MODELLING FARM PROGRAM-CROP MIX DECISIONS UNDER RISK

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The decisions about what crops to plant and how many acres to devote to these crops continue to be important to farm managers. The factors involved in such decisions are complex and often contradictory. Poor crop mix decisions can be financially devastating to an individual farm.

The importance of cropping decisions has long been recognized by agricultural economists, who have devoted much time and energy in exploring different aspects of these decisions. Some of the factors identified as important in the decisions are (a) resources required and available for production [Heady], (b) rotational considerations [Hildreth and Reiter; El-Nazer and McCarl], (c) risk management [Taylor; Freund], and (d) government program provisions [Scott and Baker; Musser and Stamoulis].

The government program participation decision is closely intertwined with the crop mix decision. When the government program was first introduced in the 1930s, the participation decision was relatively simple. If a farmer would idle a minimum amount of acreage on his farm, he would qualify for a nonrecourse loan for his crop when harvested. If he chose not to idle this acreage, he could not receive the loan. By contrast, the current programs contain numerous provisions which must be considered when deciding whether or not participation is beneficial.

Several options or levels of participation exist if a farmer chooses to be in the program. He can participate in the program for one crop but not in the program for other crops. If he operates a farm containing several Agricultural Stabilization and Conservation Service (ASCS) units, he can participate in the program for a crop on one unit but not the others. The Conservation Use Program (CUP) and Conservation Reserve Program (CRP) represent additional programs in which the farmer can participate. Base acreage, limited cross compliance, multiple loan rates, and payment limitations can all influence the participation decision. For many farmers the

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participation decision dominates the crop mix decision. And by its very nature, the participation decision often determines much of the crop mix.

Extension personnel and consulting firms have tried to meet the demand by farmers for methods to analyze the program participation question. Some of these decision aids are simple manual worksheets [Klemme and Campbell], but more complex worksheets have been designed for use with computer spreadsheet software [Pioneer Hi-Bred International; Agri-Finance]. Major limitations with most of the spreadsheet approaches is that they consider the participation options for one crop on one ASCS farm unit. The interrelated nature of the various participation and cropping options suggest that a better approach is to jointly analyze program participation-crop mix decisions for an entire farming operation.

Analysis of the joint decisions at a whole farm level has been attempted in only a few published studies. In part, this lack of research has been caused by the difficult nature of the problem. Most previous studies [Scott and Baker; Persaud and Mapp; Musser and Stamoulis] focused on the risk reducing benefits of program participation, generally using a quadratic programming framework. Modelling the all-or-nothing nature of multiple participation decisions was difficult using then existent nonlinear programming algorithms. Consequently, only participation-nonparticipation alternatives for one crop or all crops were considered.

The scarcity of previous research could also be attributed to the relative unimportance of the program participation decision during the 1970s. By contrast, the decline in market prices during the 1980s has placed many farms in a financially vulnerable position and caused them to rely more heavily on the government program for sufficient income to survive. In addition, the 1985 Farm Bill greatly complicated the decision process by providing several new participation options. Development of a methodology that can be used to analyze the program participation decision would be useful to researchers and extension personnel interested in providing more insightful recommendations to individual farm operators.

The objective of this paper is to develop and apply a methodology for analysis of the joint program participation-crop mix decisions. The approach considers the major factors relevant to the participation and (or) crop mix decisions. Presentation in the paper is as follows. First, attention is focused on the type of model formulation appropriate to the problem, with discussion about what factors may or may not be excluded from this model. A generalized model formulation is then presented and explained. The final part of the paper is devoted to an empirical application of the model.

Model Development

Most crop mix studies attempt to identify a long-run equilibrium crop mix, with all activities of known duration. This approach may be adequate in traditional crop mix models, although the solution does not indicate how one gets from his current position to the long-run optimum. It seems totally inadequate, however, in analyzing the program participation decision.

Crop rotations reflect physiological relationships which are based on laws of nature. Man can modify or enhance the effects of rotations, but much of the rotational effect is out of his control [The Furrow]. Although rotational effects are not always known with certainty, they do follow predictable patterns over a long time period. Thus following an identical rotation year after year to maximize utility seems possible in the long run, provided a stable economic and technological equilibrium has been reached.

By contrast, the effects of the government program are entirely the result of man-made laws. Consider the 1985 Farm Bill, which is in effect for the 1986-1990 period. The farm bill provides the overall framework for the farm program. Some program provisions are specifically set within the farm bill itself. Other provisions, such as loan rates, may not be specifically set, but may be based on formulas outlined within the farm bill. Finally, discretionary authority is granted to the Secretary of Agriculture to determine some program provisions. As a result, provisions can (and often do) vary from year to year.

Even the major objectives of the government program can vary from farm bill to farm bill. For example, the major thrusts of the 1981 Farm Bill were to provide farmers "some mechanism to protect themselves from roller-coaster prices, ... to assure stability in the agricultural sector, and to call forth the production that the long range change in world demand will require." [U.S. Congress, 1981, p. 10]. By 1985, the emphasis had shifted to one of reducing program costs and over production, while avoiding the collapse of agricultural credit institutions. The emergence of powerful lobbying groups for major crop and livestock commodities also portends of continued instability in farm program provisions.

In light of events occurring during the last 50 years, it is hard to support any argument that suggests the government will ultimately identify a long-run set of farm program laws which will lead to an equilibrium set of optimal program participation decisions. Thus, the long-run equilibrium approach does not seem appropriate when analyzing program participation decisions.

Another reason for rejecting the long-run approach in analysis of program participation decisions is the nature of the decision itself. In the crop mix decision, a diversified solution is feasible and acceptable. For example, a crop mix model may suggest a solution consisting of 50 percent of Crop A and 50 percent of Crop B. The all-or-nothing nature of the participation decision rules out mixed solutions. One cannot participate in the program for 50% of the acreage devoted to crop A and not participate on the other 50% (assuming one ASCS unit). However, it may be profitable to participate in the program one year for crop A and not participate the next. Providing for alternate year program participation would be difficult to incorporate into a single period, long-run equilibrium model.

An alternative to the long-run equilibrium approach is to construct a single period model which identifies the optimal participation-crop mix decisions for the current year. This approach may also be inadequate, however, because it does not account for the dynamic nature of crop rotations and program base acreage. A single period model may, for example, identify a crop mix that causes high levels of soil erosion. This mix may maximize current year's profit, but may be less than optimal in a longer run context.

When a farmer chooses to participate in the farm program for a particular crop on a particular ASCS farm unit, he must comply with any acreage idlement requirements stipulated in the program. In addition, total planted acres plus acreage idled must not exceed base acres for that crop on that farm unit. Base acres represents an historical average of acreage planted to that crop. If the farmer anticipates future program participation for a particular crop will give much more utility than production alternatives, he may want to increase future base acreage above current levels. This can be done, of course, by not participating in the program during a particular year and planting more than the base acreage for that crop (thereby raising the historical average next year). This option would not be considered in a simple, single period short-run model.

The remaining alternatives are (a) to add terminal values to the single period short-run model that account for the influence of crop rotations and (or) base acreage on future returns, or (b) to construct a dynamic mathematical programming model to include all future years that could influence current period decisions. The need for terminal values is particularly relevant to base acreage because of the nature of the farm program. Participation in the program for any crop is and has been voluntary, so future base acreage would normally never have a negative value. Therefore, as long as some probability exists that future base acreage will increase farmers' utility, the ending endowment of base acreage must have some positive value. From a modelling perspective, however, terminal conditions are not necessary if adding them has no influence on the solutions that are of interest to decisionmakers.

Aside from the issue of dynamics, other features of the program participation decision require it be given special treatment. The "all-or-nothing" nature of the program participation decision can only be adequately handled using mixed integer-linear programming techniques. There are in fact several participation decisions to be made, as was indicated before. The approach used by others [e.g., Musser and Stamoulis; Persaud and Mapp] to explicitly consider all participation decision combinations is not practical in a model of the type proposed, because millions of possible combinations could exist for some problems. Treating each decision as an integer variable represents a more efficient approach, although it too would not be adequate in identifying optimal solutions for very large problems.

Availability of resources (e.g., equipment, labor, water, etc.) has long been recognized as being important in crop mix decisions. They may also influence program participation decisions. For example, reduced equipment reliability may make it undesirable to produce a particular crop at historic acreage levels. The ability to participate in the farm program may be more favorable in this situation, because it reduces the number of planted acres (by requiring some acreage be idled).

Risk has also been identified as an important factor in both crop mix and program participation decisions [Lin, Dean, and Moore; Musser and Stamoulis]. Prices and yields have usually been identified as important sources of risk in these decisions.[1] The uncertain nature of terminal conditions suggests that this source of uncertainty also be included.

Other factors can at times be influential in deciding whether or not to be in the farm program. Landowners may or may not be in favor of participation. Lenders may provide credit only if the farmer agrees to certain participation levels. Both landowners and lenders may also have some influence on the crop mix decision.

Program Participation Options

Some of the farm program participation options available to a farmer have been alluded to briefly in the introduction. In this section discussion is aimed at providing greater detail about these options and the requirements that accompany them. A more in-depth explanation is given by Glaser.

Farm program participation decisions are made annually by a farm operator for each of his ASCS farm units. The farmer also must decide what crops he wishes to enter in each program. He is free to participate in the program for one crop and not for another on the same ASCS unit or participate in the program for a crop on one ASCS unit but not on other units for that crop. Limited cross compliance does introduce some additional limits into the decision. When in effect, limited cross compliance limits all acreage of program crops to their base acreage levels, if one or more crops are in the program.

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[1] A recent survey of farmers in Florida and Alabama suggested rainfall variability, diseases and pests and commodity prices as being extremely important sources of risk [Boggess, Anaman, and Hanson]. Although these farmers also mentioned costs as being important as a source of risk, Buccola presents empirical evidence suggesting cost uncertainty may be small when compared to revenue uncertainty.

The farmer has up to three participation options from which he can choose for each program crop. These are (1) choosing not to participate in the farm program, (2) participating in the regular program, or (3) participating in the Conservation Use Program (CUP). Nonparticipation allows the farmer freedom to plant whatever he would like, but also makes him ineligible for any program benefits. Regular participation means he is restricted as to the number of acres that can be planted, but is eligible for all program benefits. The number of base acres represents the upper limit on planted acres. Typically, the government will require that a certain percentage of base acreage be left unplanted (or set aside) for one year, with no direct compensation received for idling this acreage. In addition, the farmer may also choose to participate in paid acreage diversion programs (if they are in effect). With paid diversion, the farmer idles an additional percent of base acres for one year in exchange for a payment in cash or in kind.

The CUP is a special case of paid diversion. When participating in the CUP, the farmer must first idle the required set-aside acreage. Of the remaining eligible acreage that can be planted, up to 50 percent can be left idle for one year. In exchange, the farmer receives 92 percent of the deficiency payments he would have received that year had he planted all eligible acreage (50/92). An alternative to this program (available in 1988 for wheat and feed grains) allows all eligible acreage to be left idle in exchange for 92 percent of the deficiency payment (0/92). Alternately, the farmer can plant as many acres under the 0/92 program as he would like, provided set-aside requirements are met [USDA].

A final option that can be chosen regardless of any program participation decision is whether or not to enroll in the Conservation Reserve Program (CRP). To participate, the farmer must submit a bid indicating the minimum annual payment per acre he is willing to receive from the government in exchange for not growing any crops for ten years. The farmer can enter as many acres in this program as he desires. If the bid is accepted by the USDA, he is allowed to participate in CRP.

Benefits from regular participation or CUP participation are structured based on the level of government payments received. Target price deficiency payments are limited to $50,000 per farmer and additional deficiency payments under the Findley payment provision are limited to $200,000 per farmer. Once these limits are reached, average benefits decline as the acres enrolled in the program increase across all ASCS farm units. Thus the payment limits make participation less desirable for large farms.

Model Formulation

The program participation options, combined with the traditional crop mix options, results in a mathematical programming model containing an objective function and 17 constraints. Each equation will be presented separately, followed by a verbal explanation of the variables it contains and its purpose. Not included in this presentation are the financial and tax activities, as well as the constraints that may accompany these activities. The presentation presumes a mean-variance approach is used in modelling risk.

$$\text{(1a) Maximize } \sum_{t=1}^{T}\sum_{h=1}^{A}\sum_{k=1}^{7}\sum_{j=1}^{J}\sum_{i=1}^{C} P_{ijkht}\, X_{ijkht} + \sum_{t=1}^{T}\sum_{h=1}^{A}\sum_{i=1}^{C} M_{ht}\, N_{iht}$$

$$+ \sum_{t=1}^{T}\sum_{h=1}^{A}\sum_{i=1}^{C}\sum_{q=1}^{Q} U_{qiht}\, S_{qiht} + \sum_{h=1}^{A}\sum_{k=1}^{7}\sum_{j=1}^{J}\sum_{i=1}^{C} V_{ijh}\, X_{ijkhT}$$

$$+ \sum_{t=1}^{T}\sum_{h=1}^{A}\sum_{i=1}^{C} VB_{iht}\, W_{iht}$$

$$X_{ijkht},\ S_{qiht},\ N_{iht} \geq 0, \qquad W_{iht} \text{ is unbounded}$$

The expected returns part of the objective function (Equation 1a) contains five revenue generating terms, with each coefficient discounted so that the objective is one of maximizing Net Present Value of present and future utility. The first term relates to production and marketing of crops. The activity X_{ijkht} represents planted acres of crop i following crop rotational sequence j under government program alternative k on ASCS farm unit h in year t. P_{ijkht} represents per acre expected returns for each combination of i,j,k,h, and t, discounted to the initial time period. A total of C crops are considered in the analysis, the C^{th} crop being a fallow activity necessary to satisfy government acreage idlement requirements. The value of J represents the total number of rotational sequences, divided by C. For example, if 3 crops (including idle acreage) are considered and rotational effects are thought to last 2 years, 27 (or 3^3) rotational sequences are possible.[2] In this case, J equals 9 (or 3^2). A total of T years are explicitly considered in the model and A is the total number of ASCS farming units.

Up to seven different government program alternatives are available for a given set of i,j,h, and t values. These alternatives represent (1) nonparticipation in the farm program, (2) regular participation, receiving all benefits, (3) regular participation, receiving all but target price deficiency payments, (4) regular participation, eligible for only the nonrecourse and marketing loan programs, (5) CUP participation, receiving all benefits, (6) CUP participation, but ineligible for target price deficiency payments, and (7) CUP participation, eligible for only nonrecourse and marketing

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[2] Suppose the crops are wheat (W), potatoes (P), and fallow (F). Possible sequences include potatoes following potatoes following potatoes (PPP), potatoes following potatoes following wheat (PPW), fallow following wheat following potatoes (FWP), etc.

loan programs. Although net returns under (2) contain all returns available under (3) and (4) plus target price payments, limitations on these payments may make the farmer ineligible for (2) once acreage has reached a certain level. In similar fashion, the farmer is not eligible for (3) once the Findley payment limit has been reached. Thus it is necessary that separate activities be created for each marginal difference in per acre benefits the farmer might receive.

The second term in the objective function accounts for any direct returns received from acreage idled as part of the government farm program. Activity S_{qiht} represents the number of acres idled under idlement program q for crop i on ASCS unit h in year t. U_{qiht} represents the discounted per acre return (if any) from the q^{th} idlement program, for each i, h, and t. Coefficient Q represents the total number of idlement programs, only some of which may be in force for any particular crop each year. Specific idlement programs include CUP idle acreage (q=1) and cash paid diversion acreage (q=2).

The third objective function term accounts for returns from acreage placed in CRP. The discounted per acre return on ASCS unit h in year t (M_{ht}) is multiplied by total acres placed in CRP in year t. Although M_{ht} would be the same nominal value each year, discounting future returns results in different annual M_{ht} values. The fourth term in the objective represents expected terminal values for the inventory of land with each crop rotation available at the end of T. The coefficient V_{ijh} represents the expected future value (discounted to the present) from a rotational standpoint of having an acre that was planted to crop i following sequence j in year T on ASCS unit h. V_{ijh} can be added to P_{ijkhT} to reduce problem size.

The fifth component of the objective function accounts for the expected terminal value of changes in base acreage on all ASCS farm units. Base acreage will have value if farmers expect farm program participation in the future to increase total utility. VB_{iht} represents the per acre value beyond year T of changes in base acreage for crop i on ASCS unit h in year t. VB_{iht} would usually be greatest when t=T, because none of the future value of T period acreage for calculating base has been realized by and in year T. Acreage in period T-4, on the other hand, would have much less future value, because it is only used in T+1 base acreage calculations. W_{iht} represents the number of acres planted that is different from current years base acreage. Because changes from current base can be negative or positive, W_{iht} is an unbounded variable.

$$(1b)\ \frac{-r}{2}\ [\sum_{t1=1}^{T}\sum_{h1=1}^{A}\sum_{k1=1}^{7}\sum_{j1=1}^{J}\sum_{i1=1}^{C}\sum_{t2=1}^{T}\sum_{h2=1}^{A}\sum_{k2=1}^{7}\sum_{j2=1}^{J}\sum_{i2=1}^{C}$$

$$\sigma_{i1j1k1h1t1i2j2k2h2t2}\ X_{i1j1k1h1t1}\ X_{i2j2k2h2t2}$$

$$+\sum_{t1=1}^{T}\sum_{h1=1}^{A}\sum_{i1=1}^{C}\sum_{t2=1}^{T}\sum_{h2=1}^{A}\sum_{i2=1}^{C}\psi_{i1h1t1}\ {}_{i2h2t2}\ W_{i1h1t1}\ W_{i2h2t2}$$

$$+\sum_{t1=1}^{T}\sum_{h1=1}^{A}\sum_{k1=1}^{7}\sum_{j1=1}^{J}\sum_{i1=1}^{C}\sum_{t2=1}^{T}\sum_{h2=1}^{A}\sum_{i2=1}^{C}\theta_{i1j1k1h1t1i2h2t2}$$

$$X_{i1j1k1h1t1}\ W_{i2h2t2}]$$

The second part of the objective function (1b) contains variance calculations for each activity considered a source of uncertainty. The coefficient r is the Pratt risk aversion coefficient and weighs the relative influence of income variance on overall utility. Because the provisions for the government farm program are usually announced before farmers make program participation and crop mix decisions, all variables associated with the program are assumed known with certainty in the model. The remaining sources of uncertainty are prices, yields, and terminal conditions for rotations and base acreage.

The coefficient σ represents covariance between the various production activities for each i, j, k, h, and t. The covariances from rotation terminal values are included in σ for ease of presentation. ψ represents covariance from terminal conditions for base acreage. θ represents covariance between the production activities and base acreage terminal conditions.

Subject to

$$(2)\quad F_{iht} + G_{iht} + H_{iht} = 1\ \forall i=1,\ldots,C\text{-}1;\ h=1,\ldots,A;\ t=1,\ldots,T$$

$$(3)\quad -B_hF_{iht} + \sum_{j=1}^{J} X_{ij1ht} \leq 0\ \forall i=1,\ldots,C\text{-}1;\ h=1,\ldots,A;\ t=1,\ldots,T$$

$$(4)\quad -B_hG_{iht} + \sum_{k=2}^{4}\sum_{j=1}^{J} X_{ijkht} \leq 0\ \forall i=1,\ldots,C\text{-}1;\ h=1,\ldots,A;\ t=1,\ldots,T$$

$$(5)\quad -B_hH_{iht} + \sum_{k=5}^{7}\sum_{j=1}^{J} X_{ijkht} \leq 0\ \forall i=1,\ldots,C\text{-}1;\ h=1,\ldots,A;\ t=1,\ldots,T$$

$$F_{iht},\ G_{iht},\ H_{iht},\ \epsilon(0,1).$$

The first four constraints deal with the three participation options outlined previously. Equation (2) contains only (0,1) integer variables and insures mutual exclusivity in the participation decision. That is, if the model chooses to not participate in the farm program for crop i on ASCS unit h in year t, $F_{iht}=1$. This automatically prohibits regular participation (G_{iht}) or CUP participation (H_{iht}) from also being in solution for i,h, and t.

Equations (3)-(5) control entry of the crop production activities into solution, depending on which program participation option is selected. If $F_{iht}=1$, (3) allows any nonprogram cropping activities for crop i on ASCS unit h in year t to enter the solution, until total acreage reaches B_h (the size in acres of ASCS unit h). Constraints (4) and (5) performs the same function for regular and CUP program participation activities, respectively. When $F_{iht}=0$, all nonprogram acreage for crop i on ASCS unit h in year t must also be zero.

$$(6) \quad \sum_{k=1}^{7} \sum_{j=1}^{J} \sum_{i=1}^{C} X_{ijkht} + \sum_{i=1}^{C} N_{iht} \le B_h \qquad \forall h=1,\ldots, A; \quad t=1,\ldots, T$$

$$(7) \quad N_{iht} - N_{iht-1} = 0 \qquad \forall i=1,\ldots, C-1;\ h=1,\ldots, A;\ t=1,\ldots, T$$

Equation (6) ensures that total acreage in crop production (including acreage left fallow) plus acreage entered in CRP does not exceed total acreage (B_h) on each ASCS farm unit. Equation (7) was added to ensure that acreage in CRP for each farm unit is the same each year.[3] The subscript i is needed to designate which crop's base acreage is being tied up in CRP acreage.

$$(8) \quad \sum_{k=1}^{7} \sum_{i=1}^{C} X_{ijkh1} \le CA_{jh} \qquad \forall h=1,\ldots, A;\ j=1,\ldots, J$$

$$(9) \quad \sum_{k=1}^{7} \sum_{i=1}^{C} X_{ijkht} - \sum_{k=1}^{7} \sum_{d=1}^{C} X_{m(gd)kht-1} \le 0 \qquad \forall j=1,\ldots, J;\ h=1,\ldots, A;\ t=2,\ldots, T$$

where j = crop m preceded by crop sequence g

$\forall m = 1,\ldots C;$

$$g = \begin{cases} 1,\ldots, J/C, & \text{when rotational effects exceed one year} \\ \text{Omitted otherwise} \end{cases}$$

Equations (8) and (9) account for crop rotations over time. Equation (8) is in effect the first year only and represents the

[3] This constraint may be changed from "=" to $\le$" in any year if additional acreage can be placed in CRP.

rotation "endowment" (CA_{jh}) inherited by the farmer at the beginning of the planning horizon. Equations (9) accounts for the rotation effects transferred from year to year within the model. Crop sequence j is inherited from the previous year and is equivalent to crop m following sequence g following all crops in period t-1. Crop d is included because its rotational impact is not felt in year t. The rotational impact of $X_{m(gd)kht-1}$ is the same across all d.

$$(10)\quad \sum_{k=1}^{7} \left(\sum_{j=1}^{J} X_{ijkht} + \sum_{q=1}^{Q} S_{qiht} \right) + N_{iht} - \delta_t D_{it} \sum_{n=1}^{R_{it}} \left[\sum_{k=1}^{7} \sum_{j=1}^{J} X_{ijkht-n} + \sum_{q=1}^{Q} S_{qiht} + N_{iht-n} \right] - W_{iht} = BA_{iht} \quad \forall i=1,\ldots, C-1;\ h=1,\ldots, A;\ t=1,\ldots, T$$

where

$$\delta_t = \begin{cases} 0 & \text{when } t=1 \\ 1 & \text{otherwise} \end{cases}$$

$$R_{it} = \begin{cases} Y_{it} & \text{when } Y_{it} < t \\ t-1 & \text{when } t \le Y_{it} \end{cases}$$

$$(11)\quad -B_h F_{mht} + W_{iht} \le 0 \qquad \forall i=1,\ldots, C-1;\ h=1,\ldots, A;\ t=1,\ldots, T\quad m=1,\ldots, C-1.$$

Equation (10) imposes government program regulations for base acreage. This constraint is formulated under the assumption that base acreage is strictly an historical average of acreage for each crop. BA_{iht} is the base acreage endowment the farmer brings into year t, based on cropping decisions made prior to year 1. It is calculated as

$$(10a)\quad BA_{iht} = \sum_{r=t}^{Y_{it}} D_{it} \left[\sum_{k=1}^{7} \sum_{j=1}^{J} X_{ijkht-r} + \sum_{q=1}^{Q} S_{qiht-r} \right] \qquad i=1,\ldots, C-1;\ h=1,\ldots, A;\ t=1,\ldots, T\quad t \le Y_{it}$$

when the number of years of historical crop acreage required in the calculation (Y_{it}) is less than or equal to t. When Y_{it} is less than t, base acreage is entirely calculated within the model and BA_{iht} is zero. D_{it} is $1/Y_{it}$, or the proportion of a single year's historical acreage that contributes to period t base acreage calculations. Under the 1985 Farm Bill, Y_{it} is 5 when the farm has been in the program for crop i in the past. Verbally stated, (10) requires that, for crop i on ASCS unit h in year t, acreage planted plus that idled as part of the program plus acreage entered in CRP plus any changes in acreage from the base amount must equal the historical average (including previous years specified in the model) of acreage planted, idled, and (or) in CRP for i,h, and t. Although X_{ij1ht} (nonparticipation acreage) is not constrained by base acreage levels, it can modify future base acreage. Thus if X_{ij1ht} is larger than the current year's base,

W_{iht} enters at a positive level and the future value of this additional base is added to the objective function. Equation (11) imposes limited cross-compliance restrictions on program participation. The constraint set prevents an increase in program base for a particular crop unless all crops are out of the program on ASCS unit h in year t.

$$(12)\quad \sum_{k=2}^{7} \sum_{j=1}^{J} E_{qit}\, X_{ijkht} - S_{qiht} = 0 \qquad \forall q=1,\ldots,Q;\ i=1,\ldots,C-1;\ h=1,\ldots,A;\ t=1,\ldots,T$$

$$(13)\quad -\sum_{j=1}^{J} X_{Cj1ht} + \sum_{q=1}^{Q} \sum_{i=1}^{C-1} S_{qiht} \le 0 \qquad \forall h=1,\ldots,A;\ t=1,\ldots,T$$

Equation (12) ensures that requirements for each acreage idlement program are met each year on each ASCS unit in the program for that crop. E_{qit} represents the percent of base acreage idled under idlement program q, divided by the percent of base acreage allowed planted. Whether this is an equality or inequality constraint would depend on whether the idlement program was voluntary or mandatory and the relative profitability of the idlement program versus regular crop production. Equation (13) assures that crop C (idle acreage) is not less than acreage required idled for all programs on ASCS farm unit h in year t.

$$(14)\quad \sum_{h=1}^{A} \sum_{i=1}^{C} \Big(\sum_{j=1}^{J} O_{i2ht}\, X_{ij2ht} + O_{i5ht}\, X_{ij5ht} + \sum_{q=1}^{2} U_{qiht} S_{qiht} \Big) \le DP_t \quad \forall t=1,\ldots,T$$

$$(15)\quad \sum_{h=1}^{A} \sum_{j=1}^{J} \sum_{i=1}^{C} \Big(\sum_{k=2}^{3} Z_{ikht}\, X_{ijkht} + \sum_{k=5}^{6} Z_{ikht}\, X_{ijkht} \Big) \le FP_t \quad \forall t=1,\ldots,T$$

$$(16)\quad \sum_{h=1}^{A} \sum_{i=1}^{C} M_{ht}\, N_{iht} \le RP_t \qquad \forall t=1,\ldots,T$$

Equations (14), (15), and (16) determine that payment limitations are not exceeded. Equation (14) requires that target price deficiency payments (O_{i2ht}) plus deficiency payments on CUP acreage in production (O_{i5ht}), CUP acreage left idle (U_{1iht}) cash diversion payments (U_{2qiht}) be less than the \$50,000 payment limit. Constraint (15) keeps Findley payments from exceeding \$200,000. Constraint (16) limits CRP payments to \$50,000.

$$(17)\quad \sum_{h=1}^{A} \sum_{k=1}^{7} \sum_{j=1}^{J} \sum_{i=1}^{C} K_{ijtps}\, X_{ijkht} \le TR_{tps} \qquad \forall t=1,\ldots,T;\ p=1,\ldots,RC;\ s=1,\ldots,TS$$

Equation (17) accounts for resource demand by each activity, ensuring that total demand does not exceed supply. The constraints are entered by classes, with up to RC time periods in each class and TS resource classes. The constraints require the total amount of resources of class s used in period p of year t by all crops across all ASCS farming units must not exceed total supply of that resource for the particular t,p, and s values. Numerous resource classes, such as labor, field time, and (or) irrigation water supplies, could be included if appropriate to the farm production situation.

The objective function and 17 constraints listed here represent the program participation-crop mix portions of a more general farm planning model. Other government program provisions, such as full cross-compliance and reduced acreage conservation reserve, could also be considered by adding additional constraints and (or) modifying existing constraints.

An additional set of constraints and activities could be added to the model to account for the financial and tax aspects of the farm. Included in this set would be activities for interest costs, repayment of debt principal, federal and social security tax calculations, and off-farm income. An example approach to the financial model is given by Perry [1986]. This approach was used in the example problem presented in the next section.

Application of Methodology

Applying the proposed approach to a case farm situation better illustrates its potential usefulness. Before analytical results could be obtained, however, it was necessary to (a) identify (or develop) an algorithm which could solve the proposed class of problems, (b) obtain data for use in the case farm situation, and (c) put the data in a form compatible with the solution algorithm.

A Benders' Decomposition approach was used to solve the proposed model. Bender's Decomposition for mixed integer-linear programming problems has been explained in detail in a previous article published in the AJAE [Hilger, McCarl, and Uhrig]. The model proposed here can only be solved with a mixed integer-nonlinear programming algorithm. When this research was initiated, no known algorithms had been developed for this size problem, although smaller problems have been solved by others [Polito]. The advantage of Bender's Decomposition is that it allows a difficult to solve problem to be decomposed into two, easier-to-solve problems. In this case, the original problem was subdivided into integer and nonlinear subproblems, which were then solved iteratively until the optimal solution was identified. The nonlinear problem was solved using MINOS [Murtagh and Saunders], and the integer problem was solved by MIPZ1 [McCarl, Barton, and Schrage. Detailed documentation on implementing the procedure within MINOS is given by Perry, McCarl, and Gray.

The previous section illustrated the complexity of modelling program participation-crop mix decisions. Nevertheless, application of this approach is much the same for many types of farming operations, with only some changes in general parameters (e.g., number of crops, number of rotational sequences, etc.) and specific data unique to each farm. This similarity stimulated development of a matrix generator to create farm planning models for different farms and to aid in doing sensitivity analyses for a given farm. A copy of the computer code and documentation of this matrix generator is available from the authors.

Data from an actual farming operation was used in the empirical example. The subject farmer was invited to participate because of his perceived ability to provide necessary data, his progressive nature, and his previous interest and willingness to participate in similar studies. The results obtained may or may not be useful to other farmers in the study area, particularly if their resource endowments and (or) expectations about future events differ markedly from the subject farmer. The general approach, however, is quite applicable to these and other farmers across the country.

The subject farm is located in the Coastal Bend region of Texas, a three-county area in and around the city of Corpus Christi. Cotton and grain sorghum have traditionally been produced in this area, although corn acreage has been increasing over the last decade. These three crops, plus idled acreage (or layout) needed when government participation so requires, constitute the set of crops considered in the analysis.

Separate farm program provisions exist for cotton, rice, wheat, tobacco, peanuts, and soybeans. Feed grains (corn, sorghum, barley, and oats) are treated under the program as if they are the same crop. This means that, as an example, a farmer participating in the feed grains programs can plant corn and sorghum, but must adhere to the program provisions for both crops. The participation decision, therefore, was limited to two crops; cotton and feed grains.

The case farm has 1880 acres of tillable land. All land is rented using crop share tenure arrangements.[4] Two ASCS farm units are represented on this farm, one consisting of 640 acres and the other 1240 acres. Total base acreage of cotton plus feed grains is the same as total acreage on each ASCS farm unit. This allows the farmer to not participate in the program for cotton or feed grains, without partial cross-compliance limiting the acres planted to the crop which is not in the program. Base acreage on each farm unit for 1988 was about evenly split between cotton (46%) and feed grains (54%).

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[4] Under the share arrangement the landowner receives one-third of the cotton crop and one-fourth of the grains produced. The landowner also shares proportionally in some variable production expenses (e.g., fertilizer and harvesting costs).

Rotational effects were assumed to last one year, resulting in 16 possible rotational sequences. This means, for example, that continuous cotton (CCC) would have the same yield as cotton preceded by cotton preceded by sorghum (CCC). Rotational acreage inherited from 1987 reflected program participation on both ASCS farm units. Cotton yields on the first ASCS unit were expected to be 12.5% higher than those on the second unit. Sorghum and corn yields were expected to be 21.5% higher on the first unit than on the second.

Because the example problem represents an actual farming operation, use of subjective data obtained from the farmer was deemed appropriate for the analysis [Anderson, Dillon, and Hardaker]. That is, the farmer was asked to provide estimates of costs of production, interest rates, debt structure, government program provisions, resource requirements and resource availability for all years included in the analysis. These estimates were based on his own expectations, although in some cases (e.g., government program provisions) expert opinion was made available as an aid in making estimates. Loan rates and deficiency payment limits were reduced 8.5% based on the Gramm-Rudman deficit reduction law.

The major resource constraint faced by the farmer is field time available to perform cropping operations. Field time available is primarily a function of weather and the number of hours worked per day. Field time required was estimated based on the number of laborers available, the number of equipment complements available to perform each task (e.g., a tractor and a disc form one complement for the discing task), and the time required to perform each task. The farmer also indicated the timeframe in which each task must be accomplished. Operations were then aggregated by crop into 10 producer defined time periods. These resource needs and supplies were assumed constant in each year explicitly modelled.

<u>Dynamics and Terminal Conditions</u>

The farmer considered a three-year planning horizon appropriate when making current year (1988) program participation and cropping decisions. This planning horizon suggests he expects nothing occurring after 1990 to influence 1988 participation and cropping decisions. Several factors influenced this decision. Leases on his land are set to expire in 1991 and, because it lies near the city limits of Corpus Christi, it is not clear how much longer the land will be available for crop production. In addition, the 1985 Farm Bill provisions expire at the end of 1990, with a great deal of uncertainty currently existing about what form the farm program will take after that time. Because of this situation, terminal values for base acreage and rotational benefits were initially set equal to zero. The farmer estimated a 9.1% annual discount rate as being appropriate in weighing future versus present returns.

It was also necessary that the farmer subjectively estimate the expected returns and covariance matrix for each of the alternative activities. Use of subjective data in risk programming models has rarely been attempted because of the difficulty that individuals have in conceptualizing and making estimates of covariance [Lin, Dean, and Moore]. The approach used here was to obtain estimates of basic relationships and then use well-established statistical techniques to obtain the expected returns vector and covariance matrix.

The farmer was first asked to estimate a price distribution for each crop, assuming each distribution represented the average price he would receive for that crop in 1988. Yield distributions were also estimated for each rotational sequence. The farmer had previously participated in studies requiring subjective estimates of price distributions, so this exercise was relatively easy. With information about the price and yield distributions, calculation of a covariance matrix for the production activities was possible if a correlation matrix could be estimated. Although the farmer had had some training in statistics, estimation of correlations was difficult. A correlation matrix based on historical price and yield data supplied by the farmer was used to reeducate the farmer about correlation and what it represents. The farmer was then asked to revise this historical matrix based on his expectations of correlation relationships for the 1988-1990 period. To reduce complexity in the estimation process, correlation between 1988 and 1990 was assumed zero for all variables.

Two approaches potentially exist to use these data to obtain subjectively estimated expected returns vector and covariance matrix. The first is to use Monte Carlo simulation techniques to generate many correlated prices and yields for each crop, then use these in calculating the statistical properties of the production activities. The second can be referred to as an equation approach because it uses general statistical equations to calculate expected returns and covariance, given some knowledge about the means, standard deviations, and correlations between random variables [Bohrnstedt and Goldberger; Tew and Boggess]. Simulation was the approach used in this study.

A total of 500 random prices and yields were generated for each crop for each of the three years in the 1988-1990 time period. It was assumed each crop rotation sequence was perfectly correlated with all other rotational sequences for that same crop. Also it was assumed that rotations had no impact on crop quality. These prices and yields were used directly to calculate returns for nonparticipation in the government program. The program loan levels and target prices were then used to calculate returns when participating in the farm program.

A second model was created and terminal conditions added to see what impact these conditions (or the lack thereof) had on the optimal solution. Adding terminal conditions for rotations was relatively simple since these effects were assumed to last only one year. Rotational benefits were calculated relative to cotton since this crop had the most negative rotational effects. The additional returns obtained by following a particular crop with cotton, sorghum, or corn in 1990 were averaged, discounted by one period (since terminal conditions were for 1991), and entered as the terminal rotational benefit for that crop.

Estimates of terminal values for base acreage were more difficult to calculate because changes in base potentially would have influence on base for many years in the future. Recall that base acreage is a 5-year average of historical acreage in a particular corp. Thus, if in year 0 a farmer were to plant one more acre of a program crop than his current base, base acreage in year 1 would increase by .2 (or 1/5). Base acreage in year 2 would be increased by .2 plus the indirect benefit of having a higher base in year 1. Base in year 2 would therefore increase by .2 + .2(.2) = .24 because of the additional acre in year 0. Following this sequence creates an oscillating pattern that, eventually, approximates 0.33 in the long run.

Implicit assumptions in this process are that (a) base acreage is strictly an historical average of crop acreage, (b) this base acreage will never be reduced from the level generated in year 0, and (c) program benefits will continue for an indefinite period. Multiplying each yearly contribution of base by its marginal value and discounting (at 9.1%) to the beginning of the planning horizon yields the terminal value for base. The average difference between nonparticipation and full program participation for 1988-1990 was used to calculate the value of base each year after 1990 for both cotton and feed grains.

The general approach outlined here probably overstates the value of base since (a) it presumes the payment limits are never reached, (b) discussion about future farm programs by some government officials suggests there will be further cutbacks in program benefits to reduce costs, and (c) no uncertainty is included about the number of future years the farmer will actually benefit from additional base. The terminal values for base were about $94/acre for cotton and $93/acre for feed grains on ASCS unit 1, and $87/acre for cotton and $80/acre for feed grains on ASCS unit 2.

Analytical Results - Risk Neutrality

The brief description of the farming operation suggests a model containing 690 production activities and 36 integer variables would be needed to completely represent all participation-crop mix options, with 531,441 possible integer solutions. Aside from potential problems with memory requirements and time required to obtain a solution, the problem provided unnecessary options. For example, the farmer did not consider CRP to be a profitable option for his farm. The size of his operation was not large enough to reach the $200,000 payment limit, allowing this constraint and its related production activities to be dropped from the model. CUP is generally a profitable option if market price or nonrecourse loan are at or below the variable cost of production. His price expectations in all years suggested CUP would not be a profitable option for cotton, allowing it to also be dropped from consideration. The resulting model contained 374 production activities and 30 integer variables, with 46,566 possible integer solutions.

The government program-crop mix decisions identified as optimal by the model are reported in Table 1. The Table 1 results were generated assuming the farmer was risk neutral and that all terminal conditions

Table 1. Government Program-Crop Mix Decisions Identified as Optimal Under Risk Neutrality

	Excluding Terminal Conditions		Including Terminal Conditions	
Net Present Value ($)	288,245.		298,288.	
Standard Deviation ($)	160,041.		154,081.	
Crop Acreage	ASCS Unit 1	ASCS Unit 2	ASCS Unit 1	ASCS Unit 2
1) 1988				
Cotton	640.F[a]	499.P	262.P	886.F
Sorghum	0.	536.P	272.P	283.P
Corn	0.	0.	0.	0.
Layout	0.	205.P	106.P	71.P
2) 1989				
Cotton	313.P	842.F	631.F	538.P
Sorghum	217.P	318.P	7.P	485.P
Corn	0.	0.	0.	0.
Layout	110.P	80.P	2.P	216.P
3) 1990				
Cotton	640.F	499.P	640.F	517.P
Sorghum	0.	493.P	0.	475.P
Corn	0.	0.	0.	0.
Layout	0.	248.P	0.	248.P

[a] The abbreviation "F" refers to acreage planted outside the government program, and "P" to acreage entered in the government program.

were zero. Limited cross-compliance was also not in effect. Prior to analyzing these results, it is important to keep in mind what the results represent. The objective of the analysis is to identify the best program participation-crop mix decision for the current year (1988). These decisions are made by the farmer after considering returns from alternative decisions in the current year, as well as the impact on future profits of these current alternatives. Because of this modelling philosophy, the best program participation and crop mix solutions identified in the model for 1989 and 1990 are probably of limited value to the farmer. These later decisions are generally not made until after the 1988 decisions are implemented and the results observed. Thus a rational farmer may in 1989 identify program participation-crop mix decisions for 1989 which are quite different from what his 1988 plans were for 1989.

The future results may, however, provide additional information useful when making longer-term strategic decisions for the farm. Many capital investments (such as equipment) are purchased based on anticipated usage and returns from this usage. A change in acres devoted to a crop or set of crops may cause a change in investment plans.

The suggested risk neutral strategy for 1988 was to participate in both cotton and feed grain programs on the second ASCS unit, but not participate in either program on the first ASCS unit. All 640 acres on the first ASCS unit were planted to cotton outside the program. Plantings on the second unit were constrained by base acreage restrictions, with both cotton and feed grains planted at the maximum levels allowed under the program. Remaining acreage on the second unit was placed (as required) in layout. Total expected deficiency payments were $39,857, which was below the payment limit.

Program participation in 1989 was more or less the reverse of the 1988 solution. The first ASCS unit was entered in both cotton and feed grain programs. Feed grains on the second unit were also entered in the program, but cotton was not. Cotton was, instead, planted until harvesting resources became constraining. Participation decisions in 1990 mirrored those made in 1988. Overall net present value of returns to fixed assets and management were $288,245. Participation in CUP was not preferred in any year analyzed.[5]

Base acreage, the $50,000 payment limit, and resource limitations seemed to have major influence on the results. Several sensitivity analyses were formulated to see which of these factors were important. Cutting cotton base acreage in half on both ASCS farm units resulted in a solution in which both units were out of the 1988 cotton program. Although nonparticipation provided the model with a chance to shift base acreage from one ASCS unit to another (as compared to the base scenario), the solutions seemed to suggest movement toward a future base acreage mix roughly similar to the base acreage endowment currently held by the farmer. The rotational benefits were apparently responsible for this result.

Increasing the number of hours available to do field work in each period (by about 15%) also resulted in a different solution. In this case, the first ASCS unit was in the program in 1988 for both crops, while the second unit was out of the program and was planted entirely to cotton. This same solution was also followed in 1989.

Had all acreage been in the program for a particular year, deficiency payments would have reached the $50,000 limit. To determine whether reaching this limit would have an impact on the optimal solution, the limit was raised to a nonbinding level. The change had no impact on the results. This result was somewhat surprising, since it was presumed that nonparticipation in the cotton program on one ASCS

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[5] Because CUP was quite uncompetitive with production alternatives but greatly added to the time required to solve the model, it was dropped from consideration in subsequent analyses.

unit each year was preferable because a) the unit could only qualify for a small deficiency payment, and b) returns under the program without deficiency payments were not as high as returns under non-participation. In fact, the reason for the alternating participation solution was related to the base acreage endowment, availability of resources, and rotational considerations.

Resources prevent both farm units from being planted entirely to cotton within a particular year. There are enough resources to allow the first ASCS unit to be devoted solely to cotton, if cotton acreage is roughly at or below base acreage levels on the second unit. Because cotton acreage is limited on the second unit to approximately the base level and returns in the cotton program are greater than returns outside the program (when deficiency payments are available on all participating acres), participation on the second unit becomes the preferred option. Participation on the second unit keeps cotton acreage on that unit at relatively low levels. Because cotton following cotton generates about $20/acre less than alternative cotton rotations, it is profitable to alternate the farm on which intensive cotton production is practiced. Hence, rotations can play a role in the program participation decision.

This type of alternating solution also is beneficial because it shifts program base acreage from feed grains to cotton on both farms. The base acreage terminal conditions suggest cotton base has somewhat greater value than feed grain base, particularly on ASCS unit #2. It might be expected that, if the recommended solutions were adopted over time, cotton base would increase until it is in balance with available resources and possible cotton acreage would be approximately the same as cotton base. At that point, the farmer could plant as many acres of cotton within the program as he could outside the program. Program participation would then depend on how soon he reaches the payment limit, the amount of acreage required in layout, and the returns generated when deficiency payments are no longer available.

The model was next reformulated to include terminal conditions for base acreage and rotations. The optimal solution is also reported in Table 1. Adding terminal conditions caused a substantial shift in the solution from that generated without terminal conditions. The relative additional value of cotton versus feed grain base on ASCS unit 2 caused the model to stay out of the cotton program on this unit and enter the cotton program on unit 1. In 1989 and 1990 cotton was out of the program on ASCS unit 1 and in on ASCS unit 2. Feed grains were in the program all years. Following this strategy allowed for greater increases in cotton base acreage on ASCS unit 2 than were achieved under the non-terminal conditions solution. It is significant to note, however, that imposing the base program participation decisions on the terminal conditions model yielded an objective function value that was about $600 less than the optimum for the terminal conditions model. Because these terminal conditions probably overstate the value of program base for both crops, one could conclude that the optimal solution without terminal conditions will hold for most terminal conditions that might be considered.

It is significant to note that expected NPV was higher and standard deviation lower when terminal conditions were included. The higher expected NPV is not surprising, given both cotton and feed grain bases have a positive, expected value. The lower standard deviation can be attributed to the negative covariance between non-program activities and terminal base acreage activities. Recall that base acreage terminal conditions are NPV of returns for each year from 1991 into infinity. Each future year's return was assumed to be the same value per acre of additional base. This per acre value was the average difference between participation and nonparticipation for the 1988-1990. The lower the returns under nonparticipation, the higher the value of additional base, because the program keeps returns for participation at a higher, more stable, level.

Risk Averse Solutions

The effect of risk on the optimal solution was next examined. No attempt was made for purposes of this study to elicit a utility function or appropriate risk aversion coefficient for the subject farmer. Nor was an E-V frontier generated to pinpoint the set of utility maximizing solutions for the farm. Instead, a few solutions were generated to provide some idea of how the farming operation might avoid income risk.

The solutions without terminal conditions (Table 2) suggested a move toward greater program participation than was evident in the risk neutral solution. This result reflects the risk reducing benefits of program participation. A notable exception was the cotton program on ASCS unit 1 in 1988 when the risk aversion coefficient was 0.000018. In this case the model chose not to participate because the payment limit had already been reached and cotton outside the program had sufficiently high expected returns to make it worth the risk. Increasing the risk premium further caused the model to revert to full participation. Corn remained out of solution in these and most other scenarios because it was highly correlated with sorghum but had lower returns and higher variance than sorghum.

Two risk averse solutions were also obtained for the model containing terminal conditions. The solutions were essentially the same as those generated for the model without terminal conditions. This was somewhat surprising, given the negative covariance between non-program participation activities and their corresponding terminal base acreage activities. The advantage of this negative covariance was more than offset, however, by the greater variance introduced when cotton was produced outside vs. in the program.

Table 2. Government Program-Crop Mix Decisions Identified as Optimal for Risk Averse Scenarios - No Terminal Conditions

	Risk Aversion Coefficient			
	0.000018		0.00003	
Net Present Value ($)	253,137.		226,919.	
Standard Deviation ($)	104,789.		93,954.	
Crop Acreage	ASCS Unit 1	ASCS Unit 2	ASCS Unit 1	ASCS Unit 2
1) 1988				
Cotton	335.F[a]	499.P	262.P	373.F
Sorghum	244.P	536.P	272.P	536.P
Corn	0.	0.	0.	0.
Layout	61.P	205.P	106.P	331.
2) 1989				
Cotton	261.P	484.P	255.P	452.P
Sorghum	266.P	536.P	272.P	536.P
Corn	0.	0.	0.	0.
Layout	113.P	220.P	113.P	252.
3) 1990				
Cotton	247.P	456.P	240.P	427.P
Sorghum	265.P	536.P	272.P	536.P
Corn	0.	0.	0.	0.
Layout	128.P	248.P	128.P	277.P

[a] The abbreviation "F" refers to acreage planted outside the government program, and "P" to acreage entered in the government program.

Conclusions

This paper has explored the government program participation question that many farmers are faced with each year. The complexity and increased number of decisions regarding participation and the degree of participation suggest the need for an analytical tool to identify what set of decisions would best meet the goals of the farmers involved. A methodology has been suggested here that can be applied to the participation decision problem. To illustrate its usefulness the methodology was applied to an actual farm operation in Texas.

The empirical analysis provided several insights into the decisions faced by the Texas farmer. The suggested strategy was to always participate in the feed grain program and to alternate participation in the cotton program between ASCS units each year. The availability of resources and beginning base acreage endowment were responsible for the within year participation pattern. Rotational benefits cause participation to alternate between years. Increasing risk aversion tended to move the farm toward greater program participation.

The empirical results also seemed to support several points made in model formulation. Use of a long-run model to identify government program participation decisions may be inappropriate because of the factors involved. The availability of resources and beginning base acreage endowment were responsible for within year program participation patterns. Rotational benefits caused participation to alternate between years. Increasing risk aversion tended to move the farm toward greater program participation.

The model solutions were obtained using a 2 megabyte micro-processor designed for use in an IBM-type personal computer. Although the micro-processor operates at 20 Mhz. speed, solution time was between 12-36 hours per problem. Nevertheless, the relative low cost ($5000) of the personal computer, microprocessor, and necessary software may make the approach potentially attractive to private consultants and extension personnel who are aiding farmers in making these decisions.

The methodology developed here is quite comprehensive in its treatment of the program participation decision. As was the case in our empirical example, many of the options may not be applicable to a particular farm situation. Others may be available, but may be clearly undesirable or inferior options. Reducing model size can simplify the approach and make it more usable by farmers and others.

Further research is needed to evaluate the usefulness of this approach for farms in other parts of the U.S. For example, what role do government programs play when the major crops grown on a farm do not have a government program? Research may also provide a better understanding about the effect of dynamic factors on the current participation-crop mix decisions.

Development of the E-V frontier may provide further insights into the influence of risk on the program participation solution. The nature of the program returns suggests a MOTAD-type approach may be more appropriate when modelling risk. This is particularly true for the base acreage terminal conditions, which are definitely not normally distributed.

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