry matrix of direct coefficients;  $U$  is a  $150 \times 150$  commodity-by-industry matrix in which each column shows, for a given industry, the amount of each commodity it uses; and  $\hat{X}$  is a  $150 \times 150$  diagonal matrix with the

diagonal elements showing each industry's total domestic output. The symbol  $\hat{\cdot}$  indicates a diagonal matrix with numbers on the diagonals and zeros elsewhere. The matrix of commodity-by-industry total requirements is given by the bracketed term in the following equation:

$$(3) \quad Q = [(I - BD)^{-1}D^{-1}]Y.$$

An element of the term in brackets shows the dollar's worth of commodity  $j$  required to deliver a dollar's worth of industry  $i$ 's output to final demand,  $Y$ . The elements of the  $150 \times 150$   $D$  matrix show the fraction of total production of commodity  $j$  in the economy produced by industry  $i$ , that is,

$$(4) \quad d_{ij} = \frac{v_{ij}}{Q_j},$$

where  $d_{ij}$  is the commodity output proportion, derived by dividing the elements,  $v_{ij}$ , of the "make" matrix,  $V$ , by the total production of commodity  $j$ ; and  $Q_j = v_{1j} + v_{2j} + \dots + v_{nj}$ . The  $i$ th row of the make matrix shows the commodities produced by the  $i$ th industry in the economy, and the  $j$ th column shows the industry origins of the  $j$ th commodity.

In matrix terms equation (4) becomes:

$$(5) \quad D = V(\hat{Q})^{-1}.$$

To construct the matrix  $D$  we assume industry-based technology. That is, an industry has the same input structure regardless of its output product mix.<sup>3</sup> The 1977  $B$  matrix is given by  $B = \hat{C}U\hat{X}^{-1}$ , where  $\hat{C}$  is a diagonal matrix of 1972-base U.S. Department of Labor, Bureau of Labor Statistics commodity deflators, constructed using industry weights from the 1977 "make" table,  $\hat{X}$  is a diagonal matrix of deflated 1977 total industry output, and  $U$  is the undeflated 1977 commodity-by-industry transactions matrix.

The most revealing way to analyze energy use using input-output analysis is to construct a "hybrid" transactions table with energy flows in British thermal units (Btus) and nonenergy flows in dollars (Bullard and Herendeen; Casler and Wilbur). The transactions matrix, the output vector, and the final demand vector take the following forms:

<sup>2</sup>Insofar as possible, the notation follows that in Miller and Blair.

<sup>3</sup>The theory behind the assumptions of industry-based and commodity-based technologies has been discussed at length by Miller and Blair (pp. 159-73). A thorough discussion of these technology assumptions in the context of energy analysis is given by Flaschel.

$$U^* = \begin{bmatrix} \text{Btu} & \text{Btu} & \text{Btu} \\ \$ & \$ & \$ \\ \$ & \$ & \$ \end{bmatrix}, X^* = \begin{bmatrix} \text{Btu} \\ \$ \\ \$ \end{bmatrix},$$

$$Y^* = \begin{bmatrix} \text{Btu} \\ \$ \\ \$ \end{bmatrix},$$

where  $U^*$  is the hybrid commodity-by-industry transactions matrix,  $X^*$  is a hybrid vector of total industry output, and  $Y^*$  is a hybrid vector of final demand. Here, the first sector is an energy sector, and the other two are non-energy sectors.

The direct requirements matrix takes the form:

$$B^* = U^*(X^*)^{-1} = \begin{bmatrix} \text{Btu/Btu} & \text{Btu/\$} & \text{Btu/\$} \\ \$/\text{Btu} & \$/\$ & \$/\$ \\ \$/\text{Btu} & \$/\$ & \$/\$ \end{bmatrix}.$$

The four types of direct coefficients in the  $B^*$  matrix may be interpreted as follows:

- (a) Btu/Btu = Btus of energy by type required to produce one Btu of energy in a particular energy industry;
- (b) Btu/\$ = Btus of energy by type needed to produce a dollar's worth of non-energy sector output—this coefficient measures direct energy intensiveness;
- (c) \$/Btu = dollar cost of non-energy commodity input per Btu of energy output in a particular energy industry; and
- (d) \$/\$ = the standard direct commodity-by-industry input-output coefficient.

The 150 sector table used for the energy estimates contains five energy sectors; two primary (coal mining, petroleum, and natural gas extraction) and three secondary (petroleum refining, electric utilities, and natural gas utilities).<sup>4</sup> The secondary sectors are processors of primary energy so that all energy used by the economic system must come from the primary sectors. For example, if the demand for (fossil-fuel generated) electricity increases, this will require more inputs from one or more of the primary sectors.

Since we are concerned with the use of various types of energy as commodities, energy imports are included in our physical

energy measures. We are interested in comparing the intensity of energy use in agriculture regardless of the source of that energy. Likewise, energy used as feedstock is included in our energy IO calculations since we are interested in all primary energy use, not just fuel use. The control totals used to estimate Btu requirements are taken from the *State Energy Data Report, Consumption Estimates, 1960-1982* (U.S. Department of Energy, 1984). The *Annual Energy Review 1984* (U.S. Department of Energy, 1985) provides estimates of domestic energy production and net imports. Other sources used for the Btu data are Hoch and other reports of the U.S. Department of Energy (1978).

## ENERGY USE IN U.S. AGRICULTURE

The total energy requirements for 1972 and 1977 are shown in Table 1. These sectors vary greatly in the dollar value of output (see Appendix). The most important sectors are meat animals and feed grains, which together account for one-half of the total dollar value of agricultural output.

Some interesting patterns can be seen in Table 1. First of all, for three energy types the majority of the 14 agricultural sectors did not show a decline in the energy input-output coefficients between 1972 and 1977. The coal mining coefficients increased in seven out of the 14 agricultural sectors, petroleum refining energy coefficients increased in seven sectors, and the electricity coefficients increased in 10 sectors. The natural gas utility input-output coefficients increased in only two sectors, as did the petroleum and natural gas extraction energy coefficients. The decline in natural gas inputs per dollar of delivery to final demand is not surprising, since during the middle 1970's natural gas curtailments were common in many areas of the northeast and midwest. Perhaps the most striking pattern that emerges from Table 1 is the increase in electricity intensity of agricultural production; 10 of the 14 electricity input coefficients increased. The trend toward substituting electricity for primary fuels in the manufacturing sector has been widely observed (Gowdy, Netschert). This same trend is evidently taking place in agriculture. It is in part due to uncertainties in the supply of petroleum and natural gas, and in part to the fact that many of the latest

<sup>4</sup>Since our concern in this paper is to compare trends in energy use between two years, we considered primary energy to be comprised only of coal and crude petroleum and natural gas. Other studies have included the small amount of electricity produced by nuclear and hydro power as primary energy. For further discussion of primary energy intensity in IO analysis see Hannon et al.

TABLE 1. ENERGY INPUT-OUTPUT COEFFICIENTS IN U.S. AGRICULTURE, 1972 AND 1977<sup>a</sup>

Sector	Coal Mining	Petroleum and Natural Gas Extraction	Petroleum Refining	Electric Utilities	Natural Gas
1972					
Dairy	6.6	66.0	36.7	3.9	17.4
Poultry	10.2	84.9	44.7	5.5	25.6
Meat	8.6	74.3	39.8	5.3	21.3
Misc. Livestock	8.1	76.0	40.4	4.6	22.4
Cotton	7.3	122.0	50.3	3.6	49.9
Food grains	3.4	77.0	40.8	1.6	22.6
Feed grains	4.9	102.7	51.6	2.4	32.0
Fruits	7.0	115.8	55.4	3.4	39.1
Tree Nuts	5.4	103.4	48.7	2.7	36.3
Vegetables	3.4	52.8	25.1	1.7	17.8
Misc. crops	3.6	59.9	29.5	1.7	19.0
Oil crops	3.2	63.7	35.6	1.5	15.1
Forest, Nurseries	5.4	62.2	30.0	3.1	22.2
Forest, Fisheries	5.3	66.1	41.9	1.9	10.8
1977					
Dairy	7.9	62.9	46.6	4.7	15.8
Poultry	9.6	68.4	46.2	5.4	18.0
Meat	7.1	53.2	36.3	4.2	13.3
Misc. livestock	7.0	53.1	35.8	4.1	13.6
Cotton	10.1	79.7	47.4	6.5	25.6
Food grains	6.1	82.3	56.6	3.7	18.8
Feed grains	8.4	86.0	52.4	5.2	24.3
Fruits	6.7	71.3	49.5	4.2	17.0
Tree nuts	2.8	54.1	41.1	1.5	8.8
Vegetables	4.3	38.9	24.2	2.7	11.3
Misc. crops	6.6	53.3	32.6	4.2	16.1
Oil crops	2.6	37.8	27.4	1.6	7.5
Forest, Nurseries	10.0	103.3	47.1	5.4	31.7
Forest, Fisheries	5.1	60.5	42.5	2.6	14.4

<sup>a</sup>Tabular entries are 10<sup>3</sup> Btu per \$ of final demand.

technological advances involve the specialized use of electricity. The increase in the electricity coefficients reflects both an increase in direct electricity use in agriculture and an increase in electricity intensiveness in manufacturing inputs used in agriculture. The increase in the coal mining coefficients possibly reflects the increase in the use of coal for electricity generation in the midwest during this time period.

An estimate of the Btu cost of increasing energy intensity in agriculture can be made by solving the following equations:

$$(6) \quad (I - B_{72}D_{72})^{-1}D_{72}^{-1}X_{72}^a = Q_{72},$$

$$(7) \quad (I - B_{77}D_{77})^{-1}D_{77}^{-1}X_{77}^a = Q_{77}, \text{ and}$$

$$(8) \quad Q_{72}^e - Q_{77}^e = \Delta E,$$

where  $B_{72}$  is the hybrid direct coefficient matrix for 1972;  $X_{72}^a$  is a vector of total industry output of the various agricultural sectors for 1972;  $B_{77}$  is the hybrid direct coefficient matrix for 1977;  $D_{72}$  and  $D_{77}$  give the fractions of total production of particular commodities by particular industries in 1972 and 1977, respectively; and  $Q_{72}^e$  and  $Q_{77}^e$  are vec-

tors of total primary Btu requirements extracted from the  $Q_{72}$  and  $Q_{77}$  total commodity use vectors. The  $B$  and  $D$  matrices in equations (6) and (7) are  $150 \times 150$  square matrices. Equation (8) then shows the total change in primary Btu requirements in all agricultural sectors if the energy technology used in 1977 (represented by the 1977 hybrid IO coefficients) had been used in 1972. Table 2 gives the result of this calculation, showing the change in total energy requirements for both primary sectors combined. Negative numbers indicate that energy use would have been higher if 1977 energy technology had been used in 1972.

Table 2 shows that if 1977 energy technology had been used in 1972, primary Btu use in the agricultural sector would have been significantly lower. Approximately 18 percent less primary energy would have been required to produce the 1972 output. More than one-half of this hypothetical decrease would have occurred in the meat animal sector. Significant decreases would also have occurred in the feed grain, oil crop, and fruit sectors. Only the food grain and forest nursery sectors would have increased primary energy

use. In terms of secondary energy use, there would have been a decline of 9.9 percent with 1977 energy technology. Almost three-fourths of this decline is attributable to the meat industry. The output of this sector accounted for 38 percent of the total value of agricultural product in 1972, so relatively small changes in its input coefficients can have a large impact on total agricultural energy use.

## ENERGY USE DUE TO FERTILIZERS AND AGRICULTURAL CHEMICALS

Since fertilizers and agricultural chemicals are such important components of energy use in agriculture, we looked at the change in these inputs in detail. In this analysis we are concerned only with the crop sectors, since direct fertilizer and chemical use in the livestock and poultry sectors is relatively minor. The (deflated) dollar value of output in the crop sectors increased by 15 percent between 1972 and 1977. The direct and indirect primary energy required to produce a dollar's worth of agricultural fertilizers and chemicals decreased by 9 percent (see Table 4). Table 3 shows direct fertilizer intensity in the crop sectors.

Table 3 shows the importance of fertilizers and agricultural chemicals in crop production. In 1977, for example, more than 8 percent of the total direct cost of producing food grains, and more than 10 percent of the cost of producing feed grains, went to purchases of this input. Three of the eight sectors increased their direct use of fertilizers and agricultural chemicals.

TABLE 3. DIRECT FERTILIZER USE IN THE CROP SECTORS, 1972 AND 1977

Sector	Year	
	1972 (\$ per \$ of output)	1977
Cotton	.1239	.0802
Food grains	.0459	.0811
Feed grains	.0746	.1064
Fruits	.1542	.0479
Tree nuts	.1359	.0352
Vegetables	.0594	.0391
Misc. crops	.0648	.0821
Oil crops	.0379	.0284

We now consider direct and indirect energy used per dollar of crop production and per dollar of fertilizers and agricultural chemicals. This information is shown in Table 4. Table 4 shows that between 1972 and 1977 primary energy use increased in only one of the eight crop sectors (food grains). Direct and indirect primary energy use in the fertilizer and agricultural chemical sector also decreased. We can calculate the direct and indirect energy

TABLE 4. DIRECT AND INDIRECT USE OF PRIMARY ENERGY, 1972 AND 1977

Sector	Year	
	1972 (10 <sup>3</sup> Btu per \$ of final demand)	1977
Cotton	129.3	89.8
Food grains	80.4	88.4
Feed grains	107.6	94.4
Fruits	122.8	78.0
Tree nuts	108.8	56.9
Vegetables	56.2	43.2
Misc. crops	63.5	59.9
Oil crops	66.9	40.4
Fertilizer and Agri Chemicals	295.7	267.9

TABLE 2. CHANGE IN DIRECT AND INDIRECT BTUS REQUIRED TO DELIVER 1972 OUTPUT WITH 1977 ENERGY TECHNOLOGY

Sector	Primary Energy $\Delta E$	Secondary Energy $\Delta E$
	(10 <sup>12</sup> Btu)	
Dairy	13.5	- 38.3
Poultry	72.8	26.4
Meat	698.4	394.8
Misc. livestock	16.1	9.3
Cotton	82.6	50.9
Food grains	- 28.7	- 50.6
Feed grains	185.8	57.7
Fruits	106.5	64.6
Tree nuts	13.1	9.1
Vegetables	45.7	22.6
Misc. crops	9.3	- 7.0
Oil crops	127.1	75.3
Forest, Nurseries	- 81.2	- 51.3
Forest, Fisheries	11.4	- 9.7
Total	1272.4	548.4

from the fertilizer sector per dollar change in crop output by multiplying the coefficients in Table 3 by the fertilizer sector energy use coefficients in Table 4. Multiplying the results by total output in each crop sector gives the total direct and indirect energy used in the fertilizer sector embodied in agricultural output. (Total output in each sector is given in the Appendix.) For example, in the cotton sector in 1972 we see that for every dollar of cotton output, \$0.1239 of fertilizers and agricultural chemicals was used. Table 4 shows that the direct and indirect energy used in the fertilizer and agricultural chemical sector in 1972 was  $295.7 \times 10^3$  Btus per \$ of output. So every dollar of output of cotton increases direct and indirect energy use by the fertilizer and agricultural chemical sector by  $(0.1239)(295.7) = 36.6 \times 10^3$  Btus. Output in the cotton sector in 1972 was 2093 million dollars, so the total amount of energy embodied in the fertilizer required to support that level of output was  $36.6 \times 10^3 \times 2093 \times 10^6 = 76.6 \times 10^{12}$  Btus. In 1972 total direct and indirect primary energy use in the cotton sector was  $270.6 \times 10^{12}$  Btus so that  $76.6/270.6$  or 28 percent of total direct and indirect energy in the cotton sector is due to the contribution of the fertilizer and agricultural chemical sector. These coefficients and the share of total direct and indirect agricultural energy attributable to the fertilizer sector are shown in Table 5.

TABLE 5. AGRICULTURAL ENERGY USE DUE TO THE ENERGY CONTENT OF FERTILIZERS AND AGRICULTURAL CHEMICALS, 1972 AND 1977

	Year			
	1972 10 <sup>3</sup> Btus per \$ of output	1977 10 <sup>3</sup> Btus per \$ of output	1972 % of Total Energy	1977 % of Total Energy
Cotton	36.6	21.5	28.3	23.9
Food grains	13.6	21.7	16.9	24.5
Feed grains	22.1	28.5	20.5	30.2
Fruits	45.6	12.8	37.1	16.4
Tree nuts	40.2	9.4	36.9	16.5
Vegetables	17.6	10.5	31.3	24.3
Misc. crops	19.2	22.0	30.2	36.7
Oil crops	11.2	7.6	16.7	18.8

Although only three of the eight crop sectors show a hypothetical increase due to coefficient change, these sectors account for almost 60 percent of the value of crop output in 1977. Half of the crop sectors showed an increase in the percentage of total energy use accounted for by the energy content of fertilizers and agricultural chemicals.

Finally, Table 6 shows the total amount of energy embodied in agricultural chemicals and fertilizer, using both 1972 and 1977 technology to produce the 1972 and 1977 output by agricultural sector. Assuming crop out-

put at 1972 levels, energy embodied in fertilizers and agricultural chemicals would have been smaller by  $33.2 \times 10^{12}$  Btus with 1977 energy technology. The total decrease in primary energy use in crop production, if the 1977 technology had been used in 1972, would have been  $1272.4 \times 10^{12}$  Btus (Table 2). So less than 3 percent of the decrease in energy use, as reflected in these hypothetical calculations, was embodied in fertilizers and agricultural chemicals. Assuming crop output at 1977 levels, this embodied energy use with 1972 technology would have amounted to  $819.1 \times 10^{12}$  Btus and with 1977 technology  $790.1 \times 10^{12}$  Btus. Actual energy use embodied in fertilizers and agricultural chemicals increased from  $720.8 \times 10^{12}$  Btus in 1972 to  $790.1 \times 10^{12}$  Btus in 1977, or by 10 percent. During the same period, the value of crop output increased from 37,057 million dollars to 42,851 million dollars, an increase of 16 percent.

TABLE 6. ENERGY USE DUE TO FERTILIZERS AND AGRICULTURAL CHEMICALS, 1972 AND 1977

Sector	1972 Output 1972 Tech. 1977 Tech. (10 <sup>12</sup> Btus)		1977 Output 1972 Tech. 1977 Tech. (10 <sup>12</sup> Btus)	
Cotton	76.6	45.0	78.0	50.9
Food grains	48.8	77.8	50.9	81.2
Feed grains	311.2	401.3	367.6	474.1
Fruit	108.4	30.4	115.0	32.3
Tree nuts	10.1	2.4	13.7	3.2
Vegetables	62.0	37.0	63.0	37.6
Misc. crops	50.0	57.2	47.2	54.0
Oil crops	53.7	36.5	83.7	56.8
Total	720.8	687.6	819.1	790.1

## CONCLUSIONS

Between 1972 and 1977 energy use increased in absolute terms but decreased in terms of per dollar of output of the agricultural sector. In general, these results confirm those of earlier econometric studies. This trend toward increasing efficiency in agriculture was a consequence of a threefold increase in energy prices and recurring supply shortages. There was even some slight improvement in the energy intensity of agricultural chemical and fertilizer use, although this improvement was a result of increased energy efficiency in the production of these inputs, not a result of a decline in the intensity of their use in crop production. These results support the conclusions reached by Weaver and Binswanger.

In view of the observed Btu/output adjustment to higher energy prices, one might be tempted to conclude that specific energy policies for the agriculture sector are unnecessary. Again, this sector appeared to ad-



just fairly rapidly and fairly smoothly to higher energy prices. The following caveats should be noted, however.

First, a large part of the decrease in primary energy attributable to the change in technical coefficients came from one sector, meat animals. This suggests that policy decisions (including the decision to have a *laissez-faire* policy) should be based on more detailed information about energy-using processes in specific agricultural industries.

Second, there was, in general, a substantial increase in both direct and indirect electricity intensity in agriculture. This same trend has been apparent in manufacturing for some time and raises a variety of policy questions. Is the projected supply of electricity adequate to meet future agricultural demands? Will the growth in electricity use be constrained by air

quality problems associated with electricity generation?

Third, in crop production, there was an increase in the intensity of fertilizer use in the dominant food and feed grain industries. As suggested above, energy policies for the agricultural sector should consider indirect as well as direct energy use. The feasibility of increasing the energy efficiency of fertilizer production should be examined.

We conclude by pointing out that general economic studies of the agricultural sector, whether based on econometric or input-output techniques, should serve only as a broad guide for policy decisions. Information such as that presented above should be supplemented by detailed knowledge of specific production processes in each agricultural subsector.

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APPENDIX. VALUE OF U.S. AGRICULTURAL OUTPUT, 1972 AND 1977

	Year	
	1972	1977
	(millions of \$1972)	
Sector		
Dairy	7,508	7,886
Poultry	4,260	4,727
Meat Animals	30,903	25,366
Misc. Livestock	668	1,149
Cotton	2,093	2,130
Food Grains	3,585	3,743
Feed Grains	14,080	16,634
Fruits	2,377	2,522
Tree Nuts	252	342
Vegetables	3,522	3,580
Misc. crops	2,602	2,456
Oil crops	4,799	7,475
Forest & Nurseries	1,776	1,958
Forest & Fisheries	1,971	2,011
Total Agriculture	80,396	81,979
Total Crop Sector	33,310	38,882

Source: U.S. Department of Commerce, Bureau of Economic Analysis, 1979, 1984.

