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ENERGY-RELATED INPUT DEMAND BY CROP PRODUCERS

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Energy use in U.S. production of food and fiber is extensive and has increased rapidly. A threefold increase occurred from 1940 to 1970 (Carter and Yonde). Food and fiber production accounted for about 13 percent of the total energy consumed in the U.S. in 1980 (Duncan and Webb). Of the total energy use in food and fiber production, farm level production directly consumes about 21 percent (U.S. Senate Committee on Agriculture and Forestry).

Since the early 1970s much attention has been devoted to energy demand by agriculture. Mensah and Miranowski estimated the effects of prices, product substitution, and technology on U.S. agriculture's demand for energy. Burton and Kline considered several crop-production technologies and found that no-till is the best option for relatively high energy prices. In similar studies, Kliebenstein and Chavas, and Miranowski projected shifts toward minimum tillage as energy prices increase. They found inelastic short-run energy demand at the farm level. Capps and Havlicek reported similar elasticity estimates. McCamley and Kliebenstein concluded that the degree of producer risk aversion has a larger impact on energy use levels than do energy prices.[1]

Most previous energy-demand studies share two limitations. One limitation is the narrow measure of energy use adopted. Typically, only inputs, such as diesel fuel, propane, and gasoline, which supply energy directly are considered. An exception is the study by Eidman, Dobbins, and Schwartz. Energy required to produce other agricultural inputs is often ignored. This omission is serious because some of the commonly neglected inputs can be readily substituted for energy-supplying inputs. For example, by modifying tillage practices crop producers can substitute herbicides for diesel fuel or vice versa. Thus, studies which consider only energy-supplying inputs tend to overestimate the effects of changes in tillage practices on energy demand. For this study, fertilizers, herbicides, and pesticides, as well as the more obvious energy-supplying inputs, are considered.

A second limitation of many studies is the assumption of a risk-neutral attitude by crop producers. This assumption is inconsistent with the findings by Lin, Dean, and Moore, and others that farmers are not risk-neutral. This study examines the effect of various degrees of risk aversion on energy consumption.

The approach used in this study is consistent with the definition of simulation offered by Johnson and Rausser. An expected income-variance (E-V) analysis model of a typical farm is formulated. Since simple closed-form expressions for the demand functions implied by this model do not exist, optimal solutions are computed for many different price and risk-aversion coefficient combinations. An energy-demand function is estimated from the solution data.

METHODOLOGY

The Model

An E-V analysis model of a typical Missouri crop farm is developed. E-V efficient solutions are relevant for many alternative-risk-programming objective functions. These considerations, as well as the availability of a quadratic programming algorithm, prompt the use of E-V analysis.[2] Even though E-V analysis is chosen primarily for intuitive and practical reasons, it enjoys the added advantage of being consistent with the maximization of expected utility if the utility function is quadratic or profits (R) are normally distributed. For the latter case, Freund has shown that maximizing an expected utility function of the form

$$(1) \qquad U(R) = 1 - e^{-2\alpha R}$$

is equivalent to maximizing

$$(2) \qquad E(u) = \mu - \alpha\sigma^2$$

where μ is expected profit, σ^2 is the variance of profit, and α is a risk-aversion coefficient. It has also been shown that E-V analysis approximates other situations

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[1] In this article we use several related phrases. We use "risk-aversion coefficient" or risk-aversion measure" when referring to a coefficient in a particular objective or utility function. We use "degree(s) of risk aversion" and (more or less) "risk-averse" when discussing risk aversion in more general terms, i.e., without reference to a coefficient in a particular objective or utility function.

[2] MOTAD models and stochastic dominance techniques have increased in popularity in recent years. Buccola discussed the statistical advantages of using E-V analysis rather than MOTAD analysis. Although stochastic dominance analysis is now widely used for comparing discrete risky alternatives, it is not widely used to analyze mixtures of risky alternatives.

quite well (Levy and Markowitz). Katoaka has shown that E-V efficient solutions are also E-S (expected income/standard deviation) efficient solutions.

Activities and Resource Constraints

Farm size is assumed to be 400 acres with all labor supplied by the operator and family. Machinery and equipment complements are assumed to be comparable to those available on a typical 400-acre Missouri crop farm. Crops produced are those common to Missouri—corn, sorghum, soybeans, and wheat. Tillage practices considered are chisel plowing, disking, and planting for wheat, while conventional, reduced, and no-tillage are possibilities for the other crops. Conventional tillage involves plowing, two diskings, harrowing, and planting. Reduced tillage involves use of a field cultivator, disking, and planting. No-tillage does not require field cultivation because planting is with a no-till planter. For soybeans, both 15- and 30-inch rows are considered as alternatives. Only 30-inch-row activities are included for corn and sorghum. Altogether, there are 13 production activities: 3 for corn, 6 for soybean, 3 for sorghum, and one for wheat. Input coefficients for fuel, seed, fertilizer, chemicals, labor, and so forth were obtained from crop budgets, farm management specialists, agricultural engineers, agronomists, producers, and farm management specialists (Workman and Kirtley).

Estimation of Objective Function Coefficients

The experimental design adopted for this study requires the use of many different expected income vectors and variance/covariance matrices. A base expected income vector and a base variance/covariance matrix are computed from prices and yields for the period 1963–79. Prices are annual average prices for the respective crops (Missouri Crop and Livestock Reporting Service). Crop-yield series are based on yields at a Central Missouri experiment station (Minor et al. 1979a, 1979b, 1979c; Sechler et al.). Use of experiment station yields eliminates much of the variation due to management associated with other sources of yield data. Data appropriate for determining the effects of alternative tillage practices on yields are sparse. Discussions with crop-production specialists suggest that yields from reduced tillage are about the same as those from conventional tillage, but yields associated with no-tillage are about 5 percent less. They also suggest that 15-inch-row spacing for soybeans gives a 6 percent greater yield than does 30-inch-row spacing. These suggestions are used to construct yield series for reduced and no-tillage activities.

Gross returns are generally greater and more variable for the years 1973–79 than for the 1963–72 period. Adams, Menkhaus, and Woolery concluded that E-V frontiers obtained using expected returns and variances based on short, recent time series do a better job of approximating farmer behavior. Our approach is consistent with the spirit of their findings. The study period is divided into two subperiods, 1963–72 and 1973–79. Separate average-returns vectors are estimated for each subperiod. The base expected-returns vector is a weighted average of the average-returns vectors for the two subperiods. A greater weight (0.55) is assigned to the average-returns vector for the second sub-period. The variance/covariance matrix is computed using the formula:

$$V = \frac{\sum_{t=1}^{10} (R_t - \overline{R}_1)' (R_t - \overline{R}_1) + \sum_{t=11}^{17} (R_t - \overline{R}_2)' (R_t - \overline{R}_2)}{15}$$

where V is the estimated variance matrix, R_t is the returns vector for year t(= 1 for 1963), and R_j (j = 1, 2) is the average-returns vector for subperiod j. Since the variation in net returns is greater in the second period, the estimated-variance matrix is much more like the matrix for the second subperiod than the first.

Both the base expected-returns vector and variance/covariance matrix are "rounded" to simplify data entry. Even though the prices and yields for each crop have a correlation coefficient slightly greater than zero, it is convenient to think of the expected gross returns for any crop as being the product of the average yield and an "average" price. The expected-returns vector is adjusted so that these "average" prices are multiples of 0.05. The portion of the base-variance matrix associated with conventional (and 30-inch-row soybeans) tillage activities is:

	Corn	**Sorghum**	**Soybeans**	**Wheat**
Corn	5092	1797	1686	280
Sorghum	1797	1517	1360	450
Soybeans	1686	1360	1576	652
Wheat	280	450	652	540

Due to data limitations, net returns series were constructed for the activities associated with other tillage options by assuming that these returns are perfectly correlated with those for the conventional tillage activity for the same crop. Thus the balance of the base-variance matrix can be inferred by the reader. Klemme has recently shown that the perfect correlation assumption may not be completely valid. More research is needed on this issue.

Experimental Design

As is the case for most programming models, it is not possible to find a globally valid closed-form expression for the energy-demand function implied by the E-V analysis model. Even the expression for a given basis is more complex than usual because (as noted below) changes in crop prices affect both linear and quadratic components of the objective function. The energy-demand function is approximated by fitting linear, quadratic, and cubic functions to solutions corresponding to many combinations of prices and degrees of risk aversion. The experimental design used to generate the data involves varying six variables: energy price, four crop prices, and the risk-aversion coefficient.

Changes in the price of petroleum and other fossil fuels affect the prices of several of the inputs used by crop producers (diesel fuel, propane, chemicals, fertilizer). Diesel fuel price serves as a proxy for the prices of fossil fuels. The levels chosen for this input are \$.50, \$1.00, \$2.00, \$3.00, and \$4.00 per gallon. The prices chosen for the energy-based inputs (shown in Table 1) reflect an assumption that the ratios of energy-based input prices to diesel fuel price will remain at approximately the values which existed during the 1970s. This assumption precludes isolating the separate effects of individual energy-based input prices, but allows for a more complete treatment of output price changes. This permits a more realistic design since input prices tend to move together more than crop prices do. If input prices had been treated independently as well, 625 times as many solutions would have been required.

It is assumed that the farmer faces neither price nor quantity risks for petroleum-related inputs. This assumption is not completely valid. The amounts of harvest inputs, such as propane for crop drying, diesel fuel, and so forth, depend partly on crop yields. The harvest costs are not always known with complete certainty at planting time. Ignoring these minor price and quantity risk components for energy-based inputs simplifies the analysis. Only the expected-net-returns vector has to be modified when energy-related prices are changed.

Four price levels are selected for each commodity (corn, sorghum, soybeans, and wheat) produced (Table 2). Only the most unlikely crop price combinations are not considered.[3] Sorghum and corn are both feed grains and are highly substitutable. Therefore, it is not reasonable to consider price combinations involving a high sorghum price and a low corn price or vice versa. Omitting combinations of this sort is consistent with Eidman's suggestion that disequilibrium price combinations not be considered.

In contrast to the assumptions stated above for energy-related inputs, it is assumed that the farmer faces both price and yield risk for the crops produced. The price levels in Table 2 are regarded as average prices rather than as known prices. It is assumed that changing average commodity prices changes the expected net returns and the dispersion of net returns without changing the shape of the returns distributions. This allows obtaining the variance/covariance matrix for any trial by (pre and post) multiplying the base variance/covariance matrix by an appropriate diagonal matrix. Each diagonal element is the ratio of the average price level selected for the commodity to its average price level in the base period.[4]

Table 1. Input Prices Used in the Study

Price Level	Fuel	Nitrogen	Chemicals	Fertilizer[a/]	Propane
	dollars				
1	.50	.22	1.00	.14	.40
2	1.00	.44	2.00	.28	.80
3	2.00	.88	4.00	.56	1.60
4	3.00	1.32	6.00	.84	2.40
5	4.00	1.76	8.00	1.12	3.20

[a] Phosphorus and potassium fertilizer.

Table 2. Output Prices Used in the Study

Corn	Soybeans	Sorghum	Wheat
dollars per bushel			
2.00	4.60	1.85	2.60
3.00	6.90	2.77	3.90
4.00	9.20	3.70	5.20
6.00	13.80	5.55	7.80

The sixth factor varied is the risk-aversion coefficient. Levels for this experimental variable are not specified in advance. Instead, for each combination of energy and output prices, this coefficient is varied from 0.05 (representing a high degree of risk aversion) to zero (risk neutrality). An observation is recorded at each basis change. It is well known that this procedure generates the most relevant portion of the E-V frontier.

Demand Function Estimation

As noted elsewhere in the paper, the energy-demand functions implied by the E-V analysis model do not have a simple form. Therefore, linear, quadratic, and cubic approximations of the energy-demand function are estimated. These can be regarded as Taylor-series approximations of the energy-demand function. The dependent variable is the energy associated with diesel fuel, propane, chemicals, and fertilizer used in crop production. Energy use is measured in millions of BTU's and was computed using the factors shown in Table 3.[5] The amounts of energy used per acre for the crop activities are shown in Table 4. The independent variables are diesel fuel price (used as a proxy for the prices of all inputs derived from fossil fuels), commodity prices, and a measure of risk aversion.

Three alternative measures of risk aversion are used. The set of E-V efficient solutions is consistent with many different objective functions and thus with different attitudes toward risk. The coefficients of any of these functions are candidates for risk-aversion measures. For this paper, one family of functions of the following form are considered:

$$(3) \qquad f(\mu,\sigma) = \mu - \beta\sigma^{\delta};\ \beta \geq 0,\ \delta \geq 1$$

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[3] Candler and Cartwright suggested that the appropriate experimental design depends upon the objective of research. Rotatable designs are useful if the objective is the maximization of some function, but relatively complete "factorial" designs, such as that used in this study, allow approximation of a larger portion of the response (energy demand) function.

[4] The gross-returns vector for each set of crop prices is obtained by multiplying the base expected-gross-returns vector by the diagonal price-ratios matrix. The net-returns vector is obtained by subtracting a vector of constant (not affected by energy price) variable costs and a vector of energy input costs from the gross-returns vector.

[5] For most economic analyses, it is appropriate to measure energy use in value terms since that approach comes closer to measuring the value of all of the resources used to manufacture the energy-related inputs. However, this study is more concerned about the impact of crop production on fossil fuel resources.

Table 3. BTU Equivalents of Energy-Related Inputs

Inputs (Units)	BTU's/Unit
Diesel Fuel (Gallon)	135,000
Propane (Gallon)	84,613
Nitrogen (Pound)	25,000
Phosphorus and Potassium (Pound)	5,000
Chemicals ($1.00 at 1979 prices)	120,000

In equation (3), μ is expected income, β is the risk-aversion coefficient, σ is the standard deviation of income, and δ is the exponent of the income-variability measure. The three members of this family considered in this study are those for which $\delta = 1.0, 1.5$, or 2.0. The member for which $\delta = 2$ is simply the quadratic-programming objective function. For this member, equation (3) can be recognized as a common definition of certainty equivalence. For $\delta = 1$, the function is the "safety-first" criterion suggested by Katoaka. The member corresponding to $\delta = 1.5$ was chosen because it implies a treatment of risk intermediate to the other two. The alternative risk-aversion measures used as independent variables in the regressions are equal to α (for $\delta = 2$), $\alpha\sigma^{.5}/.75$ (for $\delta = 1.5$), and $2\alpha\sigma$ (for $\delta = 1$).[6]

To obtain regression coefficients of manageable size without changing the analysis in any meaningful way, the risk-aversion coefficient for $\delta = 2$ is multiplied by 1,000, and the one for $\delta = 1.5$ is multiplied by 100. When these two risk-aversion measures are employed, observations associated with the arbitrary starting value of $\alpha = 0.05$ are included in the set of observations used to estimate the response functions. For $\delta = 1$, the risk-aversion measure associated with the arbitrary starting value and the first basis change are the same for any given price combination. However, the energy use is quite different. Thus, an estimated response surface based on this risk-aversion measure cannot adequately explain the change that occurs between these two observations. Therefore, only observations associated with basis changes are used to estimate the response surface when $\delta = 1.0$.

RESULTS AND IMPLICATIONS

The estimated coefficients for the quadratic versions of the response surfaces are presented in Table 5. The quadratic functions provided much better approximations than the linear functions. They provided a better fit (smaller standard errors of estimate) to the data. Cubic functions provided only slightly better approximations than those of the quadratic versions. The quadratic functions (rather than the cubic functions) are presented because they provide comparable approximations and are simpler to present and interpret.

Ordinary least squares is used to compute the response-function coefficients. Although the usual regression assumptions about the random errors and so forth are not satisfied in this study, the standard error of the estimate provides some indication of the adequacy of each approximation.

Rather than attempt to interpret the quadratic functions directly, we illustrate some of their implications by presenting energy consumption elasticities for a farmer with a high degree of risk aversion. A diesel fuel price of $1.00, corresponding prices of other energy-based inputs, and average corn, soybeans, sorghum, and wheat prices of $3.00, $6.90, $2.77, and $3.90, respectively, are used. For the estimated response function associated with $\delta = 1.0$, a risk-aversion coefficient of 2.0 is selected. Comparable risk-aversion coefficient levels of 0.9698 and 0.0529 are used with the estimates associated with $\delta = 1.5$ and 2.0. The results presented in Table 6 suggest that energy consumption by a crop producer is only moderately responsive to energy price changes. Energy demand elasticities with respect to most of the crop prices are larger. As expected, increases in soybean and wheat prices would reduce total farm energy consumption, while increases in corn and sorghum prices would increase total farm energy consumption. This is true for all three risk-aversion measures.

The findings of Brink and McCarl, and Dillon and Scandizzo suggest that most farmers are less risk-averse than the farmer considered above. The estimated

Table 4. Per Acre Energy Requirements by Crop and Tillage Options

Crop/Tillage Option	BTUs/Acre
Corn	
Conventional	7,071,963
Minimum Till	6,664,263
No-till	7,773,796
Sorghum	
Conventional	6,163,507
Minimum Till	5,755,807
No-till	6,890,094
Soybeans (30 inch rows)	
Conventional	2,634,300
Minimum Till	2,226,600
No-till	3,447,900
Soybeans (15 inch rows)	
Conventional	2,634,300
Minimum Till	2,226,600
No-till	3,447,900
Wheat	2,013,100

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[6] Regardless of the value of δ, a solution is optimal only if the trade-off between expected income and the standard deviation of income implied by the objective function equals the trade-off implied by the curve describing the E,S efficient solutions. The trade-off implied by the objective function can be obtained by total differentiation of the objective function. Setting $df = 0$ gives

$$d\mu/d\sigma^2 = \delta\beta(\delta)\sigma^{\delta-2}/2$$

Setting $d\mu/d\sigma^2$ equal to α (the trade-off when $\delta = 2$) results in the risk-aversion measures shown in the text. The fact that these functions imply somewhat different attitudes toward risk may be confirmed by noting the effect of doubling all activity levels. For $\delta = 1$, this would double the "risk premium" but for $\delta = 2$, the "risk premium" would be quadrupled.

response functions imply that farmers who are less risk-averse use (directly and/or indirectly) more energy. For example, reducing the risk-aversion coefficient associated with $\delta = 1.0$ by 0.1 increases estimated energy consumption by about 27 million BTU's. Reducing the risk-aversion coefficient associated with $\delta = 2.0$ by 0.01 implies an increase in energy consumption of 65 million BTU's. Since these changes in risk-aversion coefficients do not necessarily represent equivalent changes in risk preferences, the associated changes in energy consumption are not directly comparable. However, regardless of the measure of risk aversion, the results suggest that farmers with lower degrees of risk aversion will produce crops that use more energy per acre.

Table 5. Estimated Coefficients for Crop-Producer Energy Demand Functions, by Type of Risk-Aversion Measure

Variable	Type of Risk Aversion Measure		
	δ = 1.0	δ = 1.5	δ = 2.0
Intercept	2156.99 (181.23)	1511.35 (165.85)	2151.08 (155.37)
Diesel price	-425.98 (48.68)	-85.17 (42.22)	-396.11 (39.78)
Corn price	320.94 (52.12)	140.82 (49.52)	90.39 (45.68)
Soybean price	-107.78 (19.48)	-62.08 (18.68)	-73.80 (17.23)
Sorghum price	434.34 (56.50)	175.09 (54.01)	171.96 (49.74)
Wheat price	-282.14 (33.03)	-125.14 (32.24)	-105.96 (29.64)
Risk aversion	-605.20 (44.56)	-181.38 (7.70)	-6743.36 (225.17)
(Diesel price)^2	23.02 (7.91)	10.31 (6.77)	33.08 (6.28)
Diesel price x Corn price	-39.44 (7.52)	-8.15 (6.57)	3.38 (6.14)
Diesel price x Soybean price	27.12 (2.65)	-2.67 (2.15)	4.37 (1.84)
Diesel price x Sorghum price	-57.55 (7.77)	-13.68 (6.70)	-7.76 (6.26)
Diesel price x Wheat price	40.17 (4.84)	-1.20 (4.20)	6.69 (3.95)
Diesel price x Risk aversion	37.23 (10.95)	16.76 (1.02)	3.89 (.27)
(Corn price)^2	38.97 (7.59	14.54 (7.81)	18.01 (7.19)
Corn price x Soybean price	-2.80 (2.45)	-11.49 (2.40)	-10.65 (2.21)
Corn price x Sorghum price	-79.49 (11.81)	-9.07 (12.17)	-16.73 (11.22)
Corn price x Wheat price	6.96 (5.62)	1.15 (5.72)	1.52 (5.26)
Corn price x Risk aversion	-85.28 (7.13)	-3.55 (.48)	-2.04 (.33)
(Soybean price)^2	.46 (.87)	1.35 (.85)	2.06 (.79)
Soybean price x Sorghum price	-13.82 (2.45)	-7.29 (2.45)	-7.79 (2.26)
Soybean price x Wheat price	4.69 (1.59)	11.97 (1.51)	8.69 (1.36)
Soybean price x Risk aversion	25.56 (2.59)	.65 (.15)	1.07 (.10)
(Sorghum price)^2	51.99 (8.63)	7.13 (8.79)	10.66 (8.10)
Sorghum price x Wheat price	-9.56 (4.86)	.10 (4.95)	-2.31 4.55
Sorghum price x Risk aversion	-49.12 (7.45)	-3.10 (.49)	-1.74 (.34)
(Wheat price)^2	-.79 (3.15)	-3.90 (3.20)	-3.95 (2.94)
Wheat price x Risk aversion	50.79 (4.63)	-1.88 (.38)	1.21 (.21)
(Risk aversion)^2	74.60 (6.59)	3.70 (.19)	134.09 (4.49)
R^2	.76	.77	.80
Standard Error of Estimate	296.39	366.16	337.26
Number of Observations	1508	2154	2154

Table 6. Estimated Elasticities of Energy Demand for a Risk-Averse Farmer

Variable	Type of Risk Aversion Measure		
	δ = 1.0	δ = 1.5	δ = 2.0
Diesel Fuel Price	-.208	-.108	-.218
Corn Price	.348	.283	.204
Soybean Price	-.309	-.297	-.320
Sorghum Price	.474	.270	.235
Wheat Price	-.406	-.228	-.216
Risk Aversion Coefficient	-.496	-.140	-.273

Less risk-averse farmers would also choose crop mixes which yield higher expected net incomes. The model used in this study makes it possible to relate changes in energy consumption to changes in expected net and gross income for movements along the E-V frontier. Reducing the risk aversion coefficient associated with $\delta = 1.0$ by 0.1 not only increases estimated energy consumption by about 27 million BTU's, it also increases expected income by about \$1,980. Approximately 13,800 additional BTU's are used per additional dollar of expected net income. The elasticity of energy consumption with respect to expected net returns is about 0.78, which suggests (for this portion of the E-V frontier) that lower degrees of risk aversion result in less energy use per dollar of expected net income.

On the other hand, energy consumption per dollar of expected gross receipts increases slightly in this region of the E-V frontier. Reducing the risk aversion coefficient by 0.1 increases total receipts by about \$2,030. The elasticity of BTU consumption with respect to total expected receipts is 1.07.

SUMMARY

This study uses E-V analysis to examine the effect of alternative energy and crop prices on the energy consumed (directly and indirectly) by risk-averse crop producers. Expressing fuels, chemicals, and fertilizers in terms of their BTU equivalents allows aggregating these energy-related inputs. Energy demand functions are estimated from the solutions associated with many price and risk-aversion coefficient combinations.

Quadratic approximations of the energy demand functions are presented. For input and output price levels close to those prevailing in the recent past, energy demand by crop producers is moderately responsive to changes in energy price levels. Energy consumption elasticities with respect to crop prices are generally larger than those with respect to energy price. Increases in corn and sorghum prices increase energy demand, but increases in soybean and wheat prices decrease it. As degree of risk aversion decreases, energy demand increases.

Thus, the model used in this study suggests that less risk-averse producers produce crops that use more energy per acre, less energy per dollar of expected net incomes, and a slightly greater amount of energy per dollar of expected gross income.

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