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Statistical Decision Theory in a Macro Simulation Model: Feed Grain Sector

By Fred C. White and W. C. McArthur

A method for taking uncertainty into account when formulating aggregate agricultural policies is applied to the feed grain program. The impact of alternative feed grain programs on net farm income, Government payments, and feed grain production in the Southeastern Coastal Plains is shown. A model is developed to explain planted acreages of the major competing crops. The effects of alternative feed grain programs are evaluated using Monte Carlo simulation to account for random variation. Confidence intervals are placed on estimates of income and production resulting from selected feed grain programs.

Keywords: Agricultural policies, Farm income, Methodology, Production, Simulation, Uncertainty.

Policymakers have at their disposal a wide array of policy instruments capable of affecting U.S. agricultural production and farm income. Considerable progress has been made in constructing aggregative models which can be used to forecast production changes resulting from use of these policy instruments. Results of these models have been severely limited by the nature of their forecasts. For a given combination of expected prices and Government programs, these models provide a single estimate of expected production response. Although this estimate is an important ingredient in decision-making, other valuable information is ignored.

More specifically, risk and uncertainty have not been incorporated into these models. As a result, no estimate is made of the distributions of production or farm income. Such distributions would show the probability of obtaining a specified level of production or income. Information on such probability distributions could aid policymakers in choosing among alternative policies. For instance, programs with similar expected levels of net farm income may have different probabilities of producing an unacceptably low level of net farm income.

Objectives

This study illustrates a method for developing distributions for aggregate production response and aggregate farm income and reports some empirical results of application of the method to feed grain production in the Southeastern Coastal Plains. The procedure for developing these distributions is as follows:

(1) Develop a system of simultaneous equations which can explain the production response of feed grains and competing crops to policy alternatives.

(2) Develop distributions of aggregate feed grain production and farm income under specified policy alternatives and expected price alternatives. Specifically, the impact of alternative levels of Government diversion requirements upon feed grain production, farm income, and cost of Government programs is analyzed.

Study Area

The Southeastern Coastal Plains are characterized by a diversified agriculture. Major crops include cotton, corn, soybeans, peanuts, and tobacco. The area also includes a substantial acreage of wheat and oats. Barley acreage is relatively small. Pasture crops and several minor crops occupy the rest of the cropland in this area.

Determinants of Farm Income

Net farm income derived from feed grains and related crops depends on planted acreage, yields, prices, Government payments, and production costs.

Yields and prices determine per acre gross income derived from farm marketings. Economic, technological, and institutional factors are responsible for any major trends in yields. Expected yields are based on these trends. Much of the year-to-year variation in yields is due to influences of weather. Expected prices used in this analysis are based on estimates developed for supply response research by the Aggregate Production Analysis Team (APAT) in the former Farm Production Economics Division, now the Commodity Economics Division, ERS. Actual price may deviate from expected price for any reason that shifts supply and demand of the various crops.

Economic and institutional forces which affect farmers' planting plans are major factors that determine number of acres to be planted. Certain other factors, such as weather at time of planting, may be largely responsible for deviations from expected planted acreage. A major portion of this analysis involves construction of an econometric model to explain economic factors which influence acreage planted. The nature of this model is discussed in the next section.

Government payments constitute an important component of net farm income for this area. Since these payments are based on projected yields, market price, and parity, there is considerable leeway for adjustments in the rate. Requirements to participate in the program can vary over a wide range of values. Payments may also be made for voluntary diversion above minimum requirements. Thus, there are many policy alternatives which can have an effect on net farm income.

Cost of production for different crops also influences net income. Budgets by enterprise and size of farm have been estimated for the area (*3*). These costs were assumed to apply throughout the analysis.

Planted Acreage Model

Almost all feed grain in the area is produced on commercial farms which have several alternative enterprises for which the cropland can be used. Therefore, it seems likely that farmers would respond to economic factors which change their income situation. It is hypothesized that farmers would respond to higher expected net returns by increasing their planted acreage. Actual response is restricted by the availability of land, labor, and capital.

Present Government programs for cotton, tobacco, and peanuts make these crops more profitable than feed grains.[1] Their acreage, however, is fairly well determined by Government programs. Soybeans, wheat, barley, and oats compete with feed grains for the remaining cropland acreage. As net returns from these competing crops rise, substitution for feed grain acreage is expected to occur.

[1] Budgets developed by McArthur (*3*) show relative profitability of alternative enterprises.

The Variables

Notations included in the planted acreage model are as follows:

Variables associated with commodity *i*:

A_i = number of acres planted
Y_i = yields in bushels per acre
P_i = expected price per bushel
PC_i = variable production cost per acre
NR_i = net returns to overhead, management, and fixed resources per acre excluding Government payments ($P_i \times Y_i - PC_i$)
DP_i = Government diversion payment rate for feed grain set-aside
VP_i = Government voluntary diversion payment rate for set-aside above minimum requirement
MN_i = minimum proportion of allotted base which must be set aside to participate in Government program

Subscripts (commodity):

FG = feed grains
SA = feed grain set-aside
SB = soybeans
WH = wheat
NP = nonprogram commodities (barley and oats)
TL = combined acreage of feed grains, soybeans, wheat, nonprogram crops, and feed grain set-aside

The Six-Equation Model

Equations fitted:

(1) $A_{FG} = f(A_{SA}; NR_{FG}, NR_{SB}, NR_{WH}, NR_{NP})$

(2) $A_{SA} = f(A_{FG}; MN_{FG}, DP_{FG}, VP_{FG}, NR_{SB})$

(3) $A_{SB} = f(A_{FG}, A_{SA}; NR_{SB}, NR_{WH}, NR_{NP})$

(4) $A_{WH} = f(A_{SA}; NR_{WH}, NR_{FG}, NR_{SB}, NR_{NP})$

$$(5)\ A_{NP} = f(A_{SA}; NR_{NP}, NR_{FG}, NR_{SB}, NR_{WH})$$

These equations depict the interrelationships hypothesized to exist in the feed grain planted acreage model. Endogenous relationships are expected to exist (1) among feed grain and soybean acreages and feed grain set-aside acreage and (2) among feed grain set-aside acreage and wheat and nonprogram commodity acreages. In addition, planted acreage of a commodity is expected to be related to net returns of that commodity and major competing commodities. Set-aside acreage is expected to be exogenously related to Government policy alternatives.

Equation (6) is an identity which constrains the system on planted acreage.

$$(6)\ A_{TL} = A_{FG} + A_{SA} + A_{SB} + A_{WH} + A_{NP}$$

Total acreage is equal to cropland in the area, excluding acreage of peanuts, tobacco, cotton, and set-aside acreage in nonfeed grain programs. Thus, it is the sum of acreages in feed grains, soybeans, wheat, nonprogram crops, and feed grain set-aside.

Data for the Planted Acreage Model

Data from linear programming results were used to estimate the parameters of the planted acreage model. The linear programming model used in the analysis is an aggregate crop production model designed primarily to make estimates of the impact of Government commodity programs and commodity price changes on the acreage and production of major crops for 1 or 2 years in the future. The units of analysis include aggregates of two farm-size situations within the geographic production area.

The basic linear programming model was made up of a set of expected prices for 1971 and the 1971 feed grain program. Solution of this model showing planted acreage of each commodity was used as one observation in the regression analysis. Then the expected price of one commodity was incremented by $0.05 over a range applicable to that commodity. The solution obtained with each new price produced an additional observation on planted acreages by commodity to be used in the regression analysis. In turn, expected prices were incremented for each commodity. While any one price was varying, every other price was held constant at its expected level.

In addition, observations for the regression analysis were generated from linear programming by incrementing Government policy parameters. Program alternatives underlying the analysis include a required set-aside of 25 to 30 percent of the feed grain base and 85 percent of the wheat allotment. Barley was excluded from the feed grain program. Voluntary diversion of up to 20 percent of the feed grain base and 75 percent of the domestic wheat allotment was allowed. Set-aside rates used in the analysis were $0.25 to $0.40 per bushel for feed grain and $1.66 per bushel for wheat. The analysis also included variable payment rates for voluntary feed grain set-aside ranging from $0.20 to $0.52 per bushel.

Twenty-eight observations for the regression analysis were produced from the linear programming model. Each observation showed estimates of equilibrium values for planted acreages of feed grain, soybeans, wheat, and nonprogram commodities and feed grain set-aside acreage given a specified set of expected prices and specified Government feed grain program.

Statistical Estimates of the Planted Acreage Model

Table 1 shows the planted acreage equations estimated statistically by two-stage least squares. Most coefficients are significantly different from zero, and all signs of the coefficients are those predicted by theory. These equations explained from 56 to 98 percent of the variation in the sample data on planted acreages.

The following conclusions can be drawn from the equation of feed grain acreage response. First, an increase in expected net returns of feed grains has a statistically significant effect in increasing feed grain acreage. Second, a decrease in net returns of soybeans and wheat is associated with an increase in feed grain acreage. A given decrease in net returns of soybeans is associated with a larger increase in feed grain acreage than the same reduction in net returns of wheat. Finally, the Government's feed grain program also has a significant influence on feed grain production. As feed grain set-aside acreage increases, feed grain production decreases.

Set-aside acreage under the feed grain pro-

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Table 1. Simultaneous equations explaining planted acres of feed grains, soybeans, wheat, and nonprogram crops and acres of feed grain set-aside

Variable	Planted acres of feed grains	Acres of feed grain set-aside	Planted acres of soybeans	Planted acres of wheat	Planted acres of nonprogram crops
Constant	1,332.0	168.0	2,512.0	242.4	169.9
Endogenous variables:					
Acres of:					
Feed grains		− 0.087 [a](− 2.189)	− 0.799 (− 24.01)		
Feed grain set-aside	− 0.457 (− 1.637)		− 0.7252 (− 11.32)	− 0.1006 (− 1.795)	− 0.043 (− 1.821)
Exogenous variables:					
Net revenue of:					
Feed grains	8.341 (5.881)			− 1.098 (− 3.873)	− 0.223 (− 1.874)
Soybeans	− 8.605 (− 4.126)	− 3.742 (− 6.233)	2.074 (5.181)	− 0.798 (− 1.196)	− 0.353 (− 2.015)
Wheat	− 0.331 (− 1.360)			0.089 (1.669)	
Nonprogram crops				− 0.481 (− 1.448)	1.642 (12.94)
Minimum requirement for feed grain set-aside		782.0 (5.764)			
Payment rate for feed grain set-aside		631.1 (6.799)			
Voluntary diversion payment rate for feed grains		148.5 (6.757)			
R^2	0.721	0.879	0.979	0.564	0.891

[a]Numbers in parentheses are t-values.

gram depends on program payments and requirements and on profitability of not participating. Larger set-aside payments per acre result in more set-aside acreage. An increase in the proportion of feed grain base required for set-aside to participate in the Government program results in a net increase in set-aside acreage. An increase in Government payments for voluntary diversion above the minimum requirement for participation results in an increase in set-aside acreage. Highly profitable soybean or feed grain production outside Government programs results in less participation in the feed grain program.

Each equation explaining planted acreage of soybeans, wheat, and nonprogram commodities shows a positive relationship between planted acreage of the commodity and its net returns. In other words, an increase in the net returns of a product relative to net returns of product substitutes results in an increase in production of the commodity in question. Acreages of all three commodities are endogenously related to feed grain set-aside acreage. In addition, soybean acreage is endogenously related to feed grain acreage. Acreages of wheat and nonprogram commodities are competitive with one another, as well as with feed grains and soybeans.

The planted acreage model, equations (1) to (6), forms the basis for estimating variability of production and farm income. The following section describes how the planted acreage model is combined with other information to develop probability distributions for production and farm income.

Monte Carlo Simulation

Because of the interaction of many variables and the complexity of the system, it is extremely difficult to develop distributions of net farm income, feed grain production, and feed grain set-aside acreage by standard analytical techniques.[2] However, Monte Carlo—stochastic simulation—methods can be used to determine these distributions.

[2]The study by White and Eidman (5) presents one method for developing these distributions by standard analytical techniques.

Simulating Outcomes

Simulated statistics are generated by supplying sets of random numbers (Z) into the system under study (*4*). Statistics simulated by use of these sets of random numbers can possess desired characteristics of specified means, variances, and covariances. Through repeated sampling of system outcomes from input of these random numbers, behavior of the system can be analyzed. More specifically, distributions of the desired statistics can be developed.

Generation of a series of m outcomes (prices and yields) for n events (commodities) for a given mean vector and variance-covariance matrix may be described by the following equation:

$$X_i^* = \overline{X} + CZ_i \qquad i = 1 \text{ to } m$$

where X^* is an $(n \times 1)$ vector of generated outcomes, $\overline{X}$ is an $(n \times 1)$ vector of expected outcomes, C is an $(n \times n)$ matrix of coefficients, and Z is an $(n \times 1)$ vector of random normal deviates. The C matrix, derived from the variance-covariance matrix, insures the correlation of events at the desired level. Development of the C matrix is presented in the appendix.

Using the procedure for correlating events given above and historical data, many prices and yields were generated for each commodity so that the effect of various Government policies could be studied. Since the correlating procedure used historical data, the correlation matrices for generated prices and yields were similar to the correlation matrices for the historical data.[3] Generated prices and yields of feed grains, soybeans, wheat, and nonprogram crops were used to determine production and farm income. Mean and variance-covariance matrices for the specified commodities derived from 1962-71 data are shown in table 2. The only negative relationship in yields has been between feed grains and wheat. Yields of wheat and nonprogram commodities have historically been closely related. Also, prices of feed grains and soybeans have been closely related.

The system of simultaneous equations in table 1 can be solved to determine planted acreage of each crop and set-aside acreage of feed grain. In using this system of equations for analytical purposes, the standard procedure is to insert values for the predetermined variables within the system and to simultaneously estimate all the endogenous variables. Methods for solving systems of equations are presented in Friedman and Foote (*2*, pp. 81-85).

For this analysis, planted acreages of the various commodities are the endogenous variables, while expected net returns and Government program options are considered as predetermined variables. In addition, the error terms are considered to be predetermined variables. The first step in solving this system is the substitution of the identity, equation (6), into one of the other equations. Then solution of the

[3] Since this analysis is concerned with only one area within the United States, prices and yields are assumed to be independent of each other. Techniques developed in this paper could easily take into consideration the relationship between prices and yields on a national basis.

Table 2. Means, variances, and covariances for the analysis

Commodity	Means	Variance-covariance matrices			
		Feed grain	Soybeans	Wheat	Nonprogram crops
Yields:					
Feed grain (bu/acre)	43.64	84.852	7.732	− 0.368	6.034
Soybeans (bu/acre)	20.17		10.955	6.102	6.807
Wheat (bu/acre)	30.80			23.547	24.939
Nonprogram crops (bu/acre)	39.57				32.443
Prices:					
Feed grain ($/bu)	1.30	0.045	0.045	0.005	0.002
Soybeans ($/bu)	2.60		0.075	0.014	0.002
Wheat ($/bu)	1.50			0.010	0.001
Nonprogram crops ($/bu)	0.82				0.001

condensed five-equation model ensures that estimates of acres devoted to the various crops will equal total acres available.

The error terms were generated using the random number generator discussed above. For each observation, error terms were generated for equations (1) through (5). This procedure was repeated m times. The variance-covariance matrix developed from the residuals of estimated acreage equations was used in generating the error terms. Thus, the correlation between any two error terms using generated data was similar to the correlation between the respective residuals.

Results of Monte Carlo Simulation

Given expected prices for 1971,[4] it is possible to examine the impact of alternative feed grain programs. Table 3 presents distributions of aggregate net farm income, feed grain production, and feed grain set-aside acreage for alternative payment rates for participation in the feed grain program. The table is designed so that for a given level of expected prices, policymakers can compare income (or production) distributions associated with alternative programs.

To derive this table, m was set equal to 300. Thus 300 observations of prices, yields, and equilibrium acres were calculated and used to estimate net farm income. Net income from the sale of commodity i is the difference between value of production and variable cost:

$$NI_i = (Y_i^* P_i^* - PC_i) A_i^*$$

where NI is net income, Y^* is generated yield, P^* is generated price, PC is variable production cost, and A^* is the generated number of planted acres. This calculation is made for net farm income from feed grains, soybeans, wheat, and nonprogram commodities. Summation of net farm income from the various commodities yields one observation of net farm income for the area.

This procedure is repeated 300 times to give 300 values of net farm income, feed grain production, and feed grain set-aside acreage. The 300 values of net farm income are ranked in ascending order. The probabilities of achieving various levels of net farm income are estimated from this ordered array. This scheme is used to derive the values of net farm income in table 3. The various columns of the table are found by using the above procedure and the specified participating requirements for the feed grain program and the specified expected prices. The information on feed grain production and feed grain set-aside acreage in table 3 is also estimated from the respective ordered arrays.

Results in the first data column of table 3 are interpreted as follows. This column presents the probability distributions for net farm income, feed grain production, and feed grain set-aside acreages, assuming that the set-aside requirement for feed grains is 25 percent of the feed grain base and expected prices are those prices projected for 1971. Under these conditions, there is a 5 percent probability that aggregate net farm income for the study area will be less than $1.77 million and a 10 percent probability that it will be less than $18.85 million. At the other end of the probability distribution, there is a 90 percent probability that net farm income will be less than $122.91 million and a 95 percent probability that it will be less than $138.74 million. The expected value of net farm income is $68.21 million. Expected feed grain production is 60.75 million bushels with a 5 percent probability that feed grain production will be less than 42.91 million bushels. Other columns can be interpreted in a similar manner.

This table presents two policy alternatives under two sets of expected prices. For 1971 expected prices, the two policy alternatives in data columns (1) and (3) represent alternative programs that a policymaker might actually have under consideration. The first variables that he might wish to compare are the expected values of net farm income, Government payments, and feed grain production. Average net farm income is $68.2 million and $70.5 million with set-aside requirements of 0.25 and 0.30, respectively. The higher net farm income associated with the higher set-aside requirement results from the aggregate relationship between lower volume and higher price for the United States. However, for the area under analysis, there appears to be little difference in feed grain production under the two options. Even though diverted acreage

[4] Expected prices per bushel for 1971, which were developed by APAT and used in this analysis, were $2.24 for soybeans, $1.35 for wheat, $0.78 for nonprogram commodities, $1.18 for feed grains with 0.25 set-aside requirement, and $1.23 for feed grains with 0.30 set-aside requirement.

Table 3. Distribution of net farm income, feed grain production, and feed grain set-aside acreage and expected value of Government payments by alternative set-aside requirements for participation in the feed grain program and alternative feed grain prices

Probability of obtaining smaller value	Set-aside requirements for feed grain program			
	0.25 with feed grain price at—		0.30 with feed grain price at—	
	Base	Base plus 10¢	Base	Base plus 10¢
	Net farm income (million dollars)			
.05	1.77	6.52	4.06	8.93
.10	18.85	23.13	20.56	25.23
.20	35.47	40.54	37.71	42.25
.50	67.80	73.98	70.00	76.64
.80	102.94	110.97	105.39	113.58
.90	122.91	131.71	125.39	134.39
.95	138.74	148.79	141.57	151.83
Expected value	68.21	74.82	70.45	77.23
	Government payments (million dollars)			
Expected value	20.95	20.83	19.80	19.68
	Feed grain production (million bushels)			
.05	42.91	44.89	43.14	45.13
.10	47.13	49.24	47.38	49.48
.20	51.19	53.48	51.46	53.74
.50	60.65	63.38	60.97	63.69
.80	69.73	72.74	70.09	73.09
.90	75.65	78.96	76.03	79.35
.95	80.96	84.50	81.38	84.91
Expected value	60.75	63.45	61.07	63.77
	Feed grain set-aside acreage (thousand acres)			
.05	488.88	484.71	527.50	523.32
.10	490.37	486.19	528.98	524.79
.20	493.35	489.17	531.96	527.78
.50	498.12	493.94	536.73	532.55
.80	501.89	497.71	540.50	536.32
.90	503.41	499.23	542.02	537.84
.95	504.40	500.22	543.01	538.82
Expected value	497.54	493.36	536.15	531.97

increased substantially under the higher set-aside requirement, much of the increased diversion came at the expense of commodities other than feed grains because feed grains experienced an increase in price.

In addition to expected values, the policy-maker might wish to examine the probabilities of obtaining a specified net farm income for feed grain production. He may be unwilling to support a policy that has a 0.10 probability of providing less than $20 million in net farm income from farm marketings. If so, he would prefer the set-aside requirement of 0.30 with 1971 expected prices.

Thus far, attention has been focused on the probability of obtaining a net farm income, etc., that is less than a stated value. However, a policy decisionmaker may also be interested in the probability of other interval estimates, such as the interval around the expected value of net farm income. A confidence interval can be used to state the chance that an observation will fall in a given range. The results in table 1 can easily be converted to confidence intervals as follows:

$$P(Z_L - Z - Z_U) = (1 - \alpha_L - \alpha_U)$$

where α is probability, L is lower, and U is upper.

Such a method can best be described by means of a particular example. Given expected prices and Government programs used in deriving column (1) of table 3, 90 percent of the time net farm income will be between $2 million and $139 million. The choice of 90 percent is arbitrary; we could have selected a 60 percent or 80 percent confidence interval. With a longer interval, the probability is higher that the observation will fall within the interval. However, a large interval does not offer much precision. In comparison with the 90 percent interval, 60 percent of the time net farm income will be between $35 million and $102 million.

Comparison of Simulation and Linear Programming Results

Since the simulation model is based on results from linear programming, it appears useful to compare results of the two methods. Although simulation estimates of net farm income were consistently above those from linear programming (see table 4), the effects of changing a policy variable were very similar in the two models. Note that with 1971 expected prices and 0.25 set-aside requirement, estimates of expected net income were $68.21 million with simulation and $67.94 million with linear programming. With an increase in expected feed grain price of $0.10 per bushel, simulation results showed average net farm income would increase $6.61 million, compared with $6.32 million with linear programming.

Some differences between simulation and linear programming can be accounted for by the restrictions in the linear programming formulation. Although any appropriate restrictions can be incorporated in the simulation model, the present analysis did not consider such restrictions.

Summary and Conclusions

This study developed a simultaneous equation model to explain planted acreages of feed grains, wheat, soybeans, and nonprogram crops. The statistical model quantified the impact of expected prices, yields, and production costs on planted acreages of the various crops. The impacts of selected Government program alternatives were also estimated.

The planted acreage model served to develop probability distributions for farm income and production. For a given Government program and set of expected prices, a sample of planted acreages was simulated. In addition, simulated prices and yields were combined with the

Table 4. Net farm income estimates using simulation and linear programming

Item	Set-aside requirements for feed grain program			
	0.25 with feed grain price at—		0.30 with feed grain price at—	
	Base	Base plus 10¢	Base	Base plus 10¢
	Million dollars			
Simulation:				
Net farm income	68.21	74.82	70.45	77.23
Net farm income above base column (1)		6.61	2.24	9.02
Change in net farm income from 10¢-per-bushel increase in feed grain price		[a]6.61		[b]6.78
Linear programming:				
Net farm income	67.94	74.24	69.60	76.29
Net farm income above base column (1)		6.32	1.66	8.35
Change in net farm income from 10¢-per-bushel increase in feed grain price		[a]6.32		[b]6.69

[a]Estimate is calculated by subtracting net farm income in data column (1) from net farm income in data column (2).

[b]Estimate is calculated by subtracting net farm income in data column (3) from net farm income in data column (4).

simulated planted acreages to determine an array of simulated farm income observations. These income observations represent a sample of possible values for the farm income variable which takes into consideration the historical interrelationships between prices, yields, and planted acreages. These income observations were then used to estimate the probability of obtaining a specified level of farm income. Thus the results introduce an additional dimension—variation of production and income—to conventional evaluations of policy alternatives.

Statistical decision theory provides tools to deal with the interaction of variables and with risk and uncertainty in a way that greatly increases the ability to manage complex systems such as aggregate feed grain production. By providing policymakers with information on the distribution of farm income and production, statistical decision theory will improve their understanding of the consequences of various policy alternatives. Thus they will be better prepared to choose among the alternatives according to how they perceive public preferences. Extension of procedures outlined in this study should aid income stability by improving policy decisionmaking.

This analysis did not attempt to evaluate the effectiveness of the linear programming results in predicting planted acreages. However, the variation between actual and predicted planted acreages could be incorporated in the model. This extension would improve the accuracy of the farm income and production estimates.

Since this study was concerned with production in only one region of the United States, price and quantity of a commodity were assumed to be unrelated. However, further research could extend the analysis to account for interrelationships among various price and quantity variables. Once production (per acre yields and planted acreage) is simulated, it could be inserted in an estimated demand model to determine price. This procedure could take into account current levels of such exogenous variables as per capita income and foreign demand.

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Appendix

Let V be the variance-covariance matrix of X. Clements, Mapp, and Eidman (*1*) reported that:

$$(1) \quad V = E(CZZ'C')$$

where C is lower triangular. Since ZZ' is composed of random normal deviates with expected value of zero and variance of one, the expected value of equation (1) gives the following expression of the variance-covariance matrix:

$$(2) \quad V = CC'$$

To obtain C from V, the so-called "square root method" can be used. This method provides a set of recursive formulas for the computation of the elements of C (*3*).

$$c_{i1} = \frac{\sigma_{i1}}{\sigma_{11}^{1/2}}, \quad 1 \leqslant i \leqslant m$$

$$c_{ii} = \left(\sigma_{ii} - \sum_{k=1}^{i-1} c_{ik}^2\right)^{1/2} \quad 1 < i \leqslant m$$

$$c_{ij} = \frac{\left(\sigma_{ij} - \sum_{k=1}^{j-1} c_{ik}c_{jk}\right)}{c_{jj}} \quad 1 < j < i \leqslant m\,.$$