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Farm-level nonparametric analysis of cost-minimization and profit-maximization behavior

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Abstract

This study investigates non-parametrically the optimizing behavior of a sample of 289 Kansas farms under profit-maximization and cost-minimization hypotheses. The study uses both deterministic and stochastic non-parametric tests. The deterministic results do not support strict adherence to either optimization hypothesis. The stochastic tests suggest that all 289 farms fail the profit-maximization hypothesis, whereas 171 farms failed the cost-minimization hypothesis. Allowing for non-regressive technical change does not alter the basic results; 276 farms violate the profit-maximization hypothesis and 138 violate the cost-minimization hypothesis. The evidence against cost-minimization behavior seems to be far less substantial than that against profit-maximization behavior.

Traditional analysis of production behavior maintains the hypothesis that firms maximize profits (and minimize costs) subject to technological constraints. Analyses usually proceed by postulating a functional form to represent the production function and employing parametric statistical techniques to estimate unknown parameters from observed data. Aggregate data often are used to make inferences regarding neoclassical production theory, which generally is developed within the context of profit maximization for an individual producer. This paper applies a non-parametric approach to observed farm-level production data to examine the maintained hypotheses of profit maximization and cost minimization. This approach is not a statistical test. Rather, it

checks a set of inequalities to ensure the existence of a production function that can rationalize a set of data in the context of the neoclassical optimization hypothesis.

This approach is based on previous works by Hanoch and Rothschild (1972), Afriat (1967, Afriat, 1972), and Diewert and Parkan (1983), which provide a basis for investigating the productive efficiency exhibited by observed economic behavior prior to estimation of parametric models. More recently, the non-parametric approach has been popularized by Varian (1984). Nearly every study that has empirically applied the non-parametric approach in agricultural production analysis has used data aggregated across many farms. Fawson and Shumway (1988) conducted a nonparametric investigation of the consistency of agricultural production behavior for U.S. subregions, with the joint hypothesis of profit maxi-

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mization; convex technology; and monotonic, non-regressive, technical change. They found that data from 1939 to 1982 were inconsistent with the hypothesis of profit maximization. They also found that disaggregation of inputs and outputs led to greater violations of the maintained hypotheses.

Chavas and Cox (1988) extended the non-parametric approach by incorporating output-augmenting (Hicks-neutral) technical change to analyze U.S. agricultural technology. Profit maximization without technical change was rejected for most periods, again using aggregate U.S. data. They interpreted this as strong evidence of technical change.

Lim and Shumway (1992a) applied the non-parametric approach to statewide production data for 1956 through 1982. Although results did not conform strictly to the profit-maximization hypothesis, they were consistent with that hypothesis allowing for measurement error. Lim and Shumway (1992b) have also used the non-parametric methodology to examine separability in state-level agricultural technologies.

Ray and Bhadra (1993) examined, at the farm level, the cost-minimization behavior of Indian farmers involved in the production of a single crop. They did not find strong evidence for overall cost minimization, although evidence did exist for variable cost minimization.

A limitation of many previous studies addressing optimizing behavior and the structure of technology for producers is that they have typically used national or state-level rather than individual farm data. Microeconomic theory is based upon optimization by individual agents. The use of statewide data to characterize individual agents' optimization behavior can cause problems by possibly introducing aggregation bias because of summing across farms. That is, individual agents may face differing technologies and objectives that are not recognized when aggregate data are used. In addition, different producers may face varying market conditions. Such bias is recognized widely as an important limitation in tests of neoclassical optimizing behavior using statewide or national data.

The purpose of this study is to use individual

farm-level data, collected over time, to evaluate producers' optimizing behavior. The paper applies non-parametric techniques to analyze agricultural technology and production behavior for a sample of 289 Kansas farms, using annual farm-level data for an 18-year period, 1973 to 1990. Output data are aggregated into two commodities: crops and livestock. Although aggregation across commodities is typical in analyses of agricultural production, it should be acknowledged that our results are conditioned upon aggregation across commodities. This paper also extends Varian's test (Varian, 1984) of cost minimization to the multiproduct case. Deterministic and stochastic adherence to cost-minimization and profit-maximization hypotheses is examined.

1. Non-parametric production analysis

Two types of non-parametric production analysis exist. One type compares a firm with another firm for a given year (Färe et al., 1985). The second type, which is used in this analysis, compares current input/output choices to decisions made previously (Varian, 1984). Thus, each firm is compared with itself.

The non-parametric approach examines behavioral-optimization hypotheses without specifying a functional form for the production technology. This method checks whether the inequality relationships postulated by the optimizing hypotheses hold using observed quantity and price data. This method is useful for exploring the consistency of observed data with theoretic optimizing behavior. Both deterministic and stochastic tests are available to analyze the optimization hypotheses (Varian, 1984; Varian, 1985; Varian, 1990). The deterministic test is an all-or-none test; if the optimizing hypothesis is violated once, the entire test fails. The stochastic test allows for measurement error in the data when considering consistency with the optimizing behavior. Varian (1985) and Varian (1990) derived test statistics that permit the results of the stochastic procedure to be interpreted using classical statistical testing of hypotheses. This study applies both procedures to annual data from 289 Kansas farms to determine

whether they were cost minimizers, profit maximizers, or both. Additionally, deterministic and stochastic tests are performed to allow for monotonic, non-regressive, technical change.

1.1. Deterministic tests

The notation in this article follows that of Varian (1984). Let T be the production possibility set of all input–output bundles $(-x, y)$ compatible with the available technology. T is non-empty, closed, bounded from above, and convex and allows for free disposal. A specific production plan at time t may be represented by a netput vector $Y^t = (y_1, \dots, y_m)$ in T , where positive y_i 's represent outputs and negative y_i 's represent inputs. The set of all feasible production plans, Y , is a subset of T and is closed, convex, and negative monotonic (Varian, 1984).

An efficient production frontier is represented by the boundary of the set, because no other method exists to produce a given output with fewer inputs or produce more output with given inputs. Profits (π_t) at any time t are the product of the netput vector Y_t and its price vector P_t , where $t = 1 \dots m$. Under constant technology over the sample period, the consistency of the observed data with profit maximization requires

$$P^t Y^t \geq P^t Y^s \text{ for all } t, s = 1, 2, \dots, n, \quad (1)$$

where Y^t is in Y . This is the weak axiom of profit maximization (WAPM). This axiom implies that, if profit is maximized given P^t , then that profit should be greater than or equal to any other profit generated by any other set of outputs and inputs evaluated at P^t . To determine whether farms maximize profit, the observed price vector and all other netput vectors must satisfy the WAPM. If one of the observations violates the inequalities, the hypothesis of profit-maximizing behavior is rejected.

Suppose we observe a set of data (W^t, X^t, Y^t) where $X^t = (x_1, \dots, x_m)$ is a vector of inputs, $W^t = (w_1, \dots, w_m)$ is a vector of input prices, and Y^t is a vector of outputs. Varian (1984) and Varian (1990) shows that, if the firm is cost minimizing, then the following inequalities are satisfied:

$$W^t X^t \leq W^t X^s \text{ for all } Y^s \geq Y^t \quad (2)$$

These inequalities require that the cost of inputs to produce a given output must be no greater than the cost of any other input set that produces at least the same output. This is Varian's (Varian, 1984; Varian, 1990) weak axiom of cost minimization (WACM). If the observed data do not satisfy the inequalities of the WACM, the hypothesis of cost minimization will be rejected.

1.2. Stochastic tests

The non-parametric tests specified above are deterministic, because if a violation is observed, no matter how small, the firm fails to meet the tested objective. These tests do not allow for errors nor do they consider the significance of errors. Varian (1990) suggests stochastic tests as alternatives to deterministic tests. The stochastic test is based on the attempt to test "nearly optimizing behavior" rather than "exact optimizing behavior". This method allows for measurement error in data and, thus, suggests that the firm adheres to optimizing behavior if the size of the violation is small. In addition, economic cost overage or profit foregone can be measured. This allows the economic significance of a violation to be considered (McCloskey, 1990).

The size of the violation of the profit-maximizing hypothesis is

$$V^{ts} = P^t(Y^s - Y^t) / P^t Y^t = P^t Y^s / P^t Y^t - 1 \quad (3)$$

where P and Y are vectors as defined before (Varian, 1990). The variable V^{ts} is the extra profit that the firm could have made at prices P^t if it had chosen output vector Y^s instead of output vector Y^t .

The size of a violation of the cost-minimization hypothesis is

$$C^{ts} = W^t(X^t - X^s) / W^t X^t = 1 - W^t X^s / W^t X^t \quad (4)$$

where W and X are vectors of input prices and inputs (Varian, 1990). The variable C^{ts} measures how much the firm could have saved, if it had chosen X^s rather than X^t , given the factor prices P^t .

According to Varian (1990), the variables V^{ts} and C^{ts} should be interpreted as "residuals". He

suggests that the best ways to present these residuals are to list the residual foregone profit with the observation, examine the average profit foregone, or report the largest profit foregone. We used the average profit foregone and average costs that could have been saved as measures of departure from the profit-maximization or cost-minimization hypothesis. Varian (1990) suggests that, if the violations are small, say an average foregone profit of 5%, then the firm may be considered to be optimizing.

1.3. Monotonic non-regressive technical change

The previous non-parametric tests of profit maximization and cost minimization assumed no technical change over the sample period. Equations (1) and (2) can be modified to account for monotonic, non-regressive, technical change. Technical change implies that technology used in period i may not be available in period j for all $i \geq j$. This implies that, instead of making all pair-wise comparisons, as in (1) and (2), comparisons are made only if that technology is available. For example, the choice of the netputs in 1979 at 1979 prices may not produce more profit than the choice of the netputs in 1985 at 1979 prices because the technology available in 1985 may not have been available in 1979, rendering the production bundle infeasible. Thus, the comparison is not valid. Following Fawson and Shumway (1988), the joint hypotheses of profit maximization; convex technology; and monotonic, non-regressive, technical change may be tested by changing the index in (1) as follows.

$$P^t Y^t \geq P^t Y^s \text{ for all } t > s \quad (5)$$

The condition $t > s$ restricts all comparisons to the lower diagonal of the profit matrix.

Under technical change, some observed input requirements to produce a given amount of output may be infeasible for earlier years. As a result, the comparison suggested in (2) is not valid. However, (2) can be modified by changing the index as follows:

$$W^t X^t \leq W^t X^s \text{ for all } Y^s \geq Y^t \text{ and } t > s \quad (6)$$

The condition $t > s$ restricts all comparisons to the lower diagonal of the total cost matrix. Violations given by Eqs. (5) and (6) imply technical change over the sample period. Varian's goodness-of-fit measures then are used to examine measurement error under the monotonic, non-regressive, technical change hypothesis.

The non-parametric approach examines the behavioral-optimization hypotheses without specifying a parametric form for the relationship between inputs and outputs. This method checks whether the inequality relationships postulated by the optimizing hypotheses hold by using observed quantity and price data. Both deterministic and stochastic tests are used to analyze the optimization hypotheses under technical change.

2. Data and methodology

The non-parametric approach was applied to farm-level data for 289 Kansas farms observed from 1973 to 1990. The optimizing behavior of the farms was evaluated. Specifically, consistency with profit-maximization and cost-minimization behavior was tested for each farm. The average percentage deviation from the profit-maximization and cost-minimization solution for each farm was calculated. Adherence to the profit-maximization and cost-minimization hypotheses under monotonic, non-regressive, technical change also was examined for each of the farms.

Income and balance sheet data for the 289 farms were obtained from the Kansas Farm Management Association records (Langemeier, 1990). The farms were defined to have eight inputs: family and hired labor, land and structures, seed, fertilizer, pesticides, machinery, feed, and energy. The farms were also assumed to have two outputs: crops and livestock. As previously noted, our results will be conditioned upon this aggregation across commodities. Price indexes on inputs and outputs were obtained from USDA's Kansas Agricultural Statistics (USDA, 1973–1990a) and Agricultural Prices (USDA, 1973–1990b). Physical input indices for quantities were obtained by dividing the farms' cash operating expenses in each of the eight input categories by the prices

for each input. Output indices for quantities were obtained by dividing the farms' accrual revenues by crop and livestock price indexes.

3. Results

3.1. Deterministic tests

The non-parametric test results for the deterministic profit-maximization test (Eq. (1)) are reported in Table 1. Given 18 years of data, the non-parametric tests involve 306 price-output comparisons. The number of profit-maximization violations for the individual farms ranged from 150 to 175, with a mean of 158.6 and a median of 158 violations. The standard deviation of violations was 5.0. All farms violated Varian's deterministic WAPM test.

Unlike the profit-maximization test, the number of cost-minimization comparisons varies by each farm. (The number of comparisons differs by farm because of the additional comparison in Eq. (2), $Y^s \geq Y^t$.) For the deterministic cost-minimization test, the number of comparisons per

farm ranged from a low of 29 to a high of 153, with a mean number of comparisons of 81.2 per farm (Table 1). The number of violations ranged from a low of 3 to a high of 84, with a mean of 22.9 and a median number of 19. Thus, as was the case with under profit-maximization, every farm violated the deterministic cost-minimization hypothesis.

For the profit-maximization case, 51.8% of the total profit comparisons were violated. For cost-minimization, 28.0% of the total cost comparisons resulted in violations. For the cost-minimization hypothesis, the percentage of violations out of total comparisons ranged from 2.9% to 65.2%. Although both hypotheses were violated for each farm, there were relatively fewer violations under the cost-minimization hypothesis than under the profit-maximization hypothesis.

3.2. Stochastic tests

The stochastic test of profit maximization (Eq. (3)) is reported in Table 1. Profit-maximization underage is defined as the magnitude of lost profit caused by profit maximization violations.

Table 1
Summary statistics for farm-level non-parametric analysis for 289 Kansas farms

Hypothesis	Mean	Median	Standard deviation	Minimum	Maximum
Deterministic profit-maximization violations	158.6	158	5.0	150	175
Cost comparisons	81.2	77	27.8	29	153
Deterministic cost-minimization violations	22.9	19	15.3	3	84
Cost-minimization violations divided by cost comparisons (%)	28.0	27.5	13.8	2.9	65.2
Stochastic profit maximization (%)	40.0	31.2	28.3	10.8	241.7
Stochastic cost minimization (%)	11.0	11.1	4.5	1.6	29.5
Deterministic profit maximization under non-regressive technical change	61.9	58	30.1	7	136
Cost comparisons under non-regressive technical change	29.0	25	17.8	3	110
Deterministic cost minimization under non-regressive technical change	8.7	8	6.2	0	37
Cost-minimization violations divided by cost comparisons under non-regressive technical change (%)	35.2	32.4	22.1	0	100.0
Stochastic profit maximization under non-regressive technical change (%)	25.6	20.5	20.1	6.2	167.2
Stochastic cost minimization under non-regressive technical change (%)	10.6	9.7	5.5	0	30

The magnitude of lower profits caused by profit-maximization violations (V_{ts}) was converted to percentages and averaged for each farm. The profit-maximization underage ranged from 10.8% to 241.7% with 75% of the farms having underage between 20% and 60%. The mean amount of underage across all 289 farms was 40.0%, with a standard deviation of 28.3% and a median of 31.2%. At a significance level of 10%, all 289 farms violated the profit-maximization hypothesis.

The results of the stochastic cost-minimization test (Eq. (4)) are presented in Table 1. The magnitude of higher costs caused by cost-minimization violations (C_{ts}) was converted to percentages and averaged for each farm. The overage ranged from 1.6% to 29.5% for the cost-minimization violations with a median of 11.1%. The average cost overage for 80% of the farms was between 6.5% and 18%. The average overage for the 289 farms was 11.0% and had a standard deviation of 4.5%. The results from the non-parametric analysis suggest that adherence to the cost-minimization hypothesis at a 5% level of significance occurred on 7 farms. At a level of significance of 10%, a total of 118 out of 289 farms (41%) did not violate the cost-minimization hypothesis. Using the classification system proposed by Ray and Bhadra (1993), in which overage of less than 10%

was classified as weakly violated, between 10 and 30% was moderately violated, and greater than 30% was strongly violated, we found that 118 farms weakly violated cost minimization, and the remaining 171 farms moderately violated cost minimization (Fig. 1). None of the farms strongly violated cost minimization. These results contrast with the findings of Ray and Bhadra that 90 out of 149 farms strongly violated cost minimization.

3.3. *Deterministic, monotonic, non-regressive, technical change*

A limitation of the non-parametric test is the assumption of constant technology in the above measures. A reason for violating the weak axiom of profit maximization may be technical change. Adherence to deterministic profit maximization under monotonic, non-regressive, technical change was examined using Eq. (5). Testing for profit-maximization violations under the assumption of non-regressive technical change reduced the number of pair-wise comparisons from 306 to 153. The number of violations of profit maximization under non-regressive technical change ranged from 7 to 136. The average number of violations was 61.9, with a standard deviation of 30.1 (Table 1) and a median of 58. Only 2.6% of the 289 farms had less than 10% of the maximum viola-

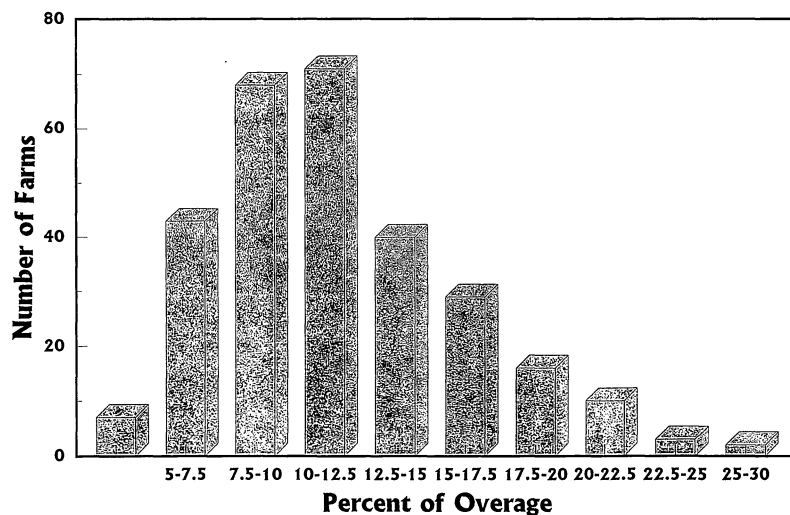


Fig. 1. Average cost-minimization overage for Kansas farms: 1973-1990.

tions. The number of farms that had less than 30% of the total violations was 103.

Adherence to deterministic cost minimization under monotonic, non-regressive, technical change was examined using Eq. (6). The average number of pair-wise comparisons for cost minimization was reduced from 81.2 to 29.0 by allowing non-regressive technical change. The number of cost comparisons per farms ranged from 3 to 110. The number of cost-minimization violations under non-regressive technical change ranged from 0 to 37. The average number of violations was 8.7, with a standard deviation of 6.2 (Table 1) and a median of 8. Ten farms had no cost-minimization violations under non-regressive technical change. The number of farms that had less than 10% of the maximum violations was 35 or 12.1%. The number of farms that had less than 30% of the maximum violations was 135 or 46.7%.

3.4. Stochastic, monotonic, non-regressive, technical change

Varian's goodness-of-fit tests also can be performed while allowing non-regressive technical change. The stochastic test of profit maximization under non-regressive technical change is reported in Table 1. Profit-maximization underage is defined as the magnitude of lost profit caused by profit-maximization violations. The levels of lower profits caused by profit maximization violations

were converted to percentages and averaged for each farm. The profit maximization underage ranged from 6.2% to 167.2%. The mean amount of underage across all 289 farms was 25.6% with a standard deviation of 20.1% and a median of 20.5%. At a significance level of 5%, all of the 289 farms violated the profit-maximization hypothesis. At a significance level of 10%, 13 farms did not violate the profit-maximization hypothesis under non-regressive technical change.

The results of the stochastic cost-minimization test under non-regressive technical change are presented in Table 1. The levels of higher costs caused by cost-minimization violations were converted to percentages and averaged for each farm. The cost overage ranged from 0.0% to 30.0%. The average overage was 10.6% for the 289 farms, with a standard deviation of 5.5% and a median of 9.7%. The results from the non-parametric analysis suggest that adherence to the cost-minimization hypothesis under non-regressive technical change at a 5% level of significance occurred on 42 farms. At a level of significance of 10%, a total of 151 out of 289 farms (52%) did not violate the cost-minimization hypothesis.

3.5. Relationship between the non-parametric tests

Further analysis was performed to examine the relationships between the non-parametric tests. Table 2 reports correlation coefficients between

Table 2
Correlation between non-parametric test results ^a

	DPM	CC	DCM	SPM	SCM	DPMTC	CCTC	DCMTC	SPMTC	SCMTC
DPM	1.00 *	-0.35 *	0.11	-0.42 *	-0.10	0.50 *	0.12 *	-0.04	-0.09	-0.26 *
CC		1.00 *	0.62 *	0.21 *	0.13 *	-0.14 *	0.44 *	0.29 *	0.04	0.06
DCM			1.00 *	-0.28 *	0.20 *	0.23 *	0.57 *	0.56 *	0 - .09	-0.02
SPM				1.00 *	0.18 *	-0.23 *	-0.10	-0.15 *	0.48 *	0.16 *
SCM					1.00 *	0.13 *	0.12 *	0.06	0.15 *	0.62 *
SPMTC						1.00 *	0.69 *	-0.04	0.50 *	-0.29 *
CCTC							1.00 *	0.33 *	0.44 *	-0.18 *
DCMTC								1.00 *	-0.17 *	0.22 *
SPMTC									1.00 *	-0.09
SCMTC										1.00 *

^a DPM, deterministic profit maximization; CC, cost comparisons; DCM, deterministic cost minimization; SPM, stochastic profit maximization; SCM, stochastic cost minimization; DPMTC, deterministic profit maximization under non-regressive technical change; CCTC, cost comparisons under non-regressive technical change; DCMTC, deterministic cost minimization under non-regressive technical change; SPMTC, stochastic profit maximization under non-regressive technical change; SCMTC, stochastic cost minimization under non-regressive technical change. * Significantly different from zero at the .05 level

different non-parametric tests. By examining the direction and the magnitude of the relationships, further information on the farmers' optimization behavior can be gathered. Those farms that had more cost-minimization violations tended to have, on average, larger cost overruns than those farms with fewer violations. This is illustrated by the positive correlation of 0.20 between the deterministic and the stochastic, non-parametric, cost-minimization tests.

Those farms that had more cost-minimization violations also tended to have more profit-maximization violations. This is in accordance with economic theory, in that profit maximization is a sufficient condition for cost minimization but not vice versa. Those farms that had large numbers of deterministic profit-maximization violations also tended to have smaller average foregone profits. A strong positive relationship also is found between the number of profit-maximization violations without technical change and with technical change (50.0%). A significant relationship did not exist between deterministic profit-maximization violations and cost-minimization violations either with or without the assumption of non-regressive technical change.

One of the concerns that may arise is that the number of comparisons is perfectly correlated with the number of cost-minimization violations. The strength of correlation between the number of cost-minimization violations and the number of comparisons is 62.0%. Although this is strong, it is not a perfect correlation, because it is significantly different than 1. Under technical change, the relationship between the number of violations and the number of comparisons made is 33.3%. Thus, although some relationship exists between the number of violations and the number of comparisons made, it would be difficult to argue that the cost-minimization hypothesis is being violated less than the profit-maximization hypothesis only because of the reduction in the number of comparisons.

An explanation for the results of this study may lie in the economic environment that farmers participated in during the 18 years of the study. High inflation, energy price shocks, volatile interest rates, and a changing policy environment could

have forced disequilibrium for a period of time, as farmers adjusted to the extreme instability. The non-parametric methodology involves a comparative statics approach. Thus, extreme shocks and the associated adjustment costs as farmers adapted to a new environment may have caused a temporary abandonment of normal behavioral motivation.

In addition, the farmer's aversion to risk may lead to an optimization hypothesis other than profit maximization. Farmers violated the cost-minimization hypothesis significantly less often than they did the profit-maximization hypothesis. This may provide some evidence that the profit-maximization hypothesis is less appropriate for modeling farmers' decision making than the cost-minimization hypothesis. Ray and Bhadra (1993) showed that when neither input prices nor quantities are random, farmers' risk aversion plays no role in the cost-minimization problem, although an unobserved technically efficient output is needed to conduct the test. Perhaps this is an explanation for fewer violations under cost minimization.

Finally, we can note that attempts to remove aggregation biases from non-parametric considerations of optimizing behavior failed to resolve perceived departures from cost minimization and profit maximization common in such studies, e.g. Chavas and Cox (1988), Fawson and Shumway (1988). In addition, the magnitude of the departures suggests that the violations cannot be explained easily as noisy data (see, for example, Lim and Shumway, 1992a). Our results suggest that U.S. farmers appear more likely to minimize costs than Indian farmers (Ray and Bhadra, 1993). These findings may reflect the presence of uncertainty or the aggregation of outputs in the empirical analysis.

4. Conclusions

This article applied Varian's non-parametric analysis of technology and production behavior to a sample of 289 individual Kansas farms for the period 1973 through 1990. Strict adherence to the joint hypotheses of profit-maximization and cost-minimization was rejected. On average, 51.8% of

the total comparisons resulted in profit-maximization violations, and 28.0% of the total comparisons resulted in cost-minimization violations. A stochastic test, which allows for measurement error, was used to examine adherence to profit maximization and cost minimization. The results of the stochastic test suggested that adherence to profit maximization was rejected on all 289 farms at the 10% level of significance. Cost minimization was rejected on 171 farms. By allowing non-regressive, monotonic, technical change, the number of farms failing the stochastic test was reduced. Thirteen farms adhered to the profit-maximization hypothesis, and 151 farms adhered to the cost-minimization hypothesis at the 10% level of significance. This sample of Kansas farmers seems to operate with stronger cost-minimizing motivations than profit-maximizing ones.

This study differs from previous analyses in that individual agents are observed rather than using aggregated data. Production economics assumes that individual agents make optimization decisions subject to their constraints. Aggregation may introduce error that could influence non-parametric tests when performed at the aggregate level. In addition, this study provides a methodology for non-parametric cost-minimization tests for a multiple-output firm. This study shows that significant violations of optimizing behavior occur at the farm level. Results from non-parametric studies can be used prior to parametric analysis to investigate certain hypotheses and complement traditional parametric procedures of production analysis.

The results of this study are not unexpected, particularly in view of the farm economy over the 18 years of the study. Different economic environments could have forced necessary changes in behavioral motivations in agricultural production. In agricultural production, the uncertainty associated with output quantities and prices is much greater than that associated with input quantities and prices. Thus, our finding that violations of deterministic profit maximization occur more often than violations of cost minimization is not surprising. One avenue of future research would involve extending the non-parametric methodology to production under uncertainty.

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