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Production economics

A NONPARAMETRIC INVESTIGATION OF AGRICULTURAL PRODUCTION BEHAVIOR FOR U.S. SUBREGIONS

by

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Abstract

This research provides an empirical application of nonparametric techniques to determine whether agricultural production behavior in the U.S. and ten farm production regions over the period 1939 to 1982 has been inconsistent with the joint hypothesis of profit maximization, convex technology, and monotonic nonregressive technical change.

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A NONPARAMETRIC INVESTIGATION OF AGRICULTURAL PRODUCTION BEHAVIOR FOR U.S. SUBREGIONS

Nonparametric investigation of the consistency between theoretical constructs of production analysis and observed production behavior has gained renewed interest in econometric literature. Early work by Hanoch and Rothschild (1972), Afriat (1972), and Diewert and Parkan (1979), which provided a foundation for examining the productive efficiency exhibited by observed behavior prior to estimation of parametric models, has been extended recently by Varian (1984) and Chavas and Cox (1987). Nonparametric techniques are recognized as potentially powerful tools for stimulating parametric model development and nonparametric testing of data consistency with theoretic structures is obtained at low cost. Yet, the applied literature has seen few applications of nonparametric techniques. Their absence in applied production literature is most likely due to difficulty in dealing with nonstationary technology which is commonly associated with production systems over time.

This paper reports an empirical application of nonparametric techniques to determine whether agricultural production behavior in the U.S. and ten farm production regions over the period 1939 to 1982 has been inconsistent with the joint hypothesis of profit maximization, convex technology, and monotonic nonregressive technical change.[1] This joint hypothesis is of particular interest because it characterizes commonly accepted maintained hypotheses which underly development of production system models.

The first section provides an overview of a nonparametric methodology for examining consistency of observed production behavior with the behavioral postulate of profit maximization under nonregressive technical change. This section, which briefly reviews and follows Varian, is included for expositional and pedagogic completeness. The second section presents and summarizes the empirical application of the proposed methodology to each of the ten production regions (which collectively comprise the contiguous 48 states) and to the continental U.S.

Nonparametric Methodology -- Consistency with Profit Maximization

Define the netput vector for period i as $Y^i = (y_1^i, \ldots, y_n^i)'$, $i = 1, \ldots, m$, where y_k^i is an output if $y_k^i > 0$ and an input if $y_k^i < 0$. In addition, define the price vector $P^i = (p_1^i, \ldots, p_n^i)$, where each $p_k^i \geq 0$ denotes the price associated with each respective element of Y^i.

The technology set T^i associated with the netput vector Y^i in period i can be represented in terms of a two-dimensional diagram by letting $Y^i = (y_1^i, y_2^i)$, where y_1 is arbitrarily designated as the output and y_2 as the input (with the i superscript dropped to reduce notational clutter). This is represented in Figure 1. All points in T^i reflect feasible combinations of (y_1, y_2) given technology in period i. All points on the frontier reflect efficient production bundles in the sense that they represent the maximum output obtainable for a given level of input usage.

If producers maximize profit and the technology structure is constant over the sample, it is possible to map a discrete approximation to the frontier of the technology set T under the assumption that the producer transforms inputs into commodities along the efficiency frontier. Defining profit at observation i as the inner product of the netput vector Y^i and its associated price vector P^i, consistency with profit maximizing behavior requires $P^iY^i \geq P^iY^j$ for all i, j = 1,...,m. A figurative mapping of isoprofit lines associated with price vector P^i and its profit maximizing production bundle Y^i into two-dimensional real space (R^2) is demonstrated in

Figure 2 for i = 1,2,3, where $\Phi^i = P^iY^i$. In this simple case it is apparent that as m increases (i.e., the number of isoprofit lines increases) and as netput bundles associated with isoprofit lines provide extensive coverage of the feasible technology frontier, a discrete approximation to the continuous frontier depicted in Figure 2 begins to take shape if the profit maximizing condition is satisfied. Varian terms the profit-maximizing condition (i.e., $P^iY^i \geq P^iY^j$ for all i,j) the weak axiom of profit maximization. He demonstrates that its satisfaction guarantees the existence of a closed, convex, negative monotonic production set T. These properties are easily observed in our simple figurative demonstration.

This methodology allows us to examine consistency of observed behavior with profit maximization postulates under two strict assumptions. First, the data must provide robust coverage of the technologically feasible production region in order to gain any relevant insight into the convexity of the production set T.[2] Second, the technology must remain constant to rule out movement in the frontier of the production set. For most empirical applications with time series data, these assumptions would seem to rule out nonparametric investigation of the production technology. However, application of the weak axiom of profit maximization to time series data does allow investigation of inconsistencies between observed netput production and price vectors and the joint hypothesis of profit maximizing behavior, monotonic nonregressive technical change and a convex technology set.[3]

Inconsistency with the joint hypothesis is investigated by constructing a binary matrix $\Pi(i,j)$ defined as follows:

$$\Pi(i,j) = \begin{cases} 1 & \text{if} \quad P^i\, Y^i \geq P^i\, Y^j \\ 0 & \text{if} \quad P^i\, Y^i < P^i\, Y^j \end{cases}$$

where, $i,j = 1,\ldots,m$ denote production periods. Interpretation of the resulting binary matrix values is demonstrated in the four cases presented below.[4]

Case 1:

Symmetry of $\Pi(i,j)$ with ones above and below the diagonal would occur if the following were demonstrated by the data: $P^iY^i \geq P^iY^j$ and $P^jY^j \geq P^jY^i$. For a figurative demonstration in two-space let point 'i' in Figure 3 represent a two-tuple production bundle (Y^i) chosen in period $i < j$. Symmetry of ones in $\Pi(i,j)$ implies that period j's two-tuple production bundle must be in region A, B or C; in addition, 'i' must be in the lower set formed by the isoprofit line in period j through period j's production bundle (i.e., $P^jY^j > P^jY^i$). The hatched region in Figure 3 represents the lower set created by the isoprofit line in period j through period j's production bundle (assumed to be in region B for demonstration purposes only).[5] Further, profit in period j would have been decreased if a production bundle chosen under a prior technology (Y^i) had been selected again in period j. If period j's production bundle is in region A or B, Case 1 behavior does not allow rejection of our joint hypothesis since the chosen bundle in each period yielded a higher profit in that period than an alternative bundle from a prior period and is not inconsistent with a monotonic, expanding convex technology frontier. If period j's production bundle is in region C, however, profit maximization would be inconsistent with monotonic nonregressive technical change or a convex technology set since period j's observed netput bundle would lie in the interior of a prior period's convex technology set (represented by the ray lines which define the boundary of region C).[6] Production behavior in region C would suggest rejection of the joint hypothesis.

Case 2:

Asymmetry of $\Pi(i,j)$ with zero above the diagonal and one below the diagonal would occur if the following were demonstrated by the data: $P^iY^i < P^iY^j$ and $P^jY^j \geq P^jY^i$. With point 'i' in Figure 4 defined as before for period $i < j$, this asymmetric case in $\Pi(i,j)$ implies that: (a) period j's two-tuple production bundle must be in region A; and (b) 'i' must be in the lower set formed by the isoprofit line in period j through period j's production bundle, (i.e., profit in period j would have been decreased if a production bundle chosen under a prior technology (Y^i) had been chosen again in period j). Case 2 behavior does not allow rejection of the joint hypothesis since observed netput and price vectors associated with observations i and j are not inconsistent with profit maximization, monotonic nonregressive technical change and a convex technology set.

Case 3:

Asymmetry of $\Pi(i,j)$ with one above the diagonal and zero below the diagonal would occur if the data yielded: $P^iY^i \geq P^iY^j$ and $P^jY^j < P^jY^i$. With point 'i' in Figure 5 as before in period $i < j$, this asymmetric case in $\Pi(i,j)$ implies that period j's two-tuple production bundle must be in regions A, B, or C; in addition 'i' cannot be in the lower set produced by the isoprofit line in period j through period j's production bundle. Case 3 behavior suggests that profit could have been increased by using a production bundle chosen under a previous technology. This behavior would mean that (a) profit was not maximized and/or (b) a previous production technology was eliminated from the feasible production set. This would lead to the rejection of our joint hypothesis since profit maximization in period j would necessarily imply intersecting production technologies if period j's chosen production bundle was in regions A or B (since 'i' would be eliminated from period j's feasible production set), and regressive technical change if period j's chosen production bundle was in region C (because more output could have been realized in period j if a prior period's feasible production technology set had been available).

Case 4:

Symmetry of $\Pi(i,j)$ with zeros above and below the diagonal would occur if the following were demonstrated by the data: $p^i y^i < p^i y^j$ and $p^j y^j < p^j y^i$. With point 'i' in Figure 6 as before in period $i < j$, symmetry of zeros in $\Pi(i,j)$ implies that period j's two-tuple production bundle must be in region A, and 'i' cannot be in the lower set produced by the isoprofit line in period j through period j's production bundle. In general terms, profit in period j could have been increased by using a production bundle chosen under a prior technology with the same possible interpretations as in Case 3. This would lead to rejection of our joint hypothesis since profit maximization in period j would necessarily imply intersecting production technologies.

Empirical Application

Annual data for the period 1939-1982 for each of ten regions and the continental U.S. were obtained from Agricultural Statistics (U.S.D.A., 1939-1983) and unpublished data provided by the Economic Research Service (ERS). The latter are used by the ERS to prepare the annual series Economic Indicators of the Farm Sector: Production and Efficiency Statistics (U.S.D.A., 1986). Except for labor, quantity data for the netput groups were obtained from the unpublished data, and the price data were obtained from Agricultural Statistics. The quantity data for labor (number of farm workers) were also taken from Agricultural Statistics. Quantity and price indices for outputs and inputs were constructed by applying a Tornqvist aggregation procedure. The data series represent an exhaustive measurement of outputs produced and inputs used in commercial production agriculture within each geographic entity. States associated with the regional classification are presented in Figure 7.

Empirical results for each region and the U.S., using a twelve-output six-input net bundle, are summarized in table 1. Column headings designated Cases 1 through 4 are the proportion of observations falling within each possible case associated with the profit maximization postulate in the set $[(i < j)]$. Recall that all observations which fall in cases 3 and 4 document behavior inconsistent with the joint hypothesis of profit maximization, convex technology and nonregressive technical change.

The largest number of observations that violate the joint hypothesis fall into Case 3 and range from 3.1% to 21.1% of the total observations for individual regions. No more than 4.9% of observations fall into Case 4 in any region. The Appalachian States Region contains the largest total number of violations (26.0%) while the Northern Plains States Region is second with 15.8%. Using a box plot procedure, violations in the Appalachian States Region would be considered as outliers.[7] Elimination of this region from the remaining set would reduce the maximum percent of total observations, over the production regions, which are inconsistent with the joint hypothesis to 15.0% for Case 3 and 1.7% for Case 4.

The fewest violations occur in the Pacific States Region (3.1%) and the Mountain States Region (5.8%). When all regions are considered jointly in the total U.S. data (contiguous 48 states) 6.2% of the observations are found to be inconsistent with the joint hypothesis. As a comparison, the median percent of violations over the ten regions is 10.85%. Geographic aggregation appears to both hide geographic variability and reduce the total magnitude of departures from the joint hypothesis.

Inconsistency with the joint hypothesis was also investigated using an aggregate-output six-input netput bundle, (the output index was obtained using a Tornqvist aggregation procedure). Empirical results from the aggregated output data are summarized in table 2. The results are not significantly affected by aggregation of the outputs; however, they do indicate a tendency to reduce the proportion of observations which are inconsistent with the joint hypothesis. Motivation for aggregating the output series was in part due to a desire to assess the number of Case 1 observations which are inconsistent with the joint hypothesis; this is not easily done with the multiple-output series. Aggregate output data revealed that very few observations satisfied the Case 1 criterion that was inconsistent with the joint hypothesis.

Using the aggregate-output six input netput bundle the fewest violations occur in the Pacific States Region (3.0%) and the Mountain States Region (5.2%). The largest number of observations that violate the joint hypothesis are again the Appalachian States Region (19.7%) and the Northern Plains States Region (15.1%). Although only 5.0% of observations violate the nonparametric test of the joint hypothesis when aggregate U.S. (contiguous 48 states) data are used, the median percent of violations over the ten regions is 9.45%. Again, the effect of geographically aggregating production data is both to hide the geographic variability and to reduce the total magnitude of departures from the joint hypothesis.

Summary

Inconsistencies with the joint hypothesis of profit maximization, monotonic nonregressive technical change, and a convex technology set were observed. Unfortunately, nonparametric tests do not provide an inferencing mechanism that allows a probability to be attached to rejection of a null hypothesis. This drawback, however, should not dilute the informational content of the nonparametric approach. The results of this nonparametric investigation document considerable differences in observed agricultural production behavior among regions of the U.S. and suggest greater apparent inconsistencies with the joint hypothesis when using regional data than when using national data. In addition, results strongly suggest caution in maintaining the joint hypothesis in estimation of agricultural production systems. The insights provided by nonparametric analysis as a heuristic tool should prove a valuable asset to conscientious efforts aimed at improving parametric modeling of production systems which are consistent with observed production behavior.

Footnotes

[1] Monotonic nonregressive technical change referred to in the joint hypothesis implies that any technology used in production period i is available in production period j for all $i<j$.

[2] By robust coverage we are referring to a large number of observed netput vectors distributed along the frontier of the feasible production set.

[3] This joint hypothesis (i.e., that the technologically feasible production set is convex, production technology j in year t is available to the producer in year t+k, k>0, and first-order conditions for profit maximization are satisfied) is frequently maintained when estimating parametric models of production systems.

[4] The i's and j's in $\Pi(i,j)$ are place holders for observation periods which allow us to assign a binary value to the matrix for all combinations of observations in the data. The order of i's and j's become important only if we are interested in interpreting <u>specific</u> production periods which produce asymmetric effects on the matrix $\Pi(i,j)$. For the case $i=j$ the value of $\Pi(i,j)=1$; this special case is ignored in discussion of properties of the binary matrix because we can't infer anything about consistency with the joint hypothesis at a point in time relative to itself. Therefore, interpretation of the matrix outlined in Cases 1 to 4 are in reference to visual properties of the constructed square binary matrix above and below the diagonal.

[5] To reduce clutter in subsequent figures, the concept of the "lower set" is not demonstrated.

[6] If production is in region A or B we cannot reject the hypothesis of a convex, monotonically nondecreasing production technology set since the boundary of region C defines the boundary of the convex technology set which contains the netput bundle from period i. If period j's production

bundle (i<j) is in region C then the production technology set for period j may be convex, but if it is, we would have to conclude that a previously available technology (i) is no longer available in period j. If, on the other hand, we assumed that there was no regressive technical change, then period i's feasible production technology set could not have been convex. In addition, under the two cases outlined above, period j production in region C could not have been a profit maximizing bundle since the condition $p^jy^j > p^jy^i$ implies that period j's isoprofit line is steeper than the rayline through the origin and period i's netput bundle.

[7] The box plot methodology is a heuristic designed to detect outliers based upon the interquartile range associated with a set of data values (see Tukey, 1977).

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FIGURE 1.

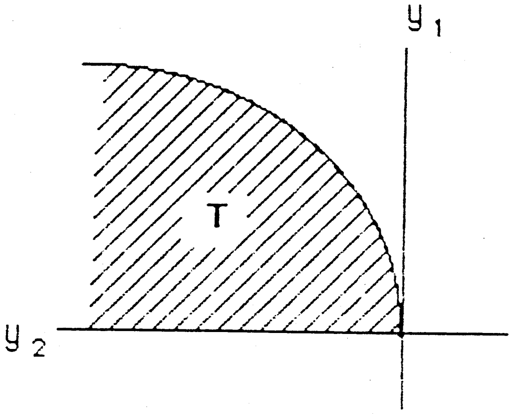


FIGURE 2.

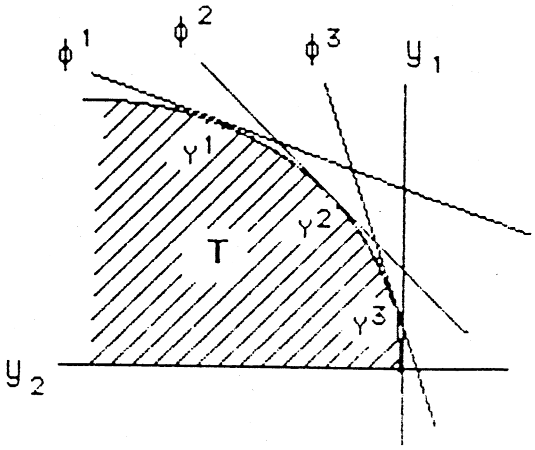


FIGURE 3.

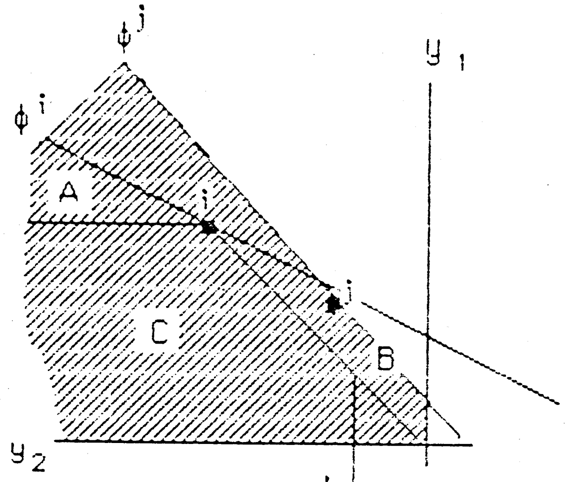


FIGURE 4.

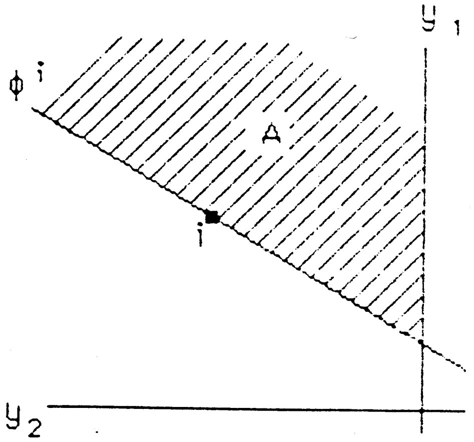


FIGURE 5.

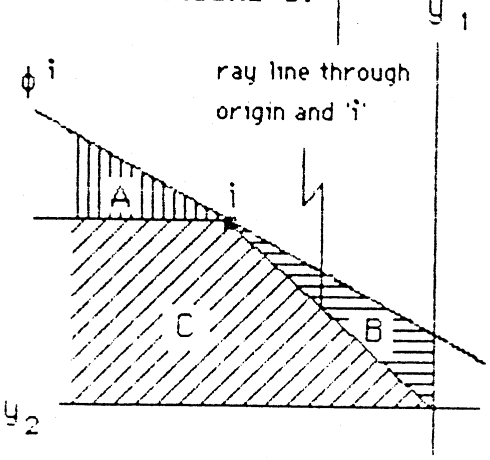


FIGURE 6.

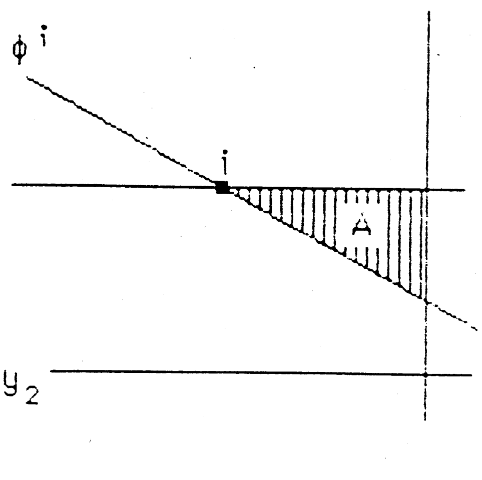
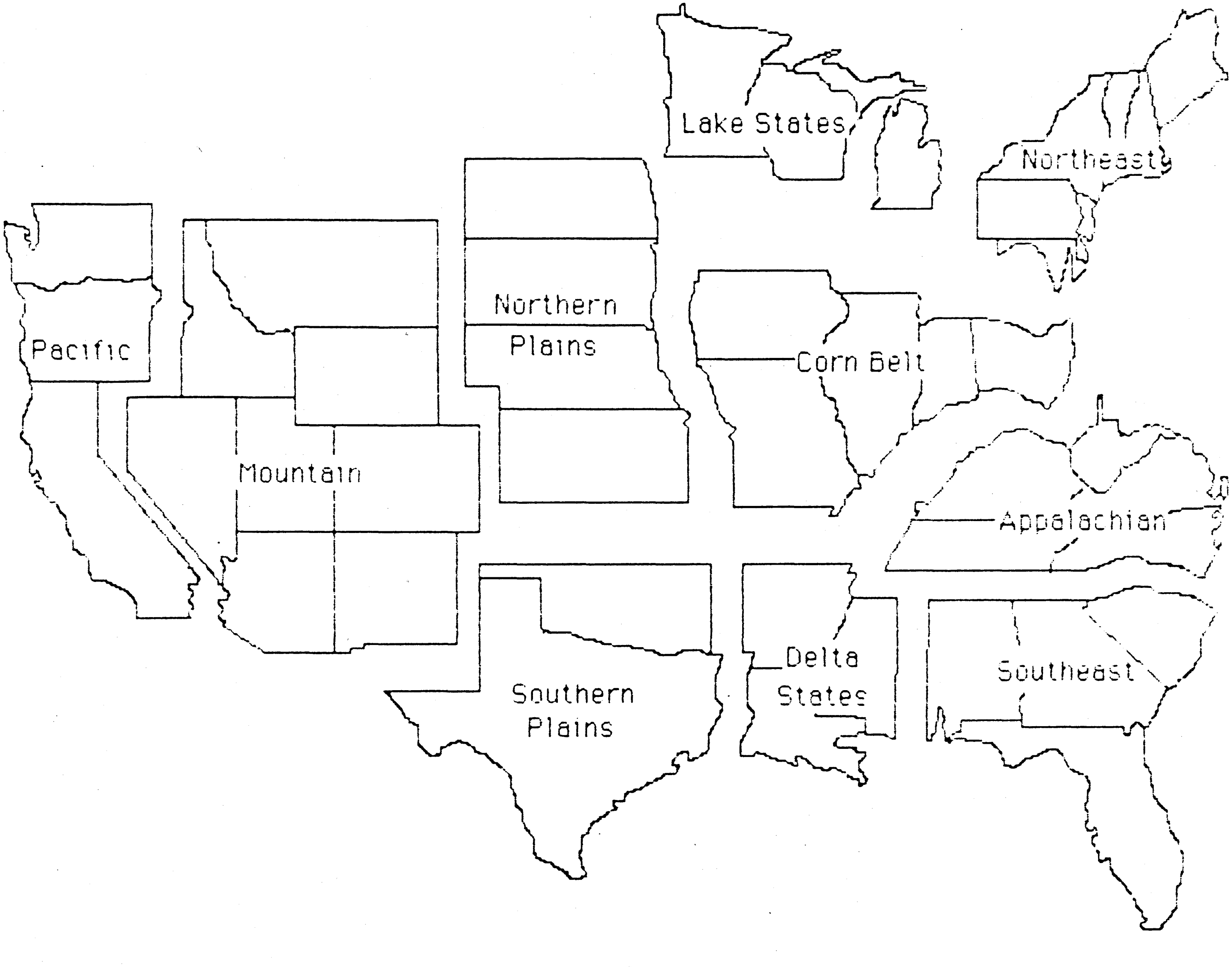


Figure 7.



FARM PRODUCTION REGIONS

Table 1. Percent of Observations Satisfying Each Nonparametric Case.
(Twelve-Output Six-Input Netput Bundle)

	Not inconsistent with joint hypothesis			Inconsistent with joint hypothesis		
Production Region	Case 1	Case 2	Total	Case 3	Case 4	Total
1. Northeastern States	2.7	85.5	88.2	11.0	0.8	11.8
2. Lake States	5.7	83.9	89.6	10.0	0.4	10.4
3. Corn Belt States	6.8	83.4	90.2	9.6	0.2	9.8
4. Northern Plains States	3.0	81.2	84.2	15.0	0.8	15.8
5. Appalachian States	10.8	63.2	74.0	21.1	4.9	26.0
6. Southeastern States	3.5	85.8	89.3	9.0	1.7	10.7
7. Delta States	2.3	86.7	89.0	9.9	1.1	11.0
8. Southern Plains States	8.2	79.0	87.2	12.0	0.8	12.8
9. Mountain States	4.2	90.0	94.2	5.3	0.5	5.8
10. Pacific States	2.8	94.1	96.9	3.1	0.0	3.1
Continental U.S.	4.9	88.9	93.8	5.5	0.7	6.2

Table 2. Percent of Observations Satisfying Each Nonparametric Case.
(One-Output Six-Input Netput Bundle)

	Not inconsistent with joint hypothesis			Inconsistent with joint hypothesis			
Production Region	Case 1[a]	Case 2	Total	Case 1[b]	Case 3	Case 4	Total
1. Northeastern States	1.3	85.6	86.9	0.4	12.1	0.6	13.1
2. Lake States	4.3	86.1	90.4	0.1	9.4	0.1	9.6
3. Corn Belt States	4.2	86.5	90.7	0.0	9.2	0.1	9.3
4. Northern Plains States	1.8	83.1	84.9	0.1	14.4	0.6	15.1
5. Appalachian States	16.8	63.5	80.3	0.0	18.9	0.8	19.7
6. Southeastern States	6.1	85.4	91.1	0.0	8.0	0.5	8.5
7. Delta States	2.6	88.5	91.1	0.0	8.7	0.2	8.9
8. Southern Plains State	3.4	84.0	87.4	1.2	11.1	0.3	12.6
9. Mountain States	1.6	93.2	94.8	0.0	5.0	0.2	5.2
10. Pacific States	1.7	95.3	97.0	0.0	3.0	0.0	3.0
Continental U.S.	3.7	91.3	95.0	0.0	4.7	0.3	5.0

[a] The percent of total observations which belong to Case 1 and are not inconsistent with the joint hypothesis.

[b] The percent of total observations which belong to Case 1 and are inconsistent with the joint hypothesis.