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Energy conservation possibilities in corn production on a central Iowa farm

by

Edward Robert Pidgeon

A Thesis Submitted to the
Graduate Faculty in Partial Fulfillment of
The Requirements for the Degree of
MASTER OF SCIENCE

Department: Economics
Major: Agricultural Economics

Signatures have been redacted for privacy

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Ames, Iowa

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CHAPTER I. THEORETICAL CONSIDERATIONS

As fossil fuels become more expensive to obtain, there could be a significant increase in the price of energy relative to other goods. The result will be significant increases in prices of those products which require a relatively high amount of energy in their manufacture. Industry should respond by utilizing those processes which require relatively less of such products. The degree to which such a substitution can take place will affect the costs of producing commodities, profit levels and the prices paid by consumers.

This study is concerned with the changes that will occur on a typical central Iowa farm if energy prices increase. It will analyze the options available to the operator of such an enterprise to reduce his use of production processes that require relatively high amounts of energy. The cost advantages of switching from one process to the other will be examined. It is hoped to discover where the greatest potential lies in reducing production costs if energy prices increase. This may prove useful in recommending to farmers in central Iowa what sort of machinery and equipment they should invest in. It may also assist those doing research in the development of agricultural methods which conserve energy.

A secondary aspect of this paper will be the analysis of the effects of a rationing system on such a farm. The effects of rationing will be compared with price increases as a means to reduce energy use in agricultural production. Different types of rationing schemes are also compared. It is thought that this may prove useful if, as occurred in the 1973 crisis, rationing is advanced as a possible means to reduce energy consumption.

Effects of Different Policies on Energy Consumption

Energy cost increases could have a number of repercussions on a central Iowa farm. If the government decides to not intervene in the market economy, then the farm firm will bear the increased expense of inputs. If the government should decide that it should involve itself, it may keep prices at present levels but impose a rationing scheme. In this study, it will be assumed that there are two types of rationing schemes possible. One is a ration on total energy use. This imposes a maximum on the number of BTU's consumed in a particular enterprise regardless of whether the energy is derived from natural gas, gasoline, electricity, etc. The second rationing scheme is one which imposes a maximum on the consumption of each of the energy sources individually.

A typical farm in central Iowa produces primarily corn, soybeans and livestock (19, p. 1). This study will concentrate primarily on the potential for energy conservation through altering tillage, harvest and drying practices in the production of corn. The model will be primarily concerned with how costs can be minimized in corn production as energy prices increase.

The production of corn may be described mathematically as a function of those energy sources used in the manufacture of inputs plus all other factors. For instance, fertilizer is produced from natural gas and other inputs such as labor, electricity and plant overhead. As fertilizer is a factor in the growing of corn, it follows that natural gas is also a factor in an indirect sense. There are a number of energy sources involved directly and indirectly in corn production. They include coal and gasoline used in the manufacture of farm machinery, L.P. gas and electricity consumed in corn drying and naphtha and other petrochemicals used in processing pesticides. If all of these energy sources were to be included in the theoretical model, the model would be very complicated. This extra complexity would not yield much more information than if the number of energy sources was limited to two. Let us therefore describe the production of corn according to the equation:

$$Q_c = f(E_1, E_2, I_o) \qquad (1\text{-}1)$$

Where:

Q_c = the yield in bushels

E_1 = the quantity of energy expressed in BTU's of one energy source which is utilized in corn production

E_2 = the quantity of energy of a different source of energy

I_o = the quantity of all other inputs

The profit for the firm will be such that

$$\phi = P_c f(E_1, E_2, I_o) - C_1E_1 - C_2E_2 - C_oI_o \qquad (1\text{-}2)$$

Where:

ϕ = profits

P_c = the price of corn

C_1 = the price of input E_1

C_2 = the price of input E_2

C_o = the price of other inputs, I_o

The first order conditions for profit maximization are:

$$\frac{d\phi}{dE_1} = P_c\ MPP_1 - C_1 = 0 \qquad (1\text{-}3)$$

$$\frac{d\phi}{dE_2} = P_c\ MPP_2 - C_2 = 0 \qquad (1\text{-}4)$$

$$\frac{d\phi}{dI_o} = P_c\ MPP_o - C_o = 0 \qquad (1\text{-}5)$$

Where:

MPP_i = the marginal physical product of E_i,

$$\frac{\partial f(E_1, E_2, I_o)}{\partial E_i} \qquad i = 1,2$$

$$MPP_o = \frac{\partial f(E_1, E_2, I_o)}{\partial I_o}$$

If the price of E_1 is increased by the amount of D_1 and E_2 by D_2, their respective marginal products must be increased to MPP_1' and MPP_2' until

$$P_c\ MPP_1' - (C_1 + D_1) = 0 \qquad (1\text{-}6)$$

$$P_c\ MPP_2' - (C_2 + D_2) = 0 \qquad (1\text{-}7)$$

To increase the marginal physical product of a factor, it is necessary to reduce its use. Let us assume that the factors E_1 and E_2 are changed to E_1' and E_2' respectively. The latter values can be expressed in terms of the two variable "a" and "M" where

$$E_1' = aM \tag{1-8}$$

$$E_2' = (1-a)M \tag{1-9}$$

E_1' and E_2' represent a total energy consumption of M. M is expressed in some common energy unit such as BTU's. "a" is the proportion of M which is accounted for by E_1. (1-a) is the proportion accounted for by E_2.

The effects of an energy price increase can be compared to a rationing system. Let us first impose a rationing system which requires that the quantity of E_1 and E_2 be reduced to the same amount as occurred when prices were increased. E_1 will not be allowed to exceed aM, E_2 will not exceed (1-a)M. The expression for profit is:

$$\phi = P_c f(E_1, E_2, I_o) - C_1E_1 - C_2E_2 - C_oI_o + \alpha(aM-E_1) + \beta((1-a)M-E_2) \tag{1-10}$$

where:

α = the marginal cost of the ration on E_1

β = the marginal cost of the ration on E_2

The first order conditions are:

$$\frac{d\phi}{dE_1} = P_c\ MPP_1 - (C_1+\alpha) = 0 \tag{1-11}$$

$$\frac{d\phi}{dE_2} = P_c\ MPP_2 - (C_2+\beta) = 0 \qquad (1\text{-}12)$$

$$\frac{d\phi}{dI_o} = P_c\ MPP_o - C_o = 0 \qquad (1\text{-}13)$$

As the amount of E_1 used in Equation (1-11) is equal to that in Equation (1-6), it follows that the values for MPP_1 for both systems are equal. Subtracting Equation (1-6) from (1-11) we get:

$$D_1 = \alpha \qquad (1\text{-}14a)$$

Similarly for Equations (1-7) and (1-12) it is found that

$$D_2 = \beta \qquad (1\text{-}14b)$$

Any rationing system will have associated with it marginal opportunity costs. These costs, α and β will have the same effect on the utilization of inputs as price increases of the same amount. The production processes of the firm will be reorganized such that the marginal physical products of the inputs are increased to either the real cost (C+D) of a price increase or $(C+\alpha)$ of a rationing system.

If a pricing system and rationing system have the same quantities of inputs, then they will necessarily have the same quantity of output,

$$f(aM,\ (1-a)\ M,\ I_o)$$

and the same revenue

$$P_c\ f(aM,\ (1-a)\ M,\ I_o)$$

The expenditures for the price system is

$(C_1+D_1)E_1$ and $(C_2+D_2)E_2$

For rationing, it is

C_1E_1 and C_2E_2

Thus, the revenues remain the same but expenses will differ. The net farm income will be higher under a rationing system by the amount

$D_1E_1 + D_2E_2$

Let us see if it is possible to devise a rationing scheme which will increase the farm income even further. We will still stipulate that the total amount of energy used must be M. The operator may use as much of the individual sources E_1 and E_2 as desired, but the maximum M on total energy use must not be exceeded.

It will be desired to alter aM and (1-a)M to maximize profits. This will occur when:

$$\frac{d\phi}{da} = 0$$

From Equation (1-6), it is determined that, at optimality:

$$\frac{d\phi}{da} = (\alpha-\beta)M = 0 \qquad (1\text{-}15)$$

$M \neq 0,\ \alpha = \beta$

The values for α and β will not necessarily be equal for any given rationing scheme. From Equation (1-11) and (1-12), it may be seen that the actual values for α and β are determined by the difference between the value marginal product of a particular input and its price.

$$\alpha = P_c \, MPP_1 - C_1 \tag{1-16a}$$

$$\beta = P_c \, MPP_2 - C_2 \tag{1-16b}$$

If it is not possible to curtail the use of E_1 without a considerable decline in production, then the value for MPP_1 will be quite high. If a curtailment of E_2 does not increase MPP_2 by a similar amount, then α will be greater than β. To achieve optimality, E_1 and E_2 should be rationed such that α is equal to β. This would be accomplished only if E_1 were to be reduced by a smaller amount that E_2 is reduced. In this way MPP_1 would not increase more quickly than MPP_2 and thus cause α to become higher than β. The derived demand for a particular input "i" is determined by the value marginal product, $P_c \, MPP_i$. Those inputs for which there is the lowest elasticity of demand have the highest increase in their marginal physical product for a given decrease in the utilization of that input. To reduce the deleterious effects of rationing, one should not curtail as severely those inputs which have a relatively low elasticity of demand. In this example, E_1 has the most inelastic demand. To maintain equilibrium between α and β, E_1 should be rationed less than E_2.

In conclusion, there are three basic policies which the farm may be subjected to. The first one will be energy prices finding their natural level. If this causes the farm income to decline to a politically unacceptable level, rationing may be considered. Rationing may be made such that energy sources are cut back the same amount they would be if their prices were increased. This type of rationing may still not raise income sufficiently. If this occurs, the government may consider altering the rationing system. This alteration will reduce total energy use to the same level, but not restrict so heavily sources which have a high value marginal product on the farm.

These three policies are the external conditions which might be imposed on a central Iowa farm. They will significantly effect farm income. A second set of conditions are the farm's internal production processes. They will determine how much the farm can adapt to changes in prices or rationing so as to minimize a loss of income.

Substitutionality

The most important internal consideration for this farm will be how it can reduce its reliance on energy intensive inputs. If the external condition is one of higher prices, it will wish to perform this substitution to reduce expenditures. If rationing is imposed, substitution will be important so that output will not be significantly reduced.

Isoquant analysis

Substitution may be analyzed employing a two factor model. Let the production of corn be represented by

$$Q_c = f(I_e, I_o) \qquad (1\text{-}17)$$

Where:

I_e = the quantity of a specific energy source used in the production of corn

I_o = the quantity of all other factors

This relationship between output and input can be represented graphically as in Figure 1.1. Each isoquant represents the combination of I_e and I_o necessary to produce a particular output. The slope at any point along the isoquant is the negative quotient of the marginal products of the factors $-\frac{MPP_e}{MPP_o}$.

The cost of production can be represented by the isocost lines C_1, $C_2 \ldots C_n$. The slope of these lines is equal to the negative of the ratio of the prices of the two factors

$$-\frac{P_e}{P_o}$$

Let us assume that the prices of the factors are those described by the isocost line C_1. The point of equilibrium will be "a", and the amount of energy used will be I_e. If the price of energy is increased, the isocost line will shift from C_1 to C_2 and establish

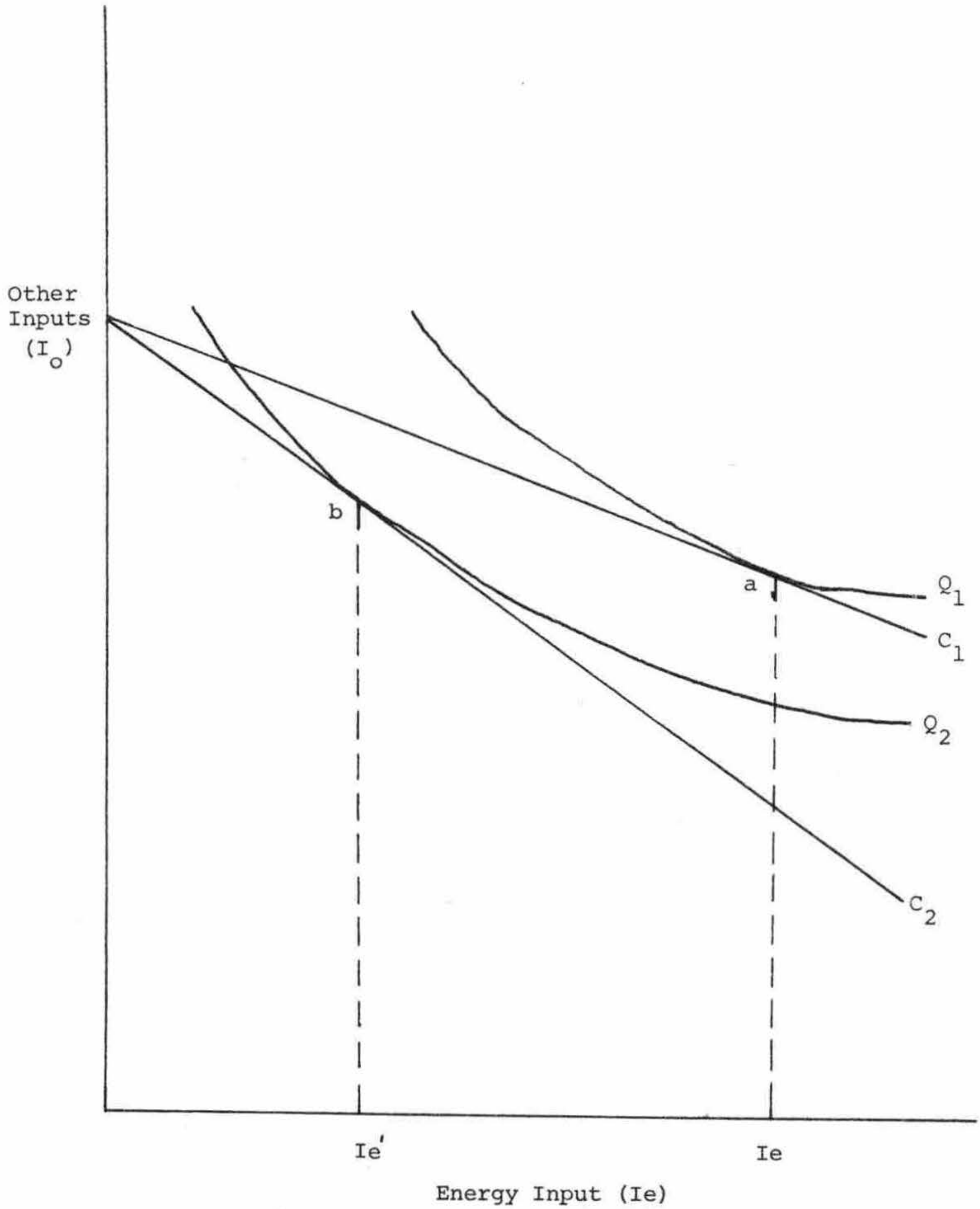

Figure 1.1. Reduction of energy input for a normal production function

a new point of tangency at "b". The energy input will be reduced from I_e to I_e', but production will also be reduced. The latter falls from Q_1 to Q_2 in this illustration.

In corn production, this sort of phenomenon may occur if the price of L.P. gas is increased substantially. Instead of drying corn artificially, it is left out in the field longer. While this saves on the use of gas, it also reduces the production of corn as higher field losses are incurred when harvesting corn which has remained longer in the field.

The elasticity of factor substitution

The magnitude of the decline in production, Q_1 to Q_2 for a given reduction in energy utilization, I_e to I_e' depends on the type of production process under consideration. If it is possible to substitute other factors of production for energy, then the loss should be less severe. The more substitution which will be possible for a particular process, the higher will be the elasticity of factor substitution, σ, where

$$\sigma = \frac{d(I_e/I_o)/(I_e/I_o)}{d(MPP_o/MPP_e)/(MPP_o/MPP_e)} \qquad (1\text{-}18)$$

For the sake of illustration, a production process with an elasticity of factor substitution of zero will be compared with one in which that elasticity is equal to one. To maintain similarity of conditions to the isoquant analysis of Figure 1.1, it will be assumed for both functions that the costs of production are fixed at the level

C. Initially, both will be producing the amount Q_1 and both will use the same amount of I_e and I_o. Both will then have the amount of I_e which can be used curtailed to I_e'. No restriction will be placed on the amount of I_o which can be used. The main consideration of this analysis will be to compare the changes in profit in both production processes for this specific decrease in the utilization of I_e.

Algebraically, the profit for either function can be described as

$$\phi = P_c f(I_e, I_o) - \lambda(C - P_e I_e - P_o I_o) - \gamma(I_e' - I_e) \qquad (1\text{-}19)$$

where:

λ = the imputed cost of restraining total costs to the level C

γ = the marginal cost of reducing I_e use to the level I_e'

The higher the value of γ, the greater will be the cost of the curtailment of I_e use to I_e'. The best production process will be one in which γ is at a minimum. Such a process will experience the least decrease in profits for a given curtailment in the use of energy inputs, I_e. The first production process under consideration is a fixed factor proportions production function. It is represented by the mathematical equation

$$Q = \min(eI_e, gI_o) \qquad (1\text{-}20)$$

where e and g are constants.

If the amount of I_e is such that eI_e is less than gI_o, then I_e is defined as the "limiting" factor. In such an instance, the amount of I_e

utilized will be Q/e. Conversely, if I_o is the limiting factor, the amount of I_o used is Q/g. Both factors will be limiting when the ratio of their rate of utilization

$$\frac{I_e}{I_o} = \frac{Q/e}{Q/g} = g/e \qquad (1\text{-}21)$$

If I_e is the limiting factor, then

$$MPP_e = \frac{dQ}{dI_e} = e \qquad (1\text{-}22)$$

If I_o is a limiting factor,

$$MPP_o = dQ/dI_o = g \qquad (1\text{-}23)$$

If either of the factors are not limiting, then a slight change in the amount of that input will not change the output Q. As a consequence, the marginal physical product of a nonlimiting factor is zero. An extremely small change in the ratio of I_e/I_o from g/e will necessarily cause one factor to decrease to zero.

The expression for profit is represented for this production function by the equation

$$\phi = P_c[\min(eI_e,\ gI_o)] + \lambda(C-P_eI_e-P_oI_o)$$

where λ is the marginal cost of constraining the costs to the level C. λ will be nonnegative for the range of this analysis. At the profit maximizing position, the first order conditions are:

$$\frac{d\phi}{dI_e} = P_c \cdot MPP_e - \lambda P_e = 0$$

$$\frac{d\phi}{dI_o} = P_c \cdot MPP_o - \lambda P_o = 0$$

It follows that

$$MPP_e = \lambda P_e / P_c \tag{1-24}$$

$$MPP_o = \lambda P_o / P_c \tag{1-25}$$

If, in Equations (1-24) and (1-25) there are nonzero values of P_e and P_o, both values of MPP_e and MPP_o will be greater than zero. It follows that, at optimality, both factors are limiting. According to Equation (1-24), the ratio of I_e/I_o is equal to g/e. Equations (1-24) and (1-25) reveal that the ratio of their marginal physical products MPP_o/MPP_e is g/e. It follows from Equation (1-18) that

$$\sigma = \frac{d(I_e/I_o)/(g/e)}{d(MPP_o/MPP_e)/(g/e)} = \frac{d(I_e/I_o)}{d(MPP_o/MPP_e)} \tag{1-26}$$

Any increase in I_e/I_o by the amount $d(I_e/I_o)$ will cause I_e to become non-limiting and its marginal physical product will fall to zero. Therefore, (MPP_o/MPP_e) will approach infinity for all values of $d(I_e/I_o)$. According to Equation (1-26), the elasticity of factor substitution for a production process of this nature will be zero.

The economic loss associated with the curtailment of I_e use to I_e' can be calculated employing Equation (1-19). The profit for such a process may be represented by the expression

$$\phi = P_c[\min(eI_e, gI_o] + \lambda(C - P_eI_e - P_oI_o) + \gamma_f(I_e' - I_e) \tag{1-27}$$

Where γ_f is the γ for a fixed factor function. The first order conditions require that

$$\frac{d\phi}{dI_e} = P_c \cdot e - \lambda P_e - \gamma_f = 0 \qquad (1\text{-}28)$$

Let Q_1 be the original value of output. As I_e is a limiting factor,

$$e = Q/I_e \qquad (1\text{-}29)$$

Substituting (1-29) into (1-20) and rearranging:

$$\gamma_f = P_c \cdot \frac{Q}{I_e} - \lambda P_e \qquad (1\text{-}30)$$

The value of γ for the fixed factor case, γ_f, is to be compared with the γ for a variable factor production function. The variable factor production function in this example is the Cobb Douglas function

$$Q = cI_e^{\,a}\, I_o^{\,b} \qquad (1\text{-}31)$$

Where a, b and c are constants

$$a + b \leq 1,\ a,b \neq 0 \qquad (1\text{-}32)$$

$$\therefore\ a,\ b < 1$$

Differentiating (1-31) by I_e and I_o, we obtain the values of the marginal products.

$$MPP_e = \frac{caI_e^{\,a} I_o^{\,b}}{I_e} = \frac{aQ}{I_e} \qquad (1\text{-}33)$$

$$MPP_o = \frac{cbI_e^{\,a} I_o^{\,b}}{I_o} = \frac{bQ}{I_o} \qquad (1\text{-}34)$$

Dividing Equation (1-33) by (1-34)

$$\frac{MPP_e}{MPP_o} = \frac{aI_o}{bI_e} \tag{1-35}$$

Differentiating MPP_e/MPP_o by I_o/I_e,

$$\frac{d(\frac{MPP_e}{MPP_o})}{d(\frac{I_o}{I_e})} = \frac{a}{b} \tag{1-36}$$

The value for σ for a Cobb-Douglas function may be obtained by incorporating the relationships of Equations (1-35) and (1-36) into the definition for σ in Equation (1-18).

The result is

$$\sigma = \frac{b}{a} \cdot \frac{\frac{I_e}{I_o}}{[\frac{aI_o}{bI_e}]} = 1 \tag{1-37}$$

The Cobb-Douglas function has a higher elasticity of factor substitution than the elasticity of substitution for the fixed factor process which had a value of zero. The loss, γ_v for a given curtailment in I_e use can be determined by incorporating (1-31) into (1-19) discussed earlier.

$$\phi = P_c\,[cI_e^{\,a}I_o^{\,b}] - \lambda(C - P_eI_e - P_oI_o) + \gamma_v(I_e{}' - I_e) \tag{1-38}$$

The first order conditions require that

$$\frac{d\phi}{dI_e} = P_c\,\frac{caI_e^{\,a}I_o^{\,b}}{I_e} - \lambda P_e - \gamma_v = 0$$

Substituting in the value Q for $cI_e^aI_o^b$ and rearranging:

$$\gamma_v = a\frac{P_cQ}{I_e} - \lambda P_e \tag{1-39}$$

Comparing γ_f given in (1-30) to γ_v of (1-39) it is noted that the only difference lies in the fact that the expression $\frac{P_cQ}{I_e}$ is multiplied by the factor a for γ_v, but not for γ_f. By inequality (1-32), a is less than one; thus γ_v is less than γ_f.

A similar analysis may be done for other production functions and the conclusions will be similar. A given curtailment of one factor will least affect that production process with the highest elasticity of factor substitution.

The values for γ_f and γ_v are represented diagramatically in Figure 1.2a and 1.2b. Figure 12a illustrates the production isoquants for a fixed proportions production function. If I_e is reduced from I_e to I'_e, the reduction in Q will be $Q_2 = e(I_e - I'_e)$ regardless of how much I_o is available. No matter what amount of I_o may be employed, only Q_2/g of it is required. It is not possible to increase production by adding more I_o than before. In Figure 1.2a, energy use is reduced from I_e to I'_e by increasing the price of energy such that the isocost line shifts from C_1 to C_2. The use of other factors, I_o, must decline along with the use of energy inputs, I_e. As both I_e and I_o are reduced, the quantity produced declines significantly from Q_1 to Q_2. In this fixed factor production function, lack of factor substitution causes a high cost in terms of foregone production for a given reduction in energy utilization.

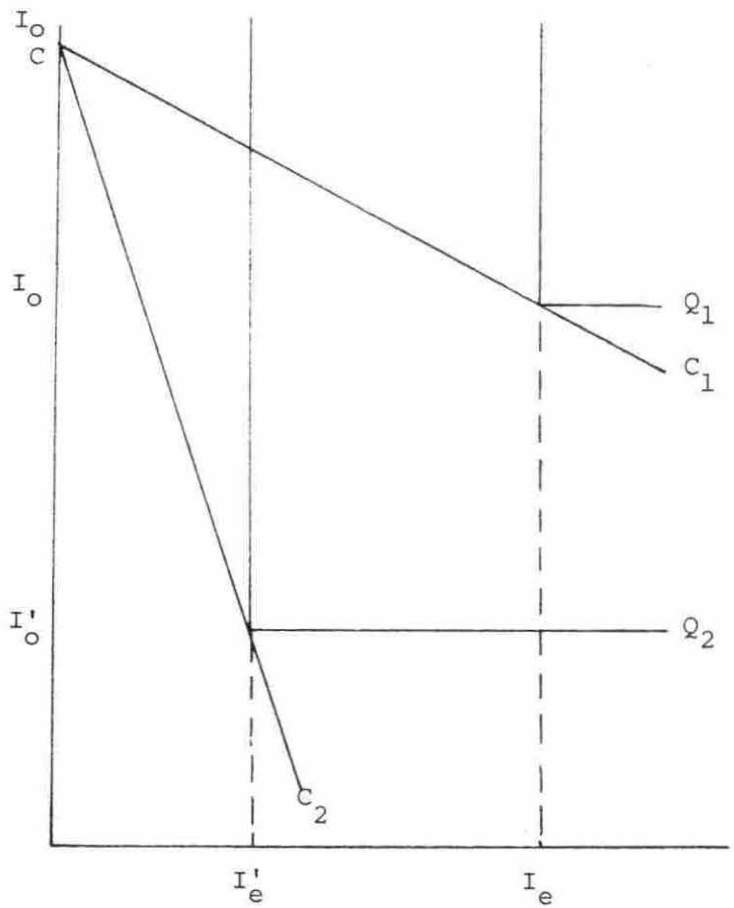

Figure 1.2a. Reduction of energy with fixed proportions production function

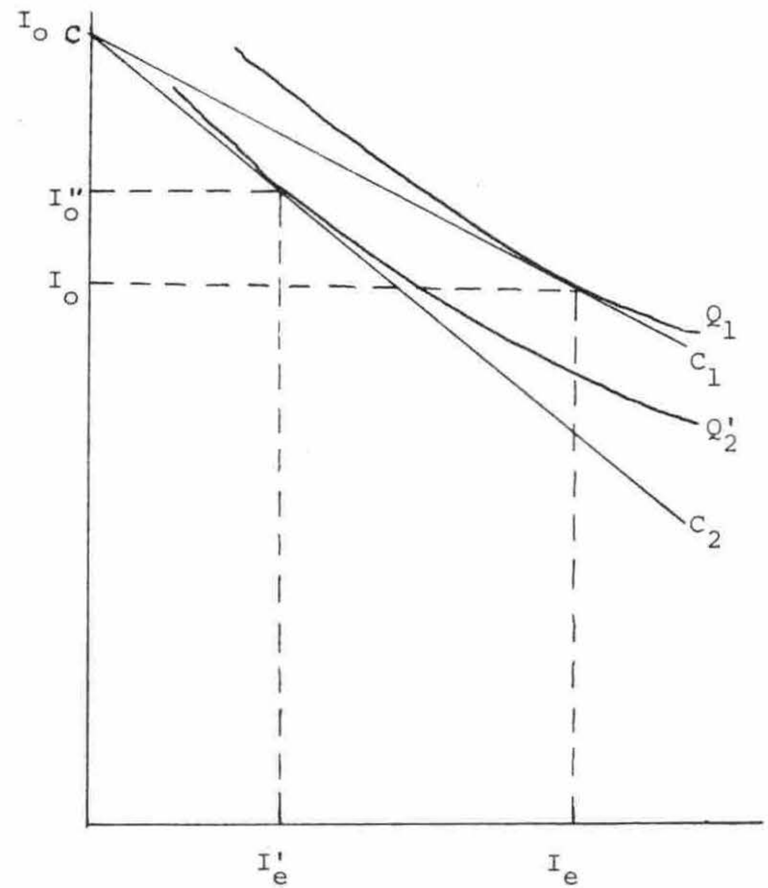

Figure 1.2b. Reduction of energy input with a variable proportions production function

The production process of Figure 1.2b has a high degree of substitution between factors. Curtailing energy use from I_e to I'_e is not as serious because the utilization of other factors may be increased to maintain production at a high level. In the Figure 1.2b, the price of energy is increased moderately so as to shift the isocost curve from C_1 to C'_2. The use of other factors increases from I_o to I_o'', and production only declines from Q_1 to Q'_2.

As was previously illustrated, the higher the elasticity of factor substitution, the less will be the loss of production for a given degree of energy use curtailment. It will be advantageous for the farm model in question to develop a set of production processes for corn which will afford it the greatest opportunity to substitute other factors for energy as energy prices increase. The ways in which this elasticity of factor substitution may be increased will be one of the major concerns of this paper.

Certain processes may exhibit a changing degree of substitution over a particular range of energy amounts. For instance, corn drying illustrated in Figure 1.3 has considerable potential for saving energy from the quantities used at I_e^1. It may be possible to dry corn down to 18 or 20 percent by leaving it in the field until late October. Even at that time, field losses are not particularly significant. Once corn has reached that moisture level, it is very difficult for it to dry further by natural processes. At that point, the degree of factor substitution declines substantially. Artificial drying must be employed to reduce it to 15 percent so that it may be stored. As will be

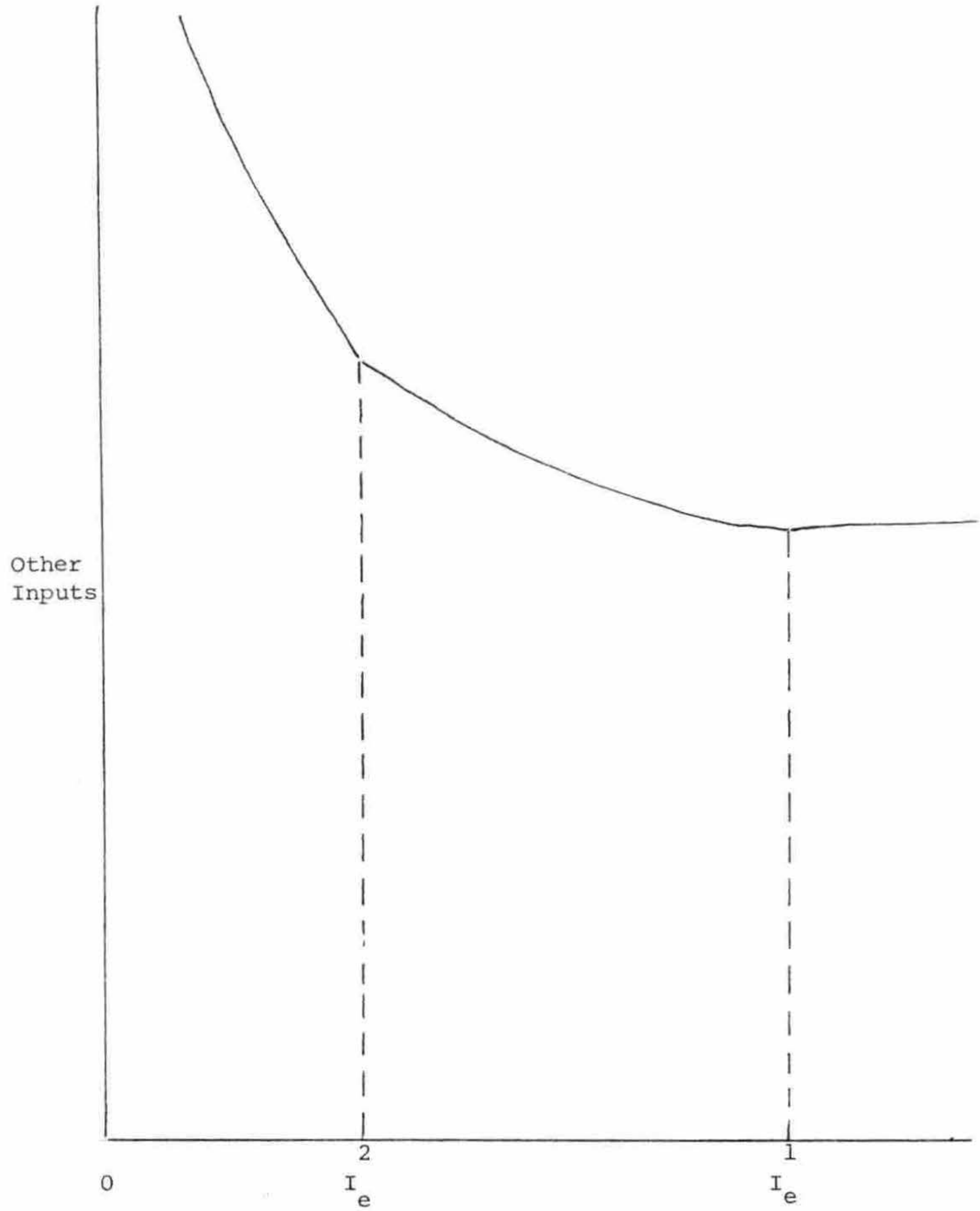

Figure 1.3. Production isoquant for corn

seen later, there is very little potential for conserving energy with any of the conventional drying methods. It will be necessary to expend a certain minimum amount, depicted as I_e^2 in Figure 1.3. To save anything beyond I_e^2 would entail a reversion to ear drying which will substantially increase losses, and necessitate investment in new equipment for drying and handling the corn. The elasticity of factor substitution changes once energy use is reduced to I_e^2. This may be seen in Figure 1.3 by the change in the shape of the isoquant at that point. Algebraically, this may be derived by expansion of the expression for σ in Equation (1-18), such that σ is expressed as a function of certain derivatives inherent in the production processes. One useful expansion of σ is (14, p. 62)

$$\sigma = \frac{MPP_1 \; MPP_o (MPP_e I_e + MPP_o \; I_o)}{I_e I_o [2 \frac{dMPP_e}{dI_o} MPP_e \; MPP_o - MPP_e^{\;2} \frac{dMPP_o}{dI_o} - MPP_o^{\;2} \frac{dMPP_e}{dI_e}]} \qquad (1\text{-}40)$$

At the point I_e^2, the slope of the isoquant, $-d\ MPP_e/d\ MPP_o$, decreases substantially. This indicates that $\frac{dMPP_e}{dI_e}$ is very high once I_e is reduced beyond I_e^2.

$\frac{dMPP_e}{dI_e}$ is less than zero for the feasible operating range of a two factor production function; therefore, the expression in the denominator

$$-(MPP_o)^2 \frac{dMPP_e}{dI_e}$$

is positive. A substantial increase in the $\frac{dMPP_e}{dI_e}$ derivative will cause the denominator of the expression in Equation (1-40) to increase, and thus σ decreases.

There are other influences from the cross partial derivatives

$$\frac{\partial^2 MPP_e}{\partial I_e \partial I_o} \quad \text{and} \quad \frac{\partial^2 MPP_o}{\partial I_o \partial I_e}$$

If the former expression is nonzero, then a change in I_o will cause the relationship between MPP_e and I_e to be altered, and thus change the derivative $\frac{dMPP_e}{dI_e}$. According to (1-40), this will have an effect on the elasticity of factor substitution, σ.

The mathematics required in calculating σ in this study would be too great for the useful information it would convey. The objective of the farm analysis will be to ascertain the relative potential for factor substitution for particular processes in a somewhat more subjective sense. Within a linear programming framework, the elasticity of factor substitution can usually be increased by increasing the number of alternative activities which the operator may engage in. Thus, the focus of the study will be to introduce many technically feasible methods of corn production. Attempts will be made to have a very great number of options with respect to time of planting and harvest, fertilization levels, and drying and tillage methods. This should afford the operator maximum opportunity to substitute nonenergy factors of production for energy factors when energy prices are increased. This will yield information as to how such an operator should adapt to changing input prices.

The isoquants for a linear programming model are similar to those of the fixed factor proportions production function of Figure 1.2a. As derived by Equations (1-24) and (1-25), both factors will be limiting for nonzero input prices. As a consequence, only the point of intersection of the two perpendicular segments need be considered for a particular process. Each process may be represented by a vector connecting that point with the origin. The curve connecting these end points of the vector is the production isoquant.

In Figure 1.4a, there is only two production processes available and the isoquant is relatively disjointed. It therefore has a lower elasticity of factor substitution. In Figure 1.4b, the number of options in production has been increased to four. Between points a and d, the slope of the isoquant is more gradual. It therefore has a higher elasticity of factor substitution. Note in Figure 1.4b that this higher degree of factor substitution is relevant only for the area in which the slope is more gradual.

These diagrams serve to illustrate that, in this model, the elasticity of factor substitution can be increased by increasing the number of different production processes which the farm operator may employ.

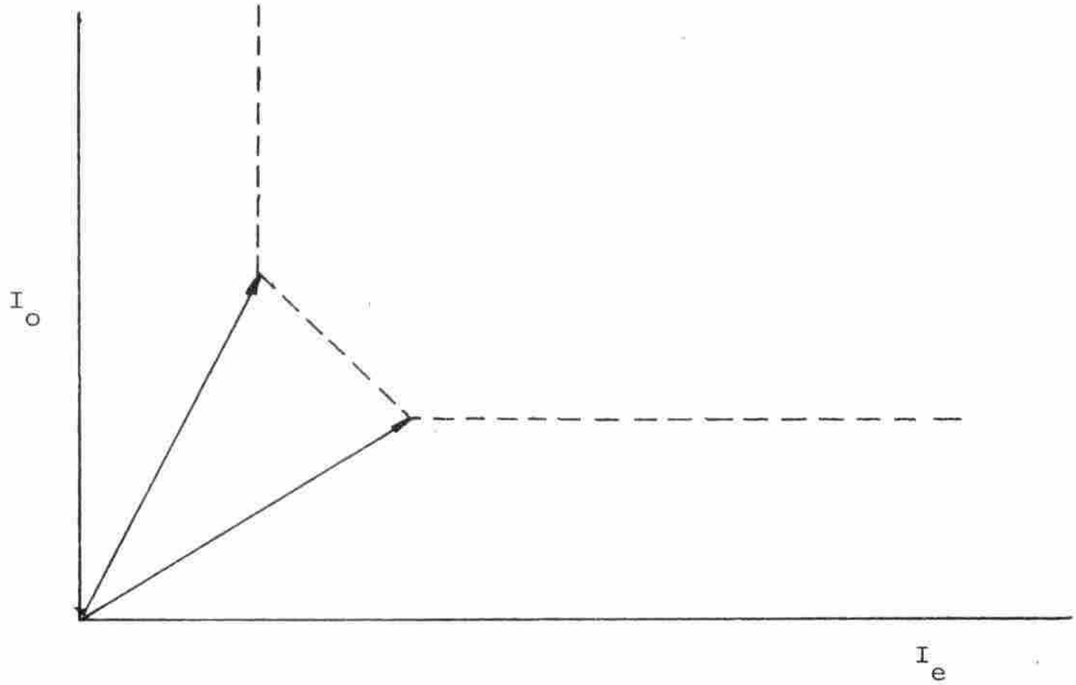

Figure 1.4a. Isoquant for two processes

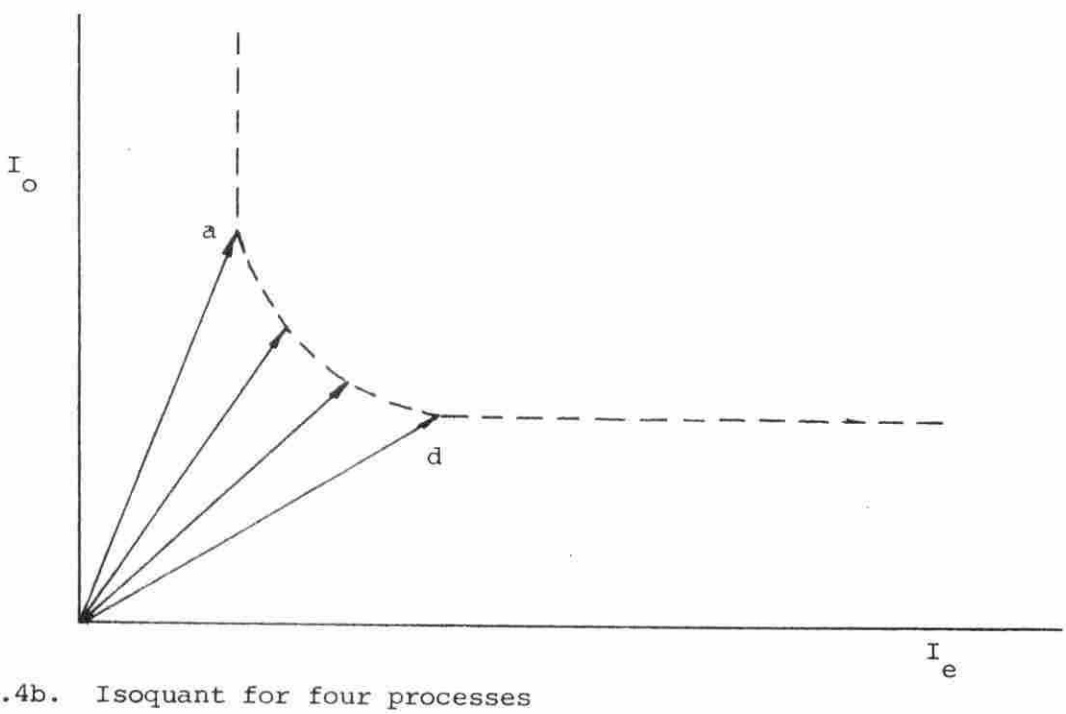

Figure 1.4b. Isoquant for four processes

Conclusions

The same effect on the farm's production processes will be observed whether energy prices are increased or if individual energy sources are rationed. If a ration is imposed on total energy use then the same reduction in energy will be observed, but the cost to the farm of such a reduction will be less.

The greater the elasticity of factor substitution for a particular product, the less will be the cost to the farmer of an increase in energy prices. In the linear programming framework, this elasticity can be increased by increasing the number of different activities which can be used to produce a given level of output. It is anticipated that, for the farm model under consideration, this elasticity of substitution will vary as the amount of energy is altered. It will be of interest to ascertain how much substitution is possible in a central Iowa farm. The more substitution which is possible, the greater will be the need for changes in present production practices.

CHAPTER II. ENERGY PRICE INCREASES AND THEIR EFFECTS ON COSTS OF CORN PRODUCTION

It is the intent of this chapter to predict both the increases in prices of energy sources by the year 1985, and then analyze what effects these changes may have on the prices of agricultural inputs. In a later chapter, an analysis will be conducted on the effects of these increases in input costs on the methods which would be employed by an Iowa farmer in producing corn.

Energy Price Increases

In predicting energy price increases, one may employ past trends or conduct on analysis of what factors will effect these prices in the future. Both methods have their limitations. Trend analysis assumes that the conditions which were prevalent in the past will be maintained in the future. A causality analysis requires that the researcher not only be capable of predicting the effects of a certain exogeneous factors on prices, but that the factors themselves can be predicted with a certain degree of accuracy.

Price trend analysis

Table 2.1 lists the indices for the general price level and the prices of the four major energy sources, petroleum, natural gas, coal and electricity. Note that, prior to the 1973 energy crisis, the inflation of energy prices was somewhat comparable to the general rise in the prices of all goods. From 1950 to 1972, the average annual

Table 2.1. Energy price indices between 1950 and 1976[a,b]

Year	General price level	Petroleum products	Natural gas	Coal	Electricity
1976	171.0	239.0	260.0	366.7	199.8
1975	161.2	211.0	218.0	387.0	191.6
1974	147.7	178.0	162.2	332.4	163.1
1973	133.1	128.7	126.7	218.1	129.3
1972	125.3	108.9	114.0	193.8	121.5
1971	121.3	106.8	108.0	181.8	113.6
1970	116.3	101.1	103.6	150.3	105.9
1969	109.8	99.6	93.3	112.0	101.8
1965	94.5	93.8	92.8	93.4	100.1
1960	88.7	95.5	87.2	95.6	101.2
1955	80.2		92.0	82.3	
1950	72.1		85.1	83.3	
Annual average increase (percent):					
1950-1972	2.5	1.1	1.34	1.73	1.54
1972-1976	8.2	21.7	22.8	17.3	13.2
Value in 1985[c] if follow trend 1972-1976	347.5	1401.0 (5.9)	1651.0 (6.4)	1539.0 (4.2)	612.0 (3.1)

[a]All price indices have a base of 100 for 1967.

[b]U.S. Department of Commerce (25, p. 47).

[c]Numbers in parentheses represent the factor by which the price of that fuel would have increased from 1976 to 1985 if the 1972 to 1976 trend continued.

percent increase for energy was between 1.1 and 1.7. For all goods, it was 2.5. Since 1972, all prices have increased at 8.2 percent while the average rate of increase for energy has been between 13.2 percent for electricity to 22.8 percent for natural gas.

In Table 2.1, the indices of each of the items under consideration for 1976 were compounded at the rate of increase they exhibited during the period 1972 to 1976. The result was the row labeled "value in 1985 if follow 72-76 trend". Note that natural gas, by increasing at 22.8 percent per annum to 1985, is 6.4 times the 1976 value by 1985. The other sources tend to be about three to six times as high as their present value. All fuels increase much more quickly than the general price level.

It may be postulated that to project prices for the next decade, it would be more accurate to employ the price trends of the previous decade rather than that from 1972. Reciprocally, it may be argued that the whole concept of energy as a free resource has been altered for both producers and consumers in 1972. Since the advent of the energy "crisis" of 1973, consumers have become more agreeable to paying high prices for energy. In recognition of this, producers may respond by obtaining energy sources by means which previously would have entailed prohibitive costs. While the actual numeric values reflected in Table 2.1 may be incorrect, there is reason to believe that the magnitudes of price increases which they reflect may prove to be valid indicators of future energy prices.

Causal relations in predicting energy prices

A further appreciation for the magnitude of future price increases may be gained by investigating the factors which determine energy prices. The impact that these factors have on the four basic energy sources are described below.

Natural gas   Natural gas has experienced the highest annual increase in price since 1972. Its limited supply may have a serious effect on prices. The factors behind natural gas costs will be:

1) The Federal Power Commission has imposed a 52 cent per thousand cubic feet maximum price for all new gas destined for the interstate market. Since the new administration assumed office in 1977, there has been speculation about its repeal. Repeal could significantly increase prices in the interstate market, but substantially increase the quantity which producers are willing to supply.

2) Environmental protection regulations encourage the burning of natural gas in preference to other fuels which have either a higher sulfur or particulate content. They increase demand and thus the price.

3) The price of fuel oil effects demand for natural gas, as most industrial establishments can convert from burning natural gas to oil with little difficulty.

4) The rate of leasing of natural gas fields in either Alaska or offshore areas will influence the supply in the long term.

5) Regulations on the importation of liquid natural gas from

Algeria will affect supplies also.

6) The development of technologies to economically synthesize gas from coal or petroleum may increase supplies. Similarly, technologies may be developed to extract natural gas from tight geological formations and Devonian shale.

Petroleum products Petroleum prices are governed by the following considerations:

1) Regulation of old oil under the Energy Policy for Conservation Act of 1975 has affected past prices. Any revision of that law in the future will have a direct impact on prices.

2) Expansion of leasing in the outer continental shelf may increase supplies for a particular time period. By 1980, it is projected that this area will be producing 2.0 MMB/day in comparison with the output of the continental United States of 7.5 MMB/day.

3) The rate of the investment tax credit will influence the impetus for expansion in oil exploration and development. This will influence supplies in the future if it is reduced from the present ten percent to seven.

4) The accuracy of present reserve assessments will influence what companies will charge for oil. If they are revised downward, there is a possibility that production will be decreased in the present, in anticipation that future shortages will bring higher prices.

5) The rate of development of the Alaskan pipeline will determine whether that project will contribute 2.0, 2.5 or 4.5 MMB/day to the

overall domestic supply of 13.5 MMB/day.

6) The rate of development of technologies required for oil shale extraction and syncrude development will affect supplies by 1985. One significant present problem in syncrude development is the lack of water near coal deposits. That must be surmounted before significant quantities of oil can be synthesized from coal.

7) Certain events outside of the United States such as the success of OPEC in maintaining discipline among its members may be critical to both supply and price.

Coal   Coal has represented an inexhaustible energy source since the discovery of large deposits of low sulfur coal in Montana and Wyoming. Coal reserves are estimated at 436 billion tons while the national rate of consumption is only one billion tons per annum (9, p. 195). In recognition of this fact, there may be a substantial increase in demand for this energy source as reserves of oil and natural gas are depleted. Some industries may convert to processes which utilize coal directly. If prices of petrochemicals make syncrude development possible, very large demands on the coal industry may be made.

Even if demand increases for coal as prices of other fuels rise, there is substantial evidence that the price of coal will not increase. The Federal Energy Administration has reported that the supply curve for coal is very elastic (9, p. 197). It bases its conclusions on elasticity on the fact that:

> Coal reserves are vast and the industry is composed of enough firms that market forces will push long term prices to a level reflecting costs plus a fair return on capital;... even in the short run (when coal supply is restrained by the time it takes to open new mines) not enough energy consumers have the capacity to burn coal to bid spot prices up to the BTU equivalent of oil (9, p. 170).

While there may be little increase in coal price due to an increase in demand, there are certain factors which will effect the supply schedule. If scrubbing is required to meet environmental regulations, the resultant increase in processing costs may be reflected in higher market prices. If other fuels are increased in price, there may be some increase in the cost of extracting and shipping coal. As most of the expense in coal mining is in labor and machinery, however, it may be assumed that rises in the prices of these other fuels will have a relatively low impact on costs of extracting coal.

In conclusion, price increases of other fuels should have little effect on both the demand and supply schedules for coal. As a result, it will be anticipated that even substantial increases in petroleum or natural gas prices will cause coal prices to experience only moderate increases.

Electricity Electricity is not a source of energy which has a supply and demand exogeneous to other fuels. The price of electricity is governed by the price of other fossil fuels for two reasons. The first is the fact that it competes with those energy sources in much the same market. The second is the fact that fossil fuels generate most of the electricity in this country. Over the past two decades, electrical generation has relied on the following fuels in the following proportions: coal, 50 percent; fuel oil, 12 percent and natural gas, 20 percent.

It may be concluded that the price of electricity will increase in proportion to the price of coal, oil and natural gas. The precise relation will be taken from that given by the Project Independence Evaluation System Report in its price scenarios (9, p. E-28).

The price scenarios

Given the great number of independent factors which contribute to the prices of each of the fossil fuels under consideration, it is impossible to derive price relations for all possible assumptions for all factors. Instead, it has been decided to calculate five price scenarios which are the most representative of the extremes which could occur in price increases. These scenarios are intended to depict not only the best examples of how energy prices may differ from the general price level, but also the best examples of how much prices of different sources might differ from one another.

The actual description of what may be the underlying causes of these price changes is found in Appendix A. The percentage increase in price for each of the scenarios is depicted in Table 2.2. The first two scenarios are possible price rises given the present trend for energy prices to increase more quickly than the general price level. The last three scenarios represent a significant rise in prices due to

Table 2.2. The percentage increase in price of each fuel associated with the energy scenarios under consideration[a]

Scenario number	Natural gas	Petroleum products	Coal	Electricity
1	100	50	10	60
2	300	100	10	100
3	400	400	50	200
4	400	900	50	200
5	900	400	50	200

[a]All figures are the percent increase from the 1976 price.

an unforseen shortage.

The Effects of Different Price Scenarios on a Central Iowa Farm

The objective of this study is to test the effects of the different price scenarios derived above on a typical farm in central Iowa. It will be assumed that output prices will not vary, and that the primary effects of the increases in energy costs will be through the increases in input expenses.

Table 2.3 lists the expenses for an average farm in the sixteen counties of central Iowa.[1] Of all expenses, "on-farm" energy use (fuel,

[1]These counties are: Pocahontas, Humboldt, Wright, Franklin, Butler, Calhoun, Webster, Hamilton, Hardin, Grundy, Greene, Boone, Story, Marshall, Dallas and Polk.

oil, and electricity used on the farm) is only about 3.3 percent. Most of the energy in agricultural production is expended in the manufacture of inputs. This will be termed as "off-farm" energy. The primary inputs tested in Table 2.3 which require energy in their manufacture are fertilizers, pesticides, and machinery. Fertilizers and pesticides comprise 13.0 percent of all farm expenses and depreciation accounts for a total of 14.0 percent. Most other expenses relate to the price of feed grains and seed, livestock, labor and real estate. These prices are assumed to be determined by factors not related to that of energy.

An increase of energy prices, according to the scenarios described earlier, will affect the costs of inputs whether they are such that they involve on-farm or off-farm energy consumption. In this study, the input price increase will be estimated by multiplying the increase in price per unit of energy for each fuel used in the production of a particular input times the units of energy of that fuel used in its production.

Table 2.4 lists the amount of energy by source which is required to produce one unit of a particular agricultural input. Note that nitrogen fertilizer will be quite responsive to the price of natural gas as 27,690 BTU's are required for the production of one pound of fertilizer. Natural gas represents 41 percent of the production costs incurred in the manufacture of nitrogen fertilizer. Pesticides have an equally high percentage of their production costs represented by inputs of both petroleum and natural gas. "Machinery" represents both

Table 2.3. Average expenses for central Iowa farms in 1975[a]

Expenses	Cost ($)	Percent of expenses (Exclusive of feed & livestock)	Percent of total expenses
Operating expenses			
Utilities (electricity)	885	1.4	1.0
L.P. gas	294	.5	.3
Diesel and gasoline	1782	2.7	2.0
Fertilizer	8324	12.9	9.1
Pesticides	3521	5.5	3.9
Machine Hire	2045	3.2	2.2
Machinery repair	3142	4.9	3.4
Auto expense	567	.9	.6
Labor hired	2486	3.9	2.7
Miscellaneous crop (seed, etc.)	3521	5.5	3.9
Miscellaneous livestock	1476	2.3	1.6
Other	628	1.0	.7
Sub-Total	28678	44.7	31.3
Fixed expenses			
Taxes-property	2859	4.4	3.1
Insurance	1359	2.1	1.5
Building repairs	1107	1.7	1.2
Depreciation: Machinery	7110	11.0	7.8
Improvements	2298	3.6	2.5
Opportunity cost of real estate (@6%)	20934	32.5	22.8
	35667	55.3	38.8
Total of fixed and operating expenses	64345	100.0	70.1
Feed purchased	15272		16.7
Livestock purchased	12083		13.2
Sub-total	27355		29.8
TOTAL	91000		100.0

[a]Source: 19, p. 6.

Table 2.4. Energy requirements in producing agricultural inputs

Input description	Unit	Cost per unit ($)	Coal[a]	Natural gas[a]	Oil[a]	Elect.[a]	Total BTU
Fuels:							
Electricity	kwh.	.04				3.41	3.41
L.P. gas	gal.	.31			92.3		92.30
Gasoline	gal.	.44			123.0		123.00
Fertilizers:[b]							
Nitrogen	lb.	.122		27.69			27.69
Phosphorus	lb.	.19			5.14		5.14
Potassium	lb.	.08			5.14		5.14
Herbicides:[b]							
Atrazine	lb.	2.95	16.77	29.67	19.35	15.91	81.68
Trifluralin	lb.		9.89	55.90	24.08	24.94	114.80
Chloramben	lb.			12.47	39.56	18.90	73.09
Propachlor	lb.		30.00	12.47	46.00	36.10	124.68
Insecticides:							
Carbofuran	lb.	3.80	24.76	37.20		15.48	77.44
Machinery:[c]							
Farm machinery	$	1.00	1.00	7.08	20.52	1.00	38.75
Drying equipment[d]	$	1.00	1.00	7.08	20.52	1.00	38.75

[a]All figures are in thousands of BTU's. It is assumed that there is no conversion loss for energy in electricity. One kilowatt is assumed equal to 3410 BTU's.

[b]M. B. Green, Imperial Chemical Industries, Manchester, England, private correspondence, 1972.

[c]The BTU/1975 dollar derived from the BTU/1974 dollar given in (4, p. 2). The actual percentage breakdown between energy sources was done employing (14, p. 124).

[d]It is assumed that drying equipment requires an input of energy/dollar of output, similar to farm machinery. This is justified on the grounds that the category "heating equipment" in the above referenced CAC document lists, the energy manufacturing requirement for all energy sources almost identical to that of "farm machinery".

depreciation and repair expenses. It requires less BTU's per dollar of output than most products. As a consequence, one should anticipate that energy price increases will not have such a significant effect on prices of either farm machinery or drying equipment.

In Table 2.5 is listed the effects on input prices by the increase in energy costs. The figures beneath a particular scenario illustrate the extra cost per unit of an input if the price of energy is raised according to that scenario. Beneath each figure in parentheses is the percentage increase in price which this particular scenario has caused for that input. Note that nitrogen fertilizer is the most responsive to energy price increases due to the high value of natural gas used in its production. When the price of natural gas increases tenfold as in scenario five, the cost of fertilizer production increases 240 percent. By contrast, machinery production is quite unresponsive to energy price increases. In scenario five, costs of producing machinery have increased only 37 percent.

The added costs of fuels, agricultural chemicals and machinery depicted in Table 2.5 should affect the methods of production in a central Iowa farm. It may prove possible to substitute an input with a lower energy cost for one in which the energy cost is relatively high. As explained in Chapter I, if there is little chance for substitution, then the farm will experience a decline in output for reduced energy use.

Table 2.5. Increases in the cost of production of agricultural inputs for certain energy price scenarios[a]

Input	Original price ($)	Scenario One	Scenario Two	Scenario Three	Scenario Four	Scenario Five
Electricity (kwh.)	.04	.064	.08	.12	.12	.12
L.P. gas (gal.)	.31	.47	.62	1.55	3.1	1.55
Gasoline (gal.)	.44	.66	.88	2.2	4.4	2.2
N. Fertilizer (lb.)	.122	.0323 (26.4)	.0997 (81.7)	.129 (105.7)	.129 (105.7)	.290 (237.9)
P. Fertilizer (lb.)	.19	.006 (3.1)	.0146 (7.7)	.0585 (30.7)	.132 (69.2)	.0585 (30.7)
K. Fertilizer (lb.)	.08	.006 (7.4)	.0146 (18.3)	.0585 (73.1)	.132 (165.0)	.0585 (73.1)
Herbicide[b]	13.50	.863 (6.4)	1.65 (12.2)	5.00 (37.0)	9.48 (70.2)	5.24 (38.8)
Insecticide (lb.) Carbofuran	3.60	.133 (3.7)	.295 (8.2)	.638 (17.7)	.963 (26.7)	.852 (23.6)
Machinery costs ($)	1.00	.045 (4.5)	.099 (9.9)	.314 (31.4)	.658 (65.8)	.367 (36.7)

[a]All figures are in dollars per unit specified for that particular input. Numbers in parenthesis indicate the percentage increase in price caused by a particular energy price scenario.

[b]The unit of herbicide is the total amount required for one acre of corn in central Iowa. In this model, that is assumed to be two pounds of atrazine and two of alachlor.

CHAPTER III. THE MODEL OF A TYPICAL FARM IN CENTRAL IOWA

It has been decided to study the effects of input price increases on the operation of a typical farm in central Iowa. A farm model has been formulated such that it represents the average scale of operations for the area. Linear programming is to be employed to determine what would be the methods of production best employed to achieve profit maximization for such a farm. As energy costs increase under the different price scenarios, the linear programming model will be subjected to altered input costs. It is anticipated that it will respond to those changes in costs by altering the production processes. As inputs which require a relatively high amount of energy will be more expensive, the linear program should adjust production processes such that they utilize less of those resources.

The details of the size of the cropping and livestock operations of this farm are found in Table 3.1. The figures reflect the average scale of operations for farms in this area. The value of the land and buildings of Table 3.1 are tabulated in Appendix B.

It is assumed that there is only one full-time operator to provide labor on this farm, although a casual laborer may be hired during periods of heavy labor demand. Appendix B lists the total amount of labor which the operator and the assistant are willing to furnish for each of the months of the year.

The linear program is so constructed as to make it possible for a

Table 3.1. The size of operations in the farm model[a]

Utilization Pattern for Cropland:	
1) Corn (Nicollett-Webster Soil)	170 acres
2) Soybeans (Nicollett-Webster Soil)	104 acres
3) Oats and Meadow (Clarion Soil)	15 acres
4) Homestead and Pasture	29 acres
Total	318 acres
Livestock Capacity:	
Beef Confinement unit (for finishing yearling steers from 650-1150 lbs.) Deep pit waste disposal	300 head/year
Hog Farrowing (4 farrowings/year)	100 litters/year
Hog Nursery	200 head/year
Hog Finishing	700 head/year

[a]Derived from figures for the average farm in central Iowa given in (19, p. 3).

number of the processes to be altered in response to changing input prices. It is anticipated that as energy prices are increased, the linear programming output will find that it is most economic to reduce the use of those inputs which require relatively high amounts of energy in their manufacture. The options available in the program will be to change the date of planting or harvesting of corn, the level of fertilizer applied, the type of tillage system employed or the method of drying. In the rest of this chapter, these options are described in detail.

Option 1: Time of Planting and Harvesting

There are assumed to be six different ten day periods from April 15 to June 14 in which planting may take place and six periods for the harvest. The greater the length of time between planting and harvest, the greater will be the drying of corn which takes place naturally. The moisture level for each combination of planting date and harvest date has been calculated for an average year and is tabulated in Appendix B. In years with greater than usual rainfall, the moisture level is greater for any combination of planting and harvest dates, as the corn does not dry as well. The converse is true in a year in which the rainfall is below normal. Table B.4 of the Appendix lists the percent moisture associated with a particular combination of planting and harvest date for different weather conditions.

Increasing the time between planting and harvest will reduce the amount of fuel required for corn drying, as corn will be harvested at a lower moisture content. As that time increases, so will the amount of corn which falls from the stalk and cannot be harvested by a combine. This "field loss" has been calculated for each different combination of planting and harvest dates. It is listed in Table B.4 along with the moisture level.

The chief factor which governs the time of planting and harvest is the number of days suitable for field work. Unless specified otherwise, this will be taken as the average number of days which have been available in the last fifteen years. This will give an appreciation of the average effect of energy price increases on the farm. In the long run, those average effects are the ones which are of interest.

For any specific year, there could be a significant change in field time available. If the spring in a particular year experiences more than average rainfall, planting may be delayed and yield penalties incurred. If the autumn has excessive rain, then it will be necessary to harvest earlier to be certain of combining all corn before December. A wet harvest will also have a higher relative humidity, and corn will be harvested at a higher moisture content. This may seriously effect the ability of the farm to conserve energy by drying corn naturally in the fields. If the price of L.P. gas is high, this could reduce income substantially.

The model is subjected to different combinations of wet and dry autumns and wet and dry springs. The precise number of field days are taken from weather data for the years 1960, 1964, 1968 and 1972. In the last fifteen years, these four represented combinations of respectively, a relatively wet spring and dry autumn, dry spring and autumn, dry spring and wet autumn, and the most wet spring and most wet autumn. The number of hours of field time for each of these years is listed in Appendix B.

Option 2: Tillage Systems for Corn

Considerable energy savings may be realized from employing minimum tillage rather than the conventional practices in use in central Iowa at present. Table 3.2a below summarizes the features of each of the tillage systems which may be employed in this model. All data concerning yields, inputs and methods are derived from a five year experiment conducted by the Department of Agricultural Engineering, Iowa State University. More detailed descriptions of each tillage method are found in Appendix C.

Note that apart from the reduced gasoline requirement and a slight reduction in repair costs, the energy input into each tillage system is the same. The minimum tillage systems require less time at critical periods because they do not require that either stalks be chopped or plowing be done in the autumn after harvest or in the spring before planting.

All systems of minimum tillage except "no till" have less variance in yield than the conventional tillage; thus one may assume that there is no "risk" factor involved in evaluating the yield of each system. The result is the simple tradeoff of yield for energy and timeliness costs. In a year in which the spring weather is poor, the timeliness costs will be greater for conventional tillage. Similarly, the increases in energy costs under the five scenarios will also increase the advantage of minimum tillage. To facilitate a comparison of these systems under different energy scenarios, it was decided to calculate

Table 3.2a. Characteristics of different tillage systems

System	Gasoline Requirement[a] (gal.)	Yield (bu/acre)	Standard Deviation of Yield (bu/acre)	Soil Loss[b] (tons/acre)
Conventional -				
Fall	10.15	141	17.6	8.6
Spring	10.15	132	18.5	6.4
Till Plant	5.15	138	16.8	2.3
Offset Disk	7.20	133	16.1	6.4
Chisel Plow	8.85	130	16.7	6.6
No Till	5.00	125	20.1	2.3

[a]All figures from an experiment conducted by the Departments of Agronomy and Agricultural Engineering of Iowa State University on Nicollet Webster soil in central Iowa. The experiment was conducted each year between 1971 and 1975 on experimental plots, each one acre in size.

Those conducting the experiment were more familiar with tillage systems other than "conventional" than the average central Iowa farmer. It may be postulated that the decreases in yield for a farmer who adopts these other systems may be greater, as there will be a learning period required. This may decrease the net return and increase the risk associated with such systems as till plant such that, initially, the latter has no economic advantage over conventional tillage.

[b]Calculated in Appendix D.

the input cost for each system. Added to this direct input cost should be an amount to account for reduced yields for systems other than conventional. The value of the reduced yield is the difference in bushels between a certain system and convention. The number of bushels is multiplied by the market price for corn of $2.40 minus drying and transport expenses for one bushel. The value of the reduced yield plus the direct expenses incurred for a tillage system is defined, as the "net" cost.

The net cost is portrayed in Table 3.2b. Beside each net cost figure, the rank of that system for the particular energy scenario is given. The system ranked (1) has the least net cost, the system ranked (5) has the most. Till plant appears to be the most efficient under all price assumptions. It uses less energy than any other system (although "no till" employs slightly less gasoline, it uses more energy in the form of herbicide). It has a higher yield than all systems except for conventional fall plow. The slight yield penalty in till plant (3 bushels) is more than offset by the 4.2 gallons of gasoline and $6.00 in machinery repair expenses which it saves. Thus, it is superior to conventional tillage even at present energy prices. Conventional tillage is the second most economical for all scenarios except in scenario four where petroleum prices are increased by a factor of 10. In comparison with chisel plow, offset disk requires less energy and gives greater yields; thus, it is always superior to the former system. No-till incurs such a large yield penalty (25 bushels/acre) that it is always the least desirable even when petroleum prices increase ten-fold. One may question why most Iowa farmers at present do not employ till plant if it is economic to do so at present input prices. It will be assumed that lack of experience with minimum tillage practices amongst Iowa farmers may increase the risk. There may also be the risk that any particular farm may be more subject to weed infestation than the experimental plots from which the yield figures

Table 3.2b. Costs of each tillage system, in dollars per acre, under different energy price assumptions[a]

System	Original	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Conventional	78.3 (2)	108.0 (2)	124.6 (2)	157.4 (2)	202.9 (4)	185.2 (2)
Till Plant	76.8 (1)	105.1 (1)	120.2 (1)	144.4 (1)	175.5 (1)	172.4 (1)
Offset	93.4 (3)	120.4 (3)	135.3 (3)	161.1 (3)	194.8 (2)	189.1 (3)
Chisel	97.0 (4)	125.6 (4)	140.4 (4)	166.0 (4)	199.6 (3)	194.1 (4)
No Till	112.5 (5)	140.4 (5)	155.4 (5)	177.1 (5)	205.6 (5)	205.2 (5)

[a]The numbers in parentheses indicate the relative order between systems. Those ranked "(1)" are the least expensive.

were derived. In that case, more herbicides will be required than that needed for conventional tillage. This would negate the economic advantage at most energy price levels. As herbicides require significant energy inputs in their manufacture, their costs should rise with energy prices. As a consequence, cost savings through less use of gasoline may be off set by increased herbicide purchases.

A further point of comparison of tillage systems is in field time a system requires. In wet years, the amount of time in which field operations may be conducted is reduced. If this time is so scarce that there are losses due to late planting, then conventional tillage will be at a disadvantage. It requires almost twice as much field time and thus will tend to have a higher "field time" cost. When this is added to net costs of Table 3.2b, it may be found that conventional tillage is less economical than other tillage systems during a year of poor weather than during one in which field time is not a restraint.

A further point of comparison between tillage systems is in the amount of soil loss which they generate. The system which allows crop residue to remain in the field longer will reduce soil loss, as the roots of such residue retain the soil. Tillage systems which minimize the amount of field operations reduce the amount of crop residue which is destroyed.

Table 3.2a lists the estimated soil loss per acre for different systems. These figures were calculated by methods outlined in Appendix D.

Note in Table 3.2a that conventional tillage has 8.6 tons per acre soil loss in comparison with 2.2 tons for till plant and no till. Soil loss and the timeliness consideration discussed above make conventional tillage less economical than figures in Table 3.2b indicate. It would make the comparison of systems in that table easier if an actual "cost" associated with different soil losses and timeliness could be ascribed to each system. As discussed in Appendix D, an actual figure for the soil cost is difficult to calculate. The cost of timeliness would depend on the weather conditions which prevailed in a particular year, and is also difficult to evaluate quantitatively.

Although actual figures cannot be ascribed to the cost of soil loss and timeliness, they are worthy of note. They will tend to enhance the relative economic attractiveness of till plant and no till and reduce returns to conventional tillage. According to surveys taken in Iowa, 24 percent of those farmers who switched from conventional to minimum tillage practices did so because of the desire to save field time. Fifty-two percent made the conversion in order that soil loss could be reduced (24, p. 15).

These two considerations are very relevant to Iowa agriculture and should be recognized in the model. The timeliness aspect will be accounted for in the linear program by shadow prices on field time during critical periods. Tillage systems which use more field time during those periods will incur a higher cost. The total soil loss for the entire farm is calculated in the model so that at least it may be compared for different systems.

Option 3: Fertilization Levels

The program is so constructed as to allow the level of fertilization to be adjusted to the economically optimal level. This level will be determined by equating the value marginal product and the price of fertilizer. The value marginal product for nitrogen fertilizer is calculated for Nicollett-Webster soil in Table 3.3 below. The marginal yield of that table is the number of bushels which will result from the application of one extra pound of nitrogen fertilizer. Note that the marginal yield is inversely related to the quantity of fertilizer applied. The value marginal product is the product of the marginal yield and the marginal revenue from a bushel of corn. The marginal revenue is the $2.40 selling price minus the cost of drying and shipping one extra bushel of corn.

As the price of energy increases, the cost of spreading natural fertilizer and the cost of purchasing artificial fertilizer will increase. One ton of manure, which contains 5.5 pounds of nitrogen effective, requires 0.2 gallons of gasoline to knife into the soil. If it is knifed in, very little of the 5.5 pounds of nitrogen will be lost through volatization. The effective cost of this method of manure spreading will be the machinery expense of $0.10 per ton plus the gasoline costs of ($.44 x 0.2 gallons per ton). This is, therefore, $0.034 per effective pound of nitrogen. An alternative method of bulk spreading the manure would require about 0.1 gallons of gasoline per ton spread. Losses through volatilization reduce the effective nitrogen to 4.0 pounds per ton. The cost of this method, calculated employing methods similar to that used above is $0.036 per pound of nitrogen effective. The price of gasoline will have a very substantial effect on the relative costs associated with these two methods of manure disposal. It will also effect the cost of manure spreading as opposed to employing artificial fertilizer. The 300 cattle and 700 hogs on this farm will produce 2,200 tons of manure in one year. Manure will supply approximately 45 percent of the nitrogen requirements of the 170 acres of corn. The remaining nitrogen requirement is met by applying anhydrous ammonia, which has a price of $0.122 per pound. As evidenced by Table 3.3, the value marginal product of nitrogen exceeds these cost figures even when fertilizer is applied at the rate of 160 pounds to the acre. Under present prices, the level of fertilization will be at least 160 pounds per acre.

The increase in fertilizer prices with increased energy costs are illustrated in Table 2.6. When prices of natural gas became ten times their present level as in scenario five, the price of artificial fertilizer rises to $0.4123 per pound. The value marginal product of fertilizer is only $.34 per pound at 160 pounds per acre application. To achieve optimality, the rate of application will have to be reduced until the value marginal product equals the new fertilizer price.

Calculating the price elasticity of demand for fertilizer will provide an appreciation of the decrease in fertilizer use resulting from an increase in energy prices. Table 3.3 lists the quantity of fertilizer which is associated with a particular marginal value product (which, in turn, is equal to what the operator is willing to pay for fertilier). The price of fertilizer may be increased 135 percent from \$.34 per pound to \$.80 per pound for a 38 percent decrease in quantity applied from 160 to 100 pounds per acre. This represents a price elasticity of less than 0.3 for rates of application less than 100 pounds per acre.

The nitrogen production function of Table 3.3 is illustrated in Figure 3.1a. The optimal rate of application will occur at "a" where the price, represented by the line segment PP is tangent to the production function. An increase in price to P'P' will cause fertilier use to decrease 20 pounds to b. In reality, the response of a farmer to such a price increase may not be so great. If a farmer had a production function with increments of five pounds per acre, the original point of equilibrium would be at point c of Figure 3.1b. The same price change from PP to PP' will elicit a smaller decrease in fertilizer application to d. In reality, a farmer may not demonstrate a response which corresponds exactly with the model due to this difference in production functions.

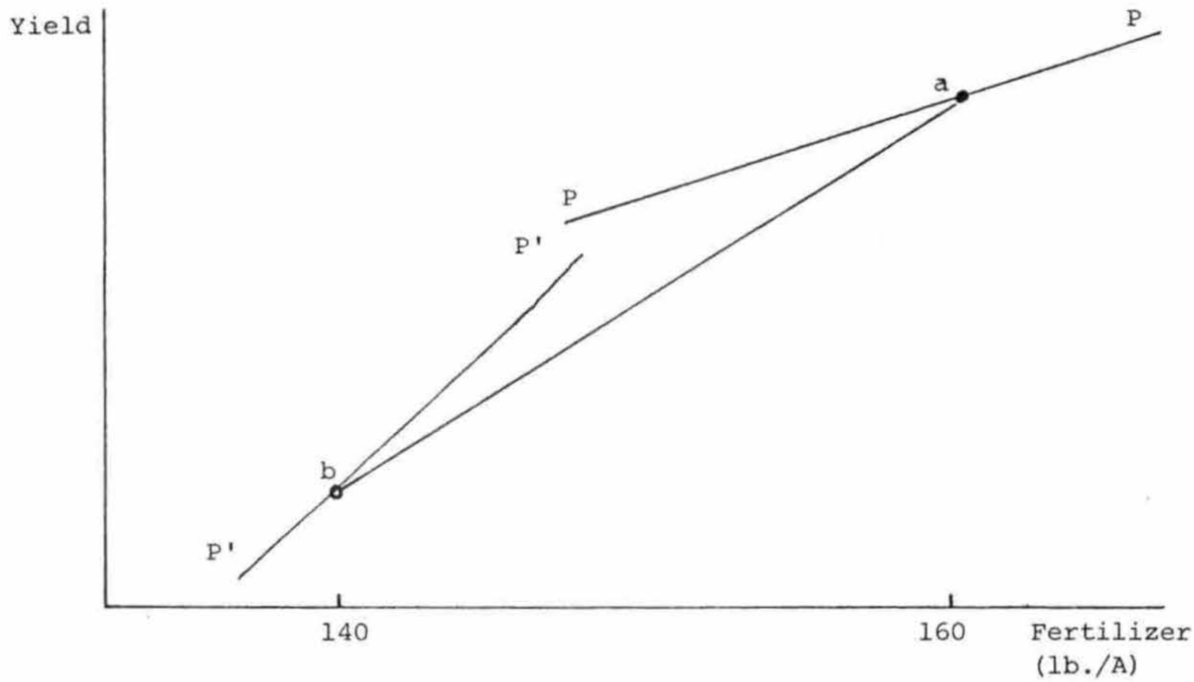

Figure 3.1a. Response function with twenty pound increments

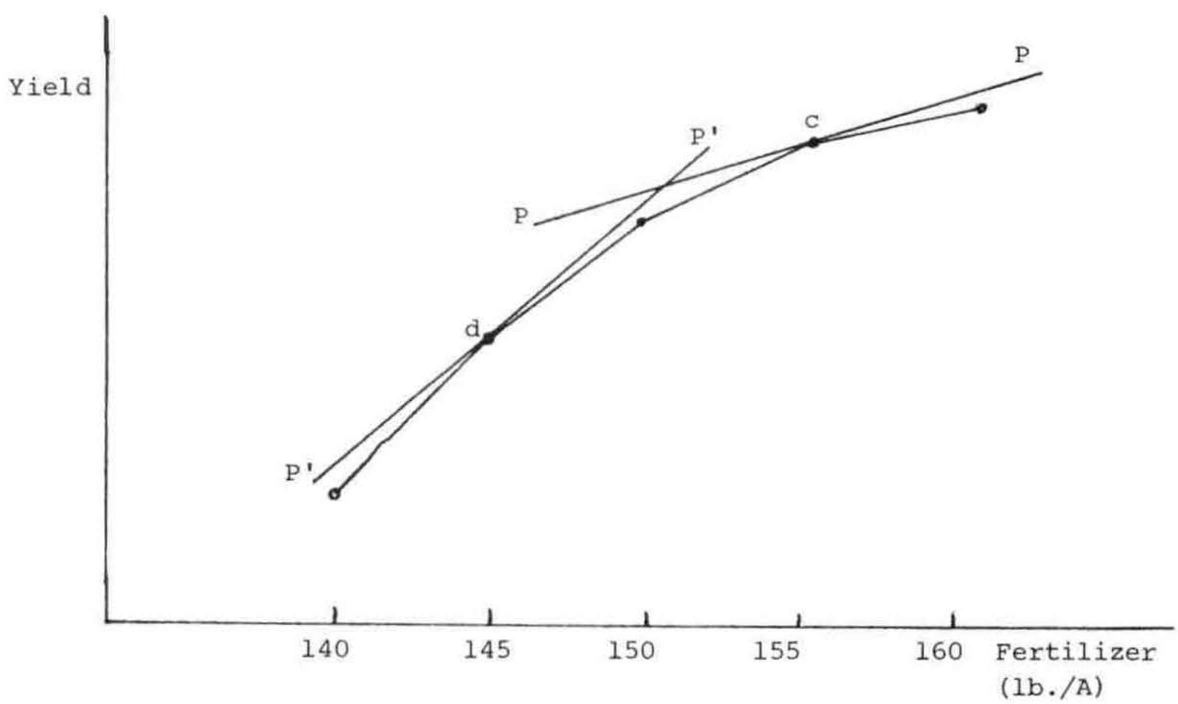

Figure 3.1b. Response function with five pound increments

Table 3.3. Value marginal product of nitrogen fertilizer on Nicollet-Webster soil[a]

Fertilizer Level (lb/acre)	Yield (bu/acre)	Marginal Yield (bu/lb)	Value Marginal Product ($/lb)
160	141	.15	.34
140	138	.25	.57
120	134	.30	.68
100	128	.35	.80
80	121	.45	1.03
40	102	.50	1.14
0	78	.60	1.37

[a]Source: 6, p. 1.

Option 4: Crop Drying and Storage Facilities

It is assumed that there are sufficient facilities on this farm to dry and store all the grain produced in one year.

With the particular cropping pattern employed, the operator realizes 23,500 bushels of corn and 4,000 bushels of soybeans. To store this quantity, he requires two 5000 and two 10,300 bushel bins. It has been assumed that the only feasible method of storage is in bins and thus there is no change possible in the program.

To preserve the corn for storage, it is necessary to either dry it to 15 percent moisture, treat it chemically or, in the case of livestock feed, store it as silage. In this model, all corn will be dried to 15 percent moisture content. Chemical treatment is not considered as

> . . . the treatments now used corrode metal structures and equipment. The cost of chemicals plus treatment is generally greater than the cost of drying for the same moisture content. The amount of petroleum feed-stock required for synthesis of propionic acid to inhibit mold is essentially equal in cost to that of the L.P. gas required to dry the grain. . . ." (20, p. 13)

Harvesting and storing of corn as corn silage is limited to that used to feed cattle being finished on the farm itself. Feeding cattle silage decreases feed costs, but increases the amount of time which cattle must remain on the farm before attaining market weight. At low costs of drying, feeding of dried shelled corn may prove more economical. As drying costs increase with increased energy prices, the converse could be true. This paper is concerned primarily with energy conservation in corn production. Adding a cattle feeding operation with a variety of possible rations would alter the amount of shelled corn produced. For some price scenarios, corn would be harvested early in the year as silage, and under other price scenarios it would be harvested and dried as grain. This would complicate the analysis and make it very difficult to identify changes in corn production strictly due to energy price increases. In recognition of this, all corn will be assumed to be dried to 15 percent moisture either before it is sold or fed to livestock.

The operator does have the option as to which drying method he may employ. It has been decided to compare only those methods which are applicable for shelled corn. It is acknowledged that this omits what is perhaps the least energy intensive method of drying, the storage of ear corn in open air drying bins. This method, like silage, is also perhaps applicable primarily where the corn is to be fed to livestock on the farm. Shelling the cobs to produce marketable grain would involve an energy input into the shelling apparatus. Unfortunately, no figures are available on the cost of shelling. It is estimated that approximately 10 percent of a crop is lost employing ear drying. The actual harvesting machine is less efficient than a combine, and the corn in storage is more susceptible to being eaten by birds, rodents and insects. A ten percent reduction represents an effective "cost" of ear drying of $0.24 per bushel (assuming a market value of $2.40). L.P. gas would have to increase to eight times its present value before the cost of artificial drying exceeds that of ear drying. One must also account for the fact that ear corn harvesting represents an increase in the amount of time required to haul corn from the field and place it in the bin. During the critical harvest months, this represents a further increase in the cost of the ear drying technique. Due to these considerations, ear corn drying will not be part of this model of a modern Iowa farm.

The four main systems for drying shelled corn will be considered. The farmer will be capable of switching from one drying method to another without incurring any opportunity cost on existing equipment. The four systems for drying shelled corn are the continuous/low, batch-in-bin, low temperature or solar drying method. The continuous/low drying is modeled after the Sukup Forway Drying System which dries the grain in a 5,000 bushel bin under continuous flow conditions. Dryeration is assumed to be accomplished by transferring the grain to the storage bins. The "batch bin" involves filling the bin to a depth of six feet and drying it overnight with L.P. gas burners. "Low temperature" is the filling of a bin to the maximum height permissible given the moisture content of the corn and then drying it by a continuous flow of air which has its temperatured increased 7 °F by an electric heater. Solar drying incorporates the same system as the low temperature during the night. During the day, the air is warmed by solar collectors instead of the electric heater. In future discussions, the batch bin and continuous flow will be described as "high temperature systems." The other two systems will be classified as "low temperature" ones.

A detailed description of the initial costs of each system for each moisture content of corn is provided in Appendix E. It will be instructive to compare both initial costs and energy inputs for each system for a bushel of corn at 24 percent initial moisture. Table 3.4 illustrates the expenses for the drying costs (exclusive of those involved with storing) at the present energy costs and at different energy scenarios.

Beneath each of the cost figures for a particular scenario is a number in parentheses. This is the percentage increase in cost caused by the increase in energy prices.

Table 3.4. Comparison of drying systems in the costs per bushel drying capacity

	Continuous[a] Flow	Batch[a] Bin	Low[b] Temperature	Solar[b]
<u>Fixed Expenses:</u>[c]				
(Energy inputs in the manufacture)				
Coal ($x10^3$ BTU/bu.)	0.609	0.437	1.053	1.053
Natural gas ($x10^3$ BTU/bu.)	0.425	0.305	0.188	0.204
Petroleum ($x10^3$ BTU/bu.)	1.255	0.905	2.170	2.201
(Fixed costs in dollars per bushel)				
Present energy prices	0.116	0.084	0.216	0.230
Scenario one	0.118	0.086	0.219	0.233
Scenario three[d]	0.132	0.096	0.242	0.257
	(14)	(14)	(12)	(11)
<u>Variable Costs:</u>				
(Energy inputs in drying)				
L.P. gas (gal./bu.)	0.095	0.098	-	-
Electricity (kwh./bu.)[e]	0.070	0.111	0.2970	0.435
Total energy ($x10^3$ BTU/bu.)[e]	9.026	9.405	10.128	8.303

[a]Figures for Superior Drying Systems (23, pp. 15-30).

[b]Source: 16, p. 11.

[c]The fixed expenses reflect the cost of annual depreciation per bushel of corn dried.

[d]Figures in parentheses represent the percent increase in cost for that scenario in comparison with the cost under present energy prices.

[e]It was assumed one kilowatt = 3410 BTU.

Table 3.4 (Continued)

	Continuous Flow[a]	Batch Bin[a]	Low Temperature[b]	Solar[b]
(Variable costs in dollars per bushel)				
Present prices	0.032	0.035	0.118	0.097
Scenario one	0.049 (53)	0.053 (53)	0.190 (61)	0.155 (59)
Scenario three	0.156 (385)	0.165 (375)	0.356 (201)	0.292 (200)
Scenario four	0.298 (828)	0.332 (857)	0.354 (200)	0.290 (200)

The fixed costs for the continuous flow and batch bin systems on a per bushel basis are noticeably less than those for the low temperature systems. Both the low temperature systems require almost the equivalent investment in installing fans, electric heaters, stirring devices for each bin that the high temperature methods require for only one 5,000 bushel bin. In addition to that, low temperature systems require an additional 5,000 bushel bin to store grain, as low temperature requires such an airflow that the storage bins cannot be filled to capacity if the moisture content of the corn exceeds 22 percent.

If energy price increases in the grain dryer industry are passed on to the customers, Table 3.4 shows that the price differential between low and high temperature systems will remain the same. At present, the batch system is .0844/.2157 = 39.1 percent the cost of the low temperature. In scenario 3, that figure is .0961/.2416 = 39.8 percent. Unless there is a significant improvement in low temperature technology, there will probably be a great cost disadvantage in an initial sense to low temperature drying regardless of energy prices.

The variable costs are about 41 percent of the fixed costs in high temperature and 54 percent of those costs in low temperature drying. Again, there appears to be a significant advantage in high temperature drying. Low temperature drying is 240 percent more expensive than batch bin at present prices. Only when L.P. gas is ten times its present price and electricity has increased thrice in scenario four are the costs more comparable. The main difficulty stems from the fact that even the most energy efficient of the low temperature systems, the solar system, uses 8,303/9405 = 88 percent of the energy of the batch system. As a consequence, it is difficult to imagine even that system proving superior to the high temperature ones unless L.P. gas was simply not available. It may be noted that for corn above 24 percent moisture content, the air flow required for low temperature drying systems is so great that even solar will require more energy per bushel dried than either of the high temperature methods.

If the farm is of a smaller size, then the per bushel fixed costs of the high temperature drying systems would be higher. In this model, the fixed costs of batch bin would be equal to those of low temperature if only 8,000 to 10,000 bushels were produced. Low temperature would still have a higher variable cost unless L.P. gas prices increased significantly in relation to electricity.

The Whole Farm Model

The chief objective of this study is to analyze energy conservation methods in corn production; thus, the options available to a farmer will primarily be in alterations in corn production methods. For a realistic farm model, it is necessary to include other crops and livestock activities.

The other crops grown include soybeans, oats and alfalfa. They require much less energy in their production than corn and thus the energy savings possible in their production should also be less. These crops require little artificial drying or nitrogen fertilizer, two major energy inputs in producing corn. If drying is not important, it is not necessary to alter the harvest time to allow the crop to dry in the fields, nor is there any need for the options in artificial drying which corn has. Oats and alfalfa do not require a significant amount of tillage. There may be some potential for conserving energy by adopting minimum tillage practices for soybeans. At present there is a lack of data for the effects of different tillage systems on soybean yields for central Iowa. This may prove to be the subject of future research once such information is available.

Energy conservation in livestock production represents another area in which there is significant potential for future research. There are potential savings in energy utilization through such methods as recycling of manure or of using manure to generate methane gas for fuel. There is a great variety of waste handling systems and rations which also may be experimented with. It was felt that an adequate analysis of this field could not be conducted without a very significant increase in the scope of this study. Secondly, this study intends to analyze the effects of energy price increases on one specific crop such as corn, it is necessary that livestock production is also not changing simultaneously. If livestock rations change so will corn production methods. Reciprocally, changes in costs of corn production would detract from the analysis of energy price impacts on types of confinement systems used. As a consequence, the model will concentrate on the changes in corn production. Livestock and other crops will be fixed in the model, but they will be added so as to contribute to the realism.

The farm model described in this chapter was set in a linear programming framework with 223 variables and 111 restraints. The technical coefficients and the restraints on all things such as field time, acreage, and livestock capacity have been described either in this chapter or the Appendix. The amount of coal, petroleum, natural gas and electricity which was involved in the manufacture of agricultural inputs were described in Chapter II. From those figures, it was possible to calculate the total amount of energy from each source which was "embodied" in a particular activity. In corn production, for instance, account was taken of all energy in pesticides, fertilizers, machinery operation, machinery manufacture, manufacture of corn drying equipment and the energy in either the L.P. gas or electricity used in drying. With an increase in the price of energy, there was a certain "cost" ascribed to each BTU of each energy source for each activity in corn production. For scenarios in which the cost of natural gas was increased, all activities which had significant amounts of nitrogen fertilizer experienced an increase in cost. For those scenarios in which L.P. gas costs were high, a greater cost was experienced by corn drying systems using that input.

Due to the complexity of the model, the actual iterations were done on a computer at Iowa State University. The output will be analyzed in Chapter IV.

CHAPTER IV. EFFECTS OF ENERGY CURTAILMENT ON THE FARM MODEL

The primary focus of this chapter will be the response of the farm model to energy price increases. As energy prices are altered from their present value to those of the five price scenarios, certain changes should occur. It is anticipated that the use of inputs which require a relatively high amount of energy in their manufacture will be curtailed. This chapter will be concerned with the extent to which these inputs are reduced, how much they can be substituted for by other inputs, and the total cost of this alteration of production processes. It will also examine the effects of weather changes in the potential for energy conservation.

In the latter part of the chapter, the farm model will be subjected to a number of energy rationing schemes so as to compare rationing with price increases as a means of energy curtailment. There will also be a comparison of a rationing system which restricts total energy use to one which regulates each source individually.

This study is concerned with the direction of long term investment of a typical Iowa farm in addition to short term changes in production methods. It has been assumed, therefore, that the operator is not committed to any particular set of past investments in either farm machinery or corn drying equipment. Changes in energy prices may make one method superior to one which was the most economical under another set of price assumptions. This will cause the operator to alter his investment in capital equipment without any "penalty" for abandoning old equipment.

Price Increases Effects with Average Weather

The impacts of the various energy price scenarios on the farm model are summarized in Table 4.1. According to that table, energy use, incomes and the methods of production were all altered considerably as energy costs increased.

Corn production

The first category of note in Table 4.1 is the amount of corn raised at each moisture level. Corn with a higher moisture content was harvested earlier and thus the field losses were less than if it remained in the field longer. At present energy prices, the field loss is more important an expense than the cost of artificial drying. As a consequence, 18492 bushels of the total 23332 bushels produced were harvested early at 28 percent moisture level. In scenario four, L.P. gas increased tenfold in price and it became more economical to incur the field loss and allow the corn to dry naturally in the field. Note for that scenario, the field losses associated with later harvesting reduce the crop from the 23332 bushels mentioned above to 20935. By letting the corn remain in the field, all of it dries naturally to 18 percent. The other scenarios illustrate less extreme reactions to L.P. gas price increases which are less than those of scenario four. In each scenario, the higher the price of energy, the greater the

Table 4.1. Comparison of the effects on the model of different energy price scenarios[a]

	Present	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Farm net income ($)	12794	9896	6326	-4048	-13259	-7043
Income if no input cost increases ($)	12794	12380	12376	10384	8593	9379
Income if no substitution ($)	12794	9895	6141	-6021	-19987	-9823
Decrease in production (%)	-	3.2	3.3	18.8	32.8	26.7
Increase in expenditures (%)	-	3.2	8.1	19.5	28.8	22.1
On-farm energy[c] consumption	655	623	615	414	373	407
Off-farm energy[c] consumption	1371	1385	1271	1263	1147	1149
Bushels of corn raised at the following moisture levels:						
28% moisture	18492	12494	12494			
22% moisture	3563	7840	7840	7833		7839
18% moisture	1277	2878	2878	14292	20935	13482
Total Bushels	23332	23210	23210	22636	20935	21321

[a]Average weather conditions are assumed.

[b]This is the percent decline of "income if no input cost increases" from present prices to the scenario in question.

[c]In millions of BTU's.

Table 4.1 (Continued)

	Present	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Tillage Systems: Penalties ($/A.)						
Conventional:						
Fall	9.81	11.34	12.94	16.26	37.39	16.26
Spring	20.54	20.37	20.17	21.04	25.22	21.05
Till Plant	-	-	-	-	-	-
Offset Disk	15.94	16.25	16.60	18.49	21.27	18.49
Chisel Plow	23.04	21.29	23.54	25.18	29.07	25.18
No Till	33.96	33.76	33.60	32.13	30.73	32.30
Fertilization (lb./acre)	160	160	140	140	120	120
Manure used (tons)	2187	2187	2187	3187	2187	2187
Bushels of corn dried with the initial moisture level of:						
28%	18.508	12493	11983			
22%	892	7840	7840	7840		7840
18%	-	-	-	14185	20935	13109
Penalties associated with individual drying systems:[d]						
Continuous Flow	.026	.024	.0225	.0127	.071	.0127
Batch bin	-	-	-	-	-	-
Low Temperature	.0245	.0509	.080	.138	.130	.138

[d]The additional cost (in dollars per bushel) of employing that drying system in reducing corn moisture content from 24 to 15 per cent.

Table 4.1 (Continued)

	Present	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Penalties associated with individual drying systems: (continued)						
Solar	.0242	.0240	.049	.102	.100	.102
Cost of drying 24%	.015	.161	.187	.334	.480	.334
Fixed Cost:						
Machinery	15677	15976 (1.9)	16337 (4.2)	17792 (13.5)	17790 (13.5)	17790 (13.5)
Cont. flow	2730					
Batch bin	1983					
Low temperature	6861					
Solar	7206					

tendency to harvest later so as to allow the corn to dry naturally.

Tillage systems

The relative economic desirability of different tillage systems can be ascertained from Table 4.1. For each scenario, Table 4.1 lists the extra cost, or income penalty, which would be incurred from forcing in one acre of a particular tillage system. The higher the cost, the more uneconomical that tillage system is. For all scenarios, the till plant system is the most efficient and has a penalty of zero. This was to be anticipated from the fact that this system uses less gasoline, less field time and less soil loss than any other. Its average yield is 138 bushels per acre which is second to the yield from conventional tillage, 141 bushels. Even at present gasoline prices, the savings in fuel offset the loss in yield with respect to conventional tillage. In Table 4.1, conventional tillage is listed as costing $9.81 per acre more even though it yields more corn. As energy prices increased, conventional tillage became progressively more expensive with respect to till plant. When gasoline prices are increased ten-fold, in scenario four, the cost of conventional tillage increases to $37.39 per acre. In comparison with all other systems in scenario four, it is the least economical. At present prices, it was the most economical next to till plant.

The other four systems do not change their positions relative to each other in any of the price scenarios. No till has the highest cost of the four, chisel plow the second highest, and conventional spring plow the third. Offset has the least cost of the four but is inferior to conventional fall plow except when gasoline prices are increased ten fold.

The income penalties are quite substantial. In relation to corn priced at $2,40 per bushel, they represent yield penalties of five to fifteen bushels per acre. As a consequence, till plant would remain superior to most systems even if relative yields were to vary within reasonable limits.

Level of fertilization

The level of fertilizer applied for each scenario is illustrated in Table 4.1. In scenario five, natural gas prices are increased ten-fold and fertilizer prices rise from $.122/lb. to $.419/lb. Increased L.P. gas costs reduce the value of the corn which results from applying more fertilizer. These two effects cause the rate of fertilizer application to decline from 160 to 120 pounds per acre. Note that the model permitted alterations in fertilizer levels only within 20 pound increments and that these increments may be smaller for an actual Iowa farmer.

It is feasible to spread manure under all price scenarios as it remains competitive with artificial fertilizer as a source of nitrogen.

On-farm drying

The corn dried category of Table 4.1 specifies the amount of corn at each moisture level which was dried artificially on the farm. The difference between the amount raised and that dried on the farm is the amount dried at the local elevator. Drying at the elevator is less expensive than on the farm, but there is a time constraint. In central Iowa, hauling two 150 bushel wagons of corn to the elevator, waiting in the queue and returning takes about three hours. During periods when there is not much field time to perform harvest operations, it proves to be more economical to dry corn on the farm.

Under present energy prices, the operator farm-dries all corn harvested in the early autumn at 28 percent. In the early autumn, the field losses tend to increase rather rapidly with respect to the time which corn is left in the field. It is important to spend the time available combining the corn rather than taking it to the elevator. Later in the autumn, the field losses do not increase so precipitously and so there is a reduced incentive to harvest as early as possible. This reduces the value of field time and it is possible to take more corn to be dried at the elevator. According to Table 4.1, only 892 of the 3563 bushels harvested later at 22 percent were dried on the farm. All of the corn harvested still later at 18 percent was taken to the elevator.

As energy prices increase, it becomes more economical to harvest the corn when it has dried longer in the fields. If harvest is confined to the latter part of autumn, then field time becomes more critical. There is less opportunity to take corn to the elevator and more corn must be dried on the farm. The overall energy use in drying on the farm still declines as the corn is at 18 percent rather than 28 percent moisture, and there is less harvested.

Drying system

Table 4.1 lists the extra cost per bushel if the operator had used a drying system which differed from the most economic one. Batch bin proved to be the most efficient for all energy price scenarios, and thus had a zero "extra cost". Although batch bin does use L.P. gas which increases ten-fold in price in scenario four, it is still more efficient than low temperature systems, as the latter require substantially more energy in their manufacture than batch bin. Five-fold increases in these manufacturing costs offset the tenfold increases in L.P. gas. The fact that low temperature systems would be less economical than batch bin, even at high energy prices, was predicted in Chapter III.

In that chapter, it was noted that much of the costs associated with corn drying are the fixed costs associated with equipment used. They are measured in terms of annual depreciation per bushel of corn dried. A low temperature system has an electric heater and fan "package" in every storage bin. The more corn harvested, the more bins must be constructed; hence, the greater the number of drying equipment "packages" which must be purchased. As the ratio of corn harvested to drying equipment remains fairly constant, the fixed cost of the low temperature system does not vary with the amount harvested. Low temperature has constant returns to scale. The batch bin and continuous flow require a larger capital outlay for heaters, fans, stirring devices, augers, etc. than is incurred in installing low temperatures in one or two bins. The batch bin system, however, has a much greater capacity. It has significantly increasing returns to scale which can be realized when the crop is in the order of 23,500 bushels. If the study was done on a much smaller farm, it is possible that these economies to scale of batch bin drying would not have been realized. In such a farm, low temperature may have proven to be the most economical. As it would have a lower value of fixed equipment per bushel dried, low temperature would have less embodied energy in the manufacture of its equipment per bushel. As energy prices increased, it is conceivable that the cost of low temperature drying would have decreased relative to batch bin or continuous flow.

There may be some advantage in low temperature drying for a farm which produces less than the average amount of corn. As the average farm in central Iowa produced an average of 15,500 bushels from 1970 to 1975, it is unlikely that the majority of farms in this region would consider low temperature as a viable drying method (19, p. 7). The actual cost of the L.P. gas will probably not affect that conclusion. In this model, even a ten-fold increase in that fuel did not change the cost of low temperature drying relative to that of batch bin. It appears that only problems in procurement of L.P. gas could reverse that relative cost relationship.

Energy utilization

Energy utilization depicted in Table 4.1 is divided into on-farm and off-farm. The former is the number of millions of BTU's used on the farm in the form of gasoline, electricity and L.P. gas. Note that on-farm energy is affected significantly by price increases. At present prices, 654.5 million BTU's are utilized. When gasoline and L.P. gas are increased ten-fold in price in scenario four, the consumption declines to 373 million. As tillage systems do not change, there is no change in gasoline consumption. The primary effect of energy prices on on-farm consumption is through the reduction of L.P. gas used in drying corn. As L.P. gas costs increase, the corn was harvested later so as to dry naturally in the fields. This reduced the amount of energy used per bushel in artificial drying. Also, increased field losses reduced the total number of bushels which had to be dried.

Off-Farm energy consumption is the total amount of energy embodied in all agricultural inputs. This includes the amount of energy required to manufacture machinery and equipment multiplied by the appropriate rate for depreciation. The latter is a very substantial proportion of the off-farm component of energy consumption, and it does not vary. As a consequence, the off-farm energy is reduced only 17 percent even when energy prices are increased ten-fold, as in scenarios four and five. The reduction which does take place in energy consumption is caused only by the reduced use of fertilizer.

These observations on the farm model give rise to an interesting hypothesis. Any policies which give preference to supplying farms with on-farm energy, but do not give similar consideration to manufacturers of agricultural inputs may not reduce farm expenses significantly. A farm of the type under analysis may be able to vary on-farm consumption considerably. It must maintain a certain complement of machinery and equipment, however. If manufacturers of such machinery have difficulty keeping prices down in the light of rising costs, the effects on the farmer could be more severe than if the effect was primarily on on-farm energy. In Chapter II, it is revealed that on-farm energy use represents only 3.3 percent of total farm expenses while machinery and chemicals are 14.0 and 13.0 percent respectively. It is logical that the farm's income position will be more effected by the latter two expenses.

It has been demonstrated that the demand for chemicals is relatively inelastic. Anhydrous ammonia increased almost four times in price from

$.122 per pound to $.419 per pound. The quantity of nitrogen applied decreased 25 percent from 160 to 120 pounds per acre. This represented a relatively inelastic demand for fertilizer within the price range in question. This inelasticity had already been predicted in the previous chapter from discussion of the fertilizer response function. It implies that the possibility of a farmer conserving off farm energy through fertilizer use reduction is not very great.

The elasticity of demand for machinery is difficult to predict in a model of this nature because the size of the machinery complement is not determined by a well-defined production function like that for fertilizer. A farm operator should select the machinery complement which represents the optimal balance between cost reduction and the desire to avoid risk. The larger the equipment, the less the risk that an operator will not be able to complete field operations. The larger equipment represents a higher degree of embodied energy and a higher depreciation expense as energy costs increase. Energy price increases thus increase the effective cost of risk aversion.

The farm model under consideration was assumed to have purchased the equipment which was best suited to the amount of land which is to be farmed. The most relevant savings through reducing the use of energy intensive inputs appears to be in on-farm energy consumption such as that required for crop drying. Any significant savings through reducing machinery and equipment is not possible.

Energy substitution in production processes

It was not possible to predict what effect energy price increases would have on the price of commodities the farm sells. As a consequence, they were left at their 1976 levels. This facilitated a better comparison between price scenarios although it may not be a very realistic assumption. According to Table 4.1, constant commodity prices made it such that income declined with rising energy prices. The decline was caused by a reduction in output and increased costs. Corn production declined due to reduced fertilizer use and greater field losses. This caused an income loss distinct from that caused by increased expenses. This loss gives an estimate of the degree to which substitution of agricultural processes can take place on the farm. In Table 4.1, is listed the "income if no input costs increases". This income is the sum of net income in a particular scenario and the extra cost of inputs caused due to energy price increases. If there is no alteration in farm processes, the output will be the same. When the extra cost of inputs is added to that figure, the result will be the same net income as was realized without energy price increases. The greater the degree of alteration of processes, the greater will be the difference between net income and net income exclusive of input cost increases.

Note in Table 4.1 that the decline in net income is accounted for primarily through input cost increases. Between present prices and scenario four, there is a 204 percent decline in income from $12,794 to minus $13,259. The decline in income due to substitution of processes is only 32 percent, from $12,794 to $8,593. The increase in expenditures listed in that table is 28.8 percent. For scenarios one, three and five, the decrease in output represented by net income exclusive of cost increases, is also comparable to the increase in expenditures. In scenario two, there is a substantial deviation from this trend. Expenditures increase 8.1 percent from the present, but the value of production declines only 3.27 percent. This confirms the hypothesis advanced in Chapter I that the degree of factor substitution would vary for different levels of output and input usage. In scenario two, even though energy price increases caused expenditures to increase by $3500 above scenario one, there was no change in output. In scenario three, expenses increased 19.5 percent from the present and production started to decline again.

A second method of estimating the amount of substitution of processes is through not permitting cropping or drying activities to be altered and observe the change in income which results from increased energy costs. If there was no substitution, there would be no difference between that income and the net income which resulted when the processes were free to vary. The greater the difference, the greater was the ability of the farm model to reduce the effects of increased costs. The "income if no substitution" is depicted in Table 4.1. For scenarios one and two, alteration in practices was not significant and there is little difference between the two. Scenarios three, four and five caused a very great change in production processes when the processes could be varied. When they were bound to old practices, the total income losses which would be incurred averaged 12 percent higher than when alteration was permitted. In scenario three, for instance, income decline from $12,794 to -$4,048 when alteration in processes was permitted. The total loss was $16,842. If the operator had not altered production processes from those used at present energy prices, the income would have declined $18,815 to $-6,021. Similar calculations reveal that in scenario four and five, substitution reduced income loss by 20.5 and 12.4 percent respectively.

Using this difference in income, it is possible to again compare the response of production processes to cost increases. In scenario two, expenditures had increased 8.1 percent but there was little change in production practices from what was followed under present energy prices. When expenses increased to 19.5 percent higher than the present level, enough changes in practices were made to reduce the net farm loss by 11.2 percent. Scenarios four and five had higher expenditures than that, and the degree of alteration in production practices was also greater.

Conclusions

In conclusion, net farm income is reduced significantly by energy price increases so long as output commodity prices remain constant. Some of this loss is avoided through substitution of methods which involve less energy expenditure. The actual amount of substitution varies depending on the increase in energy price. For moderate cost increases, there is little significant alteration. After energy price increases attain a certain level, there is a significant alteration in the quantity and method of corn production.

Effects of Weather Variation

The results in Table 4.1 were those which assumed that an average number of field days would be available for harvesting and planting. This assumption is valid for estimating the long run effects of energy price increases on farm production. It is useful when formulating decisions concerning investment in machinery and equipment.

In any particular year in central Iowa, the weather may vary considerably from the average. During relatively wet years, there will be less time for both planting and harvest as it will rain more frequently. In a wet autumn there will be less natural drying of corn. Corn which is harvested on a particular date will have a higher moisture content than that harvested on the same day of a drier year. This will reduce the ability of the farmer to economize by allowing corn to dry naturally in the fields. The result will be a reduced ability to mitigate the impact of higher L.P. gas prices through less reliance on artificial drying.

Table 4.2 illustrates the effects of different weather conditions on corn production at present energy prices. As explained in Chapter III, field day restrictions were imposed on the model which reflected weather conditions which actually prevailed in 1960, 1964, 1968 and 1972. The results of such restrictions were compared with what had prevailed under average weather.

1972 had the least number of field days of any year between 1958 and 1974. The change of the weather conditions to those which prevailed in 1972 did not affect dates of either planting or harvest. As a consequence, there was no alteration in the quantity of corn produced. This implies that the machinery in this model is sufficient to ensure that no inclement weather conditions will effect the capacity of the farm to produce. The only thing which was altered was the moisture content of the corn harvested. Under average weather conditions, most of it was harvested at 28 percent. Under 1972 conditions, that figure was 30 percent.

Extra L.P. gas was required to dry the corn and thus income declined from $12,794 to $12,531. So long as L.P. gas prices were close to present levels, the effects of 1972 weather were not very significant.

The effects of these weather conditions appear to be more serious when energy prices are higher. Much of the farm's ability to mitigate the negative effects of energy price increases is through drying corn

Table 4.2. Effects of different weather conditions on the model[a]

	Average Weather	Weather Conditions of:			
		1960[b]	1964[c]	1968[d]	1972[e]
Income ($)	12,794	13,396	13,317	12,762	12,531
On-farm BTU	654	582	566	657	715
Bushels of corn raised with the following moisture content:					
30%					15,097
28%	18,492			3,025	315
24%					7,685
22%	3,563	4,875	152	17,663	230
20%		11,960	16,366		
18%	1,276.5	6,528	6,841	2,573	
Total bushels	23,331	23,363	23,359	23,262	23,327
Tillage penalties per acre: ($)					
Conventional -					
Fall	2.4				
Spring	20.5	27.9	29.9	22.4	22.4
Till plant	0.0	0.0	0.0	0.0	0.0
Offset disk	15.9	23.0	21.4	16.0	16.0

[a]Normal energy prices are assumed.

[b]Much fewer than usual field days in spring and more than average in autumn.

[c]Most field days in both spring and autumn for the period 1958 to 1974.

[d]More than average field days in spring and much fewer than usual in autumn.

[e]Least number of field days for both spring and autumn for the period 1958 to 1974.

Table 4.2 (Continued)

	Average Weather	Weather Conditions of:			
		1960[b]	1964[c]	1968[d]	1972[e]
Tillage penalties per acre: (Continued)					
Chisel Plow	23.04	29.8	27.9	23.0	23.0
No Till	33.96	41.1	39.4	34.0	34.0
Bushels of corn dried which were originally at the following moisture levels:					
30%					15,428
28%				17,696	
24%					7,850
22%		4,838		2,718	69
20%		12,220	15,524		
18%		1,072	2,095		
Variable Cost of Drying				.075	.14
Energy in drying:					
Electricity		3.98	3.5	9.1	11.62
L.P. gas		98.5	84	249.4	303.51

naturally. In Table 4.3 is illustrated the results of these poorer weather conditions on price scenarios two and four.

With average weather, and scenario two prices, most corn was harvested at 28 percent moisture. With 1972 weather, 6900 bushels were harvested at 30 percent and the rest remained in the field to dry to 22 or 24 percent. The result of the later harvest was a reduction in the quantity produced from 23210 bushels to 23133. The extra expense of drying corn at 30 percent moisture increased on farm energy use from 614.6 million BTU's to 641 million. The net effect of this was to cause income to decline $4,000.

The 1972 weather conditions caused income to decline by almost twice that amount under scenario four prices. Weather had a very substantial effect on corn production under scenario four. Under average weather, it was possible to defer harvest until October and harvest corn at a moisture content of 18 percent. 1972 conditions were such that there were inadequate field days later in the autumn. This forced the operator to harvest at moisture levels far above 18 percent. Although production increased, expenses in drying rose very significantly. On-farm energy increased from 373 million BTU's to 593 million. The essential feature of reduced field days is the amount which it reduces the farm's ability to conserve energy. Note that, under average weather conditions, a price increase from "present" to "scenario four" could be accommodated by a 43 percent reduction in on-farm energy use. According to Table 4.3, the latter fell from 655 to

Table 4.3. Effects of very poor weather conditions on the alteration caused by energy price increases

	Present Prices		Scenario 2		Scenario 4	
	Average Weather	1972 Weather	Average Weather	1972 Weather	Average Weather	1972 Weather
Income ($)	12,794	12,531	9,896	5,844	-13,259	-20,615
On-farm energy[a]	654.5	715	614.6	641.9	373	593.2
Off-farm energy[a]	1,371		1,259	1,259	1,133	1,109
Bushels of corn raised at the following moisture content levels:						
30%		15,097		6,902		1,701
28%	18,492	315	12,494			
26%						
24%		7,685		7,849		7,849
22%	3,563	230	7,848	8,382		8,315
20%						4,364
18%	1,277		2,878		20,935	
Total (bu.)	23,332	23,327	23,210	23,133	20,935	22,229
Fertilizer (lb/acre)	160	160	140	140	120	118.5

[a]In millions of BTU.

373 million BTU's. Under 1972 weather, the on-farm energy use could be reduced only 17 percent when scenario four prices were imposed. The difference in on-farm energy is between 715 million BTU's and 592 million.

As a consequence, it may be concluded that the demand for energy is more inelastic during years of inclement weather, due to a greater necessity to dry corn artificially.

Conclusions

The five price scenarios for energy do have substantial impacts on the farm model. Farm income is reduced in scenario four from $12,794 to minus $13,259, a difference of $26,000. In that scenario, on-farm energy is decreased 42 percent from 655 to 373 million BTU's. Off-farm energy does not experience such drastic reductions. Price increases cause a significant alteration in timing of field operations and some changes in fertilization levels. They do not effect tillage or drying methods used on the farm, nor consumption of energy embodied in farm machinery. This does not infer that present farming operations could not realize significant energy savings in these areas. As will be discussed in Chapter V, there are substantial energy savings possible through proper selection and maintenance of farm machinery, adoption of minimum tillage and other techniques. In the context of the farm model under consideration, there appeared to be little savings possible as the farmer was assumed to have attained maximum efficiency at present energy prices. Increasing these prices within the range under consideration did not cause the tillage or drying methods to be altered.

Weather conditions in a particular year may have an effect on the ability of a farm operator to conserve energy. During wet years, the corn cannot be dried as effectively in the fields and thus it is necessary to use artificial drying. This reduces the ability of the operator to substitute energy savings for gains from earlier harvest. As a consequence, the substitutionality decreases.

The degree of substitution possible will change depending on what amount of energy is being used. A specific increase in energy prices may not effect energy consumption to the same degree if the processes employed already use little energy. From Table 4.1 it was pointed out that an 8.1 percent increase in expenditures in scenario two caused only a 3.3 percent decline in output. By contrast a 19.5 percent increase in costs in scenario three precipitated an almost equal decline in output of 18.8 percent. In the case of scenario two, there was less substitution than in scenario three. This alteration in substitution at different levels of energy utilization was predicted earlier in Figure 1.3. This change in substitutionality may be attributed both to the nature of the processes under consideration and the discontinuities inherent with a linear programming model.

The model does demonstrate an ability of the farm operator to reduce energy consumption as energy prices increase. Despite the fact that expenditures are reduced below the level which they would be if there was no substitution, the farm income will decline significantly.

It is possible that commodity prices increase to negate the deleterious effects of increased costs. Predicting such price increases would be very difficult. Alternatively, the government might implement a system of rationing which would decrease energy consumption, but not increase input costs. The impacts of that eventuality on the farm model may be studied within the framework of this analysis. They will be described in the next section.

Rationing

The income loss experienced due to rising energy prices is substantial. Scenario four prices, for instance cause income to decline from $12,794 to minus $13,259. It would be impossible for the farm to sustain such a loss for very long. If these declines in income were experienced by the entire agricultural sector, governmental action would probably be necessary. One alternative is to prohibit further price increases and reduce the difference between supply and demand through rationing.

Let us assume that each energy source is rationed to the level it was consumed at under different price scenarios. The farm will substitute less energy intensive processes for more energy intensive ones in the same manner as it did when price increases cause it to reduce energy inputs. The production processes of each price scenario represented the most efficient use of a particular quantity of a certain energy source. Under the rationing scheme, the operator will adjust production processes in exactly the same way. The theoretical basis for this argument is found in Chapter I. The "cost" of a particular source is composed of its price Pe plus an opportunity costs due to rationing, α. That imputed cost will be equal to the price of an input under energy price increases. The organization of farm production will be the same if the cost is the actual price or the imputed one. These changes will reduce output by the same amount regardless of the actual system which the farm faces.

The major advantage to the farmer of a rationing system is the fact that all inputs are priced at the same level as they are at present. The income which would be realized is that depicted in Table 4.1 under "income if no price effects". This income figure was calculated from the computer output separately. The gross income is that which is realized from the level of production which could have occurred if the energy price scenario was in effect. This ensures that the rationing system uses the same amount of energy as would have occurred with its associated energy price scenario. The chief difference is the fact that inputs are costed at the present prices; thus, expenditures do not increase. The actual reduction in income due to alterations in production is significantly smaller than that caused by increased expenses. Note in Table 4.1 that income declined (\$12,794 - \$-13,259)) = \$26,000 between present prices and those of scenario four. Income with no price effects declined only (\$12,794 - \$8,593) = \$4,200. The increase in expenditures was therefore (\$26,000 - \$4,200) = \$21,800. The increase in expenditures has the most significant effect on income. As rationing reduces that increase, it may prove to be one of the actions considered by the government to reduce the effects of general energy shortages on such a farm.

Rationing does have the potential for causing the same amount of energy conservation as would occur if energy prices found their natural level. This is true so long as the rationing system curtails the use of each energy source to the amount it was curtailed under an energy price increase. It is anticipated that any rationing scheme devised by the government would not curtail energy use to precisely those amounts. Let us assume that it would restrict energy consumption to 90 or 80 percent of present levels. Let us also assume that the rationing system only effects electricity, gasoline and L.P. gas used on the farm and the fossil fuels used in fertilizer production. It would be impractical within this model to portray a rationing of energy embodied in machinery and equipment.

Table 4.4 depicts the results of rationing each of these four energy sources by specified percentages. The "marginal value" of a particular energy source corresponds to the variables α and β of Equation (1-10). They represent the marginal value to income of allowing one more unit of that source of energy to be used. Gasoline has a high marginal value because reduction in its use reduces the ability to perform tillage and harvesting operations. L.P. gas curtailment is not as serious because corn can be dried naturally in the field. As a consequence, the marginal cost of gasoline rationing is not equal to the marginal cost of rationing L.P.

The optimal system of rationing would reduce each source such that the marginal costs of curtailing each source are equal. This would

Table 4.4. Effects of rationing of each individual source to a percentage of normal consumption

	No ration	Percent Curtailment		
		90%	80%	50%
Income ($)	12,794	11,913	10,764	-10,286
On-farm consumption:				
Gasoline (gal.)	3,231	2,907	2,584	1,615
L.P. gas (gal.)	2,677	2,409	2,141	1,338
Electricity (kwh.)	2,624	2,302	2,091	1,437
Total on-farm energy[a]	682.7	614.4	546	341
Value ($), of an extra gallon of:				
Gasoline	.44	1.46	1.46	20.80
L.P. gas	.31	.387	.608	0.598
Off-farm energy consumption:				
Natural gas[a]	653	587.5	522.2	326.4
Marginal value of natural gas ($)	-	3.28	10.96	10.21
Corn raised (bu)	23,332	22,870	22,266	18,749
Beans raised (bu)	4,180	4,180	4,180	815

[a]In millions of BTU's.

be possible if a system would be devised which restricted just the total energy consumed. The operator could choose what sources should be curtailed. In reality, such a scheme could not be implemented. It is still worthy of consideration as a guideline as to what sources of energy could be curtailed in times of rationing for a particular geographic area. It was noted above that a forced curtailment of a BTU of gasoline is more costly to the farm than one of L.P. gas. It would be preferable from the standpoint of the farm to minimize restrictions on gasoline. The actual ratio of gasoline curtailment to L.P. gas which would be optimal cannot be obtained from Table 4.4. It will be necessary to place a restriction on total energy use and observe the voluntary reductions of L.P. gas relative to gasoline.

In Table 4.5 are the results from rationing total BTU input to 90 and 80 percent of previous levels. Gasoline use was reduced by less than one percent, as field operations remained essentially the same. Virtually all the reduction in energy use was by reducing L.P. gas required in drying. The corn was harvested at a later date so that its moisture content was reduced. The later harvest, and reduced fertilization levels due to natural gas rationing, reduced the total corn produced. Income fell by $500 with a 90 percent rationing system and by a further $1000 at 80 percent. The source by source rationing scheme caused income declines of $800 for 90 percent rationing and $1200 for 80 percent.

There is an economic advantage to curtailing each energy source

Table 4.5. Effects of a rationing of total energy consumption regardless of source[a]

	No Rationing	Percent Curtailment 90%	80%	50%	No rationing but L.P. gas unavailable
Income ($)	12,761	12,289	11,292	3,824	7,775.2
On-farm energy consumption:[b]					
Gasoline[b]	397.5	395.0	392.0	290.3	394.0
L.P. gas[b]	275.2	210.5	147.3	48.0	-
Electricity[b]	10.02	7.52	5.82	1.7	100.8
Total energy[b]	628.7	613.02	543.62	341.0	494.8
Marginal value of on-farm energy	-	6.41	8.69	131.7	0.0
Off-farm energy[b] consumption:	1,377.5	1,295	1,213	961	1,416
L.P. gas[b]	652.8	587.5	522.2	326	0.0
Value of gas[c]	1.125	3.30	11.3	6.21	5.55
MVP of land ($/acre)	218	187	145.6	0.0	184
Land in corn (acres)	170	170	170	159	170
Fertilization (lb/acre)	160	145.6	151.3	80	160
Manure (tons)	2,187	2,187	2,187	0.0	2,187

[a]Drying corn at the local elevator is not permitted.

[b]In millions of BTU's.

[c]In dollars per 1000 BTU's.

Table 4.5 (Continued)

	No Rationing	90%	80%	50%	No rationing but L.P. gas unavailable
Bushels of corn raised at the following moisture content:					
28%	18508				
26%		13794	6380		
24%					
22%	4880		7782	7542	7840
20%					
18%	____	1242	8104	18168	14770
Total bushels	23388	22818	22026	18168	22610
Tillage Penalties:					
Conventional: Fall					
Spring	22.24	25.75	27.00	102.0	14.50
Till Plant	-	-	-	-	-
Offset Disk	15.95	16.77	17.10	37.50	14.60
Chisel Plow	23.03	24.10	24.60	52.00	8.20
No Till	33.97	32.93	32.80	19.80	30.41

Table 4.5 (Continued)

	No Rationing	90%	80%	50%	No rationing but L.P. gas unavailable
Drying System:					
Penalties associated with individual drying systems:[c]					
Continuous flow	.026	.018	.016	.40	-
Batch bin	-	-	-	-	-
Low temp.	.0245	.29	.29	.92	-
Solar	.0242	.266	.263	.66	-
Value of L.P. gas	-	-	-	-	5.55

[c]The additional cost (in dollars per bushel) of employing that drying system in reducing corn moisture content from 24 percent to 15 percent.

according to its marginal product. In this example, the same total amount of energy could be reduced at about sixty percent of the cost if the rationing system placed more emphasis on L.P. gas curtailment. It is recognized that society as a whole may not benefit from such a system. If the marginal product of gasoline is higher in the economy as a whole, then all sectors will request that they experience less rationing of that source. This paper intends only to analyze the effects of alternative rationing systems on an Iowa farm. It is hoped that the observations made above will give some appreciation as to what system will most benefit such an operation.

CHAPTER V. SUMMARY AND CONCLUSIONS

The objective of the study was to ascertain what technologies would be employed in corn production by a central Iowa farm if energy prices were increased. It was necessary to ascertain what methods would be used in the short run to maximize net profits if energy prices increased. It was also necessary to ascertain what types of equipment would be purchased in the long run to replace existing equipment. In consideration of the latter objective, it was decided to formulate the program such that the farm operator could abandon one set of equipment and adopt another, without incurring any opportunity cost. The only fixed cost *per se* was in the annual depreciation of whatever equipment was required for the most economically optimal methods used in corn production.

The Farm Model

The farm model was set in a linear programming framework. It was composed of 223 variables and 111 restraints. It was formulated so as to afford the operator the maximum number of options possible in corn production given existing data. There were 23 different combinations of times when planting and harvest could take place. For each of these combinations, the corn was a specific moisture content and a specific field loss was incurred. Plowing could be done in either the spring or the autumn. In addition to conventional tillage it was possible to utilize any of four different minimum tillage practices. For each tillage method, cognizance was taken of the specific yields and pesticide requirements needed. There were four alternative drying systems which could be employed. Some employed L.P. gas, others electricity and another incorporated solar energy. The program selected the optimal drying system for a particular value of energy prices. Account was taken of energy price increases on both the fuels used directly in corn drying and in the increased costs of corn drying equipment due to altered energy prices. A separate subprogram was incorporated into the model to calculate the optimal level of fertilization for each energy price. As energy prices increased the costs of fertilizer production, the optimal level of fertilization changed. The actual response function for fertilizer was a linear approximation of the actual observed function.

For each of the options available to the operator, account was made of the energy from each energy source which was used. Account was taken of all energy required to manufacture machinery and chemicals, in addition to the energy which was used on the farm itself. As the price of energy increases, the costs of all inputs increase according to the relative intensity of energy which is required in their manufacture. These cost increases will cause corn production methods with relatively high energy inputs to incur greater costs. If the operator can abandon such methods, he will be able to obviate a rise in expenditures. If the amount of substitution is low, then he will have to bear the higher costs.

In this model, the price realized for corn was maintained at its

1976 level, and energy prices were altered according to five scenarios. The results of the computer output were analyzed to ascertain what degree of substitution of corn production processes can take place if energy prices increase relative to all others. The model was tested for the degree of substitution which could exist under different weather conditions. If there was more than average precipitation in a particular year, the field time was reduced and the moisture content of the corn was increased. Further tests were conducted on the model for the effects of rationing as opposed to the imposition of energy price increases.

The results of the analysis are described in the following sections.

Timing of operations

The greatest potential for conserving energy use on the farm is by harvesting corn later so as to allow it to dry naturally in the fields. This reduces the amount of energy required in artificial drying. During years in which there is above average precipitation, the ability of the operator to rely on natural drying is reduced considerably. This reduces the degree to which energy can be conserved. In the linear programming model, it is necessary to assume that the farmer is aware in advance as to how many days he will have available for harvest. If energy prices are high, he may then defer harvest until later. In reality, the weather is not known with certainty and there may be a greater tendency to harvest earlier to avoid the risk of not completing the harvest before winter. The program may have overestimated the degree to which on-farm energy may be conserved by permitting corn to dry naturally. It did identify that there is at least some potential in reducing the amount of artificial drying by accepting higher field losses inherent in harvesting later in the autumn.

Tillage

There was no change in tillage systems employed under any energy price scenarios. The till plant system proved to be superior not only in the small amount of energy it required for its associated yield, but also it reduced both the field time necessary, and the soil loss through erosion. Even at present energy prices the till plant system proved to be economically superior to conventional tillage.

One may question why till plant has not gained such wide acceptance in Iowa agriculture. Mention was made in the text of this thesis as to the problems inherent in interpreting results from a controlled experiment as being applicable for actual adoption. The experiment from which the data were derived demonstrated little variation in annual yields for any minimum tillage system. A farm operator may experience a slightly higher risk as he is less acquainted with minimum tillage than he is with conventional methods. Secondly, a farm in a particular area may be more subject to weed infestation and thus require more herbicide to offset the problems inherent with reducing the amount of tillage.

In the section on tillage, mention was made on the inefficiencies inherent in not properly matching the machinery of a farm to actual needs. Significant increases in horsepower of all Iowa farms has been justified by the desire to decrease the risk of paying field time penalties. This increases the amount of energy required for equipment manufacture and also increases the amount of fuel consumed. In the long run, this risk aversion action may prove economically infeasible as energy costs increase. In the short run, it would be advisable to gear up and throttle down to conserve fuel.

Further savings in energy may be realized by combining tillage operations and properly maintaining equipment. Diesel machines can reduce energy inputs by 25 percent. There has been a very substantial increase in the purchases of diesel equipment in Iowa in the last five years (24, p. 10). It is not known if the motivation behind this change is necessarily to conserve energy, or if there are other technical considerations involved.

Drying

The batch bin drying system is the most efficient for the scale of operations of this particular farm. It has lower overhead costs than any of the low temperature systems. Although batch bin uses more energy than low temperature, there is less embodied energy in the manufacture of the drying equipment. As energy prices are increased, the batch bin system remains more economical as the extra cost of energy used on the farm is offset by cost of energy required in the manufacture of drying equipment.

The model did not consider ear corn drying as a feasible alternative due to high losses. If fed to cattle on this farm, corn could be stored at high moisture contents or as silage. Deciding on whether the cattle on the farm were to be fed corn grain or corn silage would necessitate a study on cattle rations which is beyond the scope of the present analysis. As a consequence, silage was also not considered as an alternative to drying the grain. A final alternative for corn preservation is to add propionic acid to it after harvest. The energy required to produce the acid proved to be equal to that associated with L.P. gas in artificial drying. It was therefore not seen as a viable alternative.

Fertilization

Some energy savings in corn production are realized through a reduction in fertilizer applied. Due to the fact that this reduces the ultimate yield, the energy savings per bushel produced are probably quite low. The derived demand for fertilizer has a very low elasticity and it required significant increases in fertilizer prices (and associated natural gas prices) to reduce the amount of fertilizer applied. In all energy price scenarios under consideration, manure spreading proved to be economical.

Rationing

Rationing of energy sources had significant effects on corn production. The rationing of gasoline had a very high impact as it forced the curtailment of actual acreage in corn production. It would be more acceptable for a farm of this nature to experience a greater curtailment of the use of L.P. gas than gasoline. The latter has a very inelastic demand for the processes under consideration.

Policy Considerations

In March of 1977, the Secretary of Agriculture expressed concern over the ability of American agriculture to adapt to decreased energy supplies. Of particular concern appeared to be the reliance of agriculture on petroleum and petroleum based chemicals. This statement by the Secretary may portend the importance which energy will assume in the formulation of agricultural policy in the future. Policy makers should be concerned with the encouragement of research oriented towards the substitution of renewable energy sources for the nonrenewable ones used at present. They should also consider the extension efforts which will be necessary to inform farmers in the central Iowa region as to how they may adapt to changing energy prices.

This study has concentrated on a farm firm analysis so as to be of most use in extension policy. It has demonstrated that there is considerable potential for saving energy in a central Iowa farm with present technology. Savings can be realized in both on-farm and off-farm energy consumption through alterations in production techniques.

The study demonstrated that, with the data available, minimum tillage does prove to be economically superior to the tillage practices adopted by most farm operators at present. Conventional tillage practices require 10.2 gallons per acre for growing and harvesting corn, while till plant requires only 5.2 gallons. Till plant reduces soil loss in half. It is therefore possible to reduce both energy and soil waste by directing extension efforts to encourage the adoption of till plant tillage.

Extension may also wish to emphasize the merits of harvesting later in the autumn to dry corn naturally, rather than relying on L.P. gas drying. This model demonstrated considerable savings in the latter fuel from harvesting later. As L.P. gas prices increase, it may prove to be more economical to rely on natural drying, despite the risk of increased field losses.

It does not appear from this analysis that a farm operator of this type should be encouraged to convert to a less energy intensive drying system from those which dry corn at a higher temperature. Although low temperature systems consume less energy on the farm than high temperature ones, they have a significantly higher amount of energy per bushel drying capacity embodied in equipment manufacture. If it proved impossible to synthesize L.P. gas and if natural reserves of that fuel were nearly exhausted, then low temperature drying might be the only alternative. In such an eventuality, it would be advisable for those formulating agricultural policy to encourage investment in low temperature systems.

It should be noted that this model confined itself to an analysis of a single farm in a geographically restricted zone. If one should wish to derive predictions for the reaction of the corn belt as a whole to energy price increases, more work will have to be done on regions outside of that in question. It is hoped that this representative enterprise approach may prove to be useful for work in other areas. When all results from studies of these other geographic regions are available, it may be possible to infer what the reaction of the agricultural sector of the economy will be to certain increases in energy prices. This reaction will be necessary to predict when formulating policies which will effect agriculture as a whole.

Implications for Further Research

Future research in this area could concentrate on expanding the number of activities available to the operator and in improving the method employed in deriving the change in input and output prices with changing energy prices. It will prove necessary to incorporate agriculture into a dynamic interindustry study in order that much of this price analysis is properly conducted.

Increasing the number of options in crop production is dependent upon the development of alternative technologies in tillage and drying. As data are obtained for other tillage systems for either corn or soybeans, they may be incorporated into the model. Experiments in minimum tillage for soybean production are presently being conducted at Iowa State University and may be available in a few years. Corn drying may be reduced by the use of certain breeds of corn which mature early, or by storing it at a high moisture content for on-farm consumption by livestock. Previous mention has been made of the fact that corn harvested as silage requires no drying. It is possible to store corn grain at a high moisture content in air-tight silos provided that such corn is consumed immediately after removal from the silo.

Much of the future research should concentrate in energy conservation in livestock production as much of the data in that area are presently available. If higher drying costs make on-farm feeding more economical, there may be a relative economic advantage to raising livestock on the actual farms where corn is produced. Further research in less energy intensive rations should be conducted. There are a number of experiments being conducted presently at Iowa State University in the feeding of animal wastes and corn stover to cattle. More use of silage may prove to be preferable to corn grain as energy prices increase. In livestock production, there is further potential for reducing energy use by improvements in ventilation and in waste disposal systems. It is thus conceivable that the farm model itself could be continually expanded and improved so as to increase the total number of options available to a farm operator in conserving energy.

In addition to investigating other methods of agricultural production, a very substantial improvement in the model could be made through better predictions of the types of energy price increases which could occur and the effects such increases would have on the prices of inputs and outputs in the farm model.

The formulation of plausible energy price scenarios deserves greater attention than was afforded it in this model. This paper concentrated primarily on the extremes of energy price increases which would result from certain eventualities. A more intensive analysis of energy supply and demand schedules may yield results which prove to be more plausible. It would be preferable if a farm firm analysis of this nature could be integrated into a far more comprehensive study of state or national energy markets. In the work which was done, the only forms of energy considered are those which a farm could shift to in the short term. It is possible that in the longer term, there may be alternative sources of energy developed both on and off the farm.

There are a number of different on-farm technologies which are now in the process of development. There is potential for using solar and wind power in the generation of electricity, and as a source of heat for domestic use and for drying grain. Methane generated from livestock wastes may prove to be an economical form of on-farm energy as energy prices rise or shortages develop.

Off the farm, it may be possible to synthesize substitutes for fossil fuels used in primary agriculture. Methanol could be produced from normal plant material and used in lieu of gasoline. Due to a lower energy content of this fuel, present farm machinery may have to be altered to use methanol effectively. Petroleum and natural gas may be synthesized from coal or from other organic matter. This is technologically feasible at present although not economic at present petroleum prices. Substitutes for coal and natural gas in the generation of electricity are already in existence, although one, nuclear fission, does pose certain difficulties. It may be possible to solve such problems in nuclear fission in addition to developing nuclear fusion, geothermal energy, hydrothermal or wind energy as sources of electrical power. Perhaps it will be possible to develop forms of energy which are yet unknown for use, both on the farm, and in the production of agricultural inputs.

These technological options are available in the long term to both the agricultural sector and the economy as a whole. They increase the long term demand elasticity for fossil fuels and mitigate the increase in prices which will prevail in the long term as fossil fuel reserves are diminished. They tend to reduce the possibilities of energy price increases envisioned in scenarios three to five of this study.

A second improvement in the model would be in the estimation of long term input and output prices, given increases in energy costs. The price of the chief output, corn, was left constant in this analysis as it was considered to be impossible to estimate the effects of energy price increases on it. This was not to infer that the price of corn was of secondary importance. Most of this model estimated the trade-off between corn production and energy savings. If the price of corn had increased with energy prices, there would have been no inducement to allow corn to dry naturally in the fields as the associated field losses would have had a greater cost associated with them. Similarly, less reduction in fertilizer application would have occurred if the price of corn relative to that input had remained at its present level.

In this model, the price of corn was left constant because it was not possible to estimate the effects of energy price increases on the market for corn across the nation. If all farms in the country react in a similar manner as this farm does to energy price increases, then the production of corn will decrease. A decrease in production associated with increasing costs should shift the aggregate supply curve of corn to the left. If the demand schedule for corn is constant and inelastic, the price of that feedgrain would increase significantly with a decline in output. The demand curve might also shift to the left, however, negating the effects of decreased supply. Energy price increases will induce inflationary trends which may reduce real incomes of the population as a whole. As real incomes decline, the consumer demand for meat from corn fed livestock could also decline. As a result, it is not known as to whether the price of corn would increase or decrease during a period of increasing energy prices. It may prove to be necessary to conduct a long term econometric analysis of the nation's feedgrain industry to properly estimate this. Such an analysis would be done in conjunction with a comprehensive national study of the effects of energy price increases which, as mentioned earlier, any microeconomic study of this nature should be a part.

Certain improvements should be made to the estimation of the long term effects of energy price increases on costs of agricultural inputs. The model assumed that the costs of agricultural inputs would increase only by the amount that production costs were increased. This required the demand for agricultural inputs to be inelastic and energy price increases in actual processing to exert the only effects on production costs. It also required that there be no change in the technology which was employed in producing these inputs.

These assumptions may be valid in the short run, but over the longer term there may be significantly different responses to energy price increases than were described in the model. Energy price increase will increase overhead and equipment costs in the long run. They may also increase labor costs due to increased wage demands to offset rising prices of consumer goods. This may increase input prices even further. Mitigating this upward pressure on prices may be changes in the technology employed in producing these agricultural inputs. It is possible that in machinery manufacture, electricity or coal can be substituted for natural gas. If atmospheric nitrogen could be transformed into fertilizer without the extensive use of natural gas, dependence on the latter fuel would be reduced. In pesticide manufacture, the heat for steam used in the processing could be derived from coal rather than natural gas or fuel oil. There exists a great variety of other possibilities for manufacturers to reduce their dependence upon those fossil fuels which will continue to grow more scarce. They will reduce the upward shift of the supply curve for those inputs from what was envisioned in this short term model.

Even with a given upward shift in the supply curve, price increases may be mitigated for the input market as a whole if the demand proves to be more elastic. In the model, nitrogen fertilizer exhibited a relatively inelastic demand. Artificial fertilizer <u>per se</u>

might have a demand which is more elastic. If the price increases, there may be a greater tendency to apply it closer to planting time. This will obviate the necessity of applying extra fertilizer to allow for that which is leached, eroded, denitrified or lost in other ways. Better control of runoff would reduce the waste of fertilizer, other chemicals and soil which are lost at present due to poor soil management. The growing of vetch and rotating corn with legumous crops could supply nitrogen to the soil naturally, thus reducing the dependence on artificial fertilizer. If more livestock were raised on the farm where corn is grown, there would be more manure which could be used as an alternative source of nitrogen. Future biological developments may prove it possible for corn to be bred which has its own root nodules which fix nitrogen in a way similar for what is done with legumes.

The elasticity of demand for pesticides may also prove to be greater over the long term than this short term model illustrated. For all corn growing activities, little change was allowed in the pesticide use. It might prove feasible for the farmer, in conjunction with the rest of his community, to engage in an integrated pest management scheme. County-wide control of weeds may reduce the individual dependence on herbicides. The sterilization of male insects or the use of natural predators may reduce the insecticide use for the community at large. The individual farmer may achieve some degree of natural pest control through crop rotation and more intensive cultivation. Pesticide use may be reduced simply because of better knowledge of the tradeoff between the risk of insect or weed infestation and the cost of the chemicals. It may be possible that future research will develop pesticides which require less energy per acre of application. It is also possible to breed crops which exhibit resistance to predators, or which excrete their own form of natural insecticide.

Reference has already been made to the possibility of reducing the machinery input. It is not certain as to whether large machinery is more or less energy efficient on a per acre basis. Minimum tillage may reduce both the machine time and the power required. Improvements in the efficiency of individual machines through design changes may reduce the actual machinery required. This will serve to decrease the effective demand for machinery and mitigate some of the effects which energy price increases may have on the depreciation expense.

With the above options available to agriculture in the long run, the elasticity of demand for agricultural inputs may prove to be higher than the value implied by the model. The model had concerned itself with a short term input price change for a given increase in energy costs. In the short run, there will be few options available to the agricultural sector and their demand for inputs will be relatively inelastic. As a consequence, an upward shift in the supply curve due to energy price increases will cause the price of those inputs to increase by an amount similar to the increased marginal cost of producing those inputs. In the long run, substitution of these inputs will reduce their elasticity of demand and thus reduce the increase in their price.

Due to alternative production processes available to producers of agricultural inputs, their long run upward shift in the supply curve may not be as great as the energy price increases would imply the shifts should be. Alternatively, long run overhead cost increases may act to increase the unit costs of production beyond that which was implied by this short run model.

In conclusion, the increase in input prices may be effected in the longer term by a number of considerations not accounted for in this short term model. Changes in the elasticity of supply and demand will alter the input prices to be expected for given energy cost increases. More intensive research in both the marketing and production of agricultural inputs may be necessary to correctly estimate the long term effects on their prices of energy costs.

The free market prices for inputs and outputs may reflect the long term parameters within which a model of this nature should be studied. It still may prove useful for policy considerations to have estimates of the effects of a rationing system on such a farm. This study devised certain rationing schemes which were intended more as a general illustration of the effects of rationing rather than as a study of a proposed rationing scheme. It may be instructive to subject a model of this nature to programs which are both politically and administratively feasible. It should be recalled that rationing systems which effect off-farm energy use in the manufacture of inputs may have a more serious effect on agriculture than restrictions on on-farm energy consumption *per se*. A policy maker considering a rationing system should also take cognizance of the marginal benefit to be derived from allocating energy resources to other sectors of the economy. This will require an interindustry model, and one which is neither limited to an Iowa farm firm nor even to the agricultural sector as a whole.

The above considerations were intended as suggestions as to how it may be possible to increase the accuracy of estimating effects of energy shortages on an average farm in central Iowa. One must recognize that energy shortages could change the whole concept of what constitutes a central Iowa farm. If the effects of such shortages are exhibited in structural changes within agriculture, the farm model itself may have to be revised. Mention has been made of the possibility that it may be economically necessary to feed cattle on the same farm as corn is produced. This makes it possible to reduce corn drying by harvesting it as silage or stored as wet corn. It also supplies manure which can be used as a substitute for artificial fertilizer. If technological and structural changes do not significantly reduce the relatively high energy input into raising corn fed livestock, substitutes may be demanded for this form of protein. It was previously mentioned that possible reductions in real consumer income may result from energy resource depletion. This would have a depressing effect on the demand for the more expensive forms of protein which often are the most energy intensive. It may be possible that advancements in processing vegetable protein may further decrease the competitiveness of corn fed livestock as a source of human protein. In such an eventuality, the economic viability of a central Iowa farm concentrating in feed-grain and livestock production may be seriously questioned. The resources of such a farm may be better utilized in producing crops for direct human consumption.

There may be other effects on the production activities of Iowa farms. If energy costs have a significant impact on transportation expenses, it may be necessary for agriculture to restructure itself so as to locate production closer to the market. Iowa may replace the southern states and Mexico in supplying certain foodstuffs to the industrial centers bordering on the Great Lakes.

Energy resource depletion may not only effect the model in the types of crops produced, but also in the size of the average Iowa farm. It may prove uneconomical for large family farms to exist as their use of nonhuman labor on a per acre basis may be uneconomic. It is not possible to predict such a trend at present, as there appears to be certain economies to scale in terms of energy utilization on Iowa farms. Much will depend on the actual crops produced in an energy scarce midwestern agriculture. If it is possible to realize energy savings through more labor intensive methods, then a typical Iowa farm may decrease from its present size.

In conclusion, the entire model was studied in a short run context. This may prove to be inadequate for those concerned with policy formulation. If this modelwere to be employed in policy research, it would be necessary to integrate it into a comprehensive study on the marketing and production of energy sources, agricultural inputs and agricultural outputs. Cognizance would have to be taken of both the effects on the prices with which a farm operator would have to work, and also the effects of structural changes within agriculture on what constitutes a typical Iowa farm.

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APPENDIX A: EXPLANATION OF THE FACTORS BEHIND EACH OF THE PRICE SCENARIOS

Scenario 1: Deregulation of Oil with Gas Still Regulated

Gas prices, according to FEA report will double with the deregulation of oil (9, p. 160). The same report states that to meet increasing demands and in reaction to OPEC price increases, a 50 percent increase in petroleum can be anticipated (9, p. 69). Coal prices increase only 10 percent due to higher costs of transport. As electricity relies on oil and natural gas for 40% of its fuel, a 60 percent increase is considered reasonable for that energy source.

Scenario 2: Deregulation of Oil and Natural Gas, Reduction in the Investment Tax Credit; Discouragement of the Importation of Liquid Natural Gas

Gas prices, according to FEA report (9, p. 160), will increase four-fold with deregulation such that the cost per BTU of natural gas is equal to oil. Oil prices will double from their 1976 level due to reduced impetus for expansion from the lowering of the investment tax credit, and also due to increased demand owing to increased natural gas costs. Coal price rises remain at 10 percent. Electricity, to maintain its relationship described in the PIES report (9, p. G-2), increases by 100 percent.

Scenario 3: Conservative Government Expansion of Supply

Outer Continental Shelf Leasing is curtailed, investment tax credit is only seven percent, energy reserves are one standard deviation below the present average estimate (deregulation is still permitted).

Gas and oil supplies are reduced by limitations on outer continental shelf drilling and by pessimism with respect to the long-range supply situation. This results in the price of gas and oil both increasing five-fold from their present values. Coal and electricity respond to this substantial input cost increase by increasing by 50 and 200 percent respectively.

Scenario 4: Catastrophe in Oil Supply

Oil imports, which constitute 40 percent of present consumption, are drastically curtailed due to an embargo or other political phenomenon.

The price of oil increases by a factor of ten but all other sources of energy remain the same as in scenario three. At a ten-fold increase in oil prices, coal gasification is commercially feasible, so it is assumed that prices of oil will not increase beyond that level.

Scenario 5: Catastrophe in Natural Gas Supply

The same assumptions as scenario three are made and in addition, the supply of natural gas is virtually exhausted.

Natural gas prices increase ten-fold such that extraction from

Devonian shale or synthesizing from coal is commercially feasible. All other sources exhibit the same relative price changes in scenario three.

APPENDIX B: DETAILED DESCRIPTION OF THE FARM MODEL

Table B.1. Fixed costs

Item	Initial Cost ($)	Annual Cost[a] ($)
Land (discounted at 6% value of $1700 per acre)	$540,600	$32,436
Storage facilities for grain (2 x 5,600 bu. bin, 2 x 10,300 bu. bin)	22,172	3,104
Batch bin drying facilities[b]	10,029	1,984
Tractors (60 hp and 90 hp)	28,930	5,207
Tillage equipment (four row)	5,190	980
Cultivation equipment (four row)	4,840	920
Combine, (3-30") corn head and platform	32,030	5,760
Other harvest equipment	15,991	2,810
	$95,701	$17,497
Buildings:		
Farrowing, nursery gestation facilities (25 cap)	32,000	5,600
Open front finishing (700 cap)	35,000	6,125
Cold confinement pit-field spread finishing facility (300 cap)	78,768	13,680
TOTAL	$814,270	$78,606

[a]A straight line depreciation method is employed. The buildings and storage bins are depreciated over 20 years, the related equipment over ten. No scrap value is assumed. Farm machinery is depreciated over a seven year period with a 30 percent scrap value. The opportunity cost of capital is assumed to be 9 percent, taxes and insurance add an additional 2 percent. These expenses and depreciation are the total annual costs.

[b]This may be changed if another drying system proves to be more economical.

Table B.2. Labor availability

Month	Number of hours operator available[a]	Number of hours assistant available[b]
January and February	430	180
March	241	90
April	294	112
May	279	80
June	289	193
July	299	205
August	299	205
September	302	89
October	290	94
November	292	96
December	215	110

[a]The operator is assumed to work a six day week. An allowance has been made in these figures for time for bookkeeping and contingencies.

[b]The assistant is available after school hours and on Saturdays. He is paid $3.50 per hour.

Table B.3. Amount of available field time for different weather scenarios[a]

Time period	Average	1960[b]	1964[c]	1968[d]	1972[e]
15/4 - 24/4	51.5	48	44.5	38.5	49
25/4 - 4/5	103	108	76.3	106	90
5/5 - 14/5	172.3	163.7	131	181.5	120
15/5 - 24/5	230	204	204	224	176
25/5 - 3/5	289	246.5	276	303	243
4/5 -	348	316	354	370	303
6/9 - 5/10	147	165	151	142	128
6/10 - 15/10	49	61	68	22	48
16/10 - 25/10	48	59	61	46	54
26/10 - 4/11	58	56	68	59	27

[a]It is assumed that the operator works a six day week; thus, only six-sevenths of the days suitable for field operations will be utilized. The operator must devote two hours to cattle and one hour to swine even on suitable field days. This and other contingencies make it such that he is available 10 hours for every day during tillage. The maximum amount of time his assistant may devote to field operations is an average of after school time and weekends. It is 5.6 hours per day.

During the autumn, dew on the corn in the early morning, the necessity to shut down operations occasionally to haul the corn to storage and excessive dustiness in the noon period make it such that the combine can only be operated eight hours per day.

[b]Much fewer than usual field days available in spring but a good autumn.

[c]Best spring and best fall for field days within the 18 year period.

[d]A good spring, and a very poor autumn.

[e]The least number of field days in both spring and autumn for the last 18 years.

Table B.3 (Continued)

Time period	Average	1960[b]	1964[c]	1968[d]	1972[e]
5/11 - 14/11	48	61	64	45	22
15/11 - 25/11	52	60	49	55	33
26/11 - 4/12	58	62	59	57	52
6/10 - 5/12	392	449	459	355	295
16/10 - 5/12	331	373	375	327	235
26/10 - 5/12	271	299	298	209	168
5/11 - 5/12	198	229	249	195	134
15/11 - 5/12	138	153	134	140	106
25/11 - 5/12	73	77	73	71	65

Table B.4. Corn yield penalties

Planting period	Harvest period	Yield penalty (bu/acre)	Moisture Content (percent)		
			Normal year	Dry year	Wet year
Apr. 15-24	Sep. 6 - Oct 5	0	26	20	28
	Oct. 6-15	2.2	22	18	24
	Oct. 16-25	3.7	18	18	20
	Oct. 26 - Nov. 14	5.0	18	18	20
	Nov. 15 - Dec. 4	6.0	18	18	20

Table B.4 (Continued)

Planting period	Harvest period	Yield penalty (bu/acre)	Moisture Content (percent)		
			Normal year	Dry year	Wet year
Apr. 25-May 4	Sep. 6 - Oct 5	0	28	22	30
	Oct. 6-15	1.3	22	18	24
	Oct. 16-25	3.1	20	18	22
	Oct. 26 - Nov. 14	5.0	18	18	20
	Nov. 15 - Dec. 4	6.0	18	18	20
May 5-14	Sep. 6 - Oct. 15	4.6	30	22	30
	Oct. 6-15	4.6	24	18	24
	Oct. 16-25	6.3	20	18	22
	Oct. 26 - Nov. 14	4.0	18	18	18
	Nov. 15 - Dec. 4	5.5	18	18	18
May 15-24	Sep. 6 - Oct. 5	11.9	30	22	30
	Oct. 6-15	11.3	28	20	30
	Oct. 16-25	12.4	22	18	24
	Oct. 25 - Nov. 4	13.8	20	18	22
	Nov. 5 - Dec. 4	16.0	18	18	20
May 25- June 3	Oct. 6-15	22.5	30	22	30
	Oct. 16-25	22.3	26	20	28
	Oct. 26 - Nov. 4	23.3	22	18	24
	Nov. 5-14	25.0	20	18	22
	Nov. 15 - Dec. 4	26.0	18	18	20

Table B.4 (Continued)

Planting period		Yield penalty (bu/acre)	Moisture Content (percent)		
			Normal year	Dry year	Wet year
June 4-13	Oct. 6 - 15	35.9	30	22	30
	Oct. 16-25	35.3	28	22	30
	Oct. 26 - Nov. 4	35.4	26	20	28
	Nov. 5-14	36.4	24	18	24
	Nov. 15-24	36.7	20	18	22
	Nov. 25 - Dec. 4	38.8	18	18	20

Table B.5a. Per acre cost[a] and return[b] of corn production employing conventional tillage, and maximum rate of fertilization

Input	Quantity	Price/Unit ($)	Cost ($/ac.)
Corn seed	36 lb.	.30	10.8
N Fertilizer	160 lb.	.122	19.52
P Fertilizer	80 lb.	.19	15.2
K Fertilizer	80 lb.	.08	
Herbicide (2# atrazine and 1# alachlor)			13.50
Insecticide (1# carbofuran)			3.00
Machinery repair			25.38
Gasoline	9.15 gal.	.44	4.03
			97.83

[a]All prices quoted are those of autumn 1976. Increases in energy prices will effect the prices of almost all of the above.

[b]At the fertilization of 160-80-80, the yield is 141 bushels per acre.

Table B.5b. Per acre costs and returns of soybeans costs[a]

Input	Quantity	Price ($ unit)	Cost ($/A.)
Seed			8.00
P Fertilizer	22 lb.	.19	4.18
K Fertilizer	17 lb.	.08	1.36
Herbicide (Amiben)	1.25 gal.	11.10	13.87
Machine repair			18.80
Gasoline	7.4	.44	3.15
			49.36

[a]Soybeans have an average yield of 38 bushels per acre. Their market price is assumed to be $6.00 per bushel.

Note that soybeans add 20 pounds per acre of nitrogen in land rotated with corn. They give an effective "negative expense" not accounted for in this budget, but included in the program to identify the total amount of nitrogen required for growing of corn.

Unfortunately, no figures are yet available for soybean yields under minimum tillage Nicollett-Webster soil. Chisel plowing has become increasingly popular amongst Iowa farmers recently and there does exist potential for energy conservation with this crop also.

Table B.5c. Per acre costs and return of oats

Item	Quantity (unit/A.)	Price ($ unit)	Cost ($/A.)
Costs:			
Seed	3.3	3.5	11.55
P Fertilizer	40	.10	7.60
Machine Repair			1.00
Gasoline	2.42	.44	1.06
Miscellaneous and twine			4.50
Total			$25.71

Returns: The yield is 75 bushels per acre of grain and 75 bales of straw. The grain has a value of $1.50 per hushel. The straw may be sold at $1.00 per bale.

Table B.5d. Per acre costs and returns of alfalfa

Input	Quantity (unit/A.)	Price ($ unit)	Cost ($/A.)
Costs:			
Seed	6	1.20	7.20
P Fertilizer	18	.19	3.42
K Fertilizer	50	.08	4.00
Machine repair	10.41		10.41
Gasoline	4.45	.44	1.86
Misc. expenses			4.00
Total			$30.89

Returns: The alfalfa is harvested three times per annum. The total yield is 4.0 tons per acre.

APPENDIX C: DESCRIPTION OF ALTERNATIVE TILLAGE SYSTEMS FOR CORN

Table C.1. Operations required for conventional tillage and associated costs and returns[a]

Operation	Per Acre Requirements: Time (hr/acre)	Repair cost ($)	Gasoline (gal)
Chop Stalks (6' rotary)[b]	.38	1.45	.7
Moldboard plow (3-16)[b]	.56	2.63	2.7
Apply NH_3 (7 knife)[b]	.17	1.00	.8
Tandem disk (14')[b]	.13	.91	1.0
Plant (and fert. apply) (4-30")[b]	.24	1.98	.85
Spray	.1	.50	.15
Rotary Hoe (4-30")	.1	.48	.3
Cultivate (4-30")	.34	1.48	1.0
Combine (2-30")	.85	12.175	23.5
Haul	-	.50	.3
Total		25.38	10.15

[a]Yield for conventional tillage is 141 bu./acre if plowing is done in the fall, and 130 bu./acre in spring.

[b]These operations must be complete before planting. They require 1.61 hours of field time in the spring and after harvest.

Table C.2. Operations required for till plant tillage and associated costs and returns[a]

Operation	Per Acre Requirements Time (hr/acre)	Repair cost ($)	Gasoline (gal.)
Apply NH_3[b]	.17	1.0	.8
Buffalo Till Planter[b]	.26	2.3	1.0
Apply Chemicals	.1	.5	.15
Spray	.1	.50	.15
Disk Hiller Cultivation	.16	1.00	.4
Combine	.85	12.17	2.35
Haul		.50	.3
Totals		18.17	5.15

[a]Yield for till plant done on experimental plots in central Iowa have an average of 138 bushels per acre over five years. The standard deviation for the five years was 16.1 bushels.

[b]These are the only two operations which need to be done prior to planting and thus 0.43 hours/acre are required of good field time. 0.26 hours per acre must be available during the two weeks in which planting takes place.

Table C.3. Operations required for offset disk tillage and associated costs and returns[a]

Operation	Per Acre Requirement Time (hrs/acre)	Repair cost ($)	Gasoline (gal.)
Apply NH_3[b]	.17	1.0	0.8
Offset Disk[b]	.18	1.23	1.35
No Till Planter[b]	.26	2.3	1.0
Spray	.1	.50	.15
Rolling Cultivator	.18	1.40	.6
Sweep Cultivator	.19	1.50	.65
Combine	.85	12.17	2.35
Haul		.50	.30
Totals		20.60	7.20

[a]The yield is 132 bushels per acre, with a standard deviation of 16.15.

[b]0.61 hours of field time are required before planting with this system.

Table C.4. Operations required for chisel plow tillage and associated costs and returns[a]

Operation	Per Acre Requirements Time (hr.)	Repair ($)	Fuel (gal.)
Chisel Plow (11')[b]	.17	.598	3.0
Apply NH_3[b]	.17	1.00	0.8
Sweep Cultivator	.19	1.56	.65
Plant with coulter[b]	.26	2.3	1.0
Spray	.1	0.50	.15
Rolling Cultivator	.18	1.40	0.6
Combine	.85	12.17	2.35
Haul		.50	.30
Totals		$20.03	8.85

[a]The average yield is 130 bushels per acre with a standard deviation of 16.76.

[b]0.60 hours of field time are required for planting.

Table C.5. Operations required for no till tillage and associated costs and returns[a]

Operation	Per Acre Requirements Time (hr)	Repair ($)	Fuel (gal)
Apply NH_3[b]	.17	1.00	0.8
Plant with normal planter[b]	.24	1.98	.85
Spray (twice)	.2	1.0	.30
Disk hiller cultivator	.16	1.0	0.4
Combine	.85	12.17	2.35
Haul		.50	.3
Totals		17.65	5.0

[a]The average yield is 125 bu./acre with a standard deviation of 20.06. Note that no till requires one more pound of atrazine than all other systems.

[b]0.41 hours of field time are required before planting, 0.24 during the two weeks in which planting takes place.

APPENDIX D: SOIL LOSS FOR DIFFERENT TILLAGE SYSTEMS

Method of Calculation

Soil loss for a particular tillage system is calculated from the universal soil loss equation.

Loss in tons/acre = $R \cdot K \cdot L \cdot S \cdot C \cdot P$

In this model for a central Iowa farm with Nicollet-Webster soil and slope length of 300 feet: (3, pp. 24-32)

R (rainfall) = 175

K (erodibility) = .24 for Nicollett-Webster soil

L (slope length) x S (slope) = .4

C (crop management) = .57 for fall plowing

= .38 for spring plowing

= .27 for minimum tillage

P (erosion control measures) = 1.0

The soil loss for each of the tillage systems is listed in Table 3.2a. Note that a 25 per cent savings in soil loss is realized simply through allowing the corn stalks to remain in the field during the winter. The roots of the corn stalks tend to act as a barrier against spring runoff. Till plant and no till permit the corn stalks to remain in the soil throughout the year. They reduce soil loss even further.

Economic Evaluation of Soil Loss

There are two basic techniques of evaluating the economic benefits from the reduced soil loss which minimum tillage methods produce. The first is the expense which is obviated by having to effect soil conservation methods by means such as terracing, strip cropping and contour plowing. In Nicollett-Webster, the slope does not exceed two percent and thus it is difficult to envision such methods being necessary. Calculations on steeper soil in central Iowa indicate that the cost of the above methods necessary to reduce runoff to 10 tons/acre is $2.05 ton and 5 tons/acre, $21.60/ton (1, p. 28).

The superior alternative in cost evaluation is to ascribe a value to the soil on the basis of its marginal productivity and amortize this over a period of 20 years. Studies conducted by the University of Illinois in the Hambaugh River basin indicate a decrease in the rental value of the land of $.45 per annum for a soil loss of 10 tons/acre and $1.30 at 60 tons/acre (5, p. 45). The fact that the decline in value of the soil actually decreases with increasing runoff is perhaps more indicative of the poorer quality of soil which remains after a large runoff had already taken place than an increasing marginal utility of soil with declining quantities. In the model, it is perhaps valid to assume a "cost" of about $.41/tons per acre at the present level of runoff.

APPENDIX E: CORN DRYING TECHNIQUES

All costs for corn drying systems are taken from the March 1975 price list of "Superior" Drying Systems (23, pp. 2-8, F-5, and E-3). Thirty percent is added to equipment costs for shipping, installing and miscellaneous expenses. All stationary equipment is depreciated over a twenty year period and all items such as motors, augers, etc. over ten. A straight line depreciation method is employed. It is assumed that there is no scrap value.

To the depreciation expense is added a nine percent opportunity cost of capital and two percent to cover taxes, and insurance.

Table E.1. Continuous flow drying system[a,b]

	Initial cost ($)	Cost per annum (Depreciation, taxes, insurance)
Moving Components:		
1) Vertical and external auger systems	1542	
2) Fan, heater and vaporizer	2551	
3) Internal Augers and Spreaders	4137	
	8230	
Plus installation	10664	2239
Stationary Components:		
1) Floor system	1962	
Miscellaneous	386	
Total	2348	
Plus installation	2096	495
Total for System	13760	2734

[a]This is modeled after the D-24-6 Superior Fourway Drying System. The price and description of individual components is found in (23, p. E-3). An eight horsepower fan and 24 inch propane vaporizer are used. Dryeration is achieved through transporting heated grain into the storage bins employing a vertical auger.

[b]The capacity of the system to dry corn to 15 percent moisture changes according to the final moisture content.

This capacity is tabulated below for three different moisture contents.

Moisture (%)	Drying Capacity (bu./hr.)
20	236
25	170
30	76

If this system is operated twenty hours per day, there will be no problem in drying one day's harvest of 1990 bushels.

Table E.2. Batch bin system[a,b]

	Initial Cost ($)	Per Annum Cost ($)
Moving Components:		
External augering system	1543	
Fan, heater and vaporizer	1578	
Internal auger and string	2713	
Total	5834	
Plus installation	7582	1592
Stationary Components:		
Flooring	1624	
Miscellaneous	259	
	1889	
Plus installation	2447	392
Total for system	10,029	1984

[a]This is the adaptation of a 5,600 bushel bin for a system which dries all corn harvested all at one time. The source is 23, p. D-8.

[b]In a twenty-four hour drying period, this system will have the capacity to dry the following amount of corn at the following initial moisture content:

Moisture (%)	Bushels
20	3900
25	1700
30	960

At 28 and 30 percent, this system is unable to dry all 1990 bushels of corn harvested in one day.

Table E.3. Low temperature drying[a]

	Initial cost ($)	Per Annum Cost ($)
Moving Components:		
Fans and electric heaters	12,320	
Internal augers, spreaders	3,124	
	15,444	
Plus installation	20,077	4,216
Stationary Components:		
Extra 5,600 bu. bin	4,339	
Floor support	8,276	
Miscellaneous	1,528	
	14,143	2,262
Total		6,478

[a]Low temperature drying exhibits an exponential increase in the fan horsepower required to dry corn with an increasing moisture content. For a given fan horsepower rating, the heighth to which a bin may be filled therefore decreases exponentially with the moisture content. The capacity of a low temperature bin for a given moisture is illustrated below.

Grain Moisture	Capacity	Air Flow Required (cfm/bu)
up to 22%	100%	1
up to 24%	77%	2
up to 26%	50%	3
up to 28%	37%	5

It is assumed that in most years, the moisture content will average 24 percent, so that for a crop of 23,500, a capacity of 30,500 is required. This necessitates the purchase of a 5,600 bu. bin to supplement the two 10,300 bu and one 5,600 bu for corn storage. The cost of that bin plus the expense in purchasing and installing electric heaters and fans is tabulated in the table.

Solar Drying System

The solar drying system employed in this model is described in detail a separate paper (16). That paper discusses a solar grain drying experiment conducted under central Iowa conditions by the Department of Agricultural Engineering of Iowa State University. In the experiment, the air circulated through the bin is heated to approximately 10 °F above the outdoor temperature by heating it in a solar collector made of plywood and polyethylene. At night, an electric heater such as the one in the "low temperature" system is employed.

The initial cost for such a system is the same as the "low temperature" with the additional expense of the solar collector. The materials for a collector for a 3440 bu. bin costs $150; thus it is assumed that a similar one for a system involving 31,500 capacity bins will cost $1373. The annual costs of depreciation, maintenance and interest for 3,440 bu. are $50; thus, the system under consideration will incur a cost of $458, plus the annual costs of a low temperature drying system.