ENERGY PROBLEMS AND ALTERNATIVES: IMPLICATIONS FOR THE SOUTH

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Though agriculture in the United States has been looked upon as being technically efficient in terms of output per unit of labor, it is not nearly as efficient in terms of output per unit of liquid fuels consumed (Debertin, Pagoulatos, and Boadu; Pagoulatos and Timmons). In this article, we examine the potential for substituting other inputs for liquid fuels in the agricultural production process. Studies of elasticities of substitution between energy and other inputs are reviewed. On the basis of these studies, we suggest possibilities for using other inputs instead of liquid fuels in agriculture. We present recent research results relating fuel use to tractor prices and horsepower. We compare Kentucky counties in terms of their energy use in relation to their mix of agricultural enterprises and mechanization levels. Finally, we speculate on the potential impacts of significant increases in real fuel prices on the major agricultural enterprises in the South.

THE ENERGY CRISIS

The so-called energy crisis in the U.S. is not due to a shortage in the availability of all forms of energy. Tyner, for example, has recently noted that we do not have an energy crisis as such, but rather have a liquid fuels crisis. Specifically, it is the fuels suitable for use in mobile power plants that are in short supply (Pagoulatos, Debertin, and Pagoulatos, 1978, 1979).

Oil represents 48 percent of our current consumption but only 4 percent of our reserves. Coal represents 18 percent of our consumption but 90 percent of our reserves (Tyner; Tyner and Wright). As a result, the liquid fuels crisis has a major impact on the transportation sector of our economy.

Agriculture relies heavily on liquid fuels for mobile power plants. The availability of liquid fuels at low cost provided impetus for the mechanical revolution that has taken place in agriculture in the U.S. over the past 75 years (Pagoulatos and Timmons). It was mainly the mechanical revolution within agriculture which enabled a large segment of the population to leave production agriculture.

The South produces 29.5 percent of the total value of agricultural production and uses 29.6 percent of the energy (U.S. Department of Agriculture). Hence, the South is subject to the same average conditions as the rest of the nation. Specific enterprises in the South differ greatly in their energy intensiveness.

Malthusian aspects of the energy crisis are now a popular topic. Koenig argues that if the historical rate of growth of 3.5 percent per year in the U.S. were to be sustained, it would be necessary to produce more energy in the next 20 years than has been produced in all of history up to now. Moreover, if the growth rate in world crude oil consumption were to continue at the historical 1890-1970 rate of 7.04 percent per year, even the most optimistically assessed world crude reserves would be depleted within 34 years. Koenig concludes that total energy consumption must be drastically reduced and that research, exploration, and government policy can only forestall the point in time and the manner in which the transition takes place.

Koenig defines the real cost of energy as the ratio of the cost of energy in dollars per unit to the cost of labor in dollars per hour. If trends started in 1973 continue, the cost of natural gas and electricity in relation to labor will have increased by a factor of 40 and 4, respectively, by the turn of the century. Clearly, such major shifts in the real cost of energy will have major impacts on industrial and agricultural production systems, transportation, and settlement patterns.

Past research has attempted to determine the extent to which renewable energy sources or more abundant nonrenewable sources substitute for nonrenewable sources in short supply, but has ignored relative scarcity issues for nonrenewable sources. To the extent that complementary relationships exist in extraction and processing between energy sources and other resources, market price signals are inadequate. Resource scarcity should summarize the sacrifices, both direct and indirect, made to obtain the availability of a resource (Smith and Krutella).

For example, burning coal not only produces

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pollutants, but the carbon dioxide alters the mean global temperature (d Arge and Smith; Nordhaus). Fragile lands required for biomass energy production erode and water quality is reduced. The use of crop residues for alcohol production results in similar problems. Solar energy collectors may introduce large amounts of cadmium, freon, and ethylene glycol into the environment. Hence, to the extent that common property resources are not yet priced in the market, we cannot measure relative scarcity through market prices.

ENERGY, CAPITAL, AND THE ELASTICITY OF SUBSTITUTION

Energy is only one category, albeit an important category, of inputs to the production process. The extent to which agriculture and the rest of society are able to adapt to increased real energy prices depends on the elasticity of substitution between liquid fuels and other energy sources as well as the elasticity of substitution between energy and other inputs such as capital and labor.

If other sources of energy are to be substituted for liquid fuels, market prices are not an appropriate criterion. Focus must instead be placed on the economic disruptions resulting from a shortage of each energy source. The elasticity of substitution provides an indication of the change in energy use as prices change (Brown and Field).

Suppose, for example, that we represent aggregate agricultural production as a function of energy inputs, and a bundle of non-energy-related inputs via a Constant Elasticity of Substitution (CES) production function (Arrow, Chenery, Minhas, and Solow).

$$Y = A[\alpha_1 E^{-\varrho} + \alpha_2 X^{-\varrho}]^{-1/\varrho}$$

where

Y = aggregate agricultural output
E = energy
X = a bundle of non-energy inputs to the production process

$\alpha_1, \alpha_2, \varrho$ = parameters to be estimated

$$\sigma = \frac{1}{1+\varrho} =$$

$$d \log [X/E] / d \log [(\partial Y/\partial E)/(\partial Y/\partial X)],$$

the elasticity of substitution between energy and non-energy inputs.

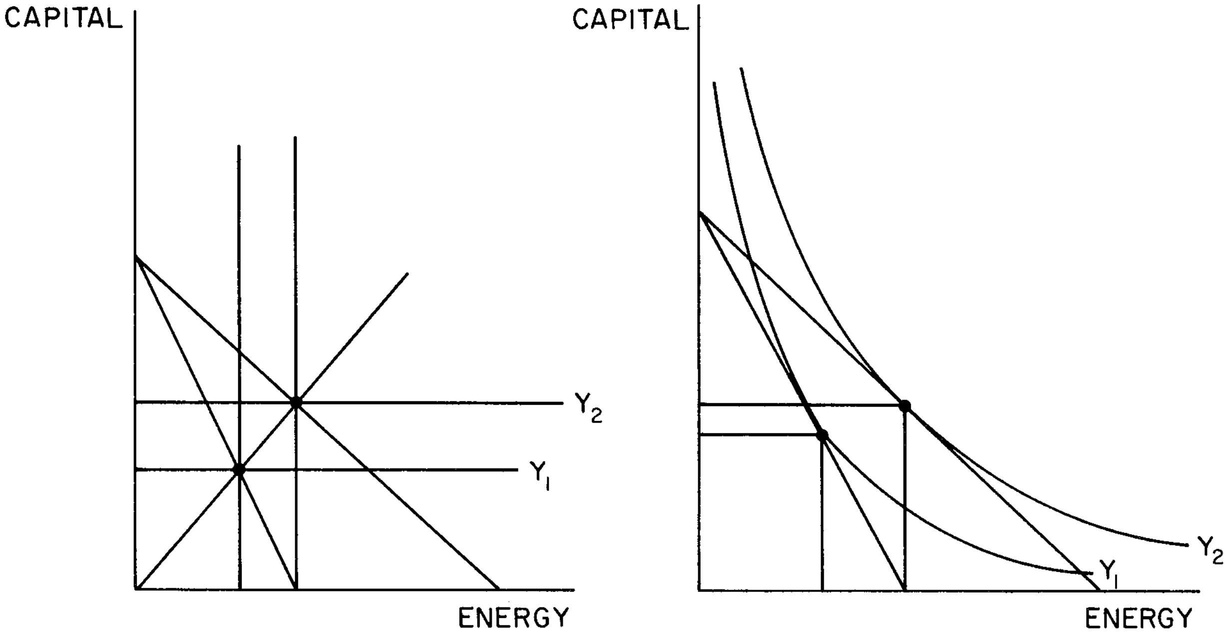
If one is interested in the extent to which adjustments in agricultural production technology can be made through the substitution of other inputs for energy, an empirical estimate of the elasticity of substitution between energy and the other inputs is extremely important. Indeed, the elasticity of substitution provides an indication of what might happen to agricultural production technology in the face of rising real energy prices.

The Cobb-Douglas production function, a special case of the CES, will generate zero output if no energy is present. However, because the elasticity of substitution is one for the Cobb-Douglas, a limited (though non-zero) availability of energy can always be compensated with a sufficiently large supply of capital. If each isoquant has relatively little curvature (ϱ approaches -1 and the elasticity of substitution approaches infinity), substitution should be relatively easy. Energy-augmenting technological change resulting in substitutes for energy would cause isoquants to flatten and to cut the energy axis.

However, suppose that the elasticity of substitution between energy and non-energy inputs to the agricultural production process is zero. Then, regardless of the real price of energy, there is no opportunity for tradeoffs between energy and non-energy inputs. The impact of increased real energy prices may be to reduce total agricultural output (Figure 1). Reductions in output levels may occur through the removal of farms which are high cost and inefficient.

The alternative to major reductions in agricultural output with increased energy prices would be major increases in food prices for the consumer. This outcome is based on the assumption of highly inelastic demand for food and zero substitution between energy and non-energy inputs.

We know that rising real energy prices do have some impact on the combination of energy and non-energy inputs used in the agricultural production processes. Farmers, like other producers, do make adjustments in response to increased energy prices. Whether such responses represent token shifts in the E/X ratio or whether the responses are substantive is an empirical issue. Examples of common responses a farmer might make to rising real energy prices include choosing new mobile power sources primarily on the basis of horsepower per unit of fuel consumed and spending additional time and money keeping engines well tuned. Because of the indirect energy embodied in a new tractor, substitution of new liquid fuels efficient tractors for old may require the use of more, not less, total



$E_S = 0$

Ratio of capital to energy use remains fixed as energy price rises.

$E_S = 1$

Ratio of capital to energy changes as energy price rises.

FIGURE 1. POSSIBLE ELASTICITIES OF SUBSTITUTION BETWEEN LIQUID FUELS ENERGY AND CAPITAL.

energy. Hence, one suspects that such responses by farmers will have only minimal impact on the E/X ratio. Therefore, though the elasticity of substitution between energy and non-energy inputs may be greater than zero, the elasticity of substitution is probably much less than one (Figure 1).

If resource pessimists are correct in arguing that we will soon be facing a serious liquid fuels problem in agriculture, they must show that (1) both the elasticity of substitution and the demand elasticity for liquid fuels and liquid fuels products is indeed very low, (2) renewable energy sources cannot be substituted for nonrenewable liquid fuels, and (3) prospects are bleak for making more efficient use of nonrenewable liquid fuels as energy resources.

RECENT RESEARCH EVIDENCE

Several studies have been conducted for the U.S. and for specific industries to determine the elasticity of substitution between capital and energy. Berndt and Christensen as well as Hudson and Jorgenson argue that energy is a substitute for labor but a complement to capital in the production process.

Griffin and Gregory use a translog function to estimate elasticities of substitution between energy and labor and between energy and capital for the U.S. and eight European countries. Using data for four years (1955, 1960, 1965, and 1969), they estimate the elasticity of substitution between labor and energy to be .87 and between capital and energy to be 1.07 for the U.S. Their estimates are slightly higher for the U.S. than for most of the other countries included in the study. For example, West Germany has an elasticity of substitution of .78 between labor and energy and 1.03 between capital and energy. Griffin and Gregory conclude that capital and energy substitute, not complement each other as suggested by the earlier studies.

It is disturbing that in an era when economic expertise is crucial for addressing energy-related problems and economists cannot even agree on whether energy and capital are gross substitutes or complements to each other. If Griffin and Gregory's estimates are correct, they suggest more potential for substitution between capital and energy than had previously been suspected.

The major difficulty faced by economists in attempts to determine whether energy and capital are gross substitutes or complements is that every capital item is unique. For example, a large expenditure on capital equipment for utilizing solar energy would certainly entail the substitution of capital equipment to produce energy formerly generated from liquid fuels. Replacement of technologically outdated equipment which is not efficient with new fuel-efficient equipment represents a substitution of capital for energy (Atkinson and Halvorsen; Berndt and Christensen). However, technological advance will proceed if profitable, regardless of whether or not the advance is energy efficient. Thus, the economic system, not energy efficiency, determines the nature of the technological change. Technological change historically takes from six to ten years and occurs in response to very large factor price changes (Binswanger, 1974a, 1974b).

As the real price of energy rises, other inputs will be substituted for energy. However, this substitution will take place only to the extent that real energy prices increase faster than the prices of other factors of production such as wages and interest rates and to the extent that the elasticity of substitution between energy and other inputs allows. However, ratios of fuel inputs to outputs have meaning only in that they suggest areas for improving capital efficiency.

Webb and Duncan recently estimated elasticities of substitution between land, labor and mechanical and chemical energy in agriculture for various regions in the U.S.[1] They conclude that land and labor can be relatively easily substituted for mechanical and chemical energy. The South does not appear to be significantly different from the rest of the nation in this regard (Table 1).

TABLE 1. ELASTICITIES OF SUBSTITUTION FOR AGRICULTURE BY REGION, 1974

Region	Land and Hired Labor	Land and Mechanical Energy	Land and Chemical Energy	Hired Labor and Mechanical Energy	Hired Labor and Chemical Energy	Mechanical Energy and Chemical Energy
United States	.77	1.36	.78	1.91	.27	1.19
Northeast	1.00	1.35	.84	2.12	.23	1.48
Appalachian[a]	.90	1.35	.87	1.99	.25	1.31
Southeast[b]	1.06	1.33	.92	1.97	.26	1.38
Lake States	.47	1.37	.80	1.98	.23	1.16
Corn Belt	-.15[e]	1.39	.80	2.26	.05	1.16
Delta States[c]	.94	1.35	.85	2.00	.25	1.33
Northern Plains	-2.19[e]	1.37	.72	2.05	.60	.96
Southern Plains[d]	.44	1.35	.76	1.79	.31	1.06
Mountain	.70	1.34	.65	1.67	.36	.99
Pacific	1.03	1.35	.72	1.98	.18	1.42

[a] Kentucky, Tennessee, Virginia, West Virginia, North Carolina.
[b] South Carolina, Georgia, Alabama, Florida.
[c] Arkansas, Mississippi, Louisiana.
[d] Oklahoma, Texas.
[e] Inputs are gross complements, not substitutes.
Source: Modified from Webb and Duncan.

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[1] Webb and Duncan use a translog rather than CES function. The function given as

$$\ln Q = \ln a_0 + \sum_i a_i \ln X_i + 1/2 \sum_i \sum_j b_{ij} \ln X_i \ln X_j$$

is a modification of a multiplicative power production function, and is easily estimated. Moreover, no assumptions are made with regard to the elasticity of substitution, which can be derived empirically from the parameter estimates (see Binswanger, 1974a, 1974b).

TRACTOR PRICES, HORSEPOWER, AND ENERGY EFFICIENCY

We examine here the interrelationships between the price of farm tractors and their liquid fuels efficiency. If capital substitutes for liquid fuel, it should be possible to purchase tractors that are more energy efficient by paying a higher price, *ceteris paribus.*

The following regression equation was estimated with data for 77 farm tractors from the Nebraska tractor tests. All tractors used in the analysis were diesel.

$$
\begin{aligned}
\text{LPRICE} = {} & \underline{5.56} + \underline{.726}\ \text{LHP} \\
& (0.65) \quad (.095) \\
& -\underline{.617}\ \text{LEER} + \underline{.279}\ \text{LMAXPULL} \\
& (.130) \qquad\qquad (.098) \\
& + \underline{.076}\ \text{LSPEED} \\
& \quad (.058) \\
R^2 = {} & .98 \\
F = {} & 1139.5
\end{aligned}
$$

where

LPRICE = the natural log of tractor price (FOB manufacturer list price as reported in the tractor bluebook)
LHP = the natural log of maximum drawbar tractor horsepower calculated by the Nebraska tractor tests
LEER = the natural log of the energy efficiency ratio defined as the ratio of horsepower hours per gallon of fuel consumed
LMAXPULL = the natural log of pounds pull at maximum horsepower
LSPEED = the natural log of maximum tractor speed at maximum horsepower.

With the exception of price data all data are from the National Farm and Power Equipment Dealers Association redbook of 1979. If tractor models are retained for more than one year, they are not necessarily retested every year and actual data for some tractors may have been collected several years earlier. The equation explains virtually all of the variation in tractor prices. The coefficient on the energy efficiency ratio is found to be strongly negative. Hence, tractor prices do not necessarily reflect energy efficiency.

The following regression was estimated with data from the same source.

(4)

$$
\begin{aligned}
\text{HP} = {} & -\underline{184.85} + \underline{22.21}\ \text{EER} \qquad (4) \\
& \ \ (87.69) \qquad (6.90) \\
R^2 = {} & .12 \\
F = {} & 10.34
\end{aligned}
$$

where

HP = tractor horsepower
EER = the energy efficiency ratio.

Higher horsepower tractors are more energy efficient although not strongly so. The simple correlation between horsepower and energy efficiency is found to be .348 (Figure 2).

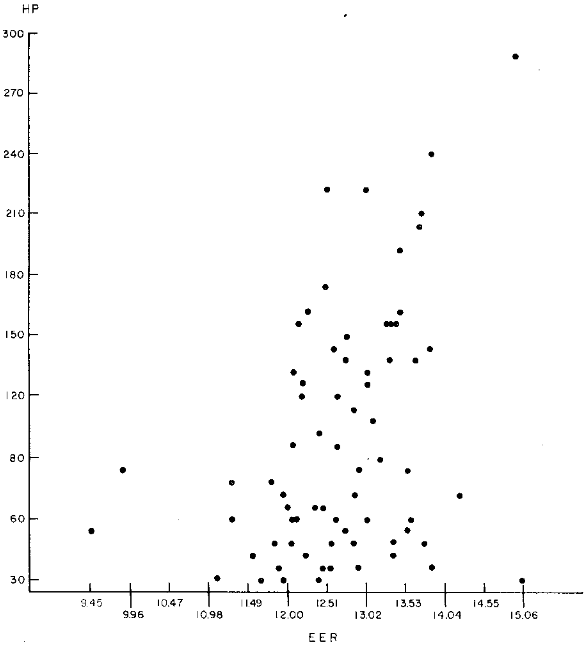

FIGURE 2. RELATIONSHIP BETWEEN TRACTOR HORSEPOWER (HP) AND ENERGY EFFICIENCY RATING (EER).

Hence, although higher horsepower tractors are more energy efficient, for a given horsepower tractor prices do not necessarily reflect energy efficiency. Farmers are probably largely unaware of the variation in energy efficiency among tractors which ranges from 9.45/1 to 15.06/1. As a result, the rather sizable differences are not reflected in market prices. Fuel costs have been historically only a small proportion of total costs for tractor operation.

AGRICULTURAL OUTPUT, MECHANIZATIONS, AND ENERGY USE

Several studies currently are being conducted at the University of Kentucky which are designed to estimate the linkages among agricultural output, agricultural mechanization, and energy use (Ghaffar; Kontomichos). The studies are being conducted with cross-sectional data from the 1974 Census of Agriculture for Kentucky counties.

The census defines two categories of inputs that are energy related. Both are measured in dollar amounts. One is expenditures for gasoline, diesel fuel, and petroleum products used in machinery operation. The other category is expenditures for fertilizer. Unfortunately, the census does not show nitrogen fertilizer expenditures separately from expenditures for potash and phosphate.

Figure 3 illustrates the relationship between total expenditures for the two input categories per farm (fuel and fertilizer) and the average value of machinery per farm. Figure 4 illustrates the relationship between the fuel category and the average value of farm machinery. In both cases the relationship appears to be simple and direct. Because data are cross-sectional all farmers have essentially the same set of prices both for energy and for farm machinery. A simple transformation of the axes allows interpretation in physical rather than dollar terms. However, a question arises as to the interpretation of the observed energy/machinery combinations in Figures 3 and 4. Most likely, these points represent the energy/machinery expansion paths along which farmers move as they expand their scale of their operations. However, the data points in Figures 3 and 4 are consistent with a wide variety of possible isoquant patterns and corresponding elasticities of substitution. An isoquant map in which the elasticity of substitution between energy and machinery is near zero (isoquants approaching right angles) could be superimposed on Figures 3 and 4. But the observed data points are also consistent with isoquant maps with larger elasticities of substitution. The high degree of correlation between observed expenditures on energy and machinery makes even speculation as to the elasticity of substitution between machinery and energy difficult.

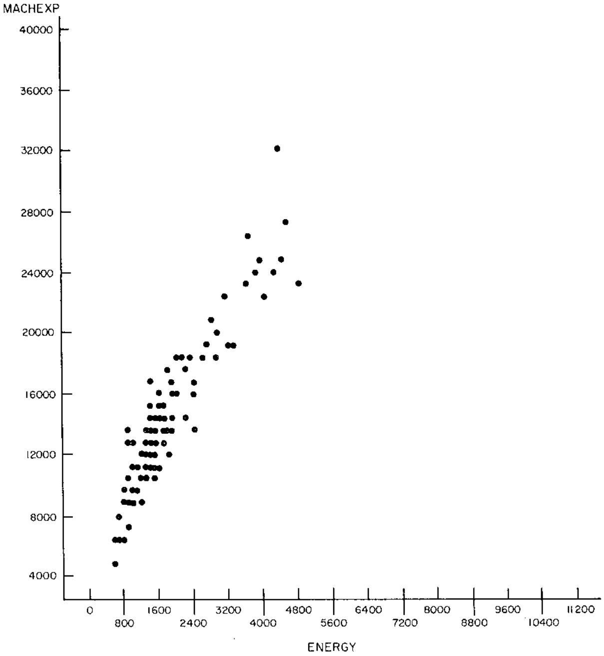

FIGURE 3. RELATIONSHIP BETWEEN AVERAGE VALUE OF MACHINERY PER FARM (MACHEXP) AND FUEL + FERTILIZER (ENERGY) EXPENDITURES, KENTUCKY COUNTIES, 1974.

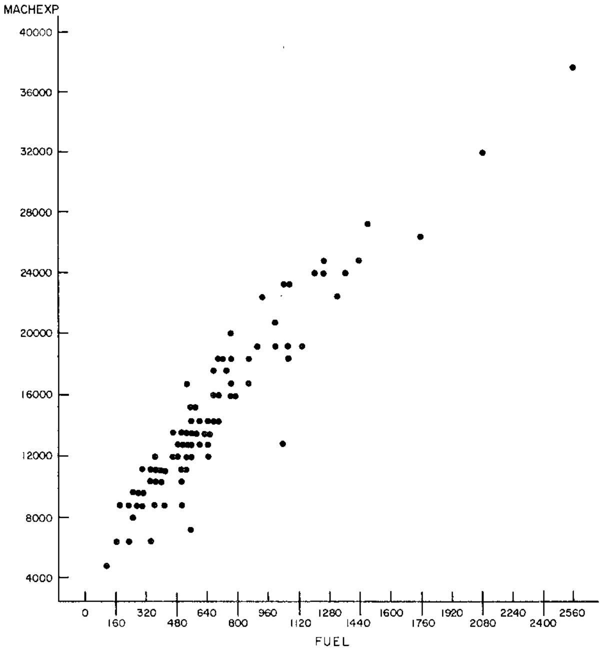

FIGURE 4. RELATIONSHIP BETWEEN AVERAGE VALUE OF MACHINERY PER FARM (MACHEXP) AND EXPENDITURES ON FUEL (FUEL) KENTUCKY COUNTIES, 1974.

Though the elasticity of substitution between mechanization and energy use is important, of equal importance is the agricultural output per unit of energy expended. Kentucky has some of the most diverse agriculture of any state. Tobacco, the crop ranking number one in dollar sales, is labor, not energy, intensive. Subsistence agriculture in eastern Kentucky tends also to be unmechanized. The Bluegrass area is mainly in livestock and tobacco and is not very mechanized. In the west, large corn and soybean operations typical of Cornbelt agriculture predominate.

A ratio of cash receipts to expenditures for fuel and fertilizer for farms with sales of more than $2500 is calculated. A similar ratio excluding fertilizer is also calculated.

Figure 5 illustrates the relationship between the value of output per dollar of fuel and the average value of machinery per farm. Results

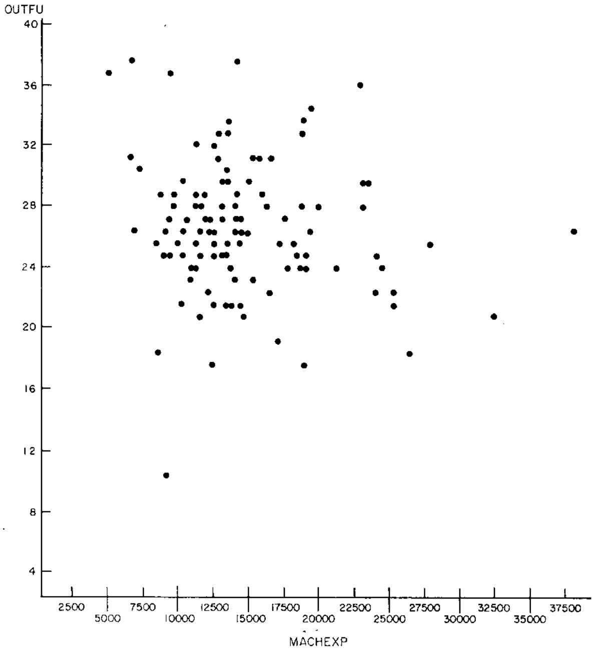

FIGURE 5. RELATIONSHIP BETWEEN OUTPUT VALUE PER DOLLAR OF FUEL (OUTFU) AND AVERAGE VALUE OF MACHINERY PER FARM (MACHEXP) KENTUCKY COUNTIES, 1974.

suggest that high average machinery values are not necessarily incompatible with high ratios of cash receipts to fuel or fuel plus fertilizer expenditures. Counties with the largest ratios of cash receipts to fuel expenditures tend to be those where tobacco is a major enterprise. In Kentucky, burley tobacco which does not require fuel for curing predominates. Its production is also very nonmechanized and labor intensive. A few counties with high cash receipts/fuel ratios are those where cow-calf operations predominate. Counties with extremely low cash receipts/fuel ratios tend to be those in coal mining regions of the state, where a subsistence agriculture is often thought of as being rather labor intensive. Such counties might be expected to have the smallest ratio of receipts to almost any measure of inputs. The commercial corn-soybean counties rank in the upper 40 percent of all counties in terms of the cash receipts to fuel ratio.

The following regression equations were estimated.

$$
\begin{aligned}
\text{OUT/EN} &= \underset{(0.78)}{\underline{8.04}} - \underset{(.00004)}{\underline{.00012}}\ \text{MACHEXP} \\
&\quad + \underset{(.26)}{\underline{1.13}}\ \text{LABOR} \\
R^2 &= .16 \\
F &= 10.4 \\
N &= 115
\end{aligned}
$$

$$
\begin{aligned}
\text{OUT/FU} &= \underset{(1.45)}{\underline{25.58}} - \underset{(.00007)}{\underline{.00022}}\ \text{MACHEXP} \\
&\quad + \underset{(0.48)}{\underline{1.53}}\ \text{LABOR} \\
R^2 &= .10 \\
F &= 6.5 \\
N &= 115
\end{aligned}
$$

where

OUT/EN = the ratio of cash receipts to expenditures on fuel and fertilizer, for farms over $2500 in sales, as taken from the 1974 Census of Agriculture

OUT/FU = the ratio of cash receipts to expenditures on fuel, for farms over $2500 in sales, as taken from the 1974 Census of Agriculture

MACHEXP = average value of machinery per farm from the 1974 Census of Agriculture

LABOR = man-year equivalents of hired labor, calculated from data in the 1974 Census of Agriculture.

Both equations suggest an inverse relationship between cash receipts per dollar of fuel plus fertilizer or fuel and machinery values, but a direct relationship between the amount of hired labor and the indices. Further analysis needs to be conducted with data for individual farms within major farming areas.

The analysis suggests that as real prices of liquid fuels increase, high levels of mechanization will not necessarily always be the most profitable. Efforts must increasingly be directed to approaches that make maximum use of resources other than liquid fuels. For example, cattle operations that do not rely more heavily on forages than on concentrates for fattening might require less liquid fuels. Moreover, labor intensive crops become increasingly economic as fossil fuel prices increase in real terms in relation to labor prices. For example, tomatoes and cabbages are becoming very common as horticultural crops in certain sections of Kentucky. However, consumer demand for such crops is essential. Both are high value in comparison to conventional grain crops, can be grown without much mechanization or liquid fuels, and are rather labor intensive. Moreover, crops with high transportation requirements might be produced nearer to final markets. In terms of liquid fuels efficiency, burley tobacco production in Kentucky would rank relatively high. It is very labor intensive and is not mechanized. Flue-cured varieties may not fare as well on a liquid fuels efficiency basis. The analysis should include the expected value of the product as well as the cost of production.

We find little evidence to suggest that a return to subsistence agriculture for grain and livestock would necessarily make agriculture more liquid fuels efficient. In fact, output in subsistence farming areas is very low, and counties having large numbers of subsistence farms are found to rank very low on an output per unit of fuel basis. Our previous analysis suggests that the low horsepower tractors used on these farms may be less efficient than larger tractors used in large-scale commercial grain farming operations.

Moreover, commercial corn-soybean production may not be as liquid fuels inefficient as might be suspected. Though the farms are highly mechanized, they often have modern high-horsepower tractors which are capable of producing greater output per gallon of fuel than tractors of 30 years ago. A small tractor which does not allow for timely planting and harvesting of crops, with subsequent yield losses, cannot be considered to be a liquid fuels efficient choice for grain production.

There is much more to liquid fuel efficiency in farming than merely choosing a tractor with low fuel consumption per hour. The relevant issue is not the horsepower of the tractor, nor necessarily its fuel consumption. What is important is the ratio of output to liquid fuels expenditure. A large tractor which consumes large amounts of fuel may be chosen in spite of rising real liquid fuels prices if the tractor more than compensates for fuel consumption through increased output as a result of timely planting and harvest operations.

AGRICULTURE IN THE SOUTH AND INCREASED ENERGY PRICES

Speculation on the impacts of increased real prices for liquid fuels on southern agriculture leads to the following conclusions.

1. There will be increased emphasis on livestock enterprises that make maximum use of available forages, particularly forages that do not require nitrogen and limit requirements for concentrates. Beef production may shift farther away from grain producing states and toward the south and west.

2. Farmers will increasingly turn to high-value labor intensive crops such as horticultural crops, particularly if real liquid fuels prices outdistance increases in real wage rates for hired labor, but a market for such crops must exist. Mechanization in the production of these crops will take place at a less rapid rate than would have been the case if real liquid fuels prices had risen less rapidly. The increase in wage rates in relation to fuel price increases is important.

3. Tobacco will continue to be a popular crop in much of the South if demand continues at high levels. Some farmers who otherwise might have shifted out of tobacco will stay in.

4. The South has some potential for crop production for use in making alcohol for liquid fuel. However, primary production will probably involve using crop residue, and the cost of transportation makes alcohol production most feasible in the Cornbelt (Literman, Eidman, and Jensen). The major potential for alcohol production in the South probably is in forestry rather than agriculture.
5. Commercial corn and soybean production techniques may not change as much as might be initially suspected. Rising real liquid fuels prices place increased cost pressures on marginal farms. Highly mechanized farms with large tractors and equipment may actually be more efficient on an output per dollar of fuel basis than their smaller counterparts. Nitrogen fertilizer use may be reduced. However, if the cost of nitrogen fertilizer increases from 15 to 30 cents per pound, and corn sells at three dollars per bushel, the last pound of nitrogen applied by farmers will need to produce .10 rather than .05 bushels of corn. The reduction in application rates required to achieve this increase in marginal product may be of little consequence.

6. Broiler production may be significantly affected by rising liquid fuels prices. Broiler production is particularly energy intensive for the heating of houses and feed transportation. To save heating costs, production may tend to move farther south. Consumers will find the price of chicken much higher in real terms under higher real liquid fuels prices.

7. Cotton is more labor intensive than grain crops. Even with higher real liquid fuels prices, mechanical harvesting is inexpensive in relation to the cost of hand harvesting. As a result, current cotton production technology would not be expected to change much.

8. Rice is unique in that few other crops in the South are extensively irrigated. Po-

tentially, the diesel and natural gas fuels currently powering irrigation pumps may be replaced with electrical energy from coal or nuclear plants. Small-scale electrical generating plants using coal or crop residues as fuel for powering the 70-100 horsepower electric motors required may eventually be feasible. Rice, which requires lower drying temperatures than other grains, may be particularly well suited for solar or heat-pump drying.

Finally, economics will dictate production technology in the future, just as it has in the past. High levels of liquid fuel use will continue if the technology is profitable.

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